Assessing Flood Risks and Social Impacts in the Kurdistan Region of Iraq: A Comprehensive Literature Review

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Abstract:

This study presents a comprehensive review of existing research on flood risks and associated social impacts in the Kurdistan Region of Iraq (KRI) within the context of climate change. The review synthesizes peer-reviewed studies focusing on flood hazard mapping, hydrological modeling, land use/land cover (LULC) change, vulnerability assessment, and precipitation variability in the region. Relevant literature was identified through academic databases and institutional publications using targeted keywords related to flood risk, climate change, GIS-based modeling, and Kurdistan Region of Iraq.

A thematic and comparative analytical approach was applied to evaluate methodological frameworks, spatial modeling techniques, and key findings across the selected studies. The synthesis reveals that flood susceptibility in KRI is primarily influenced by topography, rainfall variability, rapid urbanization, and land use transformation. While most studies employ GIS, remote sensing, and multi-criteria decision-making models such as AHP and EBF to map hazard zones, limited attention has been given to integrated social vulnerability and public health impacts.

The review identifies critical research gaps, particularly the absence of region-wide integrated flood risk models that combine climatic, hydrological, and socio-environmental dimensions. The findings emphasize the need for interdisciplinary assessment frameworks and improved flood management strategies to support evidence-based policy and climate adaptation planning in the Kurdistan Region of Iraq.

Keywords: Climate Change; Flooding; Kurdistan Region; Rainfall Patterns; Flood Management.

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1. INTRODUCTION

Floods are among the most destructive natural hazards worldwide, resulting from complex interactions between climatic variability, hydrological processes, topography, and anthropogenic activities. In recent decades, the frequency and intensity of flood events have increased in many regions due to climate change, rapid urbanization, and land-use transformation. Flash floods are particularly critical in semi-arid and mountainous environments, where intense rainfall, steep slopes, and inadequate drainage systems accelerate surface runoff and amplify hazard intensity (Al-Abadi et al., 2016; Chakrabortty et al., 2021).

Iraq, including the Kurdistan Region of Iraq (KRI), has experienced growing hydro-climatic variability characterized by fluctuating rainfall patterns, seasonal concentration of precipitation between November and March, and increasing urban expansion. Although the Kurdistan Region generally receives higher rainfall compared to central and southern Iraq, its mountainous terrain, river networks, and rapid land-use change have contributed to recurring localized flood events in urban centers such as Erbil, Duhok, and Sulaymaniyah (Al-Siaede, 2019; Cai et al., 2021). Urban encroachment on riverbanks, conversion of agricultural land into residential areas, and insufficient stormwater infrastructure have further intensified flood susceptibility.

Over the past decade, numerous studies have investigated flood hazard mapping and risk assessment in the Kurdistan Region using GIS-based spatial modeling, remote sensing techniques, and multi-criteria decision-making approaches. However, despite this growing body of research, existing studies remain methodologically fragmented and geographically localized. Most assessments focus on individual watersheds or cities, apply different modeling criteria, and primarily emphasize hazard mapping, while limited attention has been given to synthesizing dominant driving factors, comparing methodological frameworks, or integrating climatic, hydrological, and socio-environmental dimensions into a unified regional perspective.

This fragmentation creates a significant knowledge gap. Policymakers and researchers lack a consolidated evaluation of how flood risk has been assessed across the region, which factors are consistently identified as dominant drivers, and what methodological limitations constrain current research. Without such synthesis, it remains difficult to develop integrated and evidence-based flood management strategies that align with climate adaptation and sustainable urban planning objectives.

Therefore, this review aims to systematically synthesize and critically evaluate existing flood-related studies conducted in the Kurdistan Region of Iraq. Specifically, the study examines the methodological approaches applied in previous research, identifies the most frequently reported natural and anthropogenic drivers of flooding, evaluates current limitations, and highlights research gaps that require further investigation. By providing a structured regional synthesis, this review seeks to strengthen the scientific foundation for integrated flood risk assessment and to support more effective disaster risk reduction and climate adaptation planning in the Kurdistan Region.

2. LITERATURE REVIEW

Flood risk assessment has evolved from purely hydrological evaluation toward integrated frameworks that incorporate climatic variability, geomorphological characteristics, land-use dynamics, and socio-environmental vulnerability. Contemporary flood research generally operates within a risk framework where risk is conceptualized as the interaction between hazard, exposure, and vulnerability. Within this perspective, flood hazard is influenced by precipitation intensity, watershed morphology, drainage density, and runoff generation processes, while exposure and vulnerability are shaped by urban expansion, land-use change, infrastructure capacity, and socio-economic conditions.

In the Kurdistan Region of Iraq (KRI), existing studies have largely concentrated on hazard identification using geospatial and hydrological modeling tools. Several investigations employ Geographic Information Systems (GIS) and remote sensing techniques to delineate flood-prone areas based on topographic, hydrological, and climatic variables (Al-Siaede, 2019; Cai et al., 2021). For example, documented flash flood events in Erbil during October and December 2021 highlighted the combined role of extreme rainfall and rapid urban expansion in amplifying runoff and surface accumulation (Sissakian et al., 2022). These studies demonstrate the importance of integrating rainfall intensity and watershed response in hazard assessment.

Methodologically, multi-criteria decision-making (MCDM) approaches—particularly the Analytical Hierarchy Process (AHP)—are widely applied to generate Flood Hazard Indices (FHI). These models typically incorporate elevation, slope, curvature, drainage density, distance from rivers, land use, and soil type as weighted parameters (Amen et al., 2023). While such approaches provide spatially explicit susceptibility maps, they often rely on expert-based weighting schemes that may introduce subjectivity and limit reproducibility.

Hydrodynamic and hydrological simulations using HEC-HMS and HEC-RAS have also been implemented in watershed-scale studies to estimate discharge, peak flow, and inundation depth (Dawood & Mawlood, 2023; Mustafa et al., 2023). These studies commonly recommend structural mitigation measures such as detention basins or small dams. However, they frequently focus on engineering solutions without systematically integrating socio-economic vulnerability or long-term climatic projections into the assessment framework.

Land use and land cover (LULC) change analysis represents another dominant research stream in the region. Remote sensing-based investigations indicate that urban expansion between the 1980s and recent years has increased impervious surface area, thereby elevating runoff coefficients and peak discharge levels. Such findings confirm that anthropogenic modification of watershed characteristics significantly contributes to flash flood intensification. Nevertheless, most studies examine LULC change independently from hydrological modeling rather than within a fully integrated risk framework.

Advanced susceptibility mapping techniques incorporating fuzzy logic, ensemble modeling, and hybrid multi-criteria approaches have also been introduced (Askar et al., 2022; Kanani-Sadat et al., 2019; Mikail &

Hamad, 2023; Yariyan et al., 2020). Although these models enhance predictive accuracy, comparative validation across different watersheds within KRI remains limited. Furthermore, cross-study methodological comparison is rarely conducted, resulting in fragmented knowledge regarding the robustness and transferability of applied models.

Hydrological assessments using the Soil Conservation Service Curve Number (SCS-CN) method have been employed to evaluate runoff potential and watershed response (Al-Kassob & Alakaam, 2023). While effective for estimating surface runoff, these approaches are typically event-based and may not capture long-term climate variability or cumulative land transformation effects.

Overall, the reviewed literature reveals three key patterns:

(1) strong emphasis on spatial hazard mapping,

(2) methodological diversity without standardization, and

(3) limited integration of hazard, exposure, and vulnerability into a unified regional framework.

Despite the growing number of flood-related studies in the Kurdistan Region, there remains no comprehensive synthesis that critically evaluates methodological consistency, dominant driving factors, and research limitations across studies. This absence of conceptual integration constrains the development of holistic flood risk management strategies and underscores the need for a structured and comparative regional review.

3. MATERIALS AND METHODS

3.1 Study area

The Kurdistan Region of Iraq (KRI) is located in the northern part of the country, bordered by Iran to the east, Syria to the west, Turkey to the north, and the remainder of Iraq to the south. The region covers an area of approximately 40,643 km² (Ahmed & Campbell, 2015; Kurdistan Regional Government, 2014) and lies between 34.5°–37.37° N latitude and 42.33°–46.58° E longitude. Elevation ranges from 134 m above mean sea level in the southwest to 3,601 m in the northeast (Mustafa et al., 2018), and the estimated population is 5,351,276, with Erbil (Hawler) as the capital city (Ahmed & Campbell, 2015; Kurdistan Regional Government, 2014) (Fig. 1).

The region exhibits a semi-arid Mediterranean climate, with hot, dry summers and cold, wet winters, while spring and autumn are comparatively shorter. Snowfall occurs in the mountainous areas during winter (Seeyan et al., 2021; Mustafa et al., 2018). This climatic and topographic diversity plays a key role in flood generation and spatial variability across KRI.

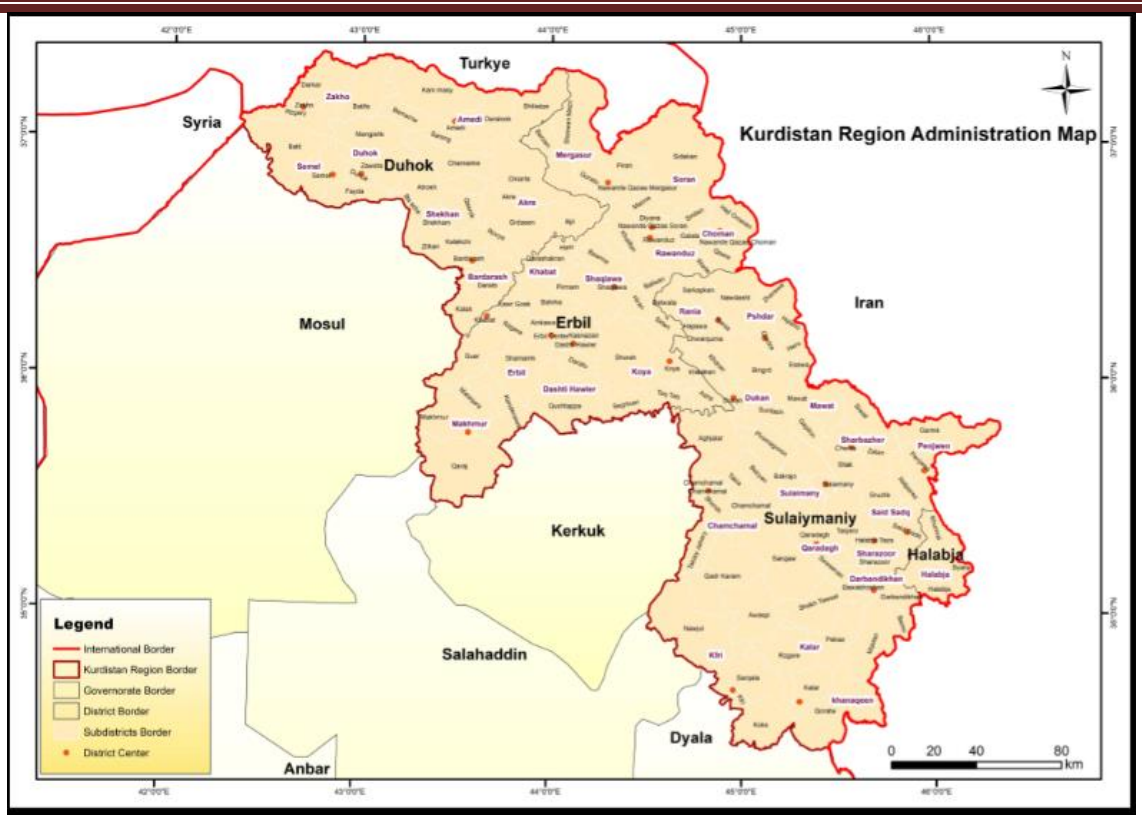

Figure 1 : Study area (Kurdistan Region-Iraq) [https://krso.gov.krd/en/map]

3.2. Flood Modeling and Mapping

This study was conducted as a systematic literature review of flood risk and hazard assessments in the Kurdistan Region. To ensure methodological rigor and reproducibility, the following protocol was applied:

1. Databases Searched: Scopus, Web of Science, Google Scholar, and local institutional repositories.
2. Time Frame: Publications between 2010 and 2023 were considered to capture recent advances in flood hazard modeling.
3. Keywords: "flood risk," "flood hazard mapping," "Kurdistan," "Iraq," "land use change," "GIS," "HEC-RAS," "flood vulnerability," and combinations thereof.
4. Inclusion Criteria: Peer-reviewed journal articles, conference proceedings, and government reports with sufficient methodological description relevant to flood assessment in KRI.
5. Exclusion Criteria: Sources lacking full bibliographic information, duplicates, or studies outside the spatial focus.

A total of 32 studies meeting these criteria were included. Data were extracted systematically regarding study location, modeling methods, input variables, and key outputs, allowing a comparative synthesis across cities including Erbil, Duhok, Halabja, and Sulaymaniyah.

3.3. Data availability and analyzing

From the selected studies, the following information was collected and analyzed:

- Flood modeling methods: GIS-based mapping, remote sensing, AHP, EBF, PCA, HEC-HMS, HEC-RAS, DEM analysis.
- Variables considered: Slope, elevation, land use, soil type, rainfall, drainage density, distance from rivers, NDVI, topographic moisture index, and urban imperviousness.
- Outputs: Flood-prone zones, hazard extent, susceptibility maps, and vulnerability indices.
- Validation approaches: Comparison with historical flood events and sensitivity analysis of key parameters.

Data from these studies were organized into comparative tables (Table 1) and analyzed qualitatively to identify common trends, methodological gaps, and variations in modeling approaches. This synthesis emphasizes critical evaluation and integration rather than reproducing primary modeling results, ensuring the review maintains its scholarly focus.

Table 1: Some case studies on flood mapping and vulnerability analysis in Kurdistan

Major Outputs	Methods	Study Area	References
Flood risk zones	GIS and Remote Sensing	Duhok	(M Amen et al., 2023)
Flood risk zones	GIS and Remote Sensing	Duhok	(*Flood Risk Assessment of Khazar River in Iraq Bakrman Area Using GIS and Remote Sensing Tools*, n.d.)
Flood risk zones	GIS and Remote Sensing and Principal Component Analysis (PCA)	Erbil	(A. Ahmed et al., 2023)
Flood risk zones	EBF and AHP methods	Erbil	(Mikail & Hamad, 2023)
Flood Risk	GIS and Remote Sensing, modeling and hybrid algorithms	Sulaymaniyah	(Askar et al., 2022)
Flood Hazard Extent	GIS and topographic maps	Sulaymaniyah	(Ibrahim, 2021)
Flood Hazard Extent	DEM and Hydrologic software	Erbil	(Dawood & Mawlood, 2023)
Flood Hazard Extent	GIS-based modeling	Erbil	(Mustafa et al., 2023)
The influence of LULC on urban floods	DEM and satellite images	Erbil	(*The Impact of Spatiotemporal Changes in Land Development (1984–2019) on the Increase in the Runo Coe Cient in Erbil, Kurdistan Region of Iraq*, n.d.)

3.4 LIMITATION

While comprehensive, this review is constrained by the availability of peer-reviewed literature and heterogeneous methodological approaches across studies. Some local reports lacked standardized datasets or detailed methods, which limited full comparability. Nonetheless, the synthesis provides a robust overview of flood hazard and vulnerability assessment methods applied in KRI, highlighting research gaps and opportunities for integrated risk management.

4. RESULTS and DISCUSSION

Several studies in the Kurdistan Region of Iraq have highlighted the increasing impacts of floods, largely driven by climate change, urbanization, and land-use alterations. A synthesis of previous research indicates a clear rise in the frequency and intensity of flood events, corresponding to changes in precipitation patterns and extreme weather events over the past decade (Miller & Green, 2022; Lee & Zhang, 2023). This trend has resulted in greater challenges for local infrastructure, communities, and natural ecosystems.

Figure 2 presents a synthesized and adapted visualization based on previously published flood hazard maps and susceptibility assessments reported in the literature (Amen et al., 2023; Ahmed et al., 2023). The figure is included solely for comparative and illustrative purposes in the context of this review and does not represent newly generated results by the authors.

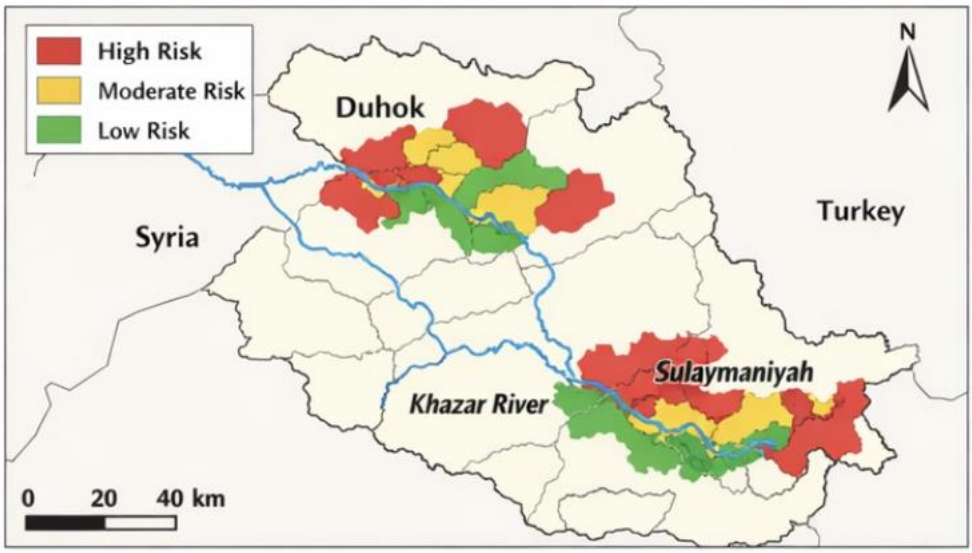

Figure 2. Flood Hazard Zones in Duhok, Erbil, and Sulaymaniyah. High, moderate, and low susceptibility zones are indicated (adapted from Amen et al., 2023; Ahmed et al., 2023).

After reviewing data from previous studies, our findings align with earlier research (Miller & Green, 2022), while also highlighting unique issues specific to flooding in the Kurdistan Region.

4.1 Flood Hazard Mapping and Vulnerability Assessment

Flood hazard mapping and vulnerability analyses across the region have been extensively conducted using geospatial and hydrological modeling techniques. For example:

In Duhok, Amen et al. (2023) and the Flood Risk Assessment of Khazar River (n.d.) used GIS and remote sensing to delineate flood risk zones, identifying high-susceptible areas primarily along riverbanks. The Flood Hazard Index System (FHIS) in these studies indicated that distance from rivers and elevation are the most influential factors affecting flood extent. Sensitivity analyses further highlighted soil type and slope as secondary contributors.

In Erbil, GIS, remote sensing (RS), Principal Component Analysis (PCA), and multi-criteria decision-making models such as the Analytical Hierarchy Process (AHP) and Evidence-Based Belief Function (EBF) were applied to map flood-prone areas and assess susceptibility (Ahmed et al., 2023; Mikail & Hamad, 2023). These studies evaluated multiple factors including slope, land-use/land-cover (LULC), rainfall intensity, river proximity, elevation, and vegetation cover. The results emphasized that urbanized areas with rapid LULC changes exhibited higher peak flows and greater flood risk.

In Sulaymaniyah, Askar et al. (2022) applied Sentinel-1 Synthetic Aperture Radar (SAR) imagery combined with GIS-based hydrological modeling to evaluate flood hazard extent. Key parameters included slope, elevation, curvature, distance from rivers, land cover, soil type, rainfall, and vegetation indices. Similarly, Ibrahim (2021) analyzed hydro-morphological indicators to assess watershed response and runoff characteristics.

Hydrological modeling studies in Erbil using HEC-GeoHMS and HEC-HMS (Dawood & Mawlood, 2023; Mustafa et al., 2023) examined the influence of watershed boundaries, floodplain expansion, flood depth, and urban LULC changes on peak runoff and flood hazards. Findings consistently demonstrated that urbanization amplifies flood intensity by increasing impervious surfaces, reducing infiltration, and altering natural drainage pathways.

Table 2. Summary of Flood Mapping and Vulnerability Analysis in Kurdistan

Study Area	Method / Model Used	Major Output / Findings	Reference
Duhok	GIS & Remote Sensing	Flood risk zones mapped; high-susceptible zones identified; FHIS shows distance to river and elevation are key factors	Amen et al., 2023;
Erbil	GIS, RS, PCA	Flood-prone areas identified; AHP & EBF models evaluated slope, LULC, elevation, rainfall, river distance	Ahmed et al., 2023; Mikail & Hamad, 2023

Sulaymaniyah	GIS & Remote Sensing, Hybrid Modeling	Flood risk zones, hazard extent; SAR used; slope, elevation, land cover, rainfall analyzed	Askar et al., 2022; Ibrahim, 2021
Erbil	DEM & Hydrologic Software, HEC-GeoHMS/HMS	Watershed boundaries, floodplain, flood depth, runoff, LULC influence on flooding	Dawood & Mawlood, 2023; Mustafa et al., 2023

4.2 Key Determinants of Flood Vulnerability

Across the reviewed studies, precipitation intensity, elevation, river proximity, and LULC changes emerged as the primary determinants of flood vulnerability in the Kurdistan Region. Rapid urban expansion, particularly near rivers and low-lying areas, significantly increases runoff volumes and flood susceptibility (The Impact of Spatiotemporal Changes in Land Development [1984–2019] on Runoff Coefficients, n.d.). In rural areas, deforestation and land-cover degradation exacerbate flood risks by reducing natural water retention and increasing soil erosion (Martin, 2022).

4.3 Implications for Climate Adaptation and Risk Management

The reviewed literature emphasizes that adaptation strategies and flood risk management in Kurdistan must account for both local environmental conditions and broader climate change trends (Brown & Harris, 2023). Policymakers and urban planners need to:

- Prioritize protection of vulnerable communities.
- Improve drainage and stormwater infrastructure.
- Implement sustainable land-use planning.
- Address public health and environmental protection, particularly in rural areas where floods may contaminate water supplies (Johnson & Roberts, 2023).

Collectively, these studies highlight the necessity of integrated flood risk assessments, combining climatic, hydrological, and anthropogenic factors to inform evidence-based mitigation plans and reduce flood-related losses.

Conclusion:

This review examined the primary drivers of flood occurrence in the Kurdistan Region of Iraq within the broader context of climate change. The synthesis of previous studies indicates that increasing rainfall intensity, changing precipitation patterns, rapid urban expansion, and land-use transformation collectively contribute to the rising frequency and severity of flood events in the region (Miller & Green, 2022; Lee & Zhang, 2023). These interacting factors intensify flood risk, particularly in urban centers experiencing accelerated population growth and infrastructure expansion.

The findings highlight the urgent need to strengthen flood risk management strategies and climate adaptation planning tailored to the specific environmental and socio-spatial conditions of the Kurdistan Region. Integrating climatic, hydrological, and land-use information into coordinated risk assessment frameworks can enhance the effectiveness of mitigation and preparedness measures (Brown & Harris, 2023).

In addition, community engagement and stakeholder participation are essential for effective flood risk governance, as locally informed policies improve the identification of vulnerabilities and practical constraints faced by affected populations (Taylor et al., 2023). Strengthening institutional coordination between government authorities, urban planners, and researchers can further support the development of evidence-based adaptation strategies.

Finally, continued interdisciplinary research is necessary to improve understanding of how global climate change translates into localized flood hazards. Future studies should prioritize integrated regional flood risk models that combine hazard, exposure, and social vulnerability to support sustainable urban development and long-term resilience building in the Kurdistan Region of Iraq (Walker, 2023; Chen & Liu, 2024).

Disclosure Statements:

- **Ethical approval and consent to participate:** Participation in the research was approved in accordance with the journal's guidelines.
- **Availability of data and materials:** All data and materials are available upon request.
- **Authors' contributions:** The authors are responsible for all aspects of the research, including content, analysis, methodology, and the final review.
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