UNIVERSIDADE ABERTA
www.uab.pt

FUTUROS DA ÁGUA
RESILIÊNCIA, GOVERNAÇÃO E ADAPTAÇÃO

02

fevereiro
2026

AD ASTRA
REVISTA ONLINE
DA UNIVERSIDADE ABERTA

FICHA TÉCNICA

AD ASTRA
REVISTA ONLINE DA UNIVERSIDADE ABERTA

PRODUÇÃO
Divisão de Comunicação e Marketing da Universidade Aberta

ISSN
3051-6773

DOI
https://doi.org/10.34627/adastra.v2i1

ÍNDICE

ABDELLAH KHOUZ, JORGE TRINDADE, PEDRO PINTO SANTOS, FATIMA EL BCHARI, SÉRGIO C. OLIVEIRA, RICARDO A. C. GARCIA, ASMA BOUGAYOU, MUSTAPHA IKIRRI, MOURAD JADOUD, SAID RACHIDI, AND BLAID BOUGADIR
Contributo de modelos estatísticos na avaliação da suscetibilidade a cheias na província de Essaouira, Marrocos
Contribution of statistical models in flood susceptibility assessment in Essaouira Province-Morocco

ASMA BOUGAYOU ; ABDELLAH KHOUZ ; FATIMA EL BACHARI; JORGE TRINDADE; MUSTAPHA IKIRRI; SIHAM AFRAOU; FARID FAIK; BLAID BOUGADIR
Avaliação do potencial de águas subterrâneas na área de Ait Abdellah com recurso à deteção remota e SIG
Assessment of groundwater potential in the Ait Abdellah area by using remote sensing and GIS

JOÃO CARRILHO, ABDELLAH KHOUZ, JORGE TRINDADE
Águas subterrâneas na governação do nexo Água-Energia-Alimentação em áreas periurbanas exteriores
Groundwater in the Water-Energy-Food nexus governance in outer peri-urban settlements

GUSTAVO DGEDGE, CELSO CHIVALE, JAIME MAGAIA, JORGE TRINDADE
Avaliação das áreas suscetíveis a cheias na sub-bacia do rio Revúboè, Moçambique
Assessing Flood Susceptibility Areas in the Revúboè river sub-basin, Mozambique

ANDREIA ALVES DA SILVA; LUÍS PEDRO ALMEIDA; ANTÓNIO H.F. KLEIN
Abordagem multiescalar baseada em dados de satélite para a análise de tendências da linha de costa em Portugal Continental
Satellite-driven multi-scale approach for shoreline trend analysis in Mainland Portugal.

ANDREIA ALVES DA SILVA, JORGE TRINDADE; JORGE ROCHA
Avaliação do perigo e da exposição à subida do nível do mar em Portugal Continental
Hazard and Exposure Assessment to Sea Level Rise in Mainland Portugal.

MOHAMED LOUAZANI, ABDERRAFIE EL MAKNISSI
Sistemas de gestão da água nos oásis saariano e o desafio da sustentabilidade face às alterações climáticas: estudo de caso dos oásis de Oued-Noun, sul de Marrocos
The Water Management Systems in Saharan Oases and the Sustainability Challenge in the Face of Climate Change: A Case Study of the Oued-Noun Oases, Southern Morocco.

RICARDO ACÁCIO XAVIER; PEDRO PINTO SANTOS; JOSÉ MANUEL MENDES
Risco de cheias em Moçambique: estratégias comunitárias para a redução da vulnerabilidade a partir de dois estudos de caso
Flood risk in Mozambique: communitarian strategies for vulnerability reduction from two case studies.

SUSANA PEREIRA; JORGE TRINDADE; ANDREIA ALVES DA SILVA; PEDRO PINTO SANTOS; EUSÉBIO REIS; JOSÉ LUÍS ZÊZERE
Perfis de risco de perigos costeiros em Portugal Continental à escala da freguesia
Risk profiles of coastal hazards in mainland Portugal at the civil parish level.

RECENSÕES

PAULO OSÓRIO

História do Pensamento Linguístico-Gramatical em Portugal e no Brasil de Batista, Ronaldo de Oliveira; Fernandes, Gonçalo; Bastos, Neusa Barbosa & Assunção, Carlos (eds) (2025).

JEFFREY CHILDS

Inventions of a Present: The Novel in its Crisis of Globalization, by Fredric Jameson

TESTEMUNHO(S)

HERMANO CARMO

Prémio Armando Rocha Trindade

Contributo de modelos estatísticos na avaliação da suscetibilidade a cheias na província de Essaouira, Marrocos

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

Abdellah Khouz
Jorge Trindade
Pedro Pinto Santos
Fatima El Bchari
Sérgio C. Oliveira
Ricardo A. C. Garcia
Asma Bougayou
Mustapha Ikirri
Mourad Jadoud
Said Rachidi
Blaid Bougadir

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

Abdellah Khouz
Jorge Trindade
Sérgio C. Oliveira
Ricardo A. C. Garcia
Centro de Estudos Globais, Universidade Aberta, Lisbon, Portugal
Centre of Geographical Studies, Institute of Geography and Spatial Planning, Universidade de Lisboa, Lisbon, Portugal
Pedro Pinto Santos
Centre of Geographical Studies, Institute of Geography and Spatial Planning, Universidade de Lisboa, Lisbon, Portugal
Fatima El Bchari
Polydisciplinary Faculty of Safi, Safi, Morocco, Department of Earth Sciences, Cadi Ayyad University, Marrakech, Morocco

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.

Asma Bougayou
Blaid Bougadir
Higher School of Technology Essaouira, Laboratory of Applied Sciences for the Environment and Sustainable Development (SAEDD), Cadi Ayyad University, Marrakech, Morocco
Mustapha Ikirri
Geology Department, Faculty of Sciences, Université Ibn Zohr, Agadir, Morocco
Mourad Jadoud
Faculty of sciences El Jadida, Geosciences and Environmental Techniques Laboratory, Chouaïb Doukkali University, El Jadida, Morocco
Said Rachidi
High School of Technology-Salé, Mohammadia School of Engineers (EMI), Mohamed V University, Rabat, Morocco

0000-0003-4514-5281
0000-0001-5610-5942
0000-0001-9785-0180
0000-0003-0942-1015
0000-0003-0883-8564
0000-0002-1036-6271
0000-0002-9971-6249
0000-0002-6992-4741
0009-0004-1044-784X

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 km^2. 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, Mejji, Tamanar, 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 km^2[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 km^2, 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 km^2, 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 km^2 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.

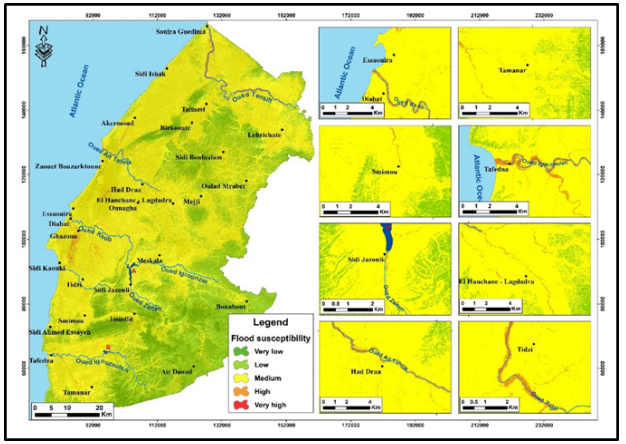

Figure 1. Flood susceptibility map derived from AHP analysis.

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.

References

MESSNER, F.; MEYER, V. Flood Damage, Vulnerability and Risk Perception – Challenges for Flood Damage Research. In *Flood risk management: hazards, vulnerability and mitigation measures*; Springer, 2006; pp. 149–167.

YU, J.; KANG, H.; PARK, D.; BANG, H.-C.; KANG, D.W. An In-Depth Analysis on Traffic Flooding Attacks Detection and System Using Data Mining Techniques. *Journal of Systems Architecture* 2013, *59*, 1005–1012.

KHOSRAVI, K.; POURGHASEMI, H.R.; CHAPI, K.; BAHRI, M. Flash Flood Susceptibility Analysis and Its Mapping Using Different Bivariate Models in Iran: A Comparison between Shannon's Entropy, Statistical Index, and Weighting Factor Models. *Environmental monitoring and assessment* 2016, *188*, 1–21.

MESSNER, F.; MEYER, V. Flood Damage, Vulnerability and Risk Perception–Challenges for Flood Damage Research. In *Flood risk management: hazards, vulnerability and mitigation measures*; Springer, 2006; pp. 149–167.

YU, J.; KANG, H.; PARK, D.; BANG, H.-C.; KANG, D.W. An In-Depth Analysis on Traffic Flooding Attacks Detection and System Using Data Mining Techniques. *Journal of Systems Architecture* 2013, *59*, 1005–1012.

KHOSRAVI, K.; POURGHASEMI, H.R.; CHAPI, K.; BAHRI, M. Flash Flood Susceptibility Analysis and Its Mapping Using Different Bivariate Models in Iran: A Comparison between Shannon's Entropy, Statistical Index, and Weighting Factor Models. *Environmental monitoring and assessment* 2016, *188*, 1–21.

SMITH, J.A.; BAECK, M.L.; ZHANG, Y.; DOSWELL, C.A. Extreme Rainfall and Flooding from Supercell Thunderstorms. *Journal of Hydrometeorology* 2001, *2*, 469–489.

YOUSSEF, A.M.; PRADHAN, B.; HASSAN, A.M. Flash Flood Risk Estimation along the St. Katherine Road, Southern Sinai, Egypt Using GIS Based Morphometry and Satellite Imagery. *Environmental Earth Sciences* 2011, *62*, 611–623.

MAHMOUD, S.H.; GAN, T.Y. Multi-Criteria Approach to Develop Flood Susceptibility Maps in Arid Regions of Middle East. *Journal of Cleaner Production* 2018, *196*, 216–229.

SAATY, T.L. How to Make a Decision: The Analytic Hierarchy Process. *European journal of operational research* 1990, *48*, 9–26.

SAATY, T.L. Decision Making—the Analytic Hierarchy and Network Processes (AHP/ANP). *Journal of systems science and systems engineering* 2004, *13*, 1–35.

MUDASHIRU, R.B.; SABTU, N.; ABUSTAN, I.; BALOGUN, W. Flood Hazard Mapping Methods: A Review. *Journal of hydrology* 2021, *603*, 126846.

MUJIB, M.A.; APRIYANTO, B.; KURNIANTO, F.A.; IKHSAN, F.A.; NURDIN, E.A.; PANGASTUTI, E.I.; ASTUTIK, S. Assessment of Flood Hazard Mapping Based on Analytical Hierarchy Process (AHP) and GIS: Application in Kencong District, Jember Regency, Indonesia. *Geosfera Indonesia* 2021, *6*, 353–376.

LIAO, X.; CARIN, L. Migratory Logistic Regression for Learning Concept Drift between Two Data Sets with Application to UXO Sensing. *IEEE Transactions on Geoscience and Remote Sensing* 2009, *47*, 1454–1466.

TEHRANY, M.S.; PRADHAN, B.; MANSOR, S.; AHMAD, N. Flood Susceptibility Assessment Using GIS-Based Support Vector Machine Model with Different Kernel Types. *Catena* 2015, *125*, 91–101.

DAHAL, R.K.; HASEGAWA, S.; NONOMURA, A.; YAMANAKA, M.; MASUDA, T.; NISHINO, K. GIS-Based Weights-of-Evidence Modelling of Rainfall-Induced Landslides in Small Catchments for Landslide Susceptibility Mapping. *Environmental Geology* 2008, *54*, 311–324.

REGMI, A.D.; DEVKOTA, K.C.; YOSHIDA, K.; PRADHAN, B.; POURGHASEMI, H.R.; KUMAMOTO, T.; AKGUN, A. Application of Frequency Ratio, Statistical Index, and Weights-of-Evidence Models and Their Comparison in Landslide Susceptibility Mapping in Central Nepal Himalaya. *Arabian Journal of Geosciences* 2014, *7*, 725–742.

POURGHASEMI, H.R.; JIRANDEH, A.G.; PRADHAN, B.; XU, C.; GOKCEOGLU, C. Landslide Susceptibility Mapping Using Support Vector Machine and GIS at the Golestan Province, Iran. *Journal of Earth System Science* 2013, *122*, 349–369.

KHOUZ, A.; TRINDADE, J.; OLIVEIRA, S.; EL BCHARI, F.; BOUGADIR, B.; GARCIA, R.; JADOUD, M. Landslide Susceptibility Assessment in Rocky Coast Subsystem of Essaouira Coastal Area – Morocco; Landslides and Debris Flows Hazards, 2022.

OHLMACHER, G.C.; DAVIS, J.C. Using Multiple Logistic Regression and GIS Technology to Predict Landslide Hazard in Northeast Kansas, USA. *Engineering geology* 2003, *69*, 331–343.

FUTUROS DA ÁGUA
RESILIÊNCIA, GOVERNAÇÃO E ADAPTAÇÃO

UNIVERSIDADE ABERTA
www.uab.pt

AD ASTRA
REVISTA ONLINE DA UNIVERSIDADE ABERTA