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Contribution of statistical models in flood susceptibility assessment in Essaouira Province-Morocco

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Resumo

As inundações são perigos naturais recorrentes nas regiões norte e central de Marrocos, causando perdas significativas. Este estudo desenvolveu um mapa de suscetibilidade a inundações nas bacias hidrográficas da província de Essaouira utilizando três modelos: Processo de Hierarquia Analítica (AHP), Razão de Frequência (FR) e Pesos de Evidência (WoE). Dez fatores condicionantes; declive, altitude, densidade de drenagem, precipitação, litologia e índice de umidade topográfica..., foram integrados num sistema SIG. A precisão dos modelos, avaliada pela área sob a curva (AUC), superou 90%, indicando alta fiabilidade. As zonas mais suscetíveis situam-se perto da cidade de Essaouira e do rio Ksob.

Palavras-chave: Suscetibilidade a inundações; Processo de Hierarquia Analítica (AHP); Modelo de Razão de Frequência (FR); Pesos de Evidência (WoE); Essaouira; Marrocos.

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Abstract

Floods are recurrent natural hazards in Morocco's northern and central regions, causing considerable losses. This study developed a flood susceptibility map for the Essaouira provincial watersheds using three models: Analytic Hierarchy Process (AHP), Frequency Ratio (FR), and Weights-of-Evidence (WoE). Ten conditioning factors; slope, elevation, drainage density, rainfall, lithology, and topographic wetness index..., were integrated within a GIS framework. Model accuracy, evaluated using the area under the curve (AUC), exceeded 90% for all methods, confirming their reliability. Highly flood-prone zones were mainly identified near Essaouira city along the Ksob River and surrounding rural centers.

Keywords: Flood susceptibility; Analytic Hierarchy Process (AHP); Frequency Ratio (FR); Weights-of-Evidence (WoE); Essaouira; Morocco.

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Introduction

Floods can cause indirect harm, including damage, to transportation systems, cultural landmarks, natural ecosystems, agriculture, bridges and the economy [1–4]. Additionally, floods lead to the loss of thousands of lives and the displacement of millions of people worldwide each year [5–8]. For flood analysis and mapping of flood areas, one popular model within the criteria analysis is the Analytic Hierarchy Process (AHP) method [9]. AHP involves an evaluation process that includes pairwise comparisons of parameters, ranking them accordingly to find the solution for a given problem [10–13]. The ratio (FR) method is an effective statistical technique with a simple yet comprehensible concept [14]. It enables the study of the impact of different factors on flooding occurrences [3,15]. Furthermore, while the weights of evidence (WoE) based method is commonly used for landslide mapping purposes, its application in flood modelling is new [16,17]. WoE utilizes the model for decision-making under uncertain conditions. This makes it suitable for hazard mapping as it considers uncertainties associated with hazard events and their relationships, with landscapes [18].

The Essaouira province in the western coastal region of Morocco has experienced severe flood occurrences in the past due to rapid urbanization. However, conducting an accurate assessment of flood susceptibility is a challenging process due to a lack of data and other obstacles. This paper aims to i) inventory the flood records and their conditioning factors, ii) elaborate susceptibility maps using the AHP model, FR model, and WoE model, and iii) validate the produced susceptibility maps and identify the most accurate one.

Materials and Methods

The study area under consideration in this research encompasses the province of Essaouira, located on the western side of the

High Atlas mountains in Morocco [19], and covers an area of approximately 6,335 km². The methodology used in the research involved several steps to assess floods susceptibility in the Essaouira province. Firstly, an inventory of flooded points was created, followed by assessing several conditioning factors responsible for the occurrence of floods. The next step involved combining remote sensing and geospatial analysis, as well as the use of the AHP, FR, and WoE models to produce flood hazard potential maps, and the most accurate map was chosen. Field surveys and validation were used to support the preparation of the data sources used in the analysis.

Results

Flood inventory and conditioning factors

The province of Essaouira experienced flooding in the city of Essaouira due to the malfunctioning of the stormwater drainage system. Other floods, caused by water inputs from peri-urban basins surrounding the centers (particularly Smimou, Essaouira, Igouzoulene, Ksob, Mejj, Tamarar, and others), led to runoff that posed a threat to the safety of residents and their properties. The flood inventory map was divided into two subsets: 70% for training and 30% for testing, following the methodology suggested by Ohlmacher and Davis 2003 [20]. After preparing the dataset, each of the 10 conditioning factors was transformed into a grid spatial database of 12.5 × 12.5 meters. The grid covered the entire Essaouira Province with an area of 6,224 km²[19].

Susceptibility modelling and validation

Analytic Hierarchy Process (AHP): After the application of weighting to all conditioning factors, the final flood susceptibility map was generated. The map was classified using the natural breaks (Jenks) grading method, as illustrated in Figure 1. In the context of the AHP method, this classification approach is considered the most suitable for delineating

flood susceptibility zones [18,19].

Regarding the distribution of flood susceptibility classes in area percentage, the lowest share was observed in the very high (0%) and very low (0.01%) classes. The high flood susceptibility class covers an area of 1.48%, while the low susceptibility class represents 31.84% of the study area. The largest share (66.67%) is attributed to the moderate flood susceptibility class.

Regarding the spatial distribution, the AHP analysis results indicate that no areas in the Essaouira province are classified as very highly susceptible to flood occurrence. However, there are areas with a high susceptibility to floods. These include Oued Ksob near Diabat village and Essaouira city, Guazoua village located in the south of Essaouira, Oued Tamanar, Oued Smimou, Had Dra village, and Souira Guedima city situated near the outlet of the major Tensift River.

Frequency ratio model (FR): Based on the results of the Frequency Ratio (FR) model, it was determined that 0.51% of the study area in the Essaouira province is categorized as having high to very high susceptibility to flood occurrence, using the Natural Breaks method for classification, which was consistently applied across all models. Conversely, over 96% of the province exhibits very low to low susceptibility to floods.

Analyzing the spatial distribution, the very high class, covering an area of 7 km², is distributed across several locations. This includes Essaouira city, where urban floods have been reported, Diabat Village located near the left limit of Ksob Oued, Smimou village, and the outlet of Ouazzi Oued. The high class, encompassing an area of 24 km², is primarily visible in Tafedna village along the Igouzoulen outlet, Tidzi and Had Dra villages, as well as the El Hanchane - Lagdadra communes situated in relatively flat areas. The remaining area, predominantly at higher altitudes and upstream of the watersheds, is occupied by the very low to low flood susceptibility classes.

Weights-of-evidence (WoE): In the previous section, all the parameters were calculated for each conditioning factor, representing the relationship between the classes of each factor and flood occurrence. Analyzing the Weight of Evidence (WoE) final results, it is evident that the slope with the built-up range of the landuse factor had the highest weight among all other factor classes. This indicates that areas with built-up landuse exhibit maximum susceptibility to flooding in the catchment.

On the other hand, the area of 490 km² classified as “high” susceptibility is predominantly visible upstream of Tafedna village along the Igouzoulen Oued. It also encompasses Oued Tidzi, Had Dra village, and the drains near El Hanchane - Lagdadra communes, along with the outlet of Ouazzi Oued. The remaining classes, namely “very low” to “low” susceptibility, cover the remaining area, particularly in higher altitudes and upstream regions of the watersheds.

About the validation, the AUC values obtained during the validation process for all models. It is worth noting that all landslide susceptibility models with AUC values exceeding 0.9 were considered outstanding, particularly the AHP model.

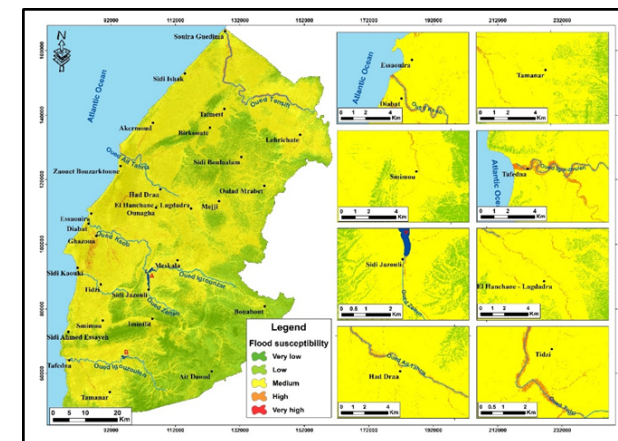


Figure 1. Flood susceptibility map derived from AHP analysis.

Conclusion

In conclusion, utilizing AHP, FR, and WoE models has enabled the classification of flood susceptibility levels in the Essaouira province without explicitly indicating water depth. The province has been categorized into five susceptibility classes. While the areas with high and very high susceptibility occupy smaller proportions, the moderate, low, and very low susceptibility classes cover larger percentages of the study area.

The severity of flood susceptibility is particularly significant in certain localities characterized by low-altitude plains and gentle slopes. These areas, including Essaouira, Smimou, Sidi Jazouli, Tafedna, and others, are exposed to high levels of risk, putting residential, agricultural, and infrastructure areas, such as roads and bridges, in danger of significant damage. The hazard exposure, along with the risk magnitude, ranges from high to very high susceptibility. The analysis of selected factors across all models consistently high-lighted the importance of slope, elevation, and stream order (flow accumulation) in determining flood susceptibility and contributing to flood occurrence.

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