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Quantitative assessment of the relative impacts of different factors on flood susceptibility modelling: case study of Fez-Meknes region in Morocco

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Abstract. The mapping and assessment of flood susceptibility is an integral component of flood mitigation and prevention programs, by determining the most vulnerable regions and the associated characteristics that influence the flood susceptibility. Hence, the aim of the present study is to identify flood-prone areas in the Fez-Meknes region (Morocco) for the first time using a multi-criteria approach, in particular the Analytical Hierarchy Process (AHP) technique and Geographic Information Systems (GIS). A total of fifteen conditioning factors for flooding were selected: distance to rivers, river network density, precipitation, flow accumulation, elevation, slope, plane curvature, TWI, aspect, NDVI, LULC, TRI, geology, soil type, and SPI. All factors were defined as raster data sets with a resolution of 30 x 30 m. The results showed that, the efficiency tests of the flood susceptibility map show a good accuracy using an area under the curve (AUC) by remarkably good number (0.90).in addition, LULC was recognized as the most significant factor, which is followed by the stream power index that affect the flood map.

1 Introduction

Many hydrological techniques have been developed in the past to forecast floods [1]. Due to extensive human activity during the Anthropocene period, such as the construction of dams, spillways, and other engineering constructions, the majority of natural rivers now have radically altered flows, making it difficult to predict floods using only hydrological data. As a result, the barrier to accessing hydrological data has made it difficult to understand the overall mechanism of flooding and susceptibility. In addition, the lack of data accessibility is one of the main limitations of hydrological modelling. In fact, the hydrological assessment of floods is usually carried out at a specific site within the watershed (usually the areas around the flow measurement stations). Therefore, for watershed or a larger area, the above-mentioned methodology cannot be used effectively. This is why, even in developed countries, a complete map of flood risk in a basin is an expensive and hard task. Recently, the integrated application of multi-criteria decision support systems and Geographic Information Systems (GIS) has been successfully applied in different studies for instance mapping of flood sensitivity [2] ; environmental studies geo-environmental studies natural hazards land delimitation, etc.). In this context, many studies have presented their strategies for susceptibility to flooding. One of the most frequently (more than 80% of published articles) used methods to apply a multi-criteria decision-making system to optimize decision-making based on a set of qualitative, quantitative, and sometimes contradictory factors is the Analytical Hierarchy Process (AHP) developed by [3], who proposed a technique consisting of organizing variables in a hierarchy from which the best possible solution is determined by a pairwise comparison. The literature contains numerous studies on the different effects of topographic, geological, hydrological, and environmental factors on flooding, and each of these studies has used a specific methodology and model [2,4]. To delineate flood-prone areas in the Fez-Meknes region, we used fifteen different variables, including flow accumulation, drainage distance, elevation, land use, precipitation, and geology, which were weighted according to their contribution to the flood maps. Elevation, slope, and distance from the drainage network were the factors with the highest weights of

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influence. Using 10 susceptibility parameters, paper published by [4]) developed a flood susceptibility map for the Kelantan River basin: curvature, digital elevation model (DEM), Resources on Earth, their structure, and the processes that affect them are the main topics of geology[5]. Geological conditions affect floods because the velocity of penetration varies from one geological formation to the next [4]. The strength of a flood can be affected by such rock characteristics or causes. By creating differing permeable and impermeable rocks, the geology influences catchment runoff [5].Distance of river, The stream power index (SPI), rainfall, land use/cover, soil type, Topography wetness index (TWI), and slope. Other authors used in flood susceptibility mapping are such (NDVI),Topographic ruggedness index (TRI), drainage density, aspect [4]. All flood susceptibility maps developed in these studies were validated against observed flood records. It seems that there is no exact method that establishes the appropriate criteria effect on floods. Therefore, the approach used in this study was based on previous published articles to identify the most crucial criteria that have a remarkable impact on the flood. Until now and to our knowledge, for the first time, the quantitative assessment of the relative impacts of different factors on flood susceptibility modellinghas been checked. However, no research has been done on the topic of flood risk categorization with the intention of being used to flood management, planning, and control in this region. According to the Secretary of State for Water and the Environment, floods have oftenoccurred in Morocco, particularly in the Fez-Meknes region, and have caused significant economic damage and fatalities. The objective of this map is to assist local managers and decision makers in creating and implementing appropriate strategies of land use management and spatial planning,

2 Study area

Fez-Meknes region is located in the north-central part of Morocco. Due to its history and geographical location in the heart of Morocco, the region of Fez-Meknes Figure 1, is a strategic crossroads for various activities, economic handicrafts, cultural and for the internal and external animation of exchanges, with an area of 23884.73 Km², representing 5.7% of the Kingdom's surface area. The region of Fez-Meknes is divided into 194 municipalities, 33 of which are urban and has a population of 3158467.00 inhabitants (13% of the total population)

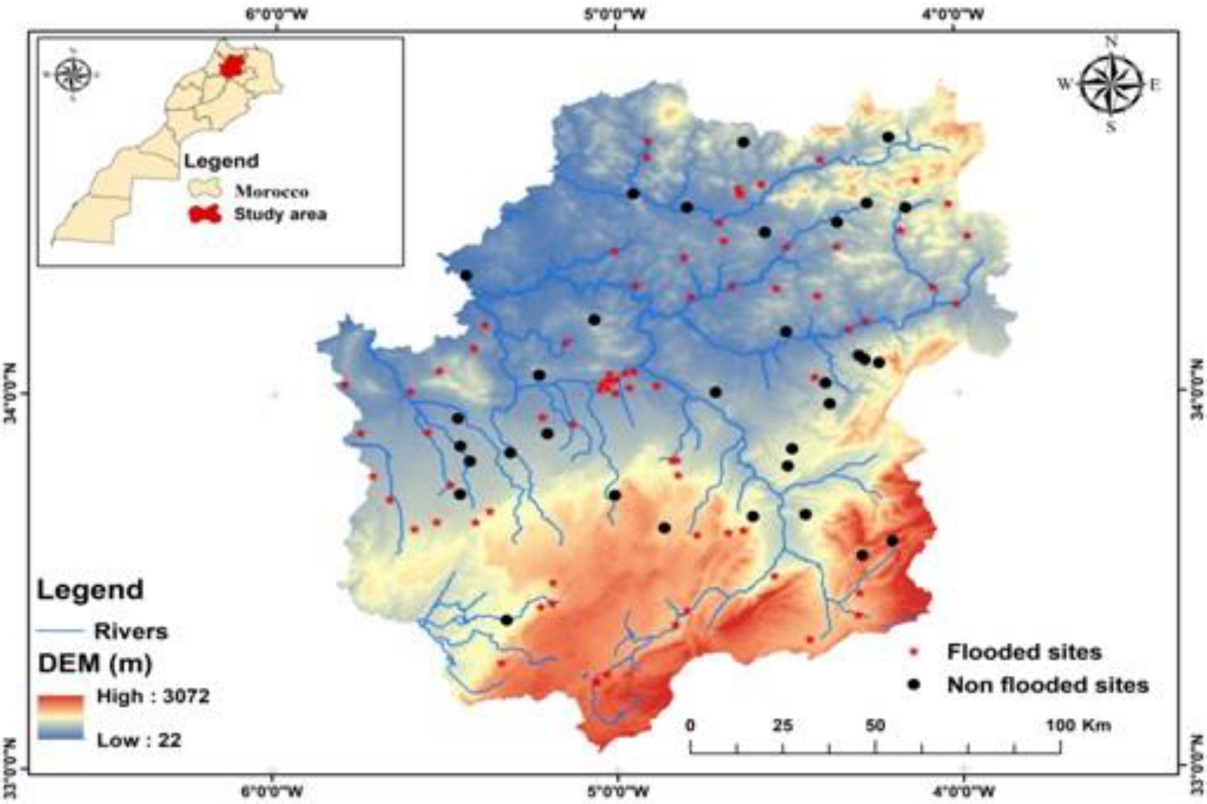

Fig. 1. Historic flood sites in Fes-Meknes region.

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3 Materials and methods

3.1 Data processing and selection of susceptibility factors

Fifteen variables were identified in the Fez-Meknes region for this analysis based on the previous literature, as shown in Table 1.

Table 1. Classification of conditioning factors.

Parameters	Effective factors
Topographical	1. Elevation, 2. Slope, 3. Plan curvature, 4. Aspect 5. Topography wetness index (TWI) 6. Stream power index (SPI), 7. topographic ruggedness index (TRI);
Geological	8. Geology,9. Soil type;
Hydrological	10. Drainage density, 11. Distance to the stream 12. Rainfall, 13. Flow accumulation;
Environmental	14. Land use/land cover (LULC), 15. Normalised difference vegetation index (NDVI).

3.2 Assignment of weights for susceptibility factors

3.2.1 Map of the flood inventory

The flood inventories included 33 non-inundated sites and 75 flooded sites. The ABHS was used to pick the flooded and unflooded sites for the inventory. Figure 1 displays the distribution of historically flooded sites based on inventory.

3.2.2 Sensitivity analysis

There are a number of flood susceptibility-related components that go into developing a flood susceptibility model. In the past, numerous flood susceptibility models based on various criteria have been investigated[15]. A sensitivity analysis of the chosen factors was performed to validate the sensitivity of the results to changes in the list of sensitivity factors considered in the analysis. This analysis was done in order to understand how each factor affects the final flood susceptibility map and to develop an appropriate flood susceptibility model for the Fez-Meknes region.

Flood sensitivity is affected by the parameters already listed in Table 2. Different weightings are produced when some susceptibility factors are removed from the model.

3.2.3 Analytical Hierarchy Process (AHP) for multiple-criteria decision-making

To get the intended result, the AHP model was applied from several angles, such as landslide assessment[6,7], gully erosion susceptibility [8] , ground water assessment [9–11] as well as flood susceptibility mapping [15,16]. Several studies have been conducted to predict flood risk using this model [14]. It has been reported as an effective, intelligible, affordable, and convenient multiple-criteria decision-making approach. The AHP concept is based on multiple steps [3]: (1) selection of different multi-criteria parameters; (2) determination of a hierarchical order of the selected parameters; (3) establishing subjective values on things to identify their relative importance; (4) setting priorities by combining the evaluations. This methodology is most helpful for industrialized nations and the area where there is a lack of acceptable data.

3.3 Flood susceptibility map

3.3.1 Flood susceptibility index

Before determining the Flood Susceptibility Index (FSI) in the GIS module, the values are multiplied by 100 after determining the relative relevance of each component and its subcategories. It has been characterised as follows, based on conditional factors and their relative influence:

$$FSI = (W_{Fi} \times R_{Fi})$$

The flood sensitivity classes were created and the total area of each class was validated against the historical flood records in the research area, where W is the weight of the factors, Ri denotes the rank value of the subcategories, and n is the number of factors.

- Case 1: all factors have been taken into account,
- Case 2: the removal of LULC,
- Case 3: SPI factor was not considered,
- Case 4: model established by [2] approach based on 7 susceptibility factors: Flux accumulation, elevation, land use, Slope, Distance to Drainage System, Annual rainfall, and geology.
- Case 5: approach of [16] based on 4 factors: Elevation, slope, distance to River, and LULC,
- Case 6: model established by [4] using various flood conditioning factors: Elevation, Slope, Distance from Roads, Distance from Rivers, Rainfall, SPI and TWI.

The acquired results in every case were contrasted to past flood records to determine the impact of each element on the final susceptibility map and to choose the best model suitable for our research area.

3.4 Model evaluation criteria

Model effectiveness was evaluated using statistical criteria. For both the training and validation data set, the training data results indicate the degree of adequacy, while the validation results provide information on the predictive capability of the proposed model data set [17].

The results of the different model predictions were evaluated: The number of pixels successfully identified as positive (flooding) forecasts, known as True Positives (TP), and the number of pixels correctly identified as negative (non-flooding) predictions, known as True Negatives (TN). In addition, we assessed the number of pixels that were incorrectly identified as positive (flood) or negative (non-flood), respectively, false positives (FP) and false negatives (FN).

$$\text{Sensitivity}=\frac{TP}{TN+FN} \quad \text{(Eq.1)}$$

$$\text{Specificity} =\frac{TN}{TN+FP} \quad \text{(Eq.2)}$$

$$\text{Accuracy}= \frac{\text{TP+TN}}{\text{TP+TN+FP+FN}} \quad \text{(Eq.3)}$$

$$\text{Kappa}== \frac{L_0-L_e}{L_t-L_e} \quad \text{(Eq.4)}$$

The expected Agreement ("L_e"), the actual Agreement ("L_o"), and the total Agreement ("L_t") are all represented by the kappa coefficient or Kappa index. One of the most significant and frequently used techniques in spatial modeling is receiver operating characteristic curve (ROC) analysis, which is a comprehensive visual tool to summarize the relationship between sensitivity and specificity, as well as a standard technique for evaluating the performance of models [19]. Two statistical indices, "sensitivity" and "specificity 100," can be traced on the vertical and horizontal axes, respectively, to create this curve [20]. The area under curve (AUC) is a recognized method for validating these MCDM models due to its simplified structure, completeness, and reasonable agreement with the forecast [5]. In this work, historical floods were used as effect data. The area under the curve (AUC) has the ability to objectively predict whether an event will occur or not [19]. A value of 1, below the zone, shows maximum precision without any bias effect. Overall, an AUC value greater than 0.9 considered a very accurate model, while an AUC value between 0.7 and 0.8 judged an acceptable model.

4 Results and Discussion

4.1 Effect of factors on flood susceptibility map

Numerous factors associated with geological, hydrological, topographical, and morphological circumstances have an impact on flooding. In this study, 15 criteria were used to assess the sensitivity of the Fez-Meknes region (Morocco) to flooding.

The relative weights of the pairwise flood control component were compared and evaluated using a multicriteria decision analysis. Following the method of [3] to estimate the associated numbers from 1 to 9 on the basic AHP scales, the weights of the causal variables were further investigated. The final flood susceptibility maps were then created by integrating all criteria in a GIS environment, and using the natural breaks approach, the different maps were classified into five groups (Table 2 and Figure 2).

Table 2. The distribution of the flood prone areas for each case studied

	Percentage of area prone to flood in each classe					
	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Very low	13.65	12.77	13.67	13.65	13.66	13.48
Low	29.65	24.72	30.70	30.07	0.71	0.97
Moderate	9.63	28.04	19.54	20.63	29.11	28.09
High	10.99	23.02	34.20	19.27	20.94	22.14
Very high	36.08	11.45	1.88	16.87	36.18	36.32

Some susceptibility factors have a larger influence than others on the final maps. LULC and SPI tend to have a greater impact on the flood maps obtained than other factors Figure 2. The distribution of the flood-prone areas for each case studied was presented in Table 2 and Figure 2 shows the final flood susceptibility map for the Fez-Meknes region for cases presented earlier. If all selected susceptibility factors were taken into account, 47% of the total area was determined to be high and very high flood susceptibility. These flood susceptibility zones will be mainly located in urban areas within center, southeastern, northeastern regions of the Fez-Meknes Figure 2(a). On the other hand, if LULC is not considered as a susceptibility factor, the susceptibility zones will be found throughout the study area, even in rural areas Figure 2(b). This shows the crucial role of LULC as a susceptibility factor. Figure 2(c) shows that by eliminating SPI from the model, the susceptibility zones will mainly locate within the center, northeast, southeastern part of the Fez-Meknes region, the high and very high classes were spread on 36% of the study area. If the same susceptibility factors are used as in [2], approximately 57% of the study area is covered by high and very high flood potential. The susceptibility zones will be mainly located within the center, southeastern, northeastern, southern, and southwestern part of the study area.

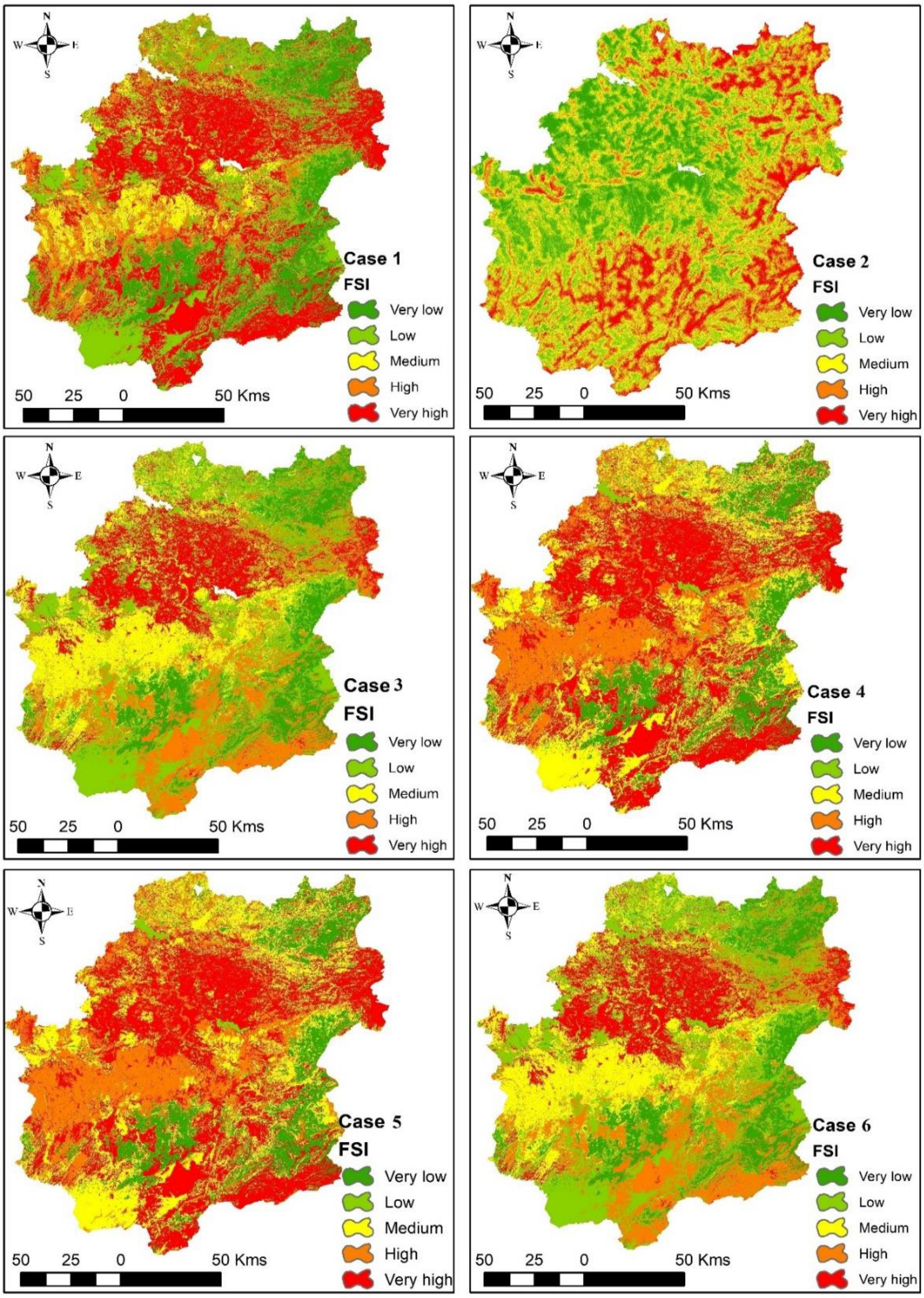

Fig. 2. The distribution of flood-prone areas for each case studied: (a) Case 1: All factors have been taken into account, (b) Case 2: The removal of LULC, (c) Case 3: SPI factor was not considered, (d) Case 4: Model established by reference [2] (e) Case 5: Approach of reference[16] (f) Case 6: Model established by reference [4].

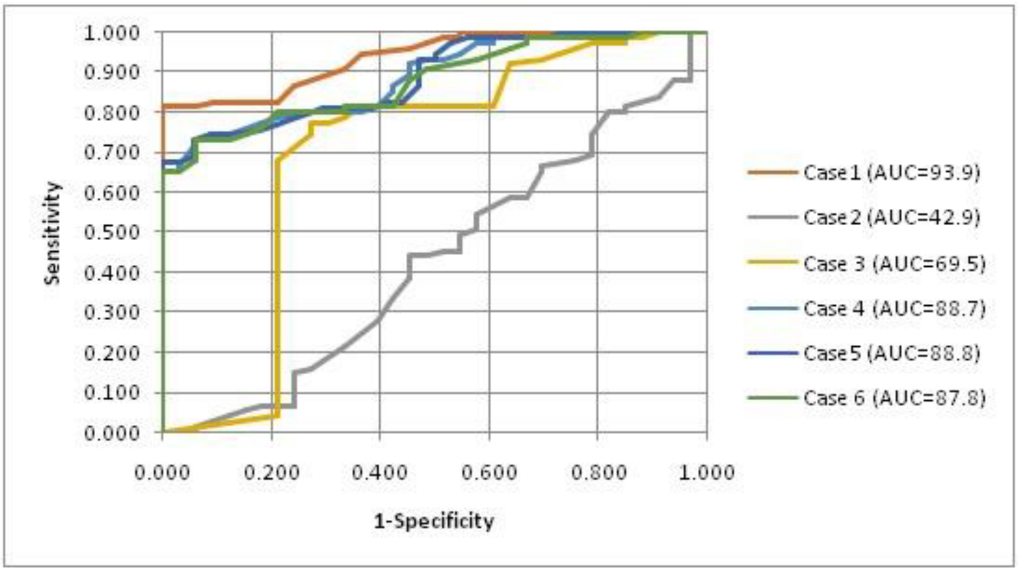

Fig. 3. AUC index-based assessment of flood susceptibility maps.

Together, if [16] approach and [4] were adopted, the high and very high flood susceptibility quantifies more than 58% and 36% of Fez-Meknes region.

In order to assess and compare the accuracy of each model, the results are validated to determine the superiority of the models. To do this we used the receptor operating characteristic (ROC) in this field of study. The area under the curve AUC is used to make a quantitative estimate and to compare the methods used to determine the flood sensitivity map. The receiver operating characteristic (ROC) is a widely accepted standard procedure used to define model performance, particularly in spatial modelling [18].

According to the AUC calculation, Case 1 where all factors are taken into account is the best performing model with an AUC equal to 0.94, the elimination of LULC and SPI lead to AUC value of 0.43 and 0.69 respectively. The models developed by [5], [2], and [17], which were used in this investigation, however, displayed an Area under the roc curve of 0.89, 0.88, and 0.89, correspondingly (Figure 3 and Table 3).

Table 3. Performance of the different model established.

Metrics	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
TP	30	17	16	21	22	21
TN	62	33	61	60	60	60
FP	13	42	14	15	15	14
FN	3	16	17	12	11	13
Sensitivity	0.91	0.52	0.48	0.64	0.67	0.62
Specificity	0.83	0.44	0.81	0.80	0.80	0.81
PPV (%)	69.77	28.81	53.33	58.33	59.46	60.00
NPV (%)	95.38	67.35	78.21	83.33	84.51	82.19
Kappa	0.68	-0.04	0.31	0.43	0.45	0.43
AUC	0.94	0.43	0.69	0.89	0.88	0.89

The tools used to classify flood and non-flood points by Equations (1) and (2) are sensitivity and specificity (2). The model's sensitivity value (0.91), which demonstrated the high performance of categorization flood points, is highest when all factors are considered. Case 4: 0.64%, Case 6: 0.67%, and Case 5: [5] are next in line: 0.62%. The model has the highest specificity value 0.83%, which indicates the high performance of the classification of non-flooded points. Case 15, in which the factor SPI was eliminated, was followed by Case 5: 0.81%, Case 4 : 0.80%, and Case 6: 0.80%. On the other hand, the specificity value showed the same trend as the sensitivity when all factors were taken into account 0.80. The Kappa index shown in Table 3 demonstrates that the prediction level is much greater at case 1 when all factors were taken in account Table 3. This suggests that even if the results are still good (AUC=0.69 %), omitting SPI from the model slightly reduces the accuracy of the flood susceptibility map created. However, the model will not be able to accurately predict the locations of historical flood records if LULC is not taken into account as a susceptibility factor.

We also assessed how the models developed by statistical inference varied from one another. The Friedman test reveals that there are performance differences between the new model and all of the reference models at the 95% confidence level Table 4.

Table 4. The Frideman's test average rank of the flash flood susceptibility models for the research area.

No	Flood models	Mean Rank	χ^2	Significance
1	Case 1	3,40	31,541	,000
2	Case 2	2,99		
3	Case 3	3,76		
4	Case 4	3,63		
5	Case 5	3,65		
6	Case 6	3,57		

Using the Wilcoxon signed ranks test, we look at differences between the models when compared in pairs Table 5. We reject the null hypothesis because Case 1 performs differently at the 95% confidencelevel compared to Case 4 and Case 5 models. There is, however, no distinction between Case 1 and Case 6. In conclusion, each data point taken into account will add more information to the model and produce more realistic results using different parameters related to geological, hydrological, topographical and morphological aspects.

Table 5. Models of performance utilizing the Wilcoxon signed-rank test (two-tailed).

No	Pair-wise comparaison	Z-value	P-value	Significance
1	Case 2 - Case 1	-1.987	0.047	No
2	Case 3 - Case 1	-2.982	0.003	Yes
3	Case 4 - Case 1	-2.138	0.033	Yes
4	Case 5 - Case 1	-1.964	0.050	Yes
5	Case 6 - Case 1	-1.500	0.134	No

4.2 Flood susceptibility map of Fez-Meknes region

The final weight of each factor, reflecting its estimated contribution to flood in Fez- Meknes region was: elevation (17,44%), slope (15.27%), distance to drainage network (12.53%), drainage density (10.01%), flow accumulation (7.9%), Topography wetness index (7,14 %) , Rainfall (5.99%) land use/ land cover (4,52%) ,soil type (3,83%), aspect (3,78 %) , geology (3,08 %) , topographic ruggedness index (2,77%), standardized vegetation index (2,12%) , stream power index (2,05%) and plan curvature (1,57%).

As illustrated in Figure 4, the final flood susceptibility map for the region of Fez-Meknes has been categorized as follows: very high, high, moderate, low, and very low susceptibility. The estimated area of each class is presented in Table 4 : 13.65% (3224.20 Km²) , 29,65% (7004.37 Km²), 9,62 % (2273.90Km²) ,10,98% (2594.84Km²), and 36,08% (8522.73 Km²) of the studied region are respectively classified as very high, high, moderate, low and very low susceptibility zones. As a consequence, approximately 56, 69% of the study area is marked by areas of very high to moderate flood susceptibility, explaining the reasons for recurrent flooding in Fez-Meknes region. Most of the areas of very high and high susceptibility to flooding are located in the urban area of the Fez-Meknes region, as shown in the flood susceptibility map. In general, highly flood-prone areas have the combined characteristics of very low elevation, low slope, and high drainage density, as various researchers have also reported [5,19].

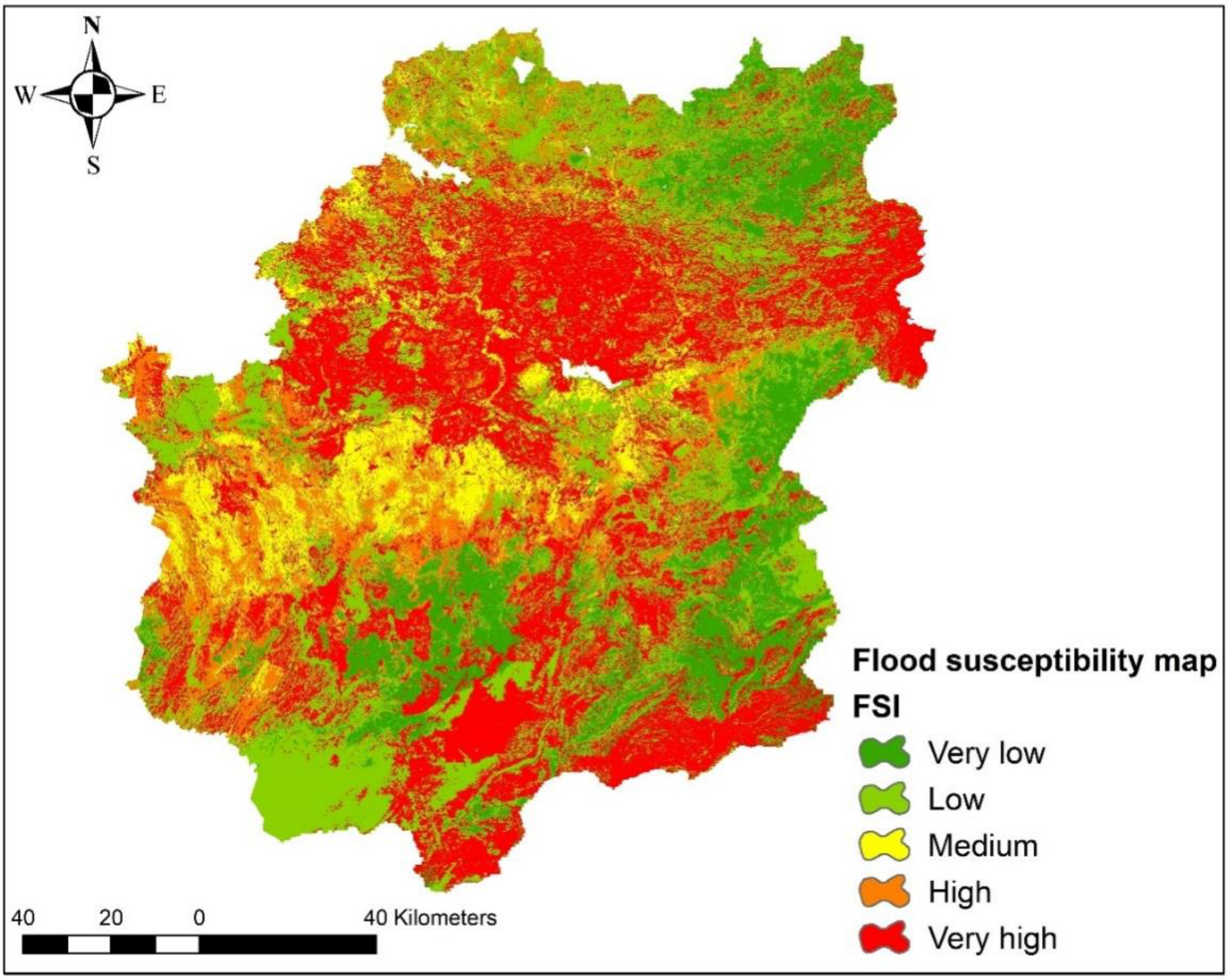

Fig. 4. The final flood susceptibility map.

Towns and urban areas near wadis are susceptible to flooding because, in case of heavy rains, there are also high to moderate sensitivity zones also exist in the core region of Fez-Meknes, there are moderate flood sensitivity sites in Wadi Sebou and the Wadi Mkes, and high sensitivity zones are located mainly in the west-northwestern part of the Fez-Meknes region. Construction sand strong urban activity in the Fez-Meknes region lead to the extension of impermeable surfaces, which considerably reduces the amount of water that has to infiltrate the soil.

5 Conclusion

This study focused on the analysis of flood hazards in the region of Fez Meknes, in a multi-criteria perspective based on Geographic Information Systems (GIS). The significance of every factor contributing to floods and the number of factors to be included in the model must also be checked against historical flood data for the region. It also proposed some strategic measures and sustainable emergency management of flood risks in Fez-Meknes region. Flood risk factors were determined through a review of the literature, personal observations, and expert opinion. Taking the Fez-Meknes region as a case study, AHP was developed to evaluate indicator weights for 15 factors.

The main causes of flooding include strong rain, outdated drainage systems, and the expansion of new urbanization on previously permeable ground. However, the rapid growth of the Fez-Meknes region in a number of directions and the lack of plans, particularly the lack of a mapping and evaluation of flood risk, have led to several floods around the city as a result of persistent rain. The results show that the LULC factor has a major impact on the flood susceptibility map because land use activities such as urbanization, deforestation, and land use can greatly change the monthly and yearly distributions of the stream flow. In particular, changes in land use and management affect the hydrology that determines flood risk. Therefore, municipal urban plans must be harmonized with emergency plans and avoid inconsistencies. The role of researchers in the future will be to find the most appropriate urban plan and modify it throughout the region.

The following recommendations are provided because effective flood risk management in urban settings needs integrated flood risk management strategies (a combination of structural and non-structural measures):

• Vulnerability quantification will give decision-makers relevant data to support loss reduction and disaster preparedness measures, especially in the social category. The likelihood of flood damage will greatly increase after a susceptibility map is complete;

•People's susceptibility can be considerably reduced through legislation, land use planning, building codes, and infrastructure design techniques;
•Urban areas were the most vulnerable; in order to reduce the effects of urban development on flooding and river pollution, a drainage system should be used in urban areas;
• Installation of an urban rainwater infiltration and storage system is useful to minimize the flood hazard;
•Construct water reservoirs for downstream flood reduction and decrease the intensity of flood risks;
• A flood diversion area and a flood storage area must be established to alter the geographical distribution of floods and thus reduce the threat of flooding in densely inhabited regions and property;
• Through effective land use management and spatial planning, it is important to coordinate urban development and flood risk;
• And finally, for sustainable flood risk management, it is necessary to map flood hazards and risks, as well as to divide regions into prohibited areas, restricted areas and development zones.

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