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Flood Hazard Index Application in Arid Catchments: Case of the Taguenit Wadi Watershed, Lakhssas, Morocco

Mustapha Ikirri [1], Farid Faik [1], Fatima Zahra Echogdali [1], Isabel Margarida Horta Ribeiro Antunes [2], Mohamed Abioui [1,*], Kamal Abdelrahman [3], Mohammed S. Fnais [3], Abderrahmane Wanaim [1], Mouna Id-Belqas [1], Said Boutaleb [1], Kochappi Sathyan Sajinkumar [4,5] and Adolfo Quesada-Román [6]

1 Department of Earth Sciences, Faculty of Sciences, Ibn Zohr University, Agadir 80000, Morocco; mustapha.ikirri@edu.uiz.ac.ma (M.I.); f.faik@uiz.ac.ma (F.F.); fatimazahra.echogdali@edu.uiz.ac.ma (F.Z.E.); a.wanaim@uiz.ac.ma (A.W.); mouna.id-belqas@edu.uiz.ac.ma (M.I.-B.); s.boutaleb@uiz.ac.ma (S.B.)
2 Institute of Earth Sciences, Pole of University of Minho, 4710-057 Braga, Portugal; imantunes@dct.uminho.pt
3 Department of Geology & Geophysics, College of Science, King Saud University, Riyadh 11451, Saudi Arabia; khassanein@ksu.edu.sa (K.A.); mfneis@ksu.edu.sa (M.S.F.)
4 Department of Geology, University of Kerala, Thiruvananthapuram 695 581, Kerala, India; sajinks@keralauniversity.ac.in
5 Department of Geological & Mining Engineering & Sciences, Michigan Technological University, Houghton, MI 49931, USA
6 Department of Geography and Water and Global Change Observatory, University of Costa Rica, San José 2060, Costa Rica; adolfo.quesadaroman@ucr.ac.cr
* Correspondence: m.abioui@uiz.ac.ma

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Abstract: During the last decade, climate change has generated extreme rainfall events triggering flash floods in short periods worldwide. The delimitation of flood zones by detailed mapping generally makes it possible to avoid human and economic losses, especially in regions at high risk of flooding. The Taguenit basin, located in southern Morocco, is a particular case. The mapping of the flood zones of this basin by the method of the Flood Hazard Index (FHI) in a GIS geographic information systems environment was based on the multi-criteria analysis, taking into consideration the seven parameters influencing these extreme phenomena, namely rainfall, slope, flow accumulation, drainage network density, distance from rivers, permeability, and land use. Average annual rainfall data for 37 years (1980 to 2016) was used in this study for floodplain mapping. A weight was calculated for each parameter using the Analytical Hierarchy Process (AHP) method. The combination of the maps of the different parameters made it possible to draw up a final map classified into five risk intervals: very high, high, moderate, lower and very lower presenting, respectively, 8.04%, 20.63%, 31.47%, 15.36%, and 24.50% of the area of the basin. The reliability of this method was tested by a Flood susceptibility analysis. The results generated by the Flood Hazard Index (FHI) model are similar to those of previous historical events. Realistic and applicable solutions have been proposed to minimize the impact of these floods as much as possible.

Keywords: climate change; Flood Hazard Index (FHI); Taguenit Wadi catchment; AHP; flood susceptibility; Morocco

1. Introduction

Water scarcity is an omnipresent reality, and with soaring demand in the future; it will continue to be a precious resource. Nonetheless, manifestations of hydrological processes, as the main cause of contrasting catastrophes, such as floods, and water–deficient events, such as droughts and desertification, owing to the effects of climate change [1,2], also require an evaluation of stakeholder actions and potential mismanagement. Meanwhile, the scenario of arid regions is difficult due to the scarcity of flow data detailing, absence of floods, and difficulty in performing natural tracing or continuous monitoring of the flow [3,4]. However, the occurrence and intensity of rain events and floods represent a real risk in arid regions for water resources management.

Floods have the greatest potential for destruction among all natural hazards, which increasingly affect many people and their activities. In recent decades, the world has been affected by severe flooding, causing thousands of deaths, disruption of economic activities, and infrastructure destruction [2,5,6]. The flooded phenomena have been studied by several researchers, particularly in the development of theories, numerical models, and statistical methodologies, to describe flood behavior and space–time evolution [7–9].

Morocco, located in North–West Africa, is characterized by arid and semi-arid river watersheds, is facing unpredictable rainfall patterns and is subject to various hydrological constraints [9,10]. However, several Morocco regions have been subject to a considerable history of flooding phenomena, and they led to losses of human life amounting to 100 deaths in 1950, 730 deaths in 1995, and 500 deaths in 2014. In parallel, the estimated economic losses reached 2,200,000US$ in 2001 and 5,200,000US$ in 2014 [11–13].The regions of the western Anti-Atlas, particularly in the southwest, have been affected by numerous flooding events. In 1995, the date of the last major flood affected the regions of Lakhssas and Sidi Ifni, inducing enormous and catastrophic damage. Three houses collapsed, and 50 houses were severely damaged while 55 were partially damaged. The famous flood that occurred on 28 November 2014 affected Sidi Ifni city [14]. A flood hazard has still loomed large over the years due to population growth and socioeconomic development, as well as climate change due to global warming. The Taguenit Wadi catchment, located in the Lakhssas region (west coast), has recorded numerous big extensive floods, with prominent floods during 2006, 2010, and 2014, causing damage to infrastructure, loss of soil, and untold suffering to the population. Because of their proximity, the Lakhssas and Sidi Ifni regions are often affected at the same time by the same storm or rainfall events. In the Lakhssas region, the violence of the 2014 floods eroded the riverbanks, taking with them the entire surrounding infrastructure. Roads, often built along the wadi beds, were destroyed, isolating the Lakhssas town. Landslides also blocked roads. On the left bank, 50 houses were flooded. The people living in them were forced to take refuge on terraces while waiting for help. During the floods, three deaths were recorded in the Sidi Ifni province. The material losses were, however, very important, including significant damage to vital infrastructure (roads, water, electricity, sanitation, and fixed and mobile telephone networks) [14]. This calls for regular characterization and river monitoring to protect the various infrastructures and human activities of the area.

Several approaches (geographic information system, remote sensing, and hydraulic models) have made it possible to accurately assess areas at high risk of flooding [15,16]. The most efficient remains hydraulic models since they make it possible to estimate and predict the depth of floods for different return periods [17]. However, they require a large set of measured data, which is not always available [18,19] due to the lack or absence of hydro–meteorological stations, especially in developing countries [17,19].

In recent years, researchers have developed other techniques to predict the impact of high-intensity and short-duration floods, namely the Weights of evidence Model [20], Frequency Ratio [21], Index of Entropy [22], Random Forest [23], Logistic Regression [24], Artificial Neural Network [25], Index of Entropy [26], Analytical Hierarchy Process [27], and Flood Hazard Index (FHI) [8,28]. The latter, widely applied in several regions of the world, has shown its effectiveness.

Flood risks on a basin-scale can be quantified, especially using Flood Hazard Index (FHI) methodologies [12,14,29]. Climate change will trigger more frequent extreme flash floods in arid environments [30–33]. Hence, the study of simulated floods on the Taguenit Wadi catchment and their spatial extension is essential to enable hydraulic operators to determine the extent of flood risk areas. The main aim of the present study is the application of the Flood Hazard Index (FHI) method to determine the most vulnerable flood areas on the Taguenit Wadi catchment.

2. Materials and Methods

2.1. Geographical Setting of the Taguenit Wadi Catchment

The Taguenit Wadi catchment, situated in the south part of Morocco between latitudes 29°10′30″ to 29°28′30″ and longitudes 9°52′30″ to 10°43′30″, covers an area of 131.52 km^2. The altitude varies between 577 and 1204 m (Figure 1), decreasing overall from east to west. The slopes, which are generally steep, vary from a few degrees (0° and 15°) on the terraces of the tributary riverbeds and downstream of the river basin to 64° on the upstream slopes. The average annual rainfall, recorded at the Adoudou station located 15 km north of the basin, is 133 mm. Aridity increases from west to east, due to the increasing distance from oceanic influences. The average temperature is 26 °C, with a maximum of 45 °C and a minimum of 12 °C [14].

Morocco has highly diverse geomorphology and a variety of landform types [34]. The geomorphology of the basin area is characterized by the dominance of the mountains of the western Anti-Atlas range, with cover vegetation dominated by Argan and euphorbia plants. The river and tributaries flow only after the first rains in October or November. The dominant surface water flow is from SE–NW (Figure 1). The hydrographic network is dense and well-branched, with a specific "Y" shape. The branching of the network is more pronounced upstream than downstream. The time of concentration of the water calculated using the Giandotti equation is 14 h. In this region, flash floods cause much human and material damage, produced by intense rains, resulting in short periods of flooding, usually within several hours. The November 2014 floods caused 100 fatalities as well as the destruction of 200 infrastructures with extensive soil erosion (Figure 2).

The Taguenit Wadi catchment is part of the Lakhssas plateau, located in the Western Anti–Atlas chain, on the west coast of Morocco. It is located between the two Precambrian massifs of Kerdous and Ifni. These geological formations are composed, from bottom to top, of carbonate facies (Tamjout dolomites and lower limestones), dolomitic limestones, marly limestones with intercalations of dolomitic-sandstone, and finally upper limestones [35–37] (Figure 3a). All of the areas are generally faulted, with the main directions of NNE–SSW, NE–SW, E–W, and ENE–WSE. The soil type in the catchment was produced by Working Group World (WRB) Reference Base for Soil Resources [38]. The soil complex is characterized by the dominance of poorly developed anthropogenic soils, namely Calcisols, Leptosols, Luvisols, and Regosols, which respectively occupy 21.13%, 9.20%, 26.99%, and 42.68% of the study area (Figure 3b). The upstream part of the basin with steep slopes is where hard limestone and dolomitic rocks are mainly outcropped. These are depleted by erosion as the topsoil is washed away by rainfall runoff. In the middle part of the basin, we find mainly Leptosols and Calcisols, which result from a saturation of the soils with calcium or magnesium and produce eroded elements of limestone and dolomites upstream of the basin. Their establishment over geological time depends on both periods favorable to pedogenesis and on human action (cultivation), which has a very strong impact on these soils. Finally, in the downstream part, Calcisols are more prevalent, younger than the other types of soil, little differentiated, and more or less stony (pebbles) and of variable texture (often loamy or sandy). They come from alluvial deposits throughout the Quaternary. The analysis of this pedological map gives a good account of the differentiation in an upstream–downstream direction of the types of soils which will behave variably to rainfall events; it emerges from this that the fluviosols located downstream of the basin, partially or saturated with water by the superficial groundwater, will generate runoff "by saturation"; this type of runoff suddenly produces catastrophic floods.

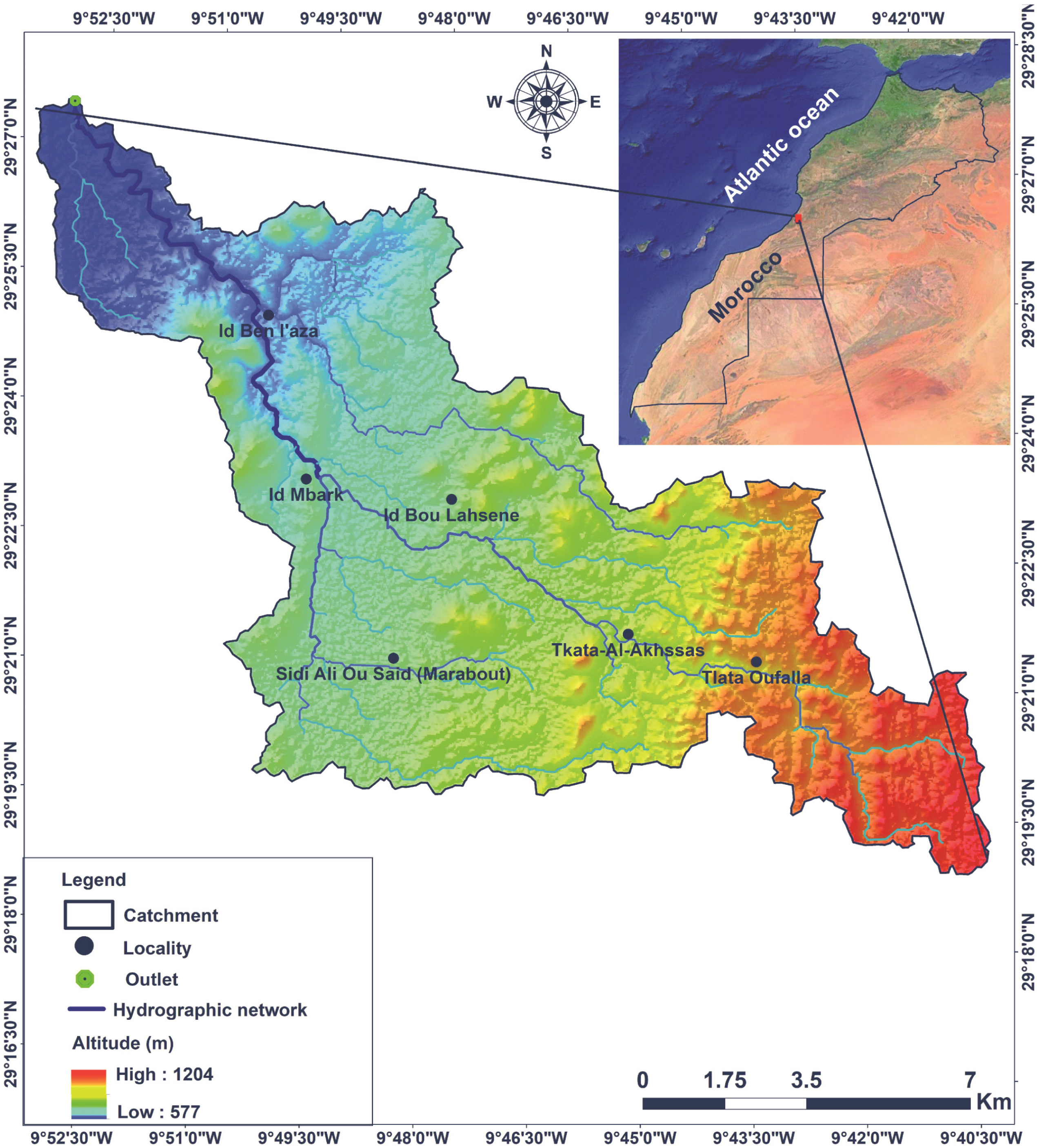

Figure 1. Geographic location of Taguenit Wadi catchment.

Figure 2. Damage to the infrastructure of the village of Lakhssas during the floods of November 2014. (**a**) Degradation of the National Road N°1; (**b**) Deterioration of the inter-provincial roads connecting Lakhssas village and Ifni city.

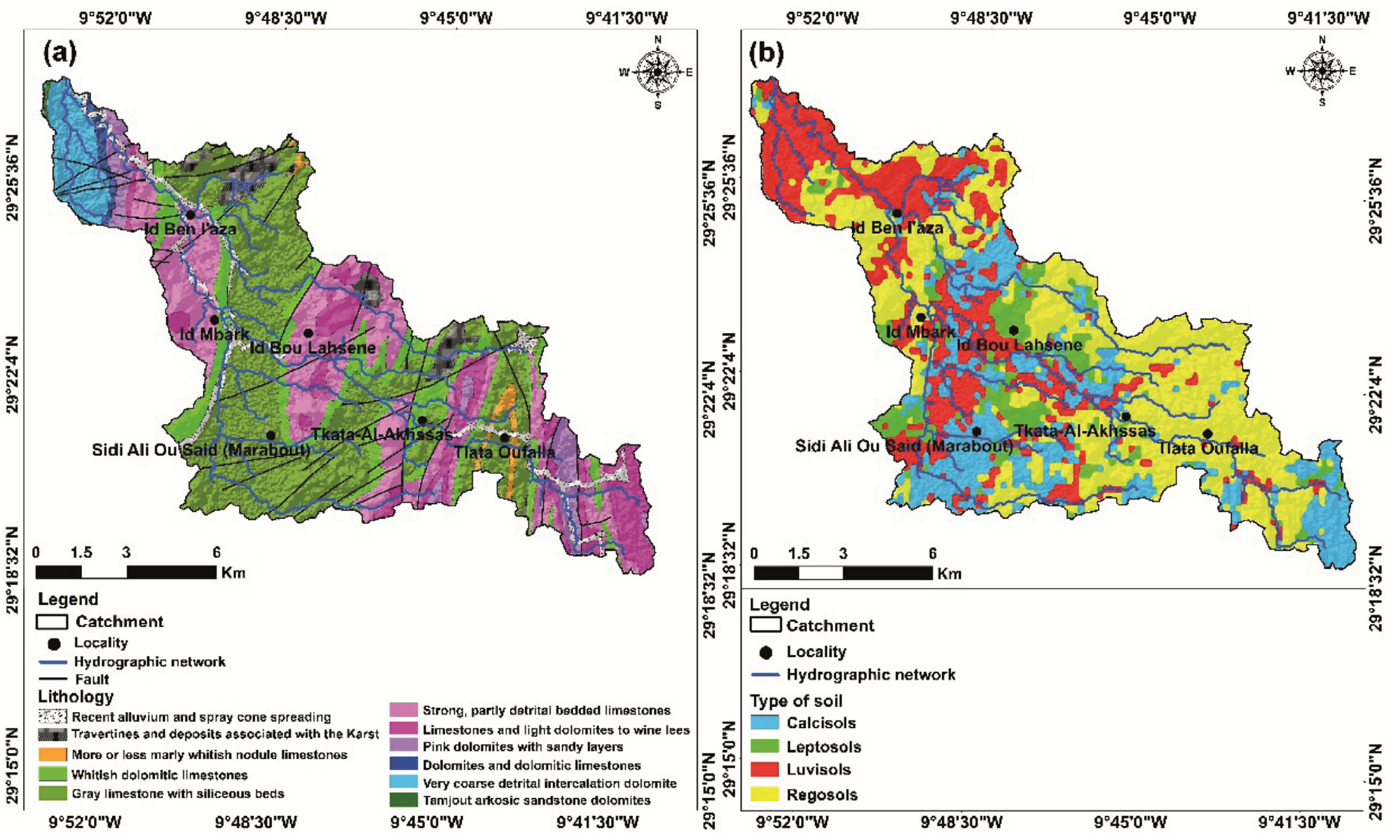

Figure 3. Taguenit Wadi River catchment: (**a**) Geological map; (**b**) Soil type map.

2.2. Flood Mapping Methodology

The Flood Hazard Index (FHI) model has been developed to define flood risk areas from a regional perspective [28,29]. The FHI index is intended to identify vulnerable areas of flooding risk.

The Flood Hazard Index (FHI) is based on the Analytical Hierarchy Process (AHP) multi-criteria decision analysis, considering the contribution of weights of seven hydro–geo–morpho–climatic factors, namely Rainfall (R), Slope (S), Flow accumulation (Fa), Drainage Network Density (DND), Distance from Rivers (DFR), Permeability (P), and Land Use (LU). The choice of these factors is theoretically based on their relevance to flood risk (Figure 4).

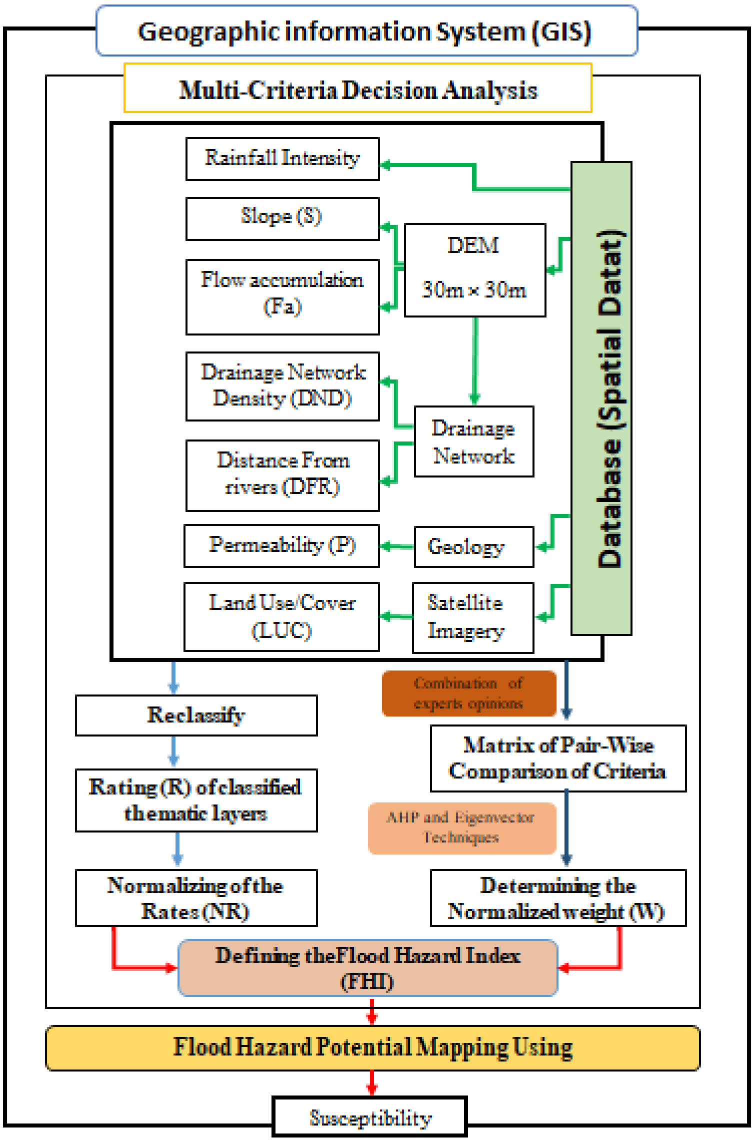

Figure 4. Schematic diagram of the integration of hydrological and AHP models in a Geographical Information System (GIS).

2.3. Flood Hazard Index (FHI) Factors

The factors considered in the spatial flood map are extracted from the DEM, with 30 m × 30 m resolution, for slope and flow accumulation, while permeability was extracted from the Lakhssas geological map on a scale of 1:100,000. The drainage network of the area was obtained using DEM data and used to produce the drainage network density and distance from rivers. With regards to rainfall, the spatial distribution map was deduced from a regional extrapolation, including four meteorological stations bordering the basin, namely Adoudou, Taghjijt, Sidi Ifni, and Youssef Ben Tachafine. Land use was obtained using Landsat 8 Oli satellite imagery of the area by supervised classification. All the information was organized in a database using ArcGIS software 10.5.

- Flow accumulation (Fa): Flow accumulation corresponds to the accumulated water flow to a specific cell drained from the cells located upstream. High values of the Fa factor indicate areas of higher concentrated water flow and, therefore, a higher risk of flooding [28,39]. In the study area, this factor varies in a range between 0 and 147.996, with the highest values coinciding with the water flow of the main tributaries of Taguenit Wadi (Table 1; Figure 5a).

- Distance from Rivers (DFR): The spatial distance of a region to the river system is a crucial factor in the delimitation of flood vulnerability zones. As the distance to the river system decreases, the degree of flood risks will increase [14,28,29]. Distances located below 200 m to the river system will correspond to areas of higher flood vulnerability. Otherwise, the areas located away from 400 m to the river system seem to present a lower or absent flood risk. The high flood vulnerability zones are mainly confined to the river networks (Table 1; Figure 5b).
- Drainage Network Density (DND): Drainage network density is proportional to the cumulative water volume from upstream to downstream in the river basin [40,41]. In the Taguenit Wadi catchment, DND values range from 0 to 5.67 m/km^2, with the lower class concentrated in the catchment (Table 1; Figure 5c).
- Rainfall (R): For a given area, rainfall is the most important factor related to the occurrence of floods, it has a direct relationship with river flow, and a large amount of rainfall in a short time can generate flash floods in semi-arid regions [1,2]. The annual rainfall data (1980 to 2016) used in this study were collected from Regional Meteorological stations (Taghjijt, Adoudou, Assaka, and Sidi Ifni stations). Thus, a rainfall map was prepared from the annual mean rainfall by inverse distance weighted (IDW) interpolation in ArcGIS 10.4 [39,42]. The annual mean rainfall varies between 122.19 to 137.71 mm/year, with decreased values from the north to the south, and the highest rainfall values are recorded in the southern part of the basin (Table 1; Figure 5d).
- Slope (S): The slope of the area influences surface runoff and water infiltration [39,43]. The slope classes vary between 0 and 64° (Table 1) and were defined according to the model applied by Demek [44]. The lower slope areas are concentrated downstream, while the higher slope areas are concentrated in the mountainous regions, located in the north of the basin (Figure 6a).
- Land use (LU): The type of land use determines the infiltration of rainwater into the soil and the resulting runoff [14,28]. Forests generally favor infiltration through the root system of trees and plants, whereas roads and buildings reduce infiltration of this water and increase surface runoff. In the Taguenit catchment area, the land use data have been reclassified into four classes displayed in Table 1. The village of Lakhssas, located in the center of the basin area and equipped with several infrastructures (e.g., roads, tracks, shops, and dwellings), amplifies the occurrence of floods downstream as it generally contains impermeable materials (Figure 6b).
- Permeability (P): In the Taguenit Wadi catchment, the impermeable or poorly permeable rocks, such as crystalline rocks, promote surface runoff. This factor was reclassified into four classes, varying between 4 to 10, according to models established by Echogdali et al. [29] and Elkhrachy [41]. About 80% of the basin′s formations are impermeable or with a low permeability, which offers an environment conducive to a higher probability of strong floods development. Carbonate formations, with lower permeability and strongly favoring runoff, were assigned a weight of 10 (Table 1), while the lowest weight (class 2) was attributed to those with a high permeability corresponding to the Quaternary formations, which extend over 20% of the Taguenit Wadi catchment (Figure 6c).

Each of the seven factors was reclassified, with a rating, according to the impact degree on the flood risk. We assigned values that varied from 2 to 10 as proposed by Kazakis et al. [28], shown in Table 1. They thus indicate the intensity of the flood hazard starting from very low (2), low (4), medium (6), high (8), and very high (10).

Table 1. Defined factor classes and corresponding ratings adopted for this study (Source: Collated from various references cited within this paper).

Factor (Units)	Class	Rating	Weight
Fa: Flow accumulation (Pixels)	97,503–147,996	10	2.73
	45,849–97,503	8	
	23,795–45,849	6	
	6384–23,795	4	
	0–6384	2	
DFR: Distance from rivers (m)	0–33	10	2.54
	33–133	8	
	133–377	6	
	377–632	4	
	632<	2	
DND: Drainage network density (m/km^2)	4.53–5.67	10	1.43
	3.40–4.53	8	
	2.26–3.40	6	
	1.13–2.26	4	
	0–1.13	2	
R: Rainfall (mm/year)	134.60–137.71	10	0.71
	131.50–134.60	8	
	128.40–131.50	6	
	125.29–128.40	4	
	122.19–125.29	2	
LU: Land use (Pixels)	Dwelling	10	0.85
	Wadi	8	
	Bare ground	6	
	Vegetation	2	
S: Slope (Degree)	0–7	10	0.55
	7–15	8	
	15–25	6	
	25–38	4	
	38–64	2	
P: Permeability (Pixels)	Impermeable	10	0.40
	Low permeability	8	
	Average permeability	6	
	High permeability	4	

2.4. Relative Weight of Factors

The weights of the factors applied in the Taguenit Wadi catchment were determined using AHP (Figure 4) [45,46]. The AHP methodology is a mathematical approach used to characterize complex problems, with a varying number of factors. Once all the factors are hierarchically sorted, a pairwise comparison matrix is constructed to allow meaningful comparison between the assessments of the factors. The relative importance of each factor was determined by five numerical scales, as shown in Table 2.

Table 2. Numerical expression of the relative importance of factors.

Importance	Scale
Very important	1
Moderate	1/2
Less important	1/3
Moderately less important	1/4
Much less important	1/5

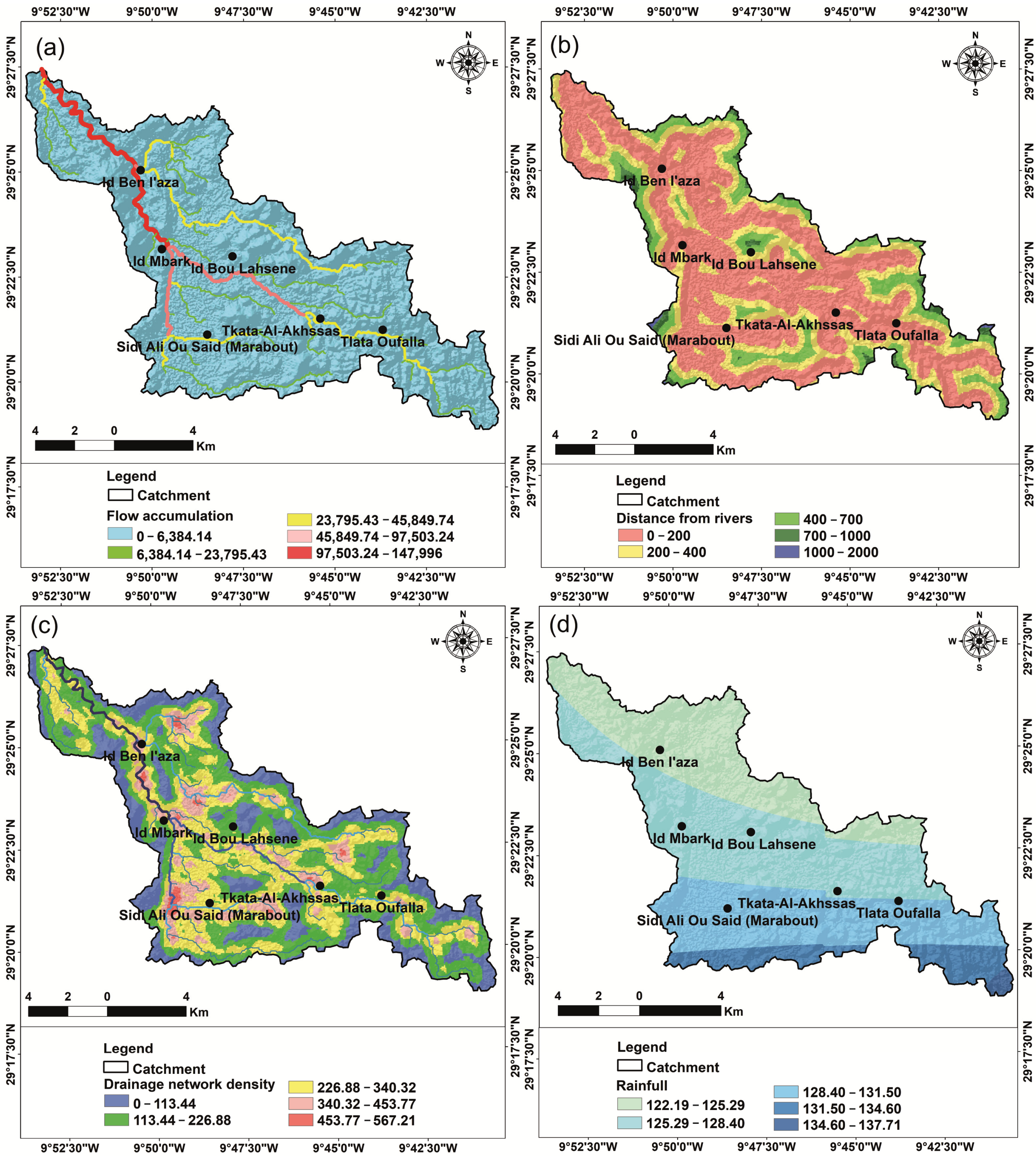

Figure 5. Spatial distribution of flood assessment factors in the Taguenit Wadi catchment: (**a**) Flow accumulation; (**b**) Distance from rivers; (**c**) Drainage network density; (**d**) Rainfall.

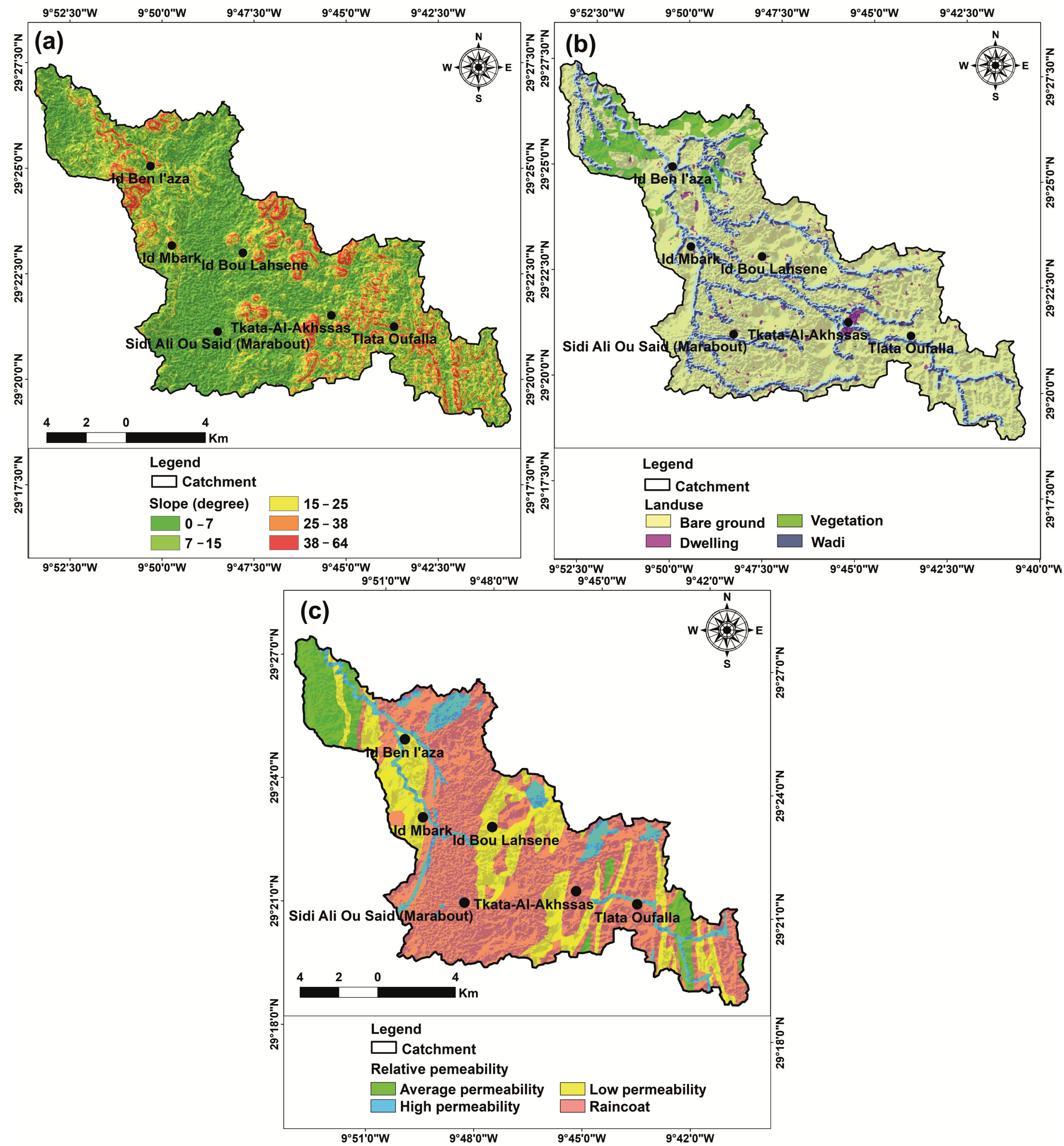

Figure 6. Spatial distribution of flood assessment factors in the Taguenit Wadi catchment (continuation): (**a**) Slope; (**b**) Land use; (**c**) Permeability.

The applied matrix is of a dimension 7 × 7, and the diagonal elements are equal to 1. The factors are structured hierarchically in Table 3.

Table 3. Pairwise comparison matrix of flood influencing factors for AHP; λmax: maximum value of the comparison matrix, RI: Random indices, CR: consistency ratio.

Factors	Flow Accumulation	Distance from Rivers	Drainage Network Density	Rainfall	Land Use	Slope	Permeability
Flow accumulation	1	2	3	5	3	5	4
Distance from rivers	1/2	1	6	4	3	4	6
Drainage network density	1/3	1/6	1	3	2	3	3
Rainfall	1/5	1/4	1/3	1	2	2	2
Land use	1/3	1/3	1/2	1/2	1	3	2
Slope	1/5	1/4	1/3	1/2	1/3	1	3
Permeability	1/4	1/6	1/3	1/2	1/2	1/3	1
n = 7	λ_{max} = 7.65		RI = 1.32			CR = 0.08	

The values presented in each row determine the correlation between two considered factors. The addition of each column value to the comparison matrix and dividing each element of the matrix by its column total could be calculated as the average of the elements in each column of the matrix [45,46]. The normalized weights for individual flood factors are presented in Table 4.

Table 4. Normalized weights determined for each flood factor.

Factors	Flow Accumulation	Distance from Rivers	Drainage Network Density	Rainfall	Land Use	Slope	Permeability	Weight
Flow accumulation	0.36	0.48	0.26	0.34	0.25	0.27	0.19	2.73
Distance from rivers	0.18	0.24	0.52	0.28	0.25	0.22	0.29	2.54
Drainage network density	0.12	0.04	0.09	0.21	0.17	0.16	0.14	1.43
Rainfall	0.07	0.06	0.03	0.07	0.17	0.11	0.10	0.71
Land use	0.12	0.08	0.04	0.03	0.08	0.16	0.10	0.85
Slope	0.07	0.06	0.03	0.03	0.03	0.05	0.14	0.55
Permeability	0.09	0.04	0.03	0.03	0.04	0.02	0.05	0.40

The average of the rows of the normalized matrix represents the corresponding weight (w) of each factor. In the Taguenit Wadi catchment, flow accumulation was considered the most relevant factor in the FHI index, followed by distance from rivers, drainage network density, rainfall, land use, slope, and permeability.

It is necessary to assess the consistency of the determined AHP eigenvector matrix. The consistency of the matrix could be assessed using the consistency ratio (CR) (Equation (1)). This ratio defines the probability of comparison between the consistency index (CI) of the matrix for the ratio index (RI) of a random type of matrix [41].

$$CR = CI/RI \tag{1}$$

With CR as the consistency ratio, CI represents the consistency index, calculated using Equation (2), and RI corresponds to the random index dependent on the number of selected factors (n) (Table 5).

Table 5. Random indices (RI) used to calculate the consistency ratio (CR), and n: number of factors selected.

n	1	2	3	4	5	6	7
RI	0	0	0.58	0.9	1.12	1.24	1.32

This index was calculated from the average consistency index of a randomly generated sample of 500 pairwise comparison matrices. If the CR value was ≤0.10, the matrix was acceptable; and if the CR value was ≥0.10, it was necessary to revise the judgments due to the inconsistency.

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{2}$$

The consistency index (CI) will depend on the λ_{max} that corresponds to the maximum value of the comparison matrix, and (n) is the number of factors. The CI was calculated for λ_{max} = 7.54, n = 7, and RI = 1.32. The eigenvector λ_{max} of the matrix was calculated, and the consistency of all the judgments was also checked, making sure that the AHP method suggested that the obtained CR value was less than or equal to 0.1 [47,48]. Since the value of CR = 0.08, which is less than the threshold (0.1), the consistency of the weights is constant. The seven selected factors were superimposed linearly with their weights calculated previously. The flood risk index was calculated using Equation (3):

$$\text{FHI} = \sum_{i=6}^{n} (\text{wi} * \text{Xi}) \quad (3)$$

With Xi being the classification of the factor at each point, Wi being the weight of each factor, and (n) being number of factors.

In the Taguenit Wadi catchment, Flood Hazard Index (FHI) was applied using Equation (4):

$$\begin{gathered}\text{FHI} = [2.73 \times (\text{Flow accumulation})] + [2.54 \times (\text{Distance From Rivers})] \\ + [1.43 \times (\text{Drainage Network Density})] + [0.71 \times (\text{Rainfall})] + [0.85 \times (\text{Land use})] \\ + [0.55 \times (\text{Slope})] + [0.40 \times (\text{Permeability})]\end{gathered} \quad (4)$$

Flood susceptibility is an analysis to test and evaluate the extent of flooding and to determine the predictive accuracy of the selected model [49]. Some models use the ratio of affected features to total vulnerable features to determine the flood vulnerability of an area [50,51]. The variable 'flood depth' could be added to determine flood susceptibility, as the degree of affected features is directly related to the flood depth. The flood susceptibility was calculated according to Equation (5).

$$S = \frac{R_{affected}}{R_{total}} * 100\% \quad (5)$$

where S is the flood susceptibility score; $R_{affected}$ is the number of affected entities; R_{total} is the amount of total vulnerable entities.

3. Results and Discussion

3.1. Flood Hazard Index (FHI) Analysis

Analysis of the results obtained from the linear combination of the selected factors showed that the three most-relevant factors for the determination of flood risk were flow accumulation, distance from rivers, and density of the river system. Five flood risk classes, varying from very low to very high, were defined according to the flood risk map of the Taguenit Wadi catchment (Figure 7). The respective areas corresponding to the different degrees of flood risk varied from 8.29% (very high risk), 20.38% (high risk), 31.47% (moderate risk), 15.36% (low risk), and 24.50% (very low risk) (Table 6). Most flood areas were located on the large flood plains extending westwards from the main Taguenit Wadi. Outside the alluvial zones, with general high flood risk, it should be noted that the zones located downstream of the catchment area, on the way to the Id–Mbark village, were the most vulnerable to high flood occurrences. These areas correspond to the road networks (National Road N°1, provincial roads N°1911, 1918, and tracks), village sites (Lakhssas village, Tlat Oufla, and Idchaoud), and the areas located close to the alluvial banks of the Taguenit Wadi (Figure 7).

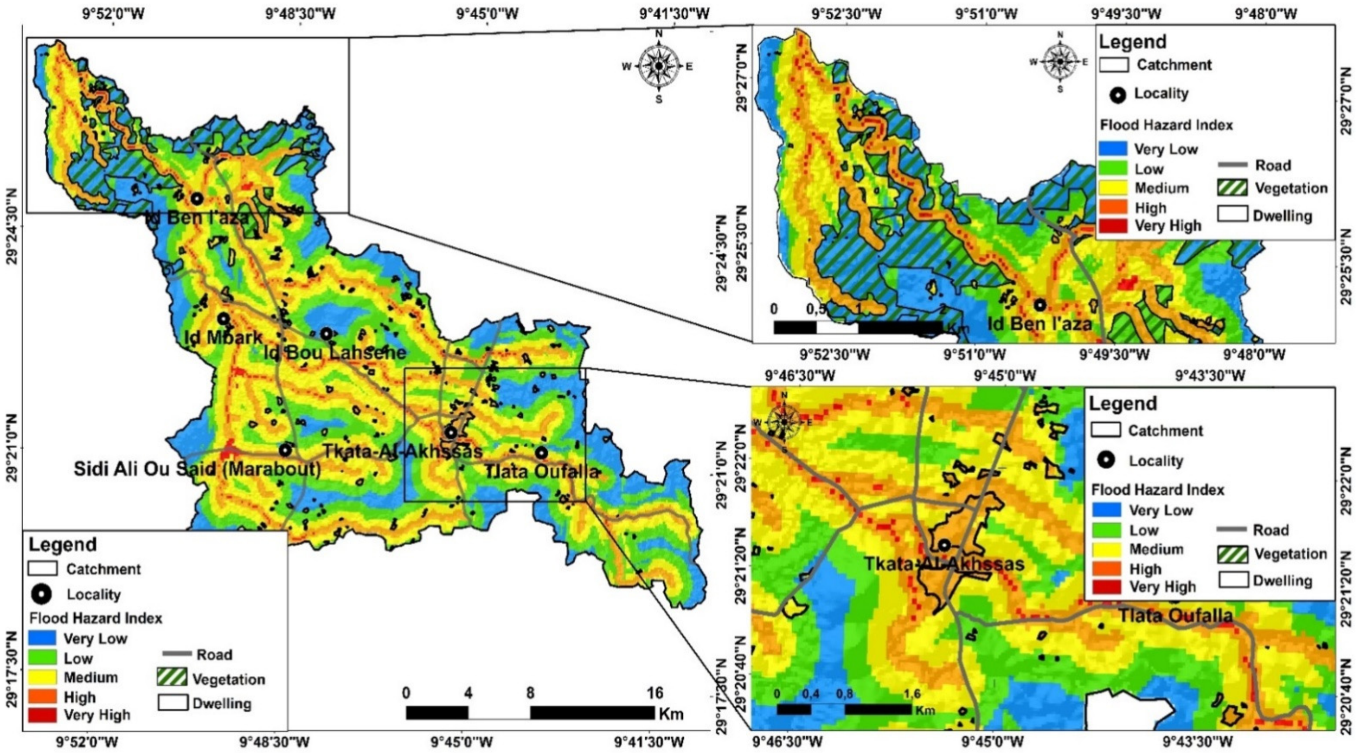

Figure 7. Map of areas likely to be flooded in the Taguenit Wadi catchment.

Table 6. Percentage of the degree of flood risk areas in the Taguenit Wadi catchment.

Degree of Flood Risk	Area (km^2)	Percentage (%)
Very high	10.57	8.04
High	27.13	20.63
Medium	41.34	31.47
Low	20.36	15.36
Very Low	32.16	24.50

The results of this study corroborated with those found by Kazakis et al. [28] since the two most important factors (flow accumulation and distance from rivers) seemed to be the most influential on flood intensity. Indeed, the respective dominant weights of these two factors in this study were of the order of 3 and 2.1. The comparison of the results of the application of the Flood Hazard Index (FHI) model established to previous historical events shows the reliability of the application of this model. Furthermore, Rahmati et al. [52] and Echogdali et al. [22] evaluated the effectiveness of the Flood Hazard Index (FHI) in identifying potential flood risk areas by comparing it to the results of a HECRAS hydraulic model, respectively, in Bashar River, downstream of Yasooj city and the El Maleh basin in Morocco. The results showed that the Flood Hazard Index (FHI) model was consistently more reliable in accurately predicting flood extent.

In addition to the three factors mentioned above, it seems that the difference in the lateral extension of flood risks in the Taguenit Wadi catchment is also because of the topography of the alluvial plains on either side of the main Wadi. Several topographic profiles transverse to the main river course reflect a variable morphology from one sector to another. The altitude of the Wadi valley varies from 6 m, at the level of the profile; 1 to 10 m at the level of profile 2; and could reach 35 m at the level of profile 6 (Figure 8). The areas of low valley incision automatically induced an overflow of water beyond the minor bed. The strong slopes in the upstream region favored significant confinement of the valleys that limited the lateral extension of river reaches. The village of Lakhssas, the largest and most populous commercial center in the region, with 5000 inhabitants, suffers greatly from these extreme and repetitive flood events [14]. Of the 50 villages in the study area, only 11 villages are in a low- to a medium-risk flood zone. The remaining 80% of agrarian villages face the danger of flooding risk and occupy the alluvial plains of various tributaries.

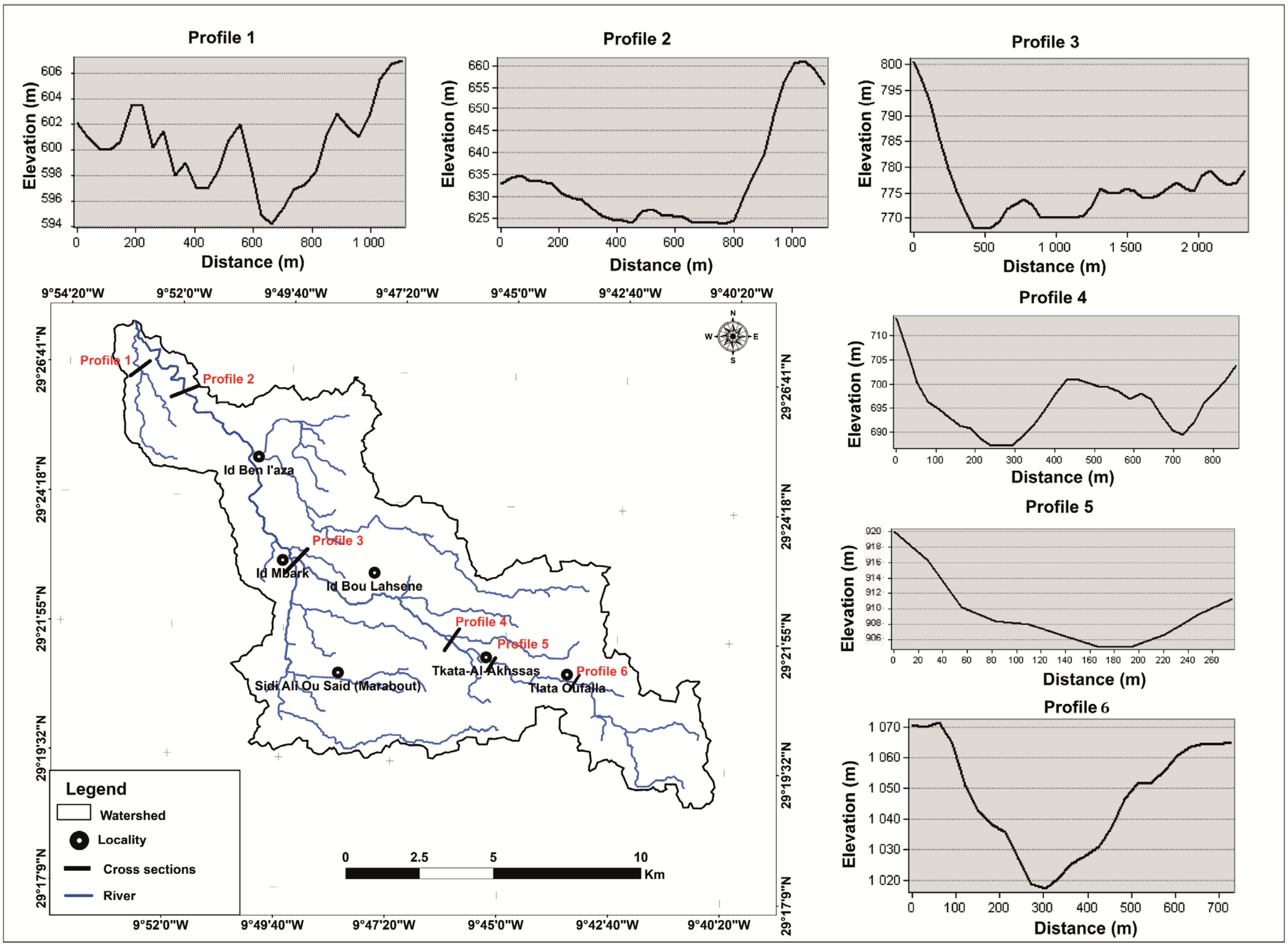

Figure 8. Topographic profiles at six cross-sections in the catchment of Taguenit Wadi.

3.2. Territorial Planning Implications of Flood Hazard Index (FHI)

The flood susceptibility test relates the potential damage to the corresponding flood extent for each land-use type. In the catchment of Taguenit Wadi, the flood susceptibility scores for each land use type tended to increase with growing proximity to the main Wadi (Figure 9). The extent of land use damage was therefore significant. The flood susceptibility of three land-use types could be individualized into two different categories: high susceptibility (residential) and medium-to-low susceptibility (roads and agriculture). Residential areas should be avoided in high flood risk areas, while land uses with medium-to-low flood susceptibility (roads and agriculture) are suitable in these flood risk areas. These results will allow for better planning of stream restoration to reduce losses and damages during floods in the Taguenit Wadi catchment.

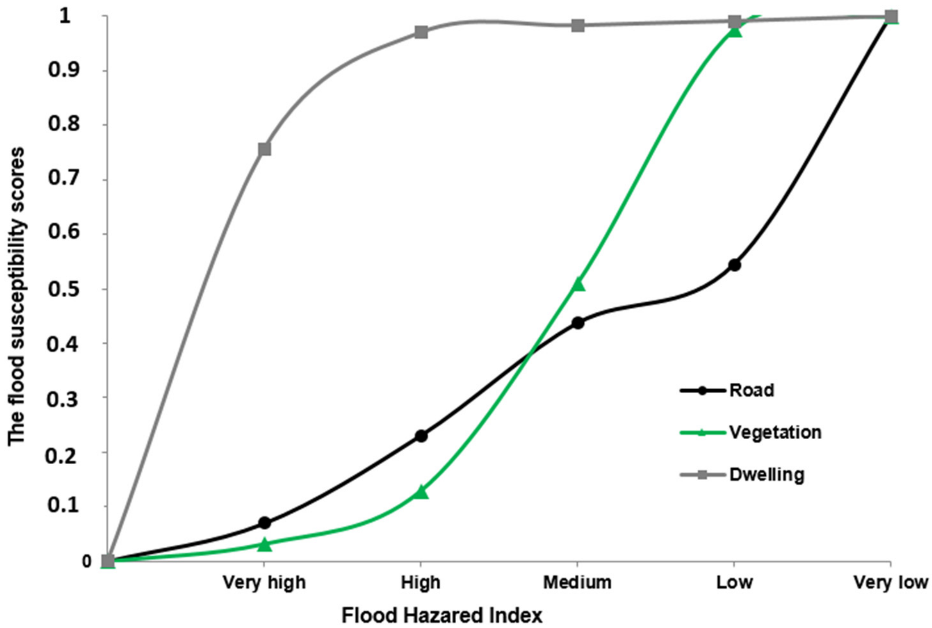

Figure 9. Flood Hazard Index (FHI) versus Flood susceptibility scores.

The spatial validation of the lateral extension of flood areas at the level of the Taguenit Wadi catchment was also carried out by the fieldwork observations of the water level during a few floods, especially the one in 2018, and by a survey of the local population. The obtained results from these surveys corroborated with the Flood Hazard Index (FHI) model results. Considering a few differences, the obtained results could be used in future land-use plans on the Taguenit Wadi catchment. In the absence of hydrometric data, the Flood Hazard Index (FHI) model allowed us, despite the limited amount of integrated data, to establish a map of the lateral spread of floods. However, it did not indicate the height of water in these areas, which did not allow us to approach the hazard of these flood zones and at what level where the infrastructures were submerged by water.

The Taguenit Wadi catchment with a high risk of flooding deserves special attention, especially in the habitable, agricultural, and infrastructure areas, to avoid disasters caused by extreme flood events. This basin must be equipped with hydrological and hydraulic infrastructures that allow for regular monitoring of water flows in, at least, three different zones of the main course (e.g., upstream, middle, and downstream). The measured hydrological data should be considered by an intergovernmental regional committee, which could announce warnings in case of high floods to evacuate people, livestock, and property and minimize the associated consequences.

It is important to install an early warning system to give signals during extreme downpours to avoid damage caused by the sudden filling of the Wadi section.

Early warning systems can be employed in arid contexts, as demonstrated in some studies [53,54]. These systems can reduce the risk of flash floods.

On the developmental plans for the Taguenit Wadi catchment, it would be prudent to limit the effect of floods whose origin is at the level of the upstream basin by the construction of a flood control dam. This infrastructure will allow for the reduction of the velocity of floodwater, which will increase the time of contact between the alluvium and the water, and the consequent gradual water infiltration and a strong supply of the alluvial layers largely used by the local farmers. The use of dams in arid environments to reduce flash floods has been used in several regions, and it shows important results [55,56].

On the margin of both the tributaries and Trunk River, it is recommended to develop the slopes with benches, protective sills, and dikes. The purpose of the benches is two-fold: to control water erosion and to reduce surface runoff by promoting infiltration.

The proposed measures and solutions to the Taguenit Wadi catchment, considering the geomorphological characteristics, are represented in Figure 10. In addition, it is important to set up Flood Risk Management Strategies (FRMS), established by the local authorities, which define prohibition zones and prescription zones, which are constructible under reserve. The implementation of the FRMS will impose an act on the existing to reduce the vulnerability of elements. The challenges to be faced are mainly financial since funding is currently directed towards large basins and agricultural plains of the northern and central regions of Morocco.

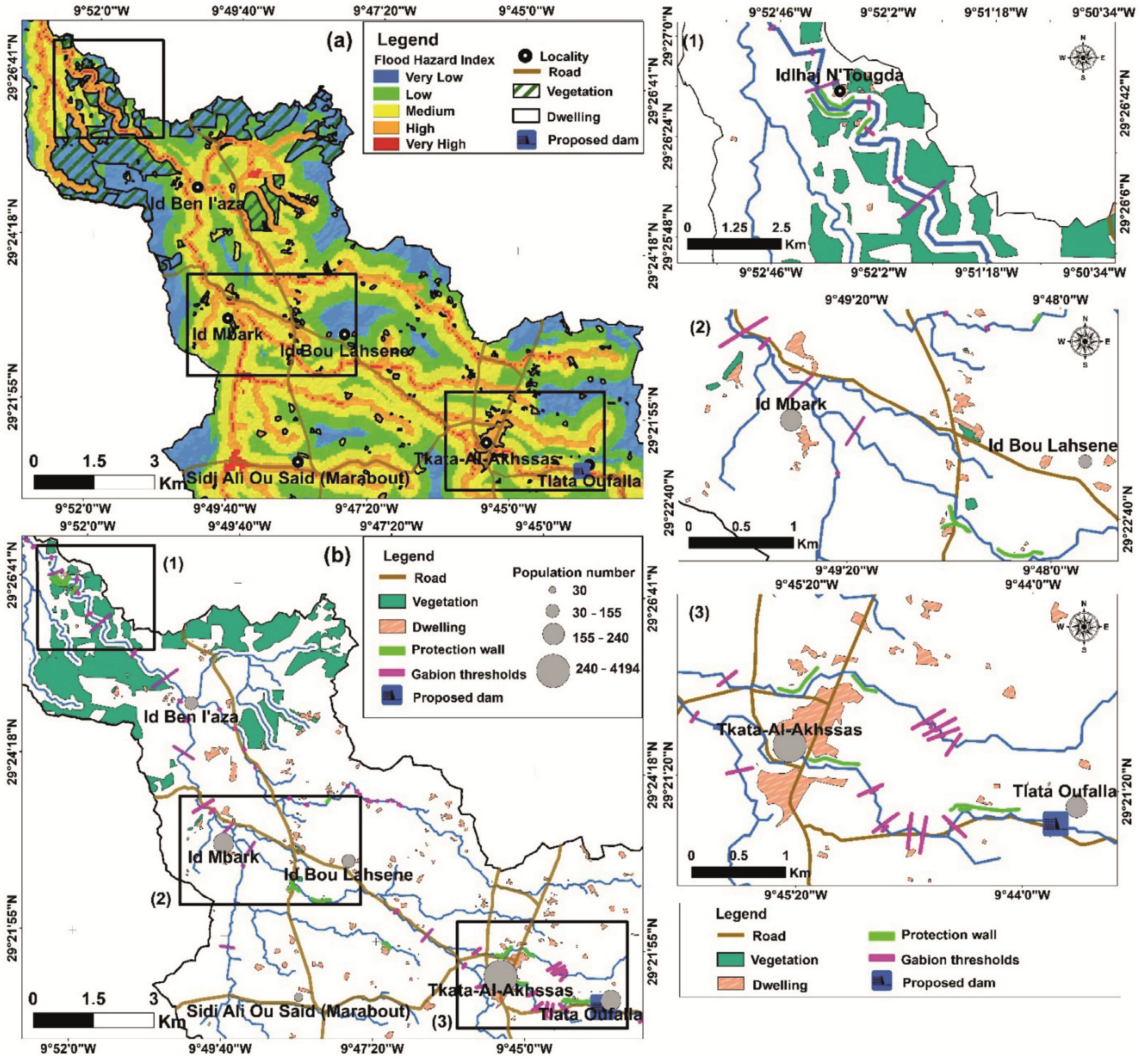

Figure 10. Proposed measures to be applied to the Taguenit Wadi catchment. (**a**) Areas likely to be flooded in the Wadi Taguenit watershed; (**b**) Land use, population density in the study area, and proposed measures: (**1**) Details of the downstream part of the basin with the proposed infrastructure; (**2**) Details of the medium flood risk area with medium population density and proposed infrastructure; (**3**) Details of the area most likely to be flooded and most densely populated with proposed infrastructure.

The study of the risks of flooding in the catchment of the Taguenit Wadi (not with monitoring equipment) is of paramount importance in the center of the basin, where the village of Lakhssas is located, which is the economic engine of the region. Water operators, as well as policymakers, should encourage the strengthening of infrastructure in this basin (e.g., hydrological stations, dams, and levees) to avoid risks related to flooding impacts, mainly associated with extreme events due to storms during the summer season. In the area, it is also recommended to prohibit new constructions in flood-prone areas, in addition to the establishment of a flood warning system involving government sectors (e.g., fire brigade, river basins, the Ministry of Interior, and municipalities). In addition, an afforestation program will be crucial on the alluvial plains to improve the infiltration of water linked to floods. Afforestation can potentially mitigate flood risk by increasing infiltration [57] and mitigating runoff [58]. Dixon et al. [59] showed that floodplain forest restoration of over 10–15% of the total catchment area led to a reduction in a peak discharge of 6% at 25 years post-restoration. The construction of bridges on the main roads exposed to the risk of flooding is also compulsory to avoid the disruption of road traffic, which sometimes lasts several days in times of flood.

4. Conclusions

The spatialization of flood risks in the watershed of the Taguenit Wadi using the Flood Hazard Index (FHI) multi-criteria analysis method has made it possible to delimit the areas exposed to flood risks, which must be taken into consideration in future land-use plans.

More than half of the surface of the basin is considered to be an area of very high-to-medium sensitivity to flooding, especially in the downstream part of the basin. The factors most impacting these floods are the flow accumulation followed by the distance from rivers, drainage density, and land use; finally, we must not neglect the impact of the topography of the alluvial zones, which determine the spread of the floods according to the state of the collection of the valley of the main course. The evaluation of the extent of flooding simulated by the Flood Hazard Index (FHI) shows agreement with previous historical events recorded in the study area, which confirms the reliability of the model

Despite the absence of hydrometric data, the Flood Hazard Index (FHI) model proves to be a very important modeling tool for a first approach to the mapping of floodplains, as shown in this case study of the basin.

The results of the application of this model enabled us to propose solutions to avoid the impact of these floods, in this case, the equipment of hydrological stations in three zones of the basin; the construction of a capping dam upstream of the basin, which will make it possible to reduce the speed of water flow and, consequently, gradual infiltration of the latter downstream; the construction of benches and bunds along with the limits of the valleys; and finally, the installation of a vigilance system, allowing the announcement of alerts during heavy floods. However, the Flood Hazard Index (FHI) model also has some limitations. Firstly, it requires a combination of datasets collected from different sources that have a high resolution. These data are not always available at a high resolution. Secondly, another limitation is that the assignment of weights to factors is based on expert opinion, and they can add or remove factors that they judge necessary for the modeling. Finally, it indicates the horizontal extent of the flooding without giving any precision on the depth of water affecting the flooded areas.

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References

1. Abdulrazzak, M.; Elfeki, A.; Kamis, A.; Kassab, M.; Alamri, N.; Chaabani, A.; Noor, K. Flash flood risk assessment in urban arid environment: Case study of Taibah and Islamic universities' campuses, Medina, Kingdom of Saudi Arabia. *Geomat. Nat. Hazards Risk* **2019**, *10*, 780–796. [CrossRef]
2. Pinos, J.; Quesada-Román, A. Flood Risk-Related Research Trends in Latin America and the Caribbean. *Water* **2021**, *14*, 10. [CrossRef]
3. El Alfy, M. Assessing the impact of arid area urbanization on flash floods using GIS, remote sensing, and HEC–HMS rainfall–runoff modeling. *Hydrol. Res.* **2016**, *47*, 1142–1160. [CrossRef]
4. Bouramtane, T.; Yameogo, S.; Touzani, M.; Tiouiouine, A.; Ouardi, J.; Kacimi, I.; Valles, V.; Barbiero, L. Statistical approach of factors controlling drainage network patterns in arid areas. Application to the Eastern Anti Atlas (Morocco). *J. Afr. Earth Sci.* **2020**, *162*, 103707. [CrossRef]
5. Tang, J.C.; Vongvisessomjai, S.; Sahasakmontri, K. Estimation of flood damage cost for Bangkok. *Water Resour. Manag.* **1992**, *6*, 47–56. [CrossRef]
6. Lekuthai, A.; Vongvisessomjai, S. Intangible flood damage quantification. *Water Resour. Manag.* **2001**, *15*, 343–362. [CrossRef]
7. Hallegatte, S.; Hourcade, J.C.; Dumas, P. Why Economic Dynamics Matter in Assessing Climate Change Damages: Illustration on Extreme Events. *Ecol. Econ.* **2007**, *62*, 330–340. [CrossRef]
8. Echogdali, F.Z.; Kpan, R.B.; Ouchchen, M.; Id-Belqas, M.; Dadi, B.; Ikirri, M.; Abioui, M.; Boutaleb, S. Spatial Prediction of Flood Frequency Analysis in a Semi-Arid Zone: A Case Study from the Seyad Basin (Guelmim Region, Morocco). In *Geospatial Technology for Landscape and Environmental Management: Sustainable Assessment and Planning*; Rai, P.K., Mishra, V.N., Singh, P., Eds.; Springer: Singapore, 2022; pp. 49–71. [CrossRef]
9. Benkirane, M.; Laftouhi, N.; El Mansouri, B.; Salik, I.; Snineh, M.; El Ghazali, F.E.; Kamal, S.; Zamrane, Z. An approach for flood assessment by numerical modeling of extreme hydrological events in the Zat watershed (High Atlas, Morocco). *Urban Water J.* **2020**, *17*, 381–389. [CrossRef]
10. Heiß, L.; Bouchaou, L.; Tadoumant, S.; Reichert, B. Multi-tracer approach for assessing complex aquifer systems under arid climate: Case study of the River Tata catchment in the Moroccan Anti-Atlas Mountains. *Appl. Geochem.* **2020**, *120*, 104671. [CrossRef]
11. El Alaoui El Fels, A.; Bachnou, A.; Alaa, N. Combination of GIS and mathematical modeling to predict floods in semiarid areas: Case of Rheraya watershed (Western High Atlas, Morocco). *Arab. J. Geosci.* **2017**, *10*, 554. [CrossRef]
12. Echogdali, F.Z.; Boutaleb, S.; Jauregui, J.; Elmouden, A. Cartography of Flooding Hazard in Semi–Arid Climate: The Case of Tata Valley (South-East of Morocco). *J. Geogr. Nat. Disast.* **2018**, *8*, 214.
13. Karmaoui, A.; Messouli, M.; Yacoubi Khebiza, M.; Ifaadassan, I. Environmental Vulnerability to Climate Change and Anthropogenic Impacts in Dryland, (Pilot Study: Middle Draa Valley, South Morocco). *J. Earth Sci. Clim. Chang.* **2014**, *11*, S11.
14. Ikirri, M.; Faik, F.; Boutaleb, S.; Echogdali, F.Z.; Abioui, M.; Al-Ansari, N. Application of HEC–RAS/WMS and FHI models for the extreme hydrological events under climate change in the Ifni River arid watershed from Morocco. In *Climate and Land Use Impacts on Natural and Artificial Systems: Mitigation and Adaptation*; Nistor, M.M., Ed.; Elsevier: Amsterdam, The Netherlands, 2021; pp. 251–270. [CrossRef]
15. Souissi, D.; Zouhri, L.; Hammami, S.; Msaddek, M.H.; Zghibi, A.; Dlala, M. GIS-based MCDM–AHP modeling for flood susceptibility mapping of arid areas, southeastern Tunisia. *Geocarto Int.* **2020**, *35*, 991–1017. [CrossRef]
16. Lyu, H.M.; Zhou, W.H.; Shen, S.L.; Zhou, A.N. Inundation risk assessment of metro system using AHP and TFN-AHP in Shenzhen. *Sustain. Cities Soc.* **2020**, *56*, 102103. [CrossRef]
17. Costache, R.; Tin, T.T.; Arabameri, A.; Crăciun, A.; Ajin, R.S.; Costache, I.; Islam, A.R.M.T.; Abba, S.I.; Sahana, M.; Avand, M.; et al. Flash-flood hazard using deep learning based on H_2O R package and fuzzy-multicriteria decision-making analysis. *J. Hydrol.* **2022**, *609*, 127747. [CrossRef]
18. Fenicia, F.; Kavetski, D.; Savenije, H.H.; Clark, M.P.; Schoups, G.; Pfister, L.; Freer, J. Catchment properties, function, and conceptual model representation: Is there a correspondence? *Hydrol. Process.* **2014**, *28*, 2451–2467. [CrossRef]
19. Luu, C.; Von Meding, J.; Kanjanabootra, S. Assessing flood hazard using flood marks and analytic hierarchy process approach: A case study for the 2013 flood event in Quang Nam, Vietnam. *Nat. Hazards* **2018**, *90*, 1031–1050. [CrossRef]

20. Costache, R.; Pham, Q.B.; Arabameri, A.; Diaconu, D.C.; Costache, I.; Crăciun, A.; Ciobotaru, N.; Pandey, M.; Arora, A.; Ali, S.A.; et al. Flash-flood propagation susceptibility estimation using weights of evidence and their novel ensembles with multicriteria decision making and machine learning. *Geocarto Int.* **2021**, 1–33. [CrossRef]
21. Siahkamari, S.; Haghizadeh, A.; Zeinivand, H.; Tahmasebipour, N.; Rahmati, O. Spatial prediction of flood-susceptible areas using frequency ratio and maximum entropy models. *Geocarto Int.* **2018**, *33*, 927–941. [CrossRef]
22. Al-Abadi, A.M.; Shahid, S. A comparison between index of entropy and catastrophe theory methods for mapping groundwater potential in an arid region. *Environ. Monit. Assess.* **2015**, *187*, 576. [CrossRef] [PubMed]
23. Mosavi, A.; Golshan, M.; Janizadeh, S.; Choubin, B.; Melesse, A.M.; Dineva, A.A. Ensemble models of GLM, FDA, MARS, and RF for flood and erosion susceptibility mapping: A priority assessment of sub-basins. *Geocarto Int.* **2020**, *37*, 2541–2560. [CrossRef]
24. Al-Juaidi, A.E.M.; Nassar, A.M.; Al-Juaidi, O.E.M. Evaluation of flood susceptibility mapping using logistic regression and GIS conditioning factors. *Arab. J. Geosci.* **2018**, *11*, 765. [CrossRef]
25. Hong, H.; Panahi, M.; Shirzadi, A.; Ma, T.; Liu, J.; Zhu, A.X.; Chen, W.; Kougias, I.; Kazakis, N. Flood susceptibility assessment in Hengfeng area coupling adaptive neuro-fuzzy inference system with genetic algorithm and differential evolution. *Sci. Total Environ.* **2018**, *621*, 1124–1141. [CrossRef]
26. Wang, Y.; Fang, Z.; Hong, H.; Costache, R.; Tang, X. Flood susceptibility mapping by integrating frequency ratio and index of entropy with multilayer perceptron and classification and regression tree. *J. Environ. Manag.* **2021**, *289*, 112449. [CrossRef] [PubMed]
27. Ghosh, A.; Kar, S.K. Application of analytical hierarchy process (AHP) for flood risk assessment: A case study in Malda district of West Bengal, India. *Nat. Hazards* **2018**, *94*, 349–368. [CrossRef]
28. Kazakis, N.; Kougias, I.; Patsialis, T. Assessment of flood hazard areas at a regional scale using an index–based approach and Analytical Hierarchy Process: Application in Rhodope–Evros region, Greece. *Sci. Total Environ.* **2015**, *538*, 555–563. [CrossRef]
29. Echogdali, F.Z.; Boutaleb, S.; Elmouden, A.; Ouchchen, M. Assessing Flood Hazard at River Basin Scale: Comparison between HECRAS–WMS and Flood Hazard Index (FHI) Methods Applied to El Maleh Basin, Morocco. *J. Water Resour. Prot.* **2018**, *10*, 957–977. [CrossRef]
30. Kundzewicz, Z.W.; Kanae, S.; Seneviratne, S.I.; Handmer, J.; Nicholls, N.; Peduzzi, P.; Mechler, R.; Bouwer, L.M.; Arnell, N.; Mach, K.; et al. Flood risk and climate change: Global and regional perspectives. *Hydrol. Sci. J.* **2014**, *59*, 1–28. [CrossRef]
31. Sipos, G.; Blanka, V.; Mezősi, G.; Kiss, T.; van Leeuwen, B. Effect of climate change on the hydrological character of River Maros, Hungary-Romania. *J. Environ. Geogr.* **2014**, *7*, 49–56. [CrossRef]
32. Yamamoto, K.; Sayama, T. Impact of climate change on flood inundation in a tropical river basin in Indonesia. *Prog. Earth Planet. Sci.* **2021**, *8*, 5. [CrossRef]
33. Gusarov, A.V.; Sharifullin, A.G.; Komissarov, M.A. Contemporary long-term trends in water discharge, suspended sediment load, and erosion intensity in river basins of the North Caucasus region, SW Russia. *Hydrology* **2021**, *8*, 28. [CrossRef]
34. Dill, H.G.; Kaufhold, S.; Techmer, A.; Baritz, R.; Moussadek, R. A joint study in geomorphology, pedology and sedimentology of a Mesoeuropean landscape in the Meseta and Atlas Foreland (NW Morocco). A function of parent lithology, geodynamics and climate. *J. Afr. Earth Sci.* **2019**, *158*, 103531. [CrossRef]
35. Sdzuy, K.; Geyer, G. The base of the Cambrian in Morocco. In *The Atlas System of Morocco*; Jacobshagen, V.H., Ed.; Springer: Berlin/Heidelberg, Germany, 1988; pp. 91–106. [CrossRef]
36. Benssaou, M.; Hamoumi, N. Le graben de l'Anti–Atlas occidental (Maroc): Contrôle tectonique de la paléogéographie et des séquences au Cambrien inférieur. *Comptes Rendus Geosci.* **2003**, *335*, 297–305. [CrossRef]
37. Soulaimani, A.; Bouabdelli, M. Le Plateau de Lakhssas (Anti–Atlas occidental, Maroc): Un graben fini–précambrien réactivé à l'hercynien. *Ann. Soc. Géol. Nord.* **2005**, *2*, 177–184.
38. IUSS Working Group WRB. World Reference Base for Soil Resources 2014, update 2015. International soil classification system for naming soils and creating legends for soil maps. In *World Soil Resources Reports*; FAO: Rome, Italy, 2015; p. 182.
39. Patrikaki, O.; Kazakis, N.; Kougias, I.; Patsialis, T.; Theodossiou, N.; Voudouris, K. Assessing flood hazard at river basin scale with an index–based approach: The case of Mouriki, Greece. *Geosciences* **2018**, *8*, 50. [CrossRef]
40. Bennani, O.; Druon, E.; Leone, F.; Tramblay, Y.; Saidi, M.E.M. A spatial and integrated flood risk diagnosis: Relevance for disaster prevention at Ourika valley (High Atlas–Morocco). *Disaster Prev. Manag.* **2019**, *28*, 548–564. [CrossRef]
41. Elkhrachy, I. Flash flood hazard mapping using satellite images and GIS tools: A case study of Najran City, Kingdom of Saudi Arabia (KSA). *Egypt J. Remote Sens. Space Sci.* **2015**, *18*, 261–278. [CrossRef]
42. Yoo, C.; Cho, E.; Na, W.; Kang, M.; Lee, M. Change of rainfall–runoff processes in urban areas due to high–rise buildings. *J. Hydrol.* **2021**, *597*, 126155. [CrossRef]
43. Aaron, C.; Venkatesh, M. Effect of Topographic Data, Geometric Configuration and Modeling Approach on Flood Inundation Mapping. *J. Hydrol.* **2009**, *377*, 131–142. [CrossRef]
44. Demek, J. *Manual of Detailed Geomorphological Mapping*; Czechoslovak Academy of Sciences: Prague, Czech Republic, 1972.
45. Saaty, T.L. How to make a decision: The analytic hierarchy process. *Eur. J. Oper. Res.* **1990**, *48*, 9–26. [CrossRef]
46. Saaty, T.L. An exposition of the AHP in reply to the paper "remarks on the analytic hierarchy process". *Manag. Sci.* **1990**, *36*, 259–268. [CrossRef]
47. Saaty, T.L. A scaling method for priorities in hierarchical structures. *J. Math. Psychol.* **1977**, *15*, 234–281. [CrossRef]

48. Saaty, T.L.; Vargas, L.G. (Eds.) The seven pillars of the analytic hierarchy process. In *Models, Methods, Concepts & Applications of the Analytic Hierarchy Process*; Springer: Boston, MA, USA, 2012; Volume 175, pp. 23–40. [CrossRef]
49. Koks, E.E.; Jongman, B.; Husby, T.G.; Botzen, W.J. Combining hazard, exposure and social vulnerability to provide lessons for flood risk management. *Environ. Sci. Policy* **2015**, *47*, 42–52. [CrossRef]
50. Hall, J.W.; Tarantola, S.; Bates, P.D.; Horritt, M.S. Distributed sensitivity analysis of flood inundation model calibration. *J. Hydraul. Eng.* **2005**, *131*, 117–126. [CrossRef]
51. Moel, H.D.; Asselman, N.E.M.; Aerts, J.C.J.H. Uncertainty and sensitivity analysis of coastal flood damage estimates in the west of the Netherlands. *Nat. Hazards Earth Syst. Sci.* **2012**, *12*, 1045–1058. [CrossRef]
52. Rahmati, O.; Zeinivand, H.; Besharat, M. Flood hazard zoning in Yasooj region, Iran, using GIS and multi-criteria decision analysis. *Geomat. Nat. Hazards Risk* **2016**, *7*, 1000–1017. [CrossRef]
53. Sorooshian, S.; Nguyen, P.; Sellars, S.; Braithwaite, D.; Agha Kouchak, A.; Hsu, K. Satellite–based remote sensing estimation of precipitation for early warning systems. In *Extreme Natural Hazards, Disaster Risks and Societal Implications*; Ismail-Zadeh, A., Urrutia Fucugauchi, J., Kijko, A., Takeuchi, K., Zaliapin, I., Eds.; Cambridge University Press: Cambridge, UK, 2014; Volume 1, pp. 99–112.
54. Cools, J.; Innocenti, D.; O'Brien, S. Lessons from flood early warning systems. *Environ. Sci. Policy* **2016**, *58*, 117–122. [CrossRef]
55. Abbasi, N.A.; Xu, X.; Lucas-Borja, M.E.; Dang, W.; Liu, B. The use of check dams in watershed management projects: Examples from around the world. *Sci. Total Environ.* **2019**, *676*, 683–691. [CrossRef] [PubMed]
56. Tarchiani, V.; Massazza, G.; Rosso, M.; Tiepolo, M.; Pezzoli, A.; Housseini Ibrahim, M.; Katiellou, G.L.; Tamagnone, P.; De Filippis, T.; Rocchi, L.; et al. Community and impact based early warning system for flood risk preparedness: The experience of the Sirba River in Niger. *Sustainability* **2020**, *12*, 1802. [CrossRef]
57. Bracken, L.J.; Croke, J. The concept of hydrological connectivity and its contribution to understanding runoff-dominated geomorphic systems. *Hydrol. Process.* **2007**, *21*, 1749–1763. [CrossRef]
58. Broadmeadow, S.; Nisbet, T.R. *Opportunity Mapping for Woodland to Reduce Flooding in the Yorkshire and the Humber Region*; Forest Research Monograph; Forest Research: Surrey, UK, 2010; Volume 1, 64p.
59. Dixon, S.J.; Sear, D.A.; Odoni, N.A.; Sykes, T.; Lane, S.N. The effects of river restoration on catchment scale flood risk and flood hydrology. *Earth Surf. Process. Landf.* **2016**, *41*, 997–1008. [CrossRef]