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Developing an Integrated Spatial Framework for Flash Flood Risk Assessment Using GIS, Multi-Criteria Decision Models, and Empirical Village-Level Data

PhD Dissertation

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Background

Flash floods lead to significant disruptions across a wide variety of living, working, social, and spatial environments, positioning them among the most lethal natural hazards globally. The extent of flood damage is influenced not just by the volume of precipitation but also by geomorphological conditions and human activities. The rapid runoff in small catchment areas, limited warning times, quickly rising water levels, and the movement of sediments render flash floods particularly hazardous to property, infrastructure, and human lives.

Flash floods are a type of natural disaster that can have profound effects on both society and the economy. As climate-related disasters continue to increase, understanding the socioeconomic consequences of flash floods has become increasingly important. These events can disrupt communities, displace populations, damage infrastructure, and lead to significant economic losses, highlighting the need for effective preparedness and response strategies.

Rural areas typically face the challenges of flash floods with less built infrastructure compared to urban regions. However, these communities often have a greater dependence on the natural environment for their livelihoods, which can make them particularly vulnerable when such natural disasters occur. Maintaining a balance between sustainable land-use practices, community-based initiatives, and the protection of natural buffers is essential for creating an effective spatial development strategy. This approach ensures that environmental conservation and community needs are both prioritized in urban and rural planning efforts. On the other hand, the probability of extreme events rises in the absence of strategic crisis management measures. Given the recurrent occurrence of diverse flash flooding events in the villages of the study area in recent years, it is imperative to address the issues stemming from such risks and their social impacts.

Problem Statement

Traditional flash flood assessments typically rely on either hydrological modeling or isolated field observations. These approaches rarely incorporate:

- Local socio-economic vulnerability,
- Institutional and managerial capacity,
- Village-level exposure patterns, and
- Environmental and land-use changes.

As a result, decision-makers often lack reliable spatial tools to prioritize vulnerable communities or allocate resources effectively. This dissertation addresses the gap by creating a unified GIS-based framework that captures both physical hazard and human vulnerability in a single spatial model.

Research Objectives

The primary objective of this PhD research is to develop a framework for flash flood risk assessment in flood-prone villages of Golestan Province, with emphasis on hazards and their social consequences. Complementary tools are acknowledged where relevant, but the analysis remains centered on hazard processes and their impacts.

The secondary objectives are to:

- Identify key indicators relevant to flash flood risk and social vulnerability.
- Analyze existing information and models of flash flood risk in the study area.
- Determine the main factors influencing hazard exposure and social impacts.
- Propose a comprehensive model tailored to the study area, based on a synthesis of findings.

Study Area

The study area lies within the Gorganrood watershed in Golestan Province, Iran, a region well known for its history of catastrophic flash floods. Rural communities are especially vulnerable due to limited financial capacity, weak institutional preparedness, and dependence on agriculture. The area provides an ideal setting for developing and testing an integrated risk framework.

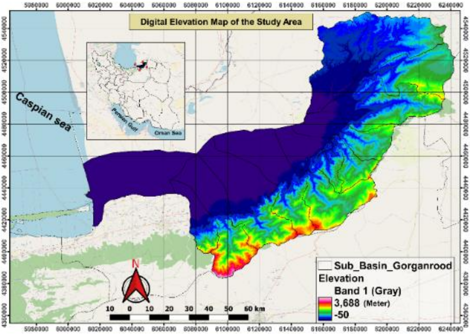

Figure Error! No text of specified style in document. The study area

Data and methods:

The methodological framework consists of two major components:

1. Hazard Assessment

A multi-layer GIS model was constructed using:
• Rainfall • Earth Curvature • Elevation • Drainage Density • Erosion • Land use/cover • Vegetation • Slope • Geomorphology •Runoff • Soil moisture •Soil type

Each variable was standardized and weighted using the Random Forest (RF) modelling. A composite hazard map was then generated, classifying areas from low to very high potential for flash flooding.

2. Vulnerability Assessment

Village-level vulnerability was measured using empirical data collected from local authorities and field studies. Five dimensions were included:

- *Environmental* – natural conditions influencing resilience.
- *Economic* – household and community economic capacity to cope with floods.
- *Socio-cultural* – traditions, norms, and cultural factors shaping responses.
- *Management-institutional* – organizational and institutional capacities.
- *Physical (land use)* – land use and land cover affecting flood occurrence and exposure.

Across these, 97 sub-indicators were identified and assessed through expert surveys and community-level questionnaires from 35 rural villages.

KEY FINDINGS

KEY FINDING 1: According to the final map, 127 rural area with a population of 138,548 people are at very high potential of flash flooding and 219 villages fall into the high potential category. In the Gorganrood watershed, we have identified several classes related to flooding potential and severity. The largest area is occupied by the class with relatively high potential (Rhp) flooding, covering approximately 2725.88 square kilometres, followed by the class with high potential (Hp) covering 2607.49 square kilometres. The relatively intermediate potential (Rip) class covers 1654.36 square kilometres, while the very high potential (Vhp) of flooding class covers 901.64 square kilometres. Finally, the low-potential (Lp) class covers 705.29 square kilometres of the watershed's total surface area. It can also be concluded that 85% of the watershed is at risk of flash flooding.

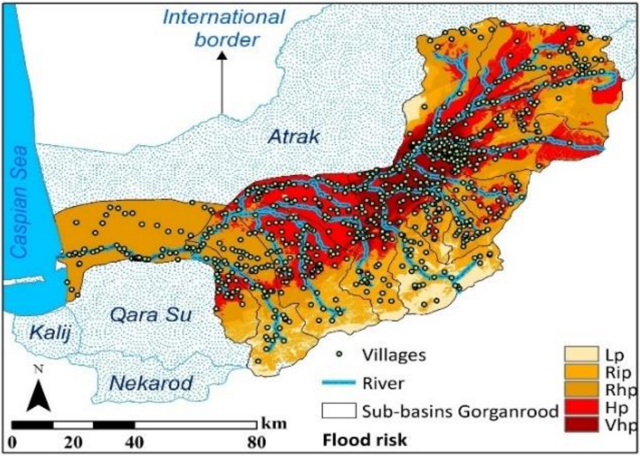

Figure 2. Flash flood susceptibility map in Gorganrood watershed

KEY FINDING 2: The first major finding highlights land-use change as the most influential driver of flash flood risk in the Gorganrood watershed. Among the five dimensions, the physical (land-use) category received the highest mean score (3.41), significantly surpassing other dimensions, as confirmed by the Duncan test

	Number of Items per Indicator	Subset for Alpha = 0.05		
		1	2	3
Indicators of environmental	18	2/9484		
Indicators of economic	15	3/1056	3/1056	
Indicators of socio-cultural	18		3/2381	3/2381
Indicators of managerial-institutional	19		3/3105	3/3105
Indicators of physical (land use)	50			3/4186
Significance Level		0/187 (NS)	0/105 (NS)	0/154 (NS)

Significance Level at 99% (**) Significance Level at 95% (*) Non-Significance (NS)

KEY FINDING 3: A second major finding is that existing flood risk frameworks in the region lack a spatial perspective. One-sample t-tests showed that all five indicators had mean values significantly lower than the expected midpoint, indicating weak overall conditions.

Spatial mapping revealed highly uneven risk patterns:

- Central and northern sub-basins exhibited high to very high risk levels
- Peripheral areas demonstrated lower exposure

WASPAS ranking results further demonstrated the absence of spatial clustering, confirming fragmented and inconsistent assessment methods currently in use.

Table 2. Average Access of Villages to Five Risk Management Indicators

INDICATOR	MEAN SCORE
Environmental	**1.86**
Economic	**1.70**
Socio-Cultural	**1.75**
Managerial–Institutional	**1.67**
Physical (Land Use)	**1.66**
Overall Mean	**1.73**

KEY FINDING 4: IMPORTANCE OF SOCIO-INSTITUTIONAL FACTORS

The third major finding emphasizes the decisive role of socio-cultural factor. Were found to influence vulnerability more strongly than physical parameters alone. Weak institutions, limited coordination, and minimal public participation emerged as central drivers of community risk. These findings highlight the need to strengthen both community-based and institutional capacities to reduce flood impacts.

Table 3. Duncan's post-hoc comparison showing that the socio-cultural factor is significantly higher than all other dimensions

Factor	Relative Position	Significance (Duncan Test)
Social-Cultural	Highest	**Significant** ($\alpha \leq 0.05$)
Environmental	Moderate–High	**Significant** subset difference
Economic	Moderate	Not significant
Physical (Land Use)	Moderate	Not significant
Managerial–Institutional	Lowest	Not significant

CONCLUSION

The dissertation demonstrates that flash flood risk in the Gorganrood watershed results from a complex interplay of land-use dynamics, environmental conditions, and socio-institutional vulnerabilities. Land-use change emerges as the most influential factor driving hazard occurrence, while socio-cultural and institutional weaknesses determine the severity of impacts. Existing assessment frameworks lack spatial depth and are fragmented. The integrated model developed here offers a more complete and coherent approach—one that aligns scientific assessments with lived realities of rural communities and can be adapted to similar environments globally.

List of Publications

Niknam, A., Taherizadeh, M., Khushemehr, J. H., Nguyen-Huy, T., & Sarli, R. (2025). Assessing the concordance between meteorological and agricultural drought indices in arid and semi-arid regions. *DYSONA – Applied Science* https://doi.org/10.30493/DAS.2025.011311

Niknam, A., Sarli, R., Taherizadeh, M., Attarroshan, S., & Pourmansouri, F. (2024). REDD implementation for greenhouse gas reduction and climate change mitigation in Hyrcanian forests: A case study of the Kojoor Watershed, Northern Iran. *Environmental Monitoring and Assessment, 196*(5), 474. https://doi.org/10.1007/s10661-024-12616-z

Niknam, A., & Mezősi, G. (in press). A Spatially Integrated GIS and Multi-Criteria Decision Analysis Model for Flash Flood Risk Zoning in Rural Iran. *Human Ecology*/ https://doi.org/10.22034/he.2025.563960

Taherizadeh, M., **Niknam, A.**, Nguyen-Huy, T., Mezősi, G., & Sarli, R. (2023). Flash flood-risk areas zoning using integration of decision-making trial and evaluation laboratory, GIS-based analytic network process and satellite-derived information. *Natural Hazards, 118*(3), 2309–2335. https://doi.org/10.1007/s11069-023-06089-5

Taherizadeh, M., Khushemehr, J. H., **Niknam, A.**, Nguyen-Huy, T., & Mezősi, G. (2023). Revealing the effect of an industrial flash flood on vegetation area: A case study of Khusheh Mehr in Maragheh–Bonab Plain, Iran. *Remote Sensing Applications: Society and Environment, 32*, 101016. https://doi.org/10.1016/j.rsase.2023.101016

Abdo, H. G., Darwish, K. S., Bindajam, A. A., **Niknam, A.**, Youssef, Y. M., … (2024). Detection of flood vulnerable areas in urban basins using multi-criteria analysis and geospatial tools: A case study from eastern Mediterranean. *Environmental Earth Sciences, 83*(17), 524. https://doi.org/10.1007/s12665-024-11801-0

Roshan, G., Sarli, R., Ghanghermeh, A., Taherizadeh, M., & **Niknam, A.** (2024). Using satellite-derived land surface temperatures to clarify the spatiotemporal warming trends of the Alborz Mountains in northern Iran. *Journal of Mountain Science, 21*(2), 449–469. https://doi.org/10.1007/s11629-023-8384-z

Abdo, H. G., Richi, S. M., Prasad, P., Katipoğlu, O. M., Halder, B., **Niknam, A.**, … (2025). Mapping landslide susceptibility in the Eastern Mediterranean mountainous region: A machine learning perspective. *Environmental Earth Sciences, 84*(9), 250. https://doi.org/10.1007/s11629-023-8384-z

Momenpour, S. E., Moghbel, M., & **Niknam, A.** (2025). Systematic bibliometric review of aerosol and atmospheric air pollutants effects on precipitation. *Modeling Earth Systems and Environment, 11*(1), 13–XX. https://doi.org/10.1007/s40808-024-02177-y