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Research paper

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The issue of using annual rainfall maps in multi-criteria analysis to identify flood-prone areas

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Summary

Interest in flood risk prevention has been growing steadily in recent years, with multi-criteria analysis frequently used to develop prevention plans. One of the common factors included in these analyses is annual rainfall. This study aims to assess the role of annual rainfall in identifying flood-prone areas, using Geographic Information Systems (GIS) to conduct the research in two stages. The first stage involved identifying at-risk areas using factors such as the Topographic Wetness Index, Height Above Nearest Drainage, proximity to watercourses, and drainage density. In the second stage, these results were integrated with annual rainfall maps, applying consistent weights across both stages. The findings suggest that while rainfall is a crucial factor in flood assessment, its inclusion in multi-criteria analysis may inadvertently distort results. This distortion occurs because rainfall distribution is influenced by topography, making it the only variable criterion among otherwise stable basin characteristics. As a result, rainfall data may shift the focus from lower basin areas, which are typically at greater risk but receive less rainfall, to higher basin areas with more rainfall. Furthermore, the study argues that annual rainfall is not a reliable basis for prevention planning, as it fails to accurately represent the characteristics of rain events – such as intensity, duration, and frequency – that are critical in flood studies. The research highlights the need for more appropriate criteria tailored to the specific study area and emphasizes the importance of developing new methods that focus on the impact of rainfall rather than just its distribution.

Keywords

rainfall • flood • prevention • multi-criteria analysis • drainage basin • Zerdaza • Algeria

1. Introduction

In recent decades, many countries have increasingly prioritized the field of natural disaster prevention to avoid the severe consequences these events can cause [Das 2020, Selvam and Antony Jebamalai 2023]. Today, flood risk prevention is one of the primary concerns of researchers who seek to develop better strategies to mitigate the various damages that may affect different aspects of development [Kumne and Samanta 2023]. This is especially critical given the new challenges posed by climate change, where it has become essential to adopt practical and more precise methods for identifying risk-prone areas [Jemai et al. 2024, Mwalwimba et al. 2024, Tout and Ghachi 2023].

Geographic Information Systems (GIS) offer a broad platform for spatial data analysis [Elsadek et al. 2024, Tout 2023]. In the context of flood risks, GIS provides an opportunity to utilize techniques that overcome many of the obstacles previously encountered in identifying hazard-prone areas. This leads to much more accurate assessments and the development of more realistic prediction models, enabling the preparation of appropriate measures to help prevent various damages [Youssef et al. 2023].

Multi-criteria analysis (MCA) is a technique provided by Geographic Information Systems (GIS) [Al-Hussein et al. 2023, Chelariu et al. 2023, Nkonu et al. 2023]. In the ArcGIS environment, MCA is one of the most commonly used applications and continues to deliver satisfactory results in identifying flood-prone areas. It enables the production of flood vulnerability maps [Al-Juaidi et al. 2018].

Flood vulnerability maps are generated by overlaying various maps that represent factors known to affect a basin's response to water. This process may involve the use of numerous factors, and the selection of these factors is subject to various constraints. Achieving satisfactory and reasonable results depends on using criteria that are truly significant and appropriately describe locations [Abdrabo et al. 2023, Ghosh et al. 2023, Tout 2023], such as the Topographic Wetness Index, Height Above Nearest Drainage, proximity to watercourses, and drainage density.

Due to its importance in creating floods, rainfall is relied upon as an influential factor in the development of protection models using multi-criteria analysis [Bhatta and Adhikari 2024, Dutta and Deka 2024, Jemai et al. 2024, Mshelia et al. 2024, Osman and Das 2023, Wedajo et al. 2024, Yaseen 2024] and this may be due to its known effects, as it is usually responsible for the rise in water levels and is involved in determining the final response of the basin to rainfall and the production of floods.

In this research, we are interested in knowing the feasibility of using rainfall, which is one of the most commonly used factors that sometimes take significant weights in research when producing vulnerability maps, which can significantly affect the resulting maps in identifying vulnerable areas or the level of exposure.

In this context, the research does not discuss the role of short-term rains in the production of floods, as their impact is known, especially with what climate change has brought about in the way they fall in terms of intensity, but discusses the use of rains in general as a contributing factor in the production of vulnerability maps.

2. Study area

Wadi Zerdaza drainage basin Figure 1 belongs to the drainage basin Wadi Safaf 0309, which in turn belongs to the Constantine Coastal Basin 03, located in northeastern Algeria, with an area of 343.8 km², this basin feeds the Zerdaza Dam, which represents its discharge point. The highest point in the basin reaches an altitude of 1211 meters and the lowest to 190 meters, that is, the altitude range reaches 1021 meters, this range in altitude creates a difference even in the distribution of rainfall, where the high areas of the basin generally record higher values of rainfall up to 800 mm per year. The basin has a Mediterranean climate, characterized by dry summers and wet and rainy winters.

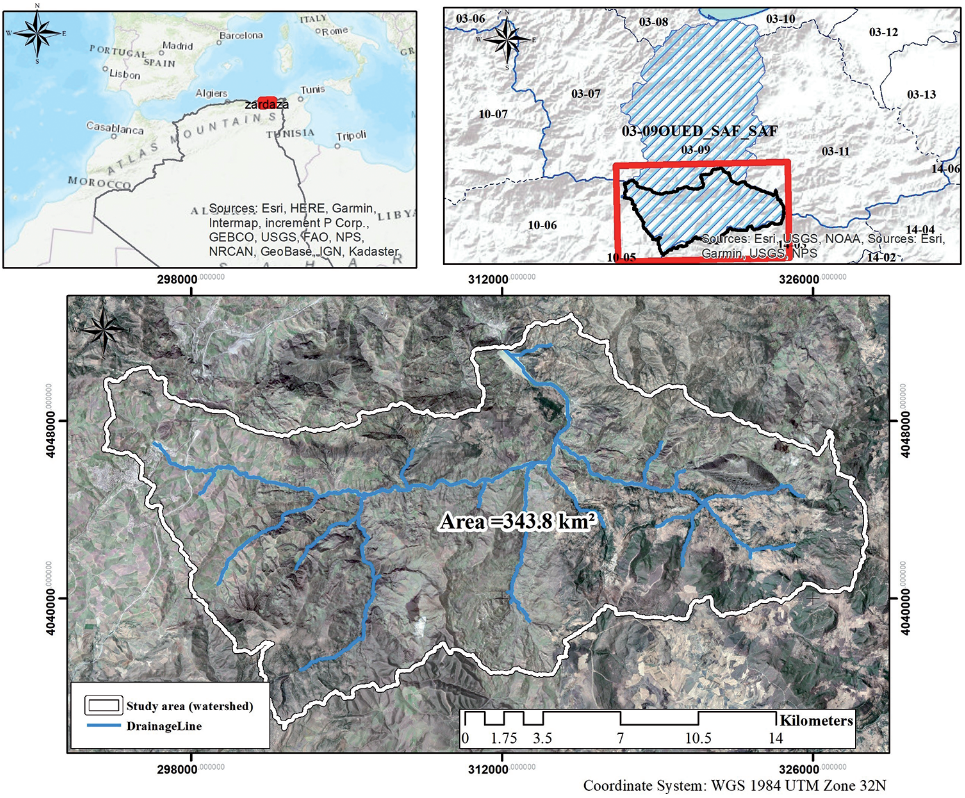

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Fig. 1. Study area

Figure 2 indicates the elevations in the Wadi Zardazza basin, while Figure 3 which was reproduced based on data from the National Agency for Water Resources that shows the distribution of annual rainfall in the basin, indicates the general proportionality between elevations and recorded rainfall values.

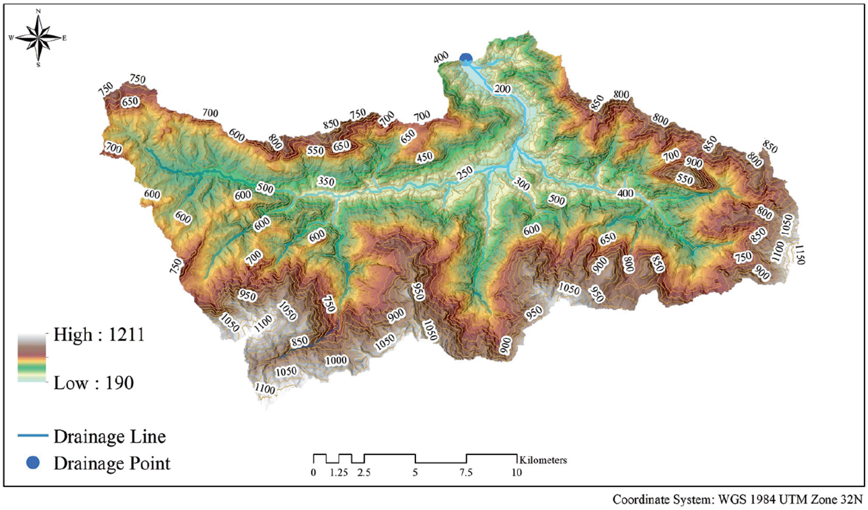

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Fig. 2 . Heights in the study area

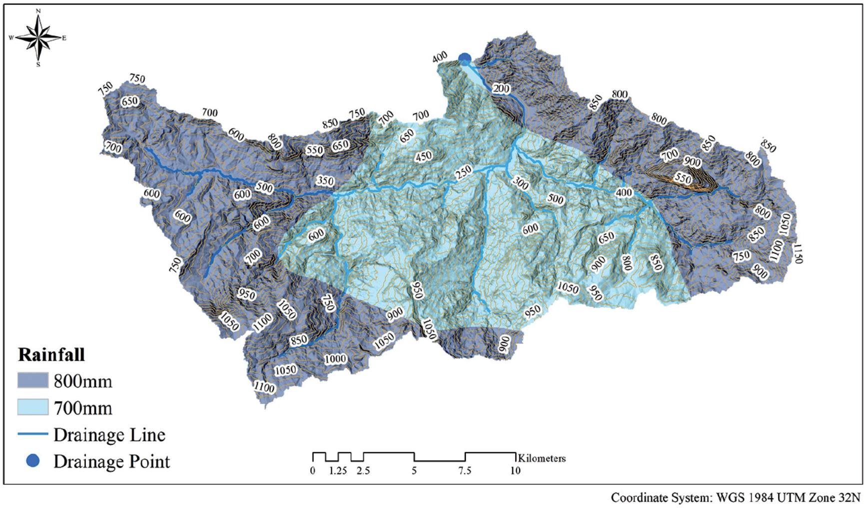

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Fig. 3. General proportionality between elevation and annual rainfall values

3. Methodology

Using one of the GIS tools (ArcGIS), we try to understand the impact of adopting rainfall as a criterion to produce a physical vulnerability map for flood risk, the research was done in two phases. The first phase required the production of a vulnerability map based on some commonly used criteria that have a good meaning in terms of identifying potential flood-prone areas, namely Topographic Wetness Index, Height Above Nearest Drainage, proximity to watercourses, and drainage density, where the same weight was adopted for all criteria. The second stage was done by adopting two criteria: the first criterion, which is the results of the first stage (the map of at-risk areas produced using the previous criteria), and the second criterion, which is the annual rainfall, where the same weight was given to both criteria. These indicators can be considered as derivatives of the srtm digital elevation model, which is available at 30-meter resolution for free on the USGS website and can be defined as follows:

- Topographic Wetness Index: It is an index that refers to topographic factors that affect the spatial distribution of water accumulation [Chowdhuri et al. 2020, Towfiqul Islam et al. 2021] and is used to predict the most flood-prone areas based on topographic features.
- Height Above Nearest Drainage: It is a topographic descriptor that refers to the difference in elevation between the elevation data in the digital elevation model and the points or paths of water discharge and has wide applications in flood simulation [Avila-Aceves et al. 2023].
- Proximity to watercourses: It is considered a critical factor in identifying areas at risk of flooding [Amen et al. 2023], and although it cannot be relied upon without taking into account topographical factors, it can be said that the less likely we are to be exposed to floods the farther away we are from the valley streams.
- Drainage density: It is a commonly used criterion [Arya and Kumar 2023, Ebodé et al. 2024, Forson et al. 2023], found by dividing the total length of valleys and streams by the area of the basin [Burayu et al. 2023], and according to this criterion, areas with high drainage density are more prone to flooding.

In order to facilitate the understanding of the results, each factor was categorized into flood-prone and non-flood-prone areas, where only illustrative classifications were used for all the criteria that entered the first phase. In the second phase of the research, a rainfall value of 800 mm was considered as flood-prone areas and the value of 700 mm as non-flood-prone areas. The Table 1 shows the values indicating flood-prone and non-flood-prone areas according to each criterion.

Table 1. Classification of at-risk areas according to the criteria used

	HAND	TWI	DD	PTW	Rainfall
Flood-prone areas	0–80	>10	0–0.29	0–100	800 mm
Non-flood-prone areas	80–705	0–10	0.29–2.74	>100	700 mm

Figure 4 indicates the criteria that were used, showing the difference in the distribution of vulnerable areas across the basin according to each criterion.

The aim of this methodology is to try to show the impact of using the rainfall map on the potential results of vulnerability maps that rely on the use of multi-criteria analysis, not to clarify the value of one criterion in relation to other criteria or to determine the rainfall values that actually contribute to the production of floods. The adoption of previous classifications cannot be adopted or built upon in a study that aims to actually identify areas at risk, as this matter requires extensive research into the exact impact of each criterion.

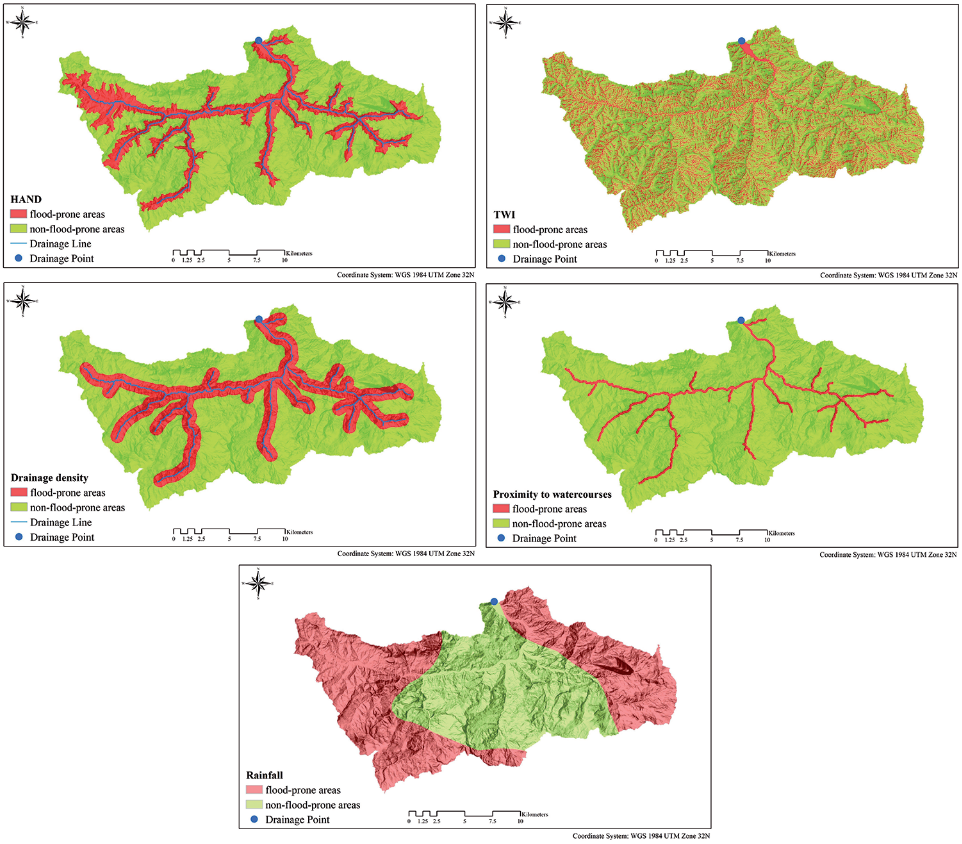

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Fig. 4. Areas at risk according to each criterion

Figure 5 shows the model that was used to produce the overlay map, where the blue colors indicate the input data, yellow the tools, and green the results.

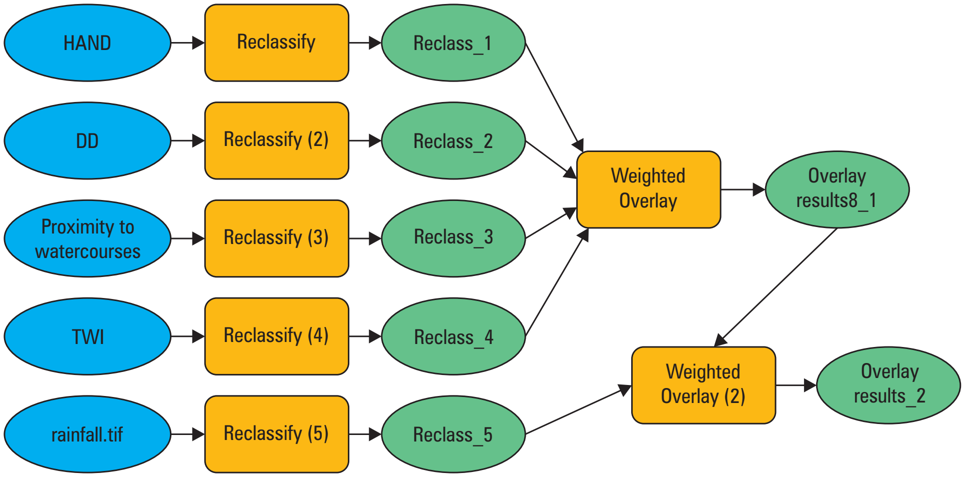

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Fig. 5. The model used to produce vulnerability maps

4. Results and discussion

In Figure 6, which reflects the results of the first phase that did not take into account rainfall, the results indicate the wide extension of the risk areas along the drainage network until the drainage area that represents the Zardaza Dam, these are the areas that provide ideal conditions for flooding and are therefore the most vulnerable, and the areas in green remain non-risky because they do not provide sufficient conditions for flooding according to the criteria used and the weights given to them [Krellenberg and Welz 2017].

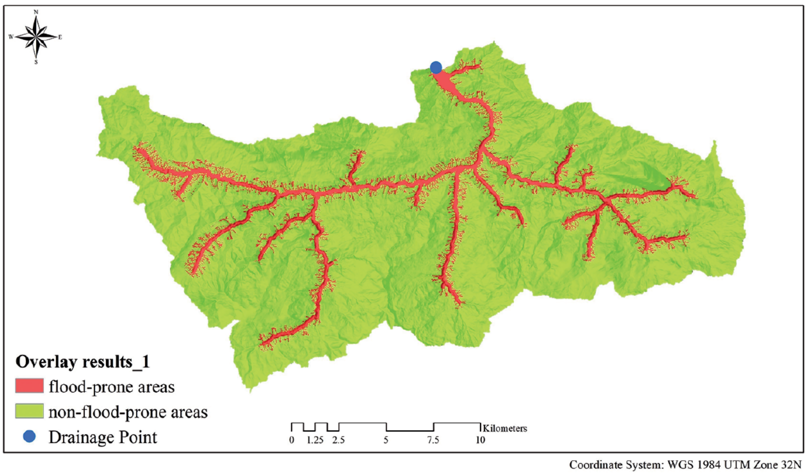

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Fig. 6. Flood-prone areas according to the results of the first phase

In Figure 7, which reflects the results of the second phase that took into account two factors, namely the results of the first phase and the rainfall factor, the map indicates the dispersion of the results, where only areas that share the results of the first phase and the annual rainfall distribution map with a value of 800 mm that was considered the value that corresponds to areas at risk of flooding, and not areas that correspond to the value of 700 mm rainfall, resulting in a large part of the lower areas of the basin being considered as areas not at risk of flooding.

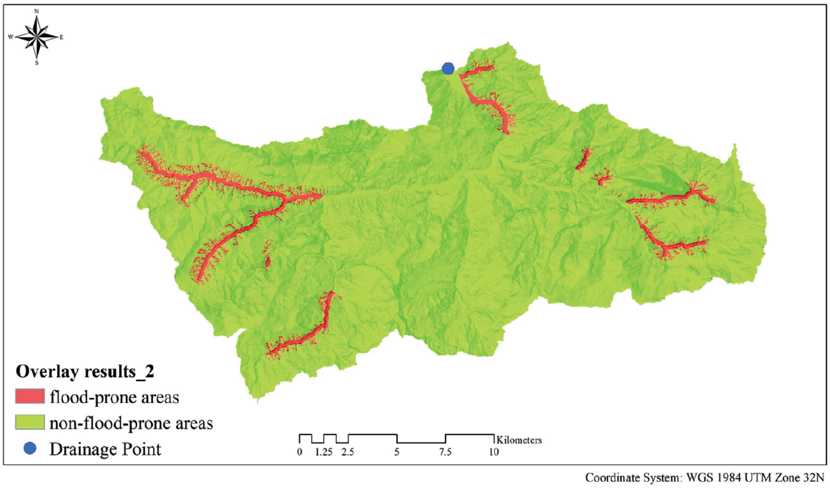

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Fig. 7. Flood-prone areas according to the results of the second phase

This dispersion in the results is due to the adoption of equal weights between the two factors: Phase 1 results and rainfall, which identified areas that corresponded in the classification of at-risk zones.

These results open a debate on the feasibility of using rainfall in general in multi-criteria analysis for predicting flood risk areas and indicate that paying attention to rainfall locations may not provide real help in identifying areas at risk of inundation as it does not adequately characterize the contribution of rainfall to flooding and does not reflect reality correctly.

The adoption of rainfall values and its localized precipitation in identifying vulnerable areas is what led to these results and not the methodology that was adopted, which was based on two stages. Even after using the rainfall criterion with the four criteria that were used in the first stage, namely the Topographic Wetness Index, Height Above Nearest Drainage, proximity to watercourses, and drainage density so that all criteria have the same weight, the results still show dispersion, as the percentage of vulnerable areas at the top of the basin is greater than the areas below Figure 8.

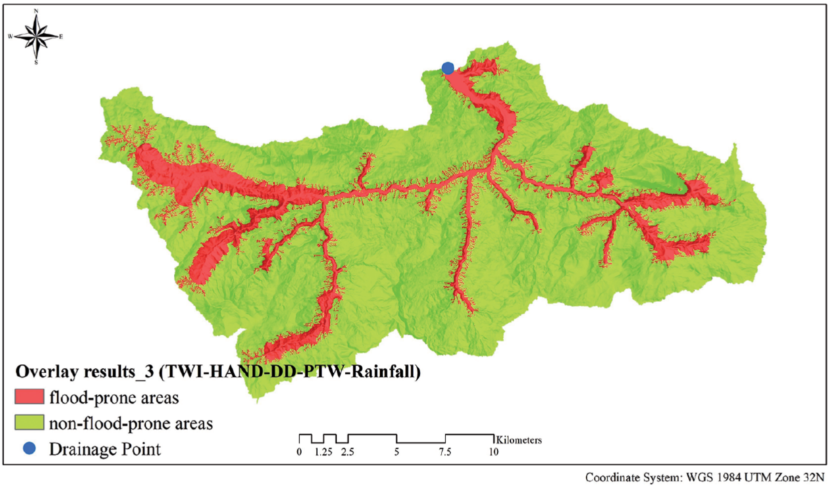

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Fig. 8. Areas at risk after using the first phase criteria with rainfall

These results indicate that although rainfall is one of the factors on which the basin response is based, it does not adequately help in identifying vulnerable areas when adopting multi-criteria analysis, and this is mainly related to the fact that it is a moving factor, unlike other factors, it moves from the top of the basin and from the water division lines to the waterways leading to the discharge points, and therefore its adoption in the current form will lead to dispersion of results instead of improving them.

The research does not indicate that inconsistency in spatial data between criteria is an inappropriate characteristic in research, as inconsistency is basically what makes multi-criteria analysis valuable, especially if appropriate criteria are adopted with their real weights to describe their real impact on the phenomenon under study, but it indicates that rainfall has not yet found the appropriate formula for inclusion in multi-criteria analysis and that this current formula refutes the known inverse relationship between elevations and floods [Megahed et al. 2023].

In addition, annual rainfall cannot really be relied upon for studying floods, as annual maximum daily rainfall and short-term rainfall are usually adopted in methodologies other than multi-criteria analysis to study flood-prone areas [Hendrayana et al. 2024].

Compared to previous studies that consider rainfall as an influential factor in the production of flood vulnerability maps, this study presents new results that could help to further refine the criteria that can be used and may require reconsideration of the results of various previous studies, especially those that relied on large weights for rainfall regardless of the differences in the study areas.

One reason that may have hindered the detection of the negative impact of using rainfall in its current form on vulnerability assessment models is the focus on the model as a whole. Many studies restrict the weights assigned to the model without individually analyzing and evaluating how the rainfall criterion affects the overall results. Additionally, these studies often overlook the actual occurrence of rainfall and the process of rainfall transport through drainage basins. This study not only points to the need to select appropriate criteria that truly reflect the factors contributing to increasing or decreasing the level of vulnerability, but also to the need for a broader study and a more accurate categorization of the values corresponding to vulnerable areas and levels of vulnerability according to each criterion in order to ensure more accurate results.

5. Conclusion

The multi-criteria analysis is considered one of the effective means to develop an appropriate assessment of geographical locations at risk of flooding, one of the reasons for reaching acceptable and logical results requires in the first stage the adoption of expressive criteria that actually affect the production of floods, in our study area the research indicates that the adoption of Topographic Wetness Index, Height Above Nearest Drainage, proximity to watercourses, and drainage density leads to homogeneous and reasonable results confirmed by the topography of the basin, While the adoption of the annual rainfall led to dispersion of the final results, as the criterion considers that the areas that receive larger amounts of water, which are usually the upper areas of the basin, are exposed to a more dangerous level, but this criterion cannot actually be adopted because it considers that the locations of water are fixed across the basin in the places where it falls, which does not reflect the reality, as a high percentage of it moves to waterways and lower areas of the basin and up to the point of discharge. The research indicates that although rainfall in general is important in understanding the response of the basin, its inclusion in prevention models that rely on multi-criteria analysis will not help in obtaining accurate results, the research also indicates that beyond multi-criteria analysis, annual maximum daily rainfall and short-term rainfall are much more important than annual rainfall, which does not provide much help in the study of floods.

References

Abdrabo K.I., Kantoush S.A., Esmaiel A., Saber M., Sumi T., Almamari M., Elboshy B., Ghoniem S. 2023. An integrated indicator-based approach for constructing an urban flood vulnerability index as an urban decision-making tool using the PCA and AHP techniques: A case study of Alexandria, Egypt. Urban Climate, 48 (August), 101426. https://doi.org/10.1016/j.uclim.2023.101426

Al-Hussein A.A.M., Hamed Y., Al-Timimy S.R., Bouri S. 2023. Application of Analytical Hierarchy Process and Frequency Ratio Model for Predictive Flood Susceptibility Mapping Using GIS for the Khazir River Basin, Northern Iraq. Iraqi Geological Journal, 56(2), 118–138. https://doi.org/10.46717/igj.56.2E.9ms-2023-11-14

Al-Juaidi A.E.M., Nassar A.M., Al-Juaidi O.E.M. 2018. Evaluation of flood susceptibility mapping using logistic regression and GIS conditioning factors. Arabian Journal of Geosciences, 11(24). https://doi.org/10.1007/s12517-018-4095-0

Arya S., Kumar A. 2023. AHP GIS-aided flood hazard mapping and surface runoff estimation in Gurugram, India. Natural Hazards, 117(3), 2963–2987. https://doi.org/10.1007/s11069-023-05973-4

Avila-Aceves E., Plata-Rocha W., Monjardin-Armenta S.A., Rangel-Peraza J.G. 2023. Geospatial modelling of floods: a literature review. Stochastic Environmental Research and Risk Assessment, 37(11), 4109–4128. https://doi.org/10.1007/s00477-023-02505-1

Bhatta S., Adhikari B.R. 2024. Comprehensive risk evaluation in Rapti Valley, Nepal: A multi-hazard approach. Progress in Disaster Science, 23 (June), 100346. https://doi.org/10.1016/j.pdisas.2024.100346

Burayu D.G., Karuppannan S., Shuniye G. 2023. Identifying flood vulnerable and risk areas using the integration of analytical hierarchy process (AHP), GIS, and remote sensing: A case study of southern Oromia region. Urban Climate, 51 (April), 101640. https://doi.org/10.1016/j.uclim.2023.101640

Chelariu O.E., Minea I., Iațu C. 2023. Geo-hazards assessment and land suitability estimation for spatial planning using multi-criteria analysis. Heliyon, 9(7), e18159. https://doi.org/10.1016/j.heliyon.2023.e18159

Chowdhuri I., Pal S.C., Chakrabortty R. 2020. Flood susceptibility mapping by ensemble evidential belief function and binomial logistic regression model on river basin of eastern India. Advances in Space Research, 65(5), 1466–1489. https://doi.org/10.1016/j.asr.2019.12.003

Das S. 2020. Flood susceptibility mapping of the Western Ghat coastal belt using multi-source geospatial data and analytical hierarchy process (AHP). Remote Sensing Applications: Society and Environment, 20 (April), 100379. https://doi.org/10.1016/j.rsase.2020.100379

Dutta P., Deka S. 2024. A novel approach to flood risk assessment: Synergizing with geospatial based MCDM-AHP model, multicollinearity, and sensitivity analysis in the Lower Brahmaputra Floodplain, Assam. Journal of Cleaner Production, 467 (March), 142985. https://doi.org/10.1016/j.jclepro.2024.142985

Ebodé V.B., Onguéné R., Braun J.J. 2024. Flood susceptibility mapping in the Tongo Bassa watershed through GIS, remote sensing and frequency ratio model. Hydrology Research, 55(4), 484–497. https://doi.org/10.2166/nh.2024.152

Elsadek W.M., Wahba M., Al-Arifi N., Kanae S., El-Rawy M. 2024. Scrutinizing the performance of GIS-based analytical Hierarchical process approach and frequency ratio model in flood prediction – Case study of Kakegawa, Japan. Ain Shams Engineering Journal, 15(2). https://doi.org/10.1016/j.asej.2023.102453

Forson E.D., Amponsah P.O., Hagan G.B., Sapah M.S. 2023. Frequency ratio-based flood vulnerability modeling over the greater Accra Region of Ghana. Modeling Earth Systems and Environment, 9(2), 2081–2100. https://doi.org/10.1007/s40808-022-01616-y

Ghosh A., Chatterjee U., Pal S.C., Towfiqul Islam A.R.M., Alam E., Islam M.K. 2023. Flood hazard mapping using GIS-based statistical model in vulnerable riparian regions of sub-tropical environment. Geocarto International, 38(1). https://doi.org/10.1080/10106049.2023.2285355

Hendrayana H., Riyanto I.A., Nuha A., Ruslisan. 2024. Multi-Parameter Approach to Determine the Floods Causes in North Luwu, South Sulawesi. IOP Conference Series: Earth and Environmental Science, 1378(1). https://doi.org/10.1088/1755-1315/1378/1/012004

Jemai S., Belkendil A., Kallel A., Ayadi I. 2024. Assessment of flood risk using Hierarchical Analysis Process method and Remote Sensing systems through arid catchment in south-eastern Tunisia. Journal of Arid Environments, 222 (December), 105150. https://doi.org/10.1016/j.jaridenv.2024.105150

Krellenberg K., Welz J. 2017. Assessing Urban Vulnerability in the Context of Flood and Heat Hazard: Pathways and Challenges for Indicator-Based Analysis. Social Indicators Research, 132(2), 709–731. https://doi.org/10.1007/s11205-016-1324-3

Kumne W., Samanta S. 2023. Geospatial Mapping of Inland Flood Susceptibility Based on Multi-Criteria Analysis – A Case Study in the Final Flow of Busu River Basin, Papua New Guinea. International Journal of Geoinformatics, 19(6), 31–48. https://doi.org/10.52939/ijg.v19i6.2693

M Amen A.R., Mustafa A., Kareem D.A., Hameed H.M., Mirza A.A., Szydłowski M., Bala B.K. 2023. Mapping of Flood-Prone Areas Utilizing GIS Techniques and Remote Sensing: A Case Study of Duhok, Kurdistan Region of Iraq. Remote Sensing, 15(4). https://doi.org/10.3390/rs15041102

Megahed H.A., Abdo A.M., Abdel Rahman M.A.E., Scopa A., Hegazy M.N. 2023. Frequency Ratio Model as Tools for Flood Susceptibility Mapping in Urbanized Areas: A Case Study from Egypt. Applied Sciences (Switzerland), 13(16). https://doi.org/10.3390/app13169445

Mshelia Z.H., Nyam Y.S., Moisès D.J., Belle J.A. 2024. Geospatial analysis of flood risk hazard in Zambezi Region, Namibia. Environmental Challenges, 15 (March). https://doi.org/10.1016/j.envc.2024.100915

Mwalwimba I.K., Manda M., Ngongondo C. 2024. Flood vulnerability assessment in rural and urban informal settlements: case study of Karonga District and Lilongwe City in Malawi. Natural Hazards (Issue 0123456789). Springer Netherlands. https://doi.org/10.1007/s11069-024-06601-5

Nkonu R.S., Antwi M., Amo-Boateng M., Dekongmen B.W. 2023. GIS-based multi-criteria analytical hierarchy process modelling for urban flood vulnerability analysis, Accra Metropolis. Natural Hazards, 117(2), 1541–1568. https://doi.org/10.1007/s11069-023-05915-0

Osman S.A., Das J. 2023. GIS-based flood risk assessment using multi-criteria decision analysis of Shebelle River Basin in southern Somalia. SN Applied Sciences, 5(5). https://doi.org/10.1007/s42452-023-05360-5

Selvam R.A., Antony Jebamalai A.R. 2023. Application of the analytical hierarchy process (AHP) for flood susceptibility mapping using GIS techniques in Thamirabarani river basin, Srivaikundam region, Southern India. Natural Hazards, 118(2), 1065–1083. https://doi.org/10.1007/s11069-023-06037-3

Tout F. 2023. Assessing Urban Vulnerability to Flood Risk. A Case Study in Batna City, in Northeast Algeria. Cuadernos de Geografía de La Universitat de València, 111, 81–96. https://doi.org/10.7203/CGUV.111.26271

Tout F., Ghachi A. 2023. A scenario of blockage of water tunnel that protects Batna city from flooding, Algeria. Acta Geographica Silesiana, 1(49). https://doi.org/https://ags.wnp.us.edu.pl/download/wydawnictwa/ags/tom_49_5.pdf

Towfiqul Islam A.R.M., Talukdar S., Mahato S., Kundu S., Eibek K.U., Pham Q.B., Kuriqi A., Linh N.T.T. 2021. Flood susceptibility modelling using advanced ensemble machine learning models. Geoscience Frontiers, 12(3). https://doi.org/10.1016/j.gsf.2020.09.006

Wedajo G.K., Lemma T.D., Fufa T., Gamba P. 2024. Integrating Satellite Images and Machine Learning for Flood Prediction and Susceptibility Mapping for the Case of Amibara, Awash Basin, Ethiopia. Remote Sensing, 16(12). https://doi.org/10.3390/rs16122163

Yaseen Z.M. 2024. Flood hazards and susceptibility detection for Ganga river, Bihar state, India: Employment of remote sensing and statistical approaches. Results in Engineering, 21 (December), 101665. https://doi.org/10.1016/j.rineng.2023.101665

Youssef A.M., Pourghasemi H.R., Mahdi A.M., Matar S.S. 2023. Flood vulnerability mapping and urban sprawl suitability using FR, LR, and SVM models. Environmental Science and Pollution Research, 30(6), 16081–16105. https://doi.org/10.1007/s11356-022-23140-3