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THE IMPACT OF LITHOLOGICAL FEATURES AND LANDFORM CHARACTERISTICS ON THE PREVALENCE OF GEOMORPHOLOGICAL HAZARDS IN THE ARANGEH CATCHMENT, (CENTRAL ALBORZ MTS, NORTHERN IRAN)

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Abstract:
In recent years, the impacts of natural disasters on rural areas, urban settings, farmlands, transportation systems, and constructed infrastructures have received considerable focus. This study began with recognizing natural hazards by evaluating available data and conducting field research. Following that, a risk layer was created by superimposing environmental elements that affect the likelihood of risks, including geological features and landform types, which were analyzed through geomorphon techniques. The research also measured the probability of risk occurrence across various categories of independent variables. Results indicate that geological and topographical elements are vital in influencing the types of natural hazards within the Arangeh catchment. In particular, rock formations such as conglomerate, green tuff, sand, shale, and young alluvium found in young terraces exhibit the highest potential for hazards. The likelihood and variety of hazards amplify when these lithological units are located on elevated and steep landscapes. Additionally, the presence of faults significantly influences hazards associated with mass movements, including rock falls. The widest range of hazards within the Arangeh catchment can be found in slope, hollow, and valley landforms. To prevent an increase in risks, it is essential to avoid expanding settlements in these areas designated for garden purposes.

Key words: geological and geomorphological hazards, landform characteristics, geological features, Central Alborz Mts, Arangeh catchment.

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INTRODUCTION

In recent decades, increasing attention has been paid to various natural hazards in Iran and other parts of the world (Shu *et al.*, 2024). Annually, these hazards inflict significant damage on rural and urban areas, agricultural lands, transportation networks, facilities, and human-made infrastructures, leading to the disintegration of social structures and resulting in both financial and human losses. Furthermore, human activities, particularly through industrialization and alterations in land use, have substantially impacted the environment and landscape, thereby exacerbating the incidence of geomorphological hazards such as floods, landslides, snow avalanches, and soil erosion (Alcántara and Goudie, 2010; Nakano *et al.*, 2015; Vipin *et al.*, 2018). These hazards arise under particular geological, geomorphological, and hydrological conditions that may recur over time (Alcántara-Ayala, 2002; Borrelli *et al.*, 2018). Numerous studies indicate that the manifestation of hazards in a given area is closely linked to its geological characteristics (such as rock type), geological structure (Cerri *et al.*, 2017; Segoni *et al.*, 2020), topography and geomorphic

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landforms of that area. Understanding these characteristics is crucial for managers to make informed decisions aimed at mitigating these hazards (Jin *et al.*, 2020; Lahai *et al.*, 2021). Consequently, thorough investigations into natural hazardous phenomena and a comprehensive analysis of the geological and geomorphological factors contributing to their emergence are essential (Ivanik *et al.*, 2019; Lupiano *et al.*, 2019).

Geological hazards refer to geological events that can adversely affect humans and the natural environment. These hazards arise from both the Earth's natural internal and external dynamic processes as well as from environmental degradation caused by human activities (Cheng *et al.*, 2024).

Numerous research efforts have shown that geological factors significantly influence the occurrence of natural hazards, as variations in lithology and structure often lead to differences in the strength and permeability of both soils and rocks (Pradhan *et al.*, 2010). Among the various factors affecting the likelihood of hazards, lithology stands out as particularly significant due to its type and its physical, chemical, and mineralogical characteristics, along with its spatial distribution, which all contribute to the potential for hazards in a specific area (Hansen, 1984; Guzzetti *et al.*, 1996; Ayalew *et al.*, 2004; Safaei *et al.*, 2012). The research conducted by Safaei *et al.* (2012) indicated that lithology is a key factor contributing to landslides in the Southern Sari Hillslope regions.

Geomorphic hazards are associated with changes in the landscape that impact human systems (Gares *et al.*, 1994). The consequences of any land deformation that adversely affects the geomorphic stability of a location and poses negative socio-economic impacts on human systems are classified as geomorphic hazards (Marston *et al.*, 2017). Essentially, the notion of geomorphic hazards encompasses all natural and technological hazards that influence the Earth's surface and frequently induce morphological alterations.

Geomorphological studies offer both theoretical frameworks and practical strategies for mitigating natural disasters by examining the origins and dynamics of physical processes. Furthermore, geomorphologists contribute significantly to understanding the interplay between natural hazards, which denote natural vulnerability, and the communities affected, representing human vulnerability (Alcántara-Ayala, 2002).

Research conducted by geomorphologists encompasses not only the comprehension of Earth's surface processes but also the surveying and modeling of these processes, many of which have direct implications for human activities and societal structures. Moreover, there is a growing involvement of geomorphologists in addressing social issues, which can be articulated through vulnerability assessments, as well as hazard and risk evaluation and management. Consequently, the studies of geomorphologists are crucial for a disaster prevention (Alcántara and Goudie, 2010).

Mountainous regions globally are susceptible to natural hazards, which have historically resulted in significant loss of life and property (Ivanik *et al.*, 2019, Lahai *et al.*, 2021, Lin *et al.*, 2021). Thus, a comprehensive understanding of the surface, geological, and geomorphological characteristics of foothills and mountainous areas is essential for mitigating this worldwide threat to human safety, infrastructure, and the environment.

The Arangeh catchment located in the Central Alborz Mts (North of Tehran and Karaj provinces), characterized by its steep slopes and distinctive geological formations, is particularly vulnerable to various hazards. These hazards are intrinsically linked to geomorphological factors and are vital components of the dynamics of the Earth's surface. Consequently, it is crucial to carry out studies and research in this field to mitigate vulnerability and pinpoint potential risks. Lately, the increase in second homes on the outskirts of large urban areas has resulted in swift changes in seasonal housing and considerable growth in road construction and other infrastructure projects. These changes have led to environmental instability and the rise of several environmental dangers, such as landslides, floods, and other ecological threats.

In the realm of prevention, it is essential to implement appropriate rural and tourism strategies, alongside effective planning and construction management. This approach must prioritize the preservation of lands and gardens adjacent to the river, as well as the management of land use, which necessitates accurate information regarding the areas in question and an understanding of their current conditions. Consequently, it is imperative to conduct studies and research focused on risk reduction and the identification of existing threats within the examined region, particularly concerning summer cottages, tourism potential, gardens, and villas situated along the river.

Analysis of documentation and interviews with local officials and residents has revealed that the study area has experienced various hazards in recent years, including floods and mass movements (rockfall and landslide) and riverbank undercutting. Notably, a significant flood event in 2014 devastated Sijan village, resulting in the destruction of agricultural lands, bank erosion, numerous casualties, and subsequent impacts on downstream villages. This evidence underscores the area's susceptibility to flooding and other hazards, such as rock falls, landslides, soil creep, and erosion.

The objective of this research is to explore the correlation between the types and distribution of geological formations and the various geomorphological landforms that contribute to environmental hazards in the summer area of the Arangeh catchment in Karaj County. Additionally, this study aims to enhance understanding of the intricate relationship between human activities and natural processes in the context of geomorphological hazards.

STUDY AREA

The Arangeh Catchment, part of the Karaj River sub-catchment, covers roughly 100.98 km² and is located in Alborz Province, north of Karaj City and downstream from the Karaj Dam. The elevation in this area varies between a

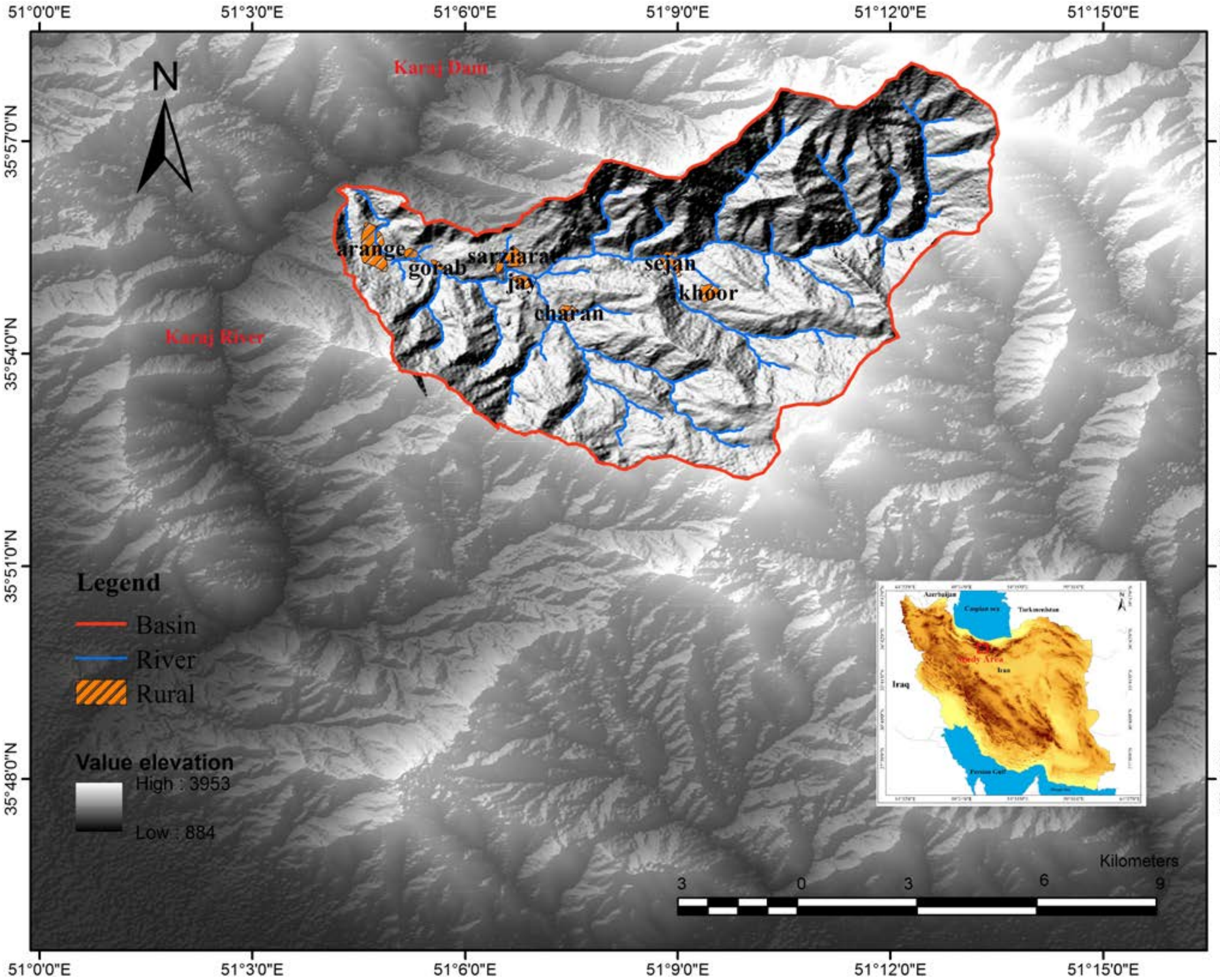

Fig. 1. Location of study area – Arangeh catchment in Central Alborz.

minimum of 1637 m a.s.l. and a maximum of 3665 m a.s.l., with an average altitude of 2,689 m a.s.l. (refer to Fig. 1). This region is home to eight villages: Arangeh, Abharak, Gorab, Sarziart, Jay, Charan, Sijan, and Khor. In recent years, the region's attractive climate and picturesque landscapes have led to a rise in the development of villas and apartments, resulting in an influx of labor migrants looking for work and housing in the catchment.

The predominant area of the catchment, accounting for 37%, is located within the altitude range 2800–3000 m a.s.l. The slope class exhibiting the highest percentage covers 30.98 km², specifically within the 21–25-degree inclination, while the average slope across the region measures 25 degrees. Data from the Karaj Dam Meteorological Station indicate that the climate in this area is characteristic of mountainous regions. Due to its location in the central Alborz Mts, this region has cold, humid winters and hot, semi-arid summers. Winters are also long, lasting 4 to 6 months. The average annual precipitation in this area is approximately 570 mm. The maximum average monthly temperature recorded in August is 24.5ºC, whereas February sees an average minimum monthly temperature of -1ºC, with the annual average temperature at the Karaj station being 16.5ºC.

Given the mountainous terrain, a significant portion of the catchment is dominated by pastures, with good and average pastureland comprising 18.85% and 66.89%, respectively. Additionally, gardens account for 5.8%, rock outcrops for 6.72%, and settlements, including villages located on slopes and riverbanks, represent less than 2% of the land use within the study area.

The area under study is situated in the southern section of the Central Alborz Zone (CAZ). Geologically, this region features a significant syncline known as the Arangeh syncline, which has an axis oriented in a northwest-southeast direction; this axis lies in the southern portion of the investigated area, where the lithological units of the Kandovan shale member, the upper tuff section, and the Quaternary formations are visible (Fig. 2). Additionally, an anticline axis aligns with the syncline axis in the northern section of the area, where the lithological units of the Asara shale section can be observed.

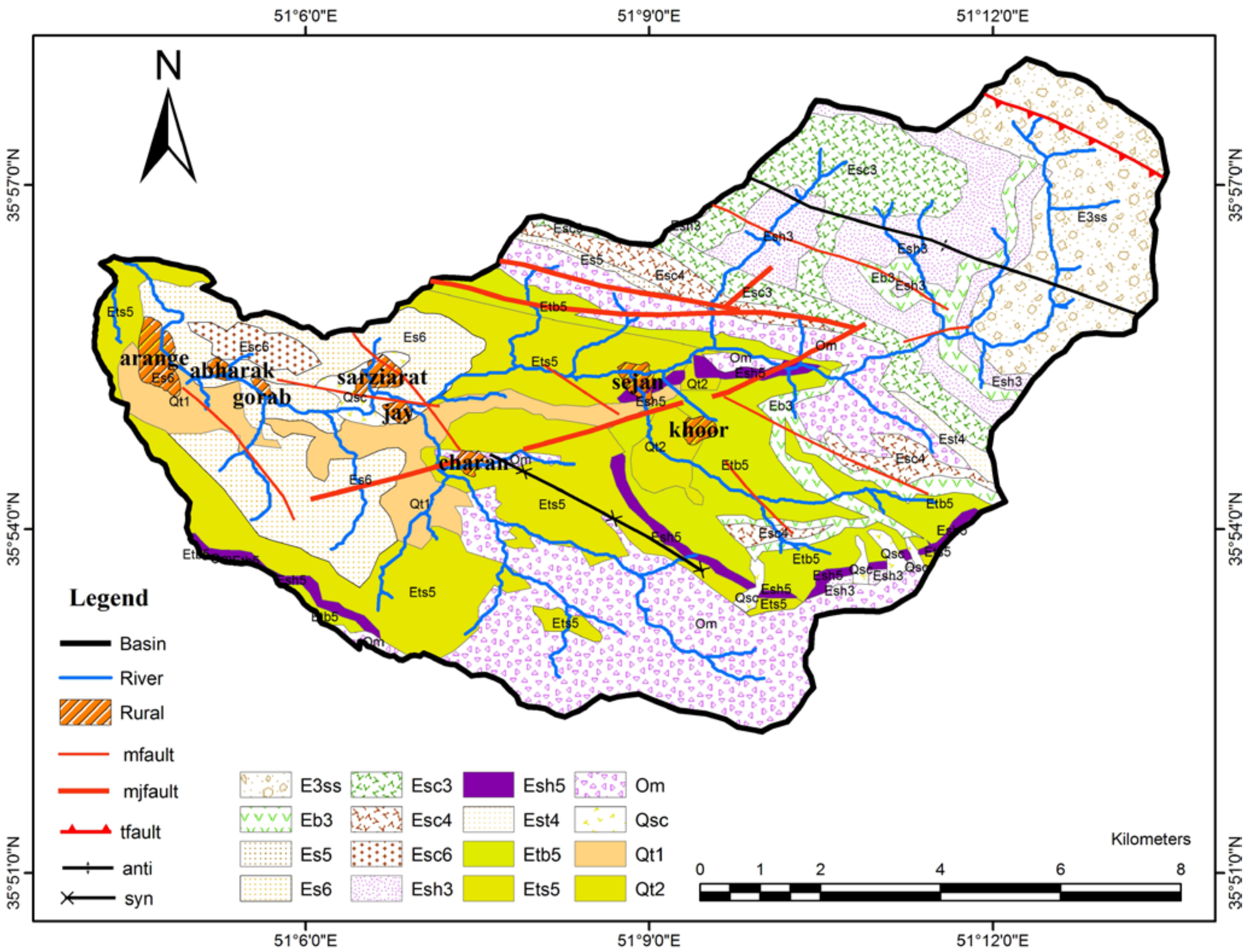

Fig. 2. Geological map of study area.

Table 1. Distribution of geomorphic hazards related to geological formations.

Lithological units	Hazards												Total
	Mass wasting						Soil erosion		River erosion and floods				
	Land slide	Rock fall	Rock debris	Debris	Creep	Talus, Deposit cone	Soil erosion	Soil debris	Fluvial erosion	Flood area	Water erosion	No risk	
	LS	RF	RD	DS	CP	TS	SE	SD	FE	FA	WE	Z	
E3ss	0	0	0	0	0	0	0	0	0	0	2.20	6.41	8.61
Eb3	0	0.07	0.02	0	0	0	0.09	0	0	0	0.01	3.25	3.44
Es5	0	0.23	0	0	0	0	0	0	0	0	0	0.03	0.26
Es6	0	0.32	0	0.09	0.01	0.02	0.38	0.02	0	0	0.52	7.48	8.84
Esc3	0	0.86	0	0	0	0	0	0	0	0	0.11	5.51	6.48
Esc4	0	0.81	0	0	0	0	0.16	0	0	0	0	1.46	2.43
Esc6	0	0	0	0	0	0	0	0	0	0	0	0.79	0.80
Esh3	0	0.20	0	0	0	0	0	0	0	0	0.15	6.53	6.88
Esh5	0	0.31	0.01	0	0	0	0.01	0	0	0	0	1.34	1.66
Est4	0	0.01	0	0	0	0	0	0	0	0	0	0.41	0.41
Etb5	0	0.57	0.13	0	0	0	0.24	0	0.02	0	0	6.99	7.96
Ets5	0.16	1.66	0.07	0.06	0	0	0.15	0.03	0	0.08	0.17	12	14.38
Om	0.01	1.25	0.16	0	0	0	0	0.01	0	0	0.06	14.06	15.55
Qsc	0	0	0	0	0	0	0.01	0	0	0	0.02	1.12	1.15
Qt1	0.10	0	0.04	0.01	0	0.01	0.04	0.02	0	0	0.10	4.27	4.58
Qt2	0	0.12	0	0	0	0	0.23	0	0	0	0	0.75	1.11
Total	0.27	6.40	0.43	0.16	0.01	0.03	1.32	0.08	0.02	0.08	3.34	72.40	84.54

The central and western regions of the Arangha Catchment host several significant and minor faults. These faults run alongside the syncline axis in a northwest-southeast orientation. Nonetheless, a primary fault measuring 10 km in length and oriented perpendicularly to the fold axis has formed in the central section of the Arangeh Catchment, also following a northwest-southeast direction.

The geological map of the Tehran with a scale of 1:100,000 (Geological Survey & Mineral Exploration of Iran), along with findings from field investigations, indicates that the stratigraphic units and sediments within the study area are predominantly of relatively recent origin, dating from the Eocene epoch to the present. These units comprise various geological materials, including tuff, shale, tuffite, sandstone, tuffaceous sandstone, conglomerate, and igneous rocks (such as andesite, trachyte, and dacite), intrusive masses as well as Quaternary alluvium and colluvium (see Fig. 2). The geological map of the area identifies 16 distinct rock units distributed throughout the region. These rock units are associated with the Karaj formation and comprise the Kandovan shale member (Es6, Esc6) from the upper Eocene, the upper tuff member (Es5, Esh5, Etb5, Ets5), and the Asara shale member (E3ss, Est4, Esh3, Esc4, Esc3, Eb3) from the middle Eocene, as well as intrusive masses of Monzodiorite/Monzogabbro (Om) linked to the later Eocene and Quaternary formations (Qt1, Qt2, Qsc) (Table 1).

DATA AND METHODS

This research examines the relationship between hazards, treated as the dependent variable, and geological (lithology) as well as geomorphological (landform) attributes, which are regarded as independent variables. The geological layer of the catchment was developed using a geological map of Tehran in scale 1:100,000 (provided by the Geological Survey & Mineral Exploration of Iran). To generate the geomorphic units' layer, the digital elevation model of the area was employed using SAGAGIS (version 9.0.1) software, segmenting the region into ten separate landform zones.

These zones encompass peak (PK), ridge (R), spur (SP), slope (SL), hollow (H), valley (V), pit (P) flat surfaces (F), shoulders or flat ridges (FR), foot slopes (FS), collectively referred to as geomorphic units (Fig. 3). As illustrated in Fig. 3 and detailed in Table 1, slopes exhibited the highest occurrence, accounting for 50.44% of the total landforms, while peaks were found to have the lowest frequency, comprising only 0.17%.

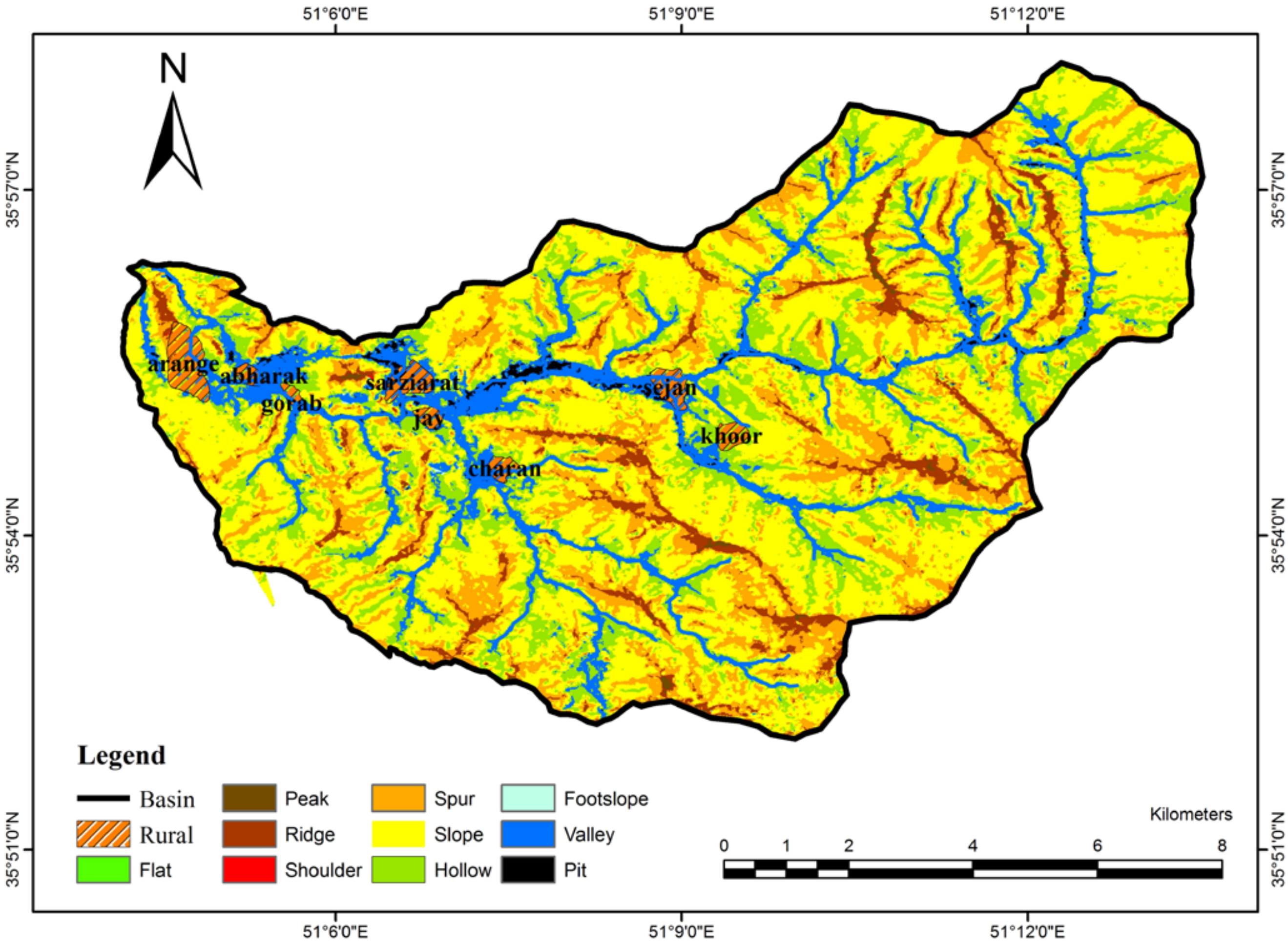

Fig. 3. Landforms map of study area; peak (PK), ridge (R), spur (SP), slope (SL), hollow (H), valley (V), pit (P) flat surfaces (F), shoulders or flat ridges (FR), foot slopes (FS).

Due to their minimal area, three of these units: flat, shoulder and foot slope were combined with adjacent classes, leading to a final classification of the region into seven distinct geomorphic units. To conduct this research, the initial identification of natural hazards was performed using images from Google Earth. Field surveys were subsequently carried out to validate the preliminary findings and ascertain the distribution of natural hazards. The primary hazards identified in the area were categorized into three groups: mass wasting (including landslide (LS), rock fall (RF), rock debris (RD), debris flow (DS), creep (CP), talus and deposit cones (TS)), soil erosion (encompassing soil erosion (SE) and soil debris (SD)), and river erosion and flooding (comprising fluvial erosion (FE), flood-prone areas (FA), and water erosion (WE)).

The locations and boundaries of these hazards were delineated on a map, and by correlating the data with Google Earth imagery, the extent and limits of each hazard were established through the separation and layering of hazards within the Arangeh catchment. Subsequently, the risk layer, incorporating environmental factors influencing the occurrence of hazards, such as geological and landform units, was overlaid and analyzed in the context of geomorphons, allowing for the determination of the percentage of risk occurrence across each class of independent variables.

The data table generated from the output layer within the ARC GIS software environment was organized and categorized using the Summarize command. This process yielded quantitative information derived from the overlay operation, which was subsequently formatted into a table and exported to the Excel environment. In Excel, various tables and graphs were created, including a table detailing the relative frequency of hazards and a table illustrating the distribution of hazards across different classes of influencing factors, such as geology and landforms.

RESULTS

Hazards and geology

Geological formation is a significant factor influencing the occurrence of hazards (Ivanik *et al.*, 2019). The type of rock present is crucial in determining the likelihood of hazards. Various geological formations exhibit differing conditions that affect the potential for environmental hazards. Certain formations are characterized by greater instability.

The primary lithological components of the Asara shale member consist of shale, greenish tuffite, basaltic-andesitic hyaloclastites, and green tuff, with occasional occurrences of conglomerate and sandstone tuff. In the upper tuff member, the rock formations are characterized by dark grey shales, shale tuffite and tuffite, interspersed with tuffaceous layers. The Kandovan shale member is composed of siltstone, sandstone, grey-brown shale, and conglomerate. The Quaternary rocky members encompass ancient terraces and alluvial sediments, as well as recent alluvium manifested as valley terraces and talus deposits. Additionally, debris and sediment deposits are prevalent in the vicinity of Sarziart village, extending into a small section of the study area adjacent to Gorab village (Fig. 2).

The most significant intrusive body in the region is the monzodiorite/monzogabbro, which appears as lopolite and thick silt within the Arangeh catchment. An analysis of the overlay between the hazard map and the geological map revealed the presence of hazards across 16 formations within the study area (Fig. 4). The resulting map delineates the types of natural hazards and quantifies the percentage of hazard-affected areas within each formation (Table 1).

The research conducted in the designated study area reveals that the geological formations Ets5 and E3ss account for 19.5% and 18.08% of the total area, respectively, and exhibit the highest levels of risk. The predominant risks identified are associated with slope movements, specifically rockfalls, as well as fluvial erosion, particularly bank undercutting. Conversely, the Est4 geological formation presents the lowest risk, quantified at less than 0.1%, while the Esc6 formation has been assessed as posing no risk at all. Out of the total area of 84.55 km² examined, 72.40 km² has been classified as risk-free. Notably, despite the Om and Ets5 formations occupying the largest geological areas in the region, measuring 15.55 km² and 14.38 km² respectively, they exhibit the lowest risk ratios of 0.10 and 0.17. In contrast, the Es5 formation, which is the smallest at 0.26 km², has the highest risk ratio of 0.88, primarily due to mass movement hazards (rockfalls). Furthermore, the study's findings indicate that the most prevalent hazards in the region include mass movements, especially rockfall covering 6.40 km², bank erosion, especially bank undercutting spanning 3.34 km², and soil erosion affecting 1.32 km² (refer to Table 2).

Table 2. The area of geological formations, geohazards occurring in each formation and the ratio of the hazard area / lithological units area.

Lithological units	Lithological units		Hazards		Hazard area / Lithological units area
	km^2	%	km^2	%	
E3ss	8.61	10.18	2.20	18.08	0.26
Eb3	3.44	4.07	0.19	1.56	0.06
Es5	0.26	0.31	0.23	1.89	0.88
Es6	8.84	10.46	1.36	11.18	0.15
Esc3	6.48	7.67	0.98	8.05	0.15
Esc4	2.43	2.87	0.97	7.97	0.40
Esc6	0.80	0.95	0	0	0
Esh3	6.88	8.14	0.35	2.88	0.05
Esh5	1.66	1.96	0.33	2.71	0.20
Est4	0.41	0.48	0.01	0.08	0.02
Etb5	7.96	9.42	0.97	7.97	0.12
Ets5	14.38	17.01	2.38	19.56	0.17
Om	15.55	18.39	1.49	12.24	0.10
Qsc	1.15	1.36	0.04	0.33	0.03
Qt1	4.58	5.42	0.31	2.55	0.07
Qt2	1.11	1.31	0.36	2.96	0.32
Total	84.54	100	12.17	100	2.98

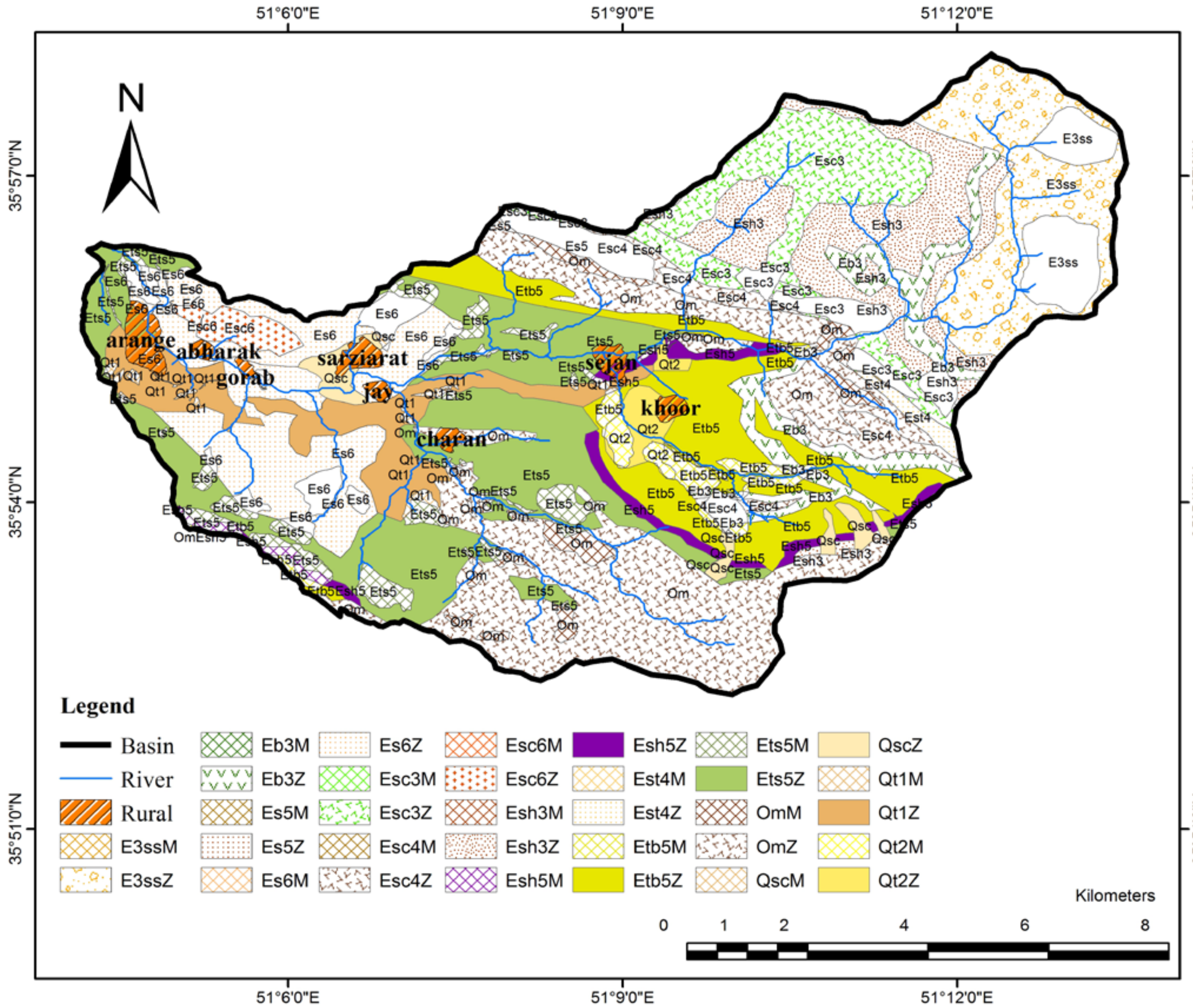

Fig. 4. Map of the geomorphic hazards distribution: Mokh: lithological unit with hazards, Z: lithological unit without hazards.

Hazards and landforms (geomorphons)

The mountainous characteristics of the study region contribute to a significant variety of features and landforms. Analyzing these landforms, alongside other elements such as geology and land use, is essential for understanding the types of hazards present, their development, and the areas they affect. According to the geomorphological map of the area (Fig. 3), the Arangeh Catchment is categorized into ten distinct topographical regions. Among these, three landforms: flat, shoulder and footslope were excluded from hazard modeling due to their limited size and high dispersion, and were subsequently combined with adjacent geomorphological units. Surveys conducted indicate that hazards are unevenly distributed across the landforms, with varying frequencies and extents of occurrence (Fig. 6). The analysis reveals that while the peak poses no risk, the depression exhibits the lowest risk level at 0.41%, whereas the slopes represent the highest risk area, accounting for 66.58%. Out of a total of 83.8 km² across the seven landforms, 71.7 km² are classified as risk-free (Table 4). In terms of hazard diversity, the predominant types include watercourse erosion, rockfall, soil erosion, debris flow, creep, talus and debris slope, river erosion, rock debris, and landslides, which are primarily found in hollows, slopes, spurs, and valleys (Table 3).

Analyzing the proportion of hazardous areas relative to the area of each landform reveals that the slope landform, with a ratio of 0.19, and the hollow, with a ratio of 0.16, exhibit the highest risk ratios among the region's landforms. In contrast, the valley landform, despite possessing the lowest ratio of hazard area to total landform area at 0.05 and accounting for only 3.8% of the total hazard area within the catchment, demonstrates the greatest diversity of hazards (see Table 4).

Table 3. Distribution of geomorphic hazards related to landform units.

Landform	Hazards												Total
	Mass wasting						Soil erosion		River erosion and floods				
	Land slide	Rock fall	Rock debris	Debris	Creep	Talus, Deposit cone	Soil erosion	Soil debris	Fluvial erosion	Flood area	Water erosion	No risk	
	LS	RF	RD	DS	CP	TS	SE	SD	FE	FA	WE	Z	
Pit (P)	0	0.002	0	0	0	0.004	0.005	0	0.04	0	0	0.67	0.72
Hollow (H)	0.06	1.17	0.05	0	0.004	0.01	0.26	0.002	0	0.003	0.64	11.56	13.78
Ridge (R)	0.004	0.11	0	0	0	0	0	0	0	0	0.01	3.75	3.88
Slope (SL)	0.19	4.07	0.33	0.12	0	0.006	0.88	0.05	0	0.002	2.40	34.22	42.27
Spur (SP)	0.003	0.80	0.01	0	0	0	0.12	0.003	0	0	0.24	12.62	13.81
Peak (PK)	0	0	0	0	0	0	0	0	0	0	0	0.14	0.14
Valley (V)	0.008	0.22	0.04	0.01	0	0.007	0.05	0.01	0.04	0.02	0.05	8.74	9.20
Total	0.27	6.38	0.42	0.13	0.004	0.029	1.32	0.07	0.08	0.025	3.34	71.70	83.82

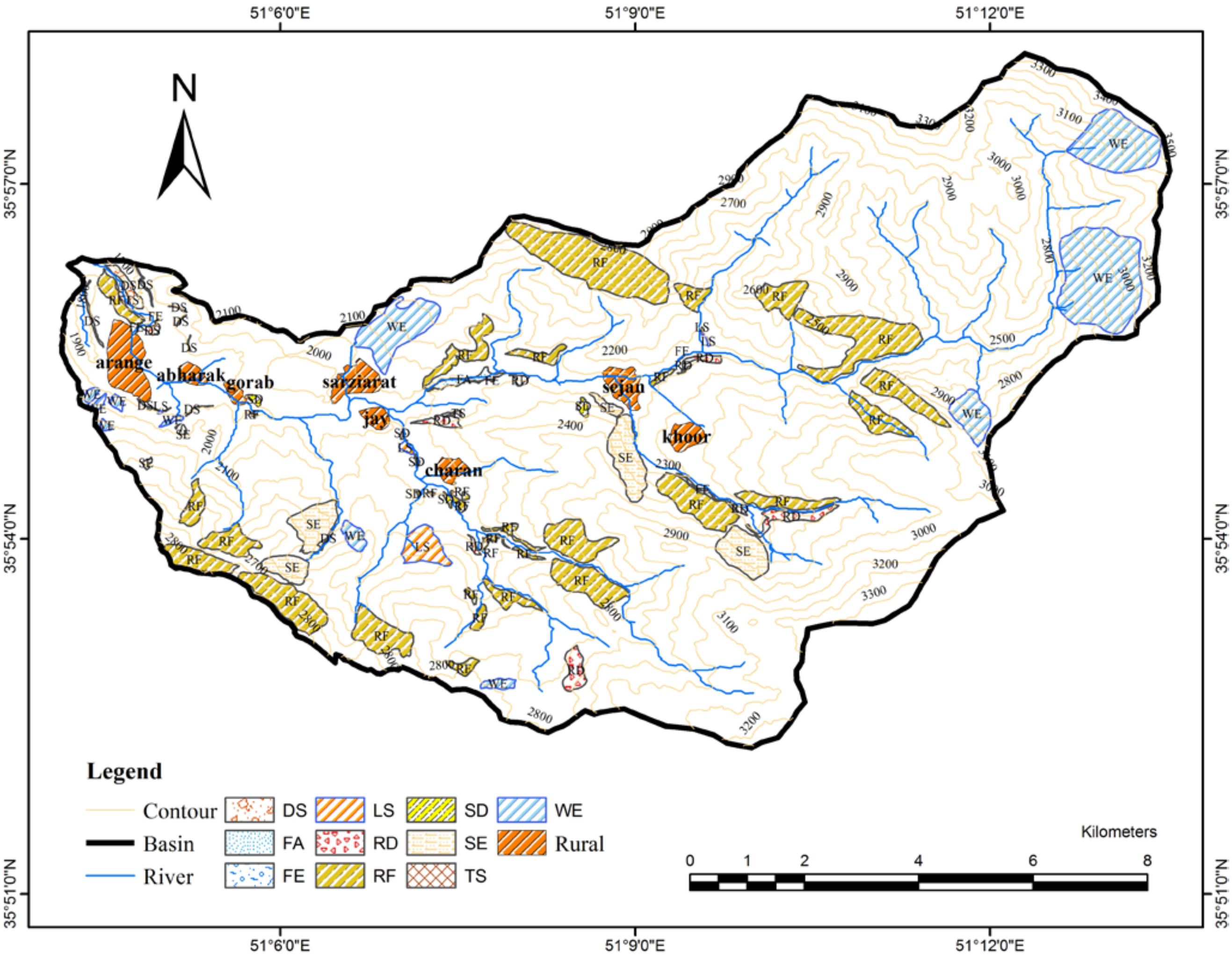

Fig. 5. Hazards map of study area; landslide (LS), rock fall (RF), rock debris (RD), debris flow (DS), creep (CP), talus and deposit cones (TS), soil erosion (SE), soil debris (SD), fluvial erosion (FE), flood-prone areas (FA), water erosion (WE), No risk (Z).

DISCUSSION

The occurrence and variety of natural hazards, such as mass wasting, soil erosion, river erosion, and flooding, can be significantly influenced by the geological characteristics and landforms of the area under investigation. Geological parameters, especially lithology, affect the occurrence of natural hazards in a region, depending on its type, physical and chemical properties, mineralogy, and location (Hansen, 1984; Guzzetti *et al.*, 1996; Ayalew *et al.*, 2004; Pradhan *et al.*, 2010; Safaei *et al.*, 2012). This research examines the impact of the geological conditions in the Arangeh Catchment

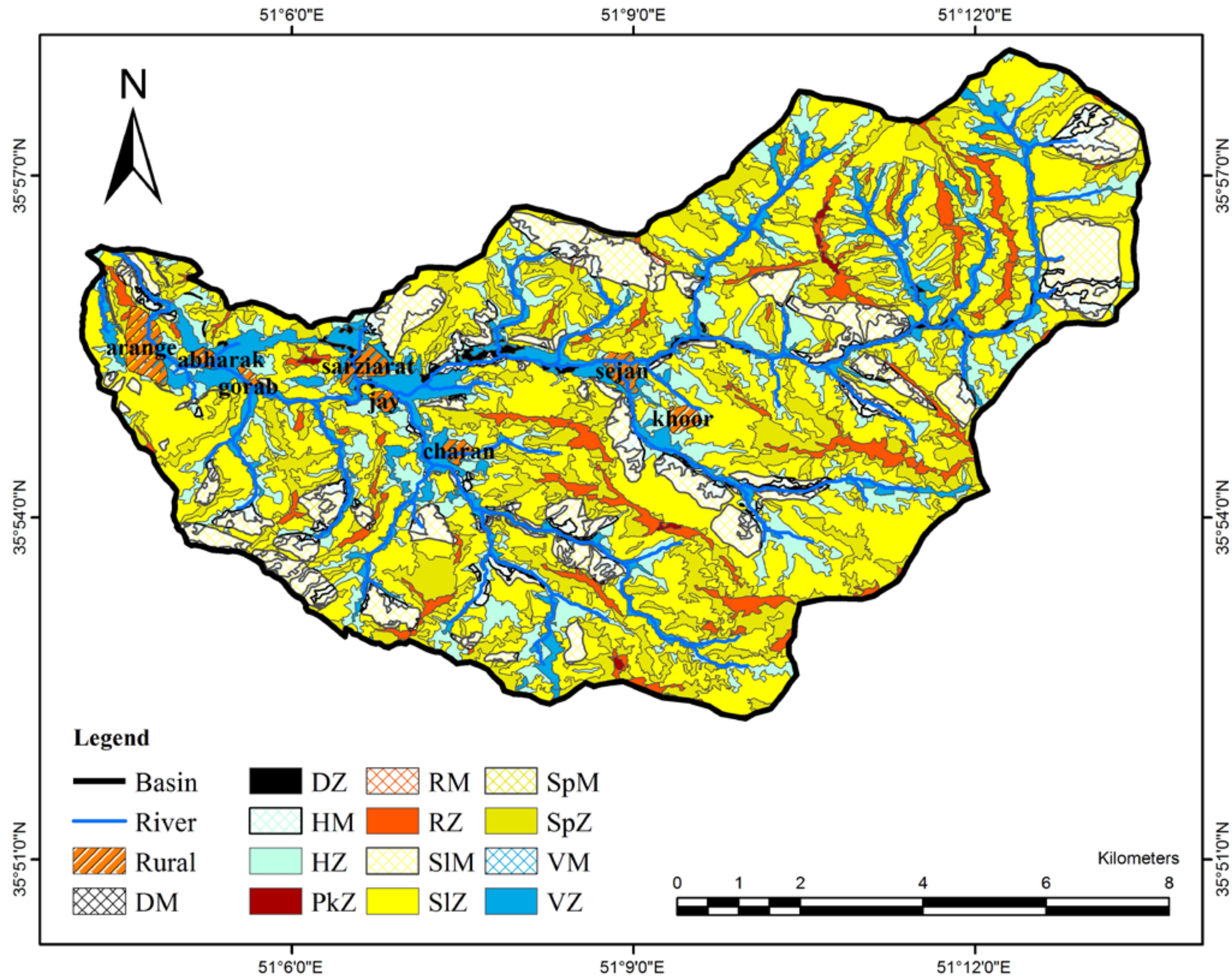

Fig. 6. Distribution map of geomorphic hazards related to landform units: Mokh: Geomorphic unit with hazards, Z: Geomorphic unit without hazards.

on the occurrence of natural hazards, utilizing fieldwork and the integration of hazard and geological formation layers.

The area of study is characterized structurally as a syncline (Arangeh syncline) with a northwest-southeast orientation within the Alborz zone. Consequently, the predominant slope directions are northeast and southwest, with the eastern slopes of the syncline trending westward. Centrally located within the syncline is the Kandovan shale member (Es6, Esc6), which occupies 11.5% of the total area and is situated at elevations ranging from 1800 to 2200 meters, exhibiting an average slope of less than 20 degrees.

In this segment, the gentle and low-gradient terrain restricts mass movements primarily to rock falls and debris flows, while the predominant hazards include soil erosion, water erosion, bank erosion, and flood. Although this area experiences a range of hazards, the ratio of hazard extent to the lithological unit's area is relatively low, ranking 8th among the 16 lithological units in the region. The presence of loose and erodible materials, such as shale and siltstone, does not significantly elevate the hazard severity in this unit due to its flat topography.

The upper tuff member (Es5, Esh5, Etb5, Ets5) is situated at the base and lower section of the Arangeh synclinal ridge, at altitudes ranging from 2200 to 2800 m a.s.l. and an average slope of 20 to 35 degrees. This member comprises four outcrop rock units, which exhibit a higher ratio of hazard area to lithological unit area compared to other rock units. Within this member, 32.12% of the hazard area is attributed to mass wasting processes (including rock falls,

Table 4. The area of landform, hazards occurring in each landform and the ratio of the Hazard area / landform area.

Landform	Landform		Hazards		Hazard area / Landform area
	km^2	%	km^2	%	
Pit	0.72	0.86	0.05	0.41	0.07
Hollow	13.78	16.44	2.22	18.36	0.16
Ridge	3.88	4.63	0.13	1.08	0.03
Slope	42.27	50.44	8.05	66.58	0.19
Spur	13.81	16.48	1.18	9.76	0.09
Peak	0.14	0.17	0	0	0
Valley	9.2	10.98	0.46	3.80	0.05
Total	83.8	100	12.09	100	0.59

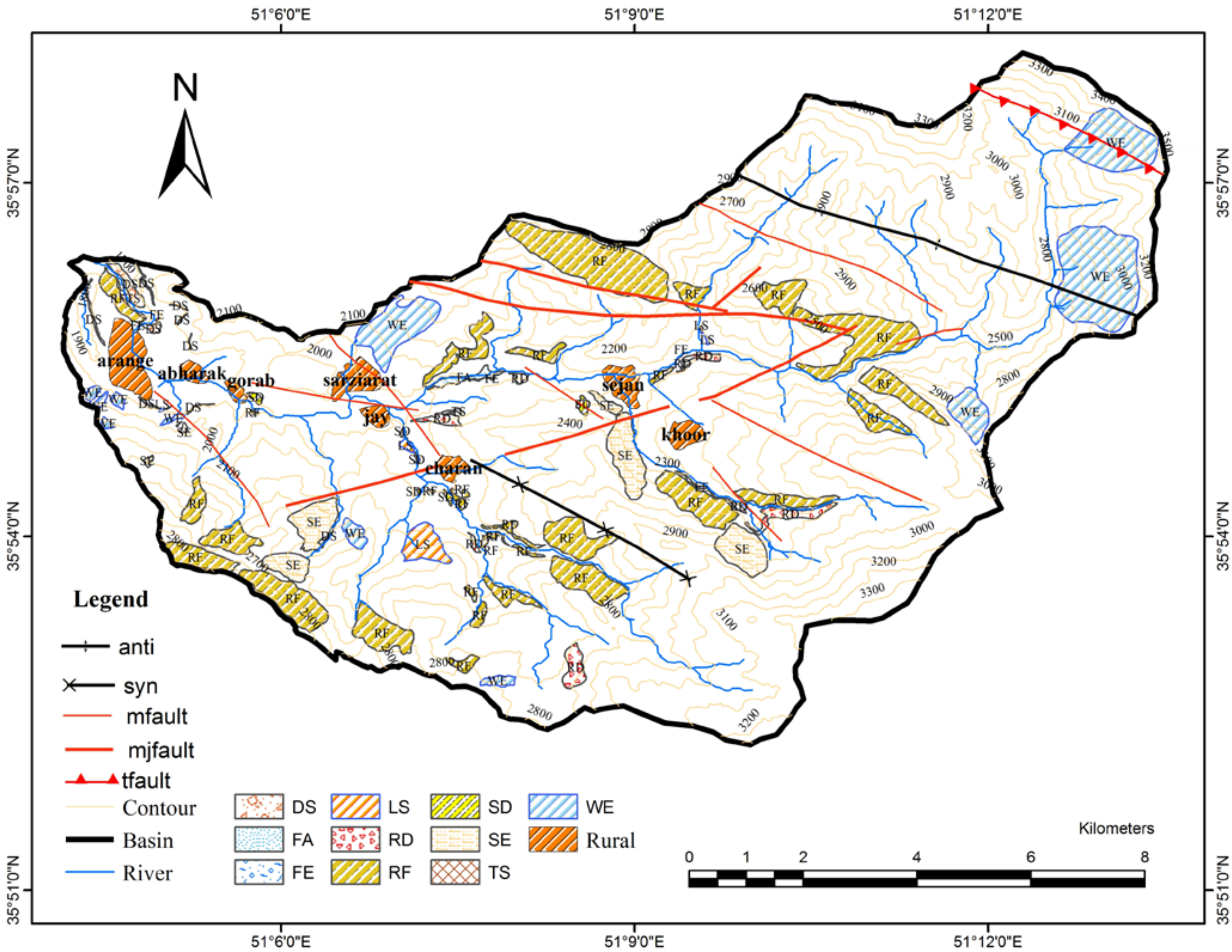

Fig. 7. Distribution map of geomorphic hazards related to faults.

debris flows, creep, and landslides), soil erosion, river erosion, and flooding (encompassing watercourse erosion and flood zones). The predominance of shale, tuffite, and siltstone, combined with the steep topography, has resulted in a high variety and extent of hazards in this geological section, affecting the villages located within it, such as Arangeh Bozorg, Ji, Charan, and Sijan, which face various risks.

The Asara shale member (E3ss, Est4, Esh3, Esc4, Esc3, Eb3), which is part of the middle Eocene geological period, is characterized by a predominance of sandstone, tuff, conglomerate, green tuff, shale, and alternating layers of shale and siltstone. This member is situated at elevations exceeding 2600 m a.s.l. on the northern flank of the Arangeh syncline. The area's geological features, including rocky outcrops, significant elevation, steep slopes, and a predominantly cold climate, contribute to a high incidence of physical weathering. Consequently, approximately 38.7% of the region is susceptible to various risks, including mass wasting (such as rock falls and rock debris), soil erosion, and fluvial erosion, which encompasses both watercourse and river erosion. Within this member, the rock unit Esc4, composed of conglomerate, green tuff, and sandstone, exhibits the highest hazard-to-lithological unit ratio (0.4).

Monroe Diorite/Monroe Gabbro (Om) intrusive masses from the later Eocene epoch occupy 18% of the area and account for 12.24% of the risk-prone zones, primarily located in the central sections of the northern and southern ridges of the syncline. This area is similarly affected by mass movements (including rock falls and rock debris), soil erosion, and fluvial erosion and flooding. The robust structure of this rock unit, combined with its altitude of 2800 m a.s.l. and above, has led to a predominance of physical weathering, resulting in frequent occurrences of rock falls and debris. The Charan village, the sole settlement within this catchment, is situated on this formation and faces various hazards associated with the geological characteristics of the rock unit.

The Quaternary formations (Qt1, Qt2, Qsc), which cover 8% of the total area, are situated in the central region of the syncline and along the Arangeh River. Within this area, 5.84% of the hazards, including mass movements (such as rock falls, landslides, and debris flows), soil erosion (including both erosion and soil debris), as well as river erosion and flooding (watercourse erosion), have been recorded. The Late Pleistocene–Holocene alluvial deposits found in the floodplain and the terrace deposits of the Arangeh River and its tributaries significantly contribute to the occurrence of erosion, landslides, and flooding in this region. The favorable topographical conditions have led to the establishment of numerous rural settlements on these formations, rendering them vulnerable to the aforementioned risks.

The analysis of the correlation between fault distribution and hazard occurrences in the examined region indicates that the risks associated with soil erosion, river erosion, and flooding are not significantly influenced by the geological features, such as faults, anticlines, and synclines. Instead, it is the topographic characteristics—particularly slope, range orientation, and elevation—that predominantly determine the distribution and frequency of these hazards. Conversely, the dispersion of faults has a pronounced effect on hazards related to mass movements, such as rockfall. The fragmentation of rocks and the formation of fault escarpments and steep inclines have created conditions conducive to rockfall events in the area (Fig. 7).

The geomorphological characteristics of the area serve as critical criteria and predictive indicators for the emergence and manifestation of natural hazards. Research findings indicate that a substantial portion of the region is characterized by slopes, depressions, spurs, and river valleys. These landforms account for 98.5% of the recorded natural hazards. The slopes and valleys, due to their inherent characteristics and the presence of inclines, generate the necessary energy for external processes, including material movement and the onset of hazards. The nature of the slopes, in terms of the types of constituent materials (whether unconsolidated materials or rock outcrops) and the orientation of the layers relative to the slope, can lead to the manifestation of various natural hazards.

The observations conducted revealed the presence of various hazards associated with slope dynamics. These hazards encompass watercourse erosion, multiple forms of mass movements such as rock falls, rock debris, landslides, and soil erosion. In regions characterized by thicker soil layers, particularly on the northern and western slopes, incidents of soil erosion and landslides are more prevalent. Conversely, areas dominated by rocky outcrops, notably on the southern and eastern slopes, experience a higher frequency of rock falls and debris flows. Additionally, the valley's landform, situated at the base of these slopes, has concurrently experienced slope-related hazards, including riverbank erosion and flooding. Given that many gardens and villages in the area are located in proximity to rivers and valleys, these land uses are consequently vulnerable to various risks.

The findings indicate a notable increase in human settlement within the valley over recent decades, particularly on the slopes. While early inhabitants primarily settled in floodplains and depressions, the proximity to Tehran and the metropolitan area of Karaj has led to a rapid rise in the number of residences designated as second homes or summer houses. This expansion has resulted in a swift increase in the number of villages along the riverbanks and slopes adjacent to the valleys. Such developments render the region increasingly susceptible to the natural hazards previously discussed.

CONCLUSIONS

The diversity of natural hazards within the Arangeh catchment appears to be largely influenced by geological and geomorphological factors, with these environmental conditions playing a crucial role in shaping external processes and the manifestation of hazards.

The analysis indicates that rock formations comprising conglomerate, green tuff, sand, shale, tuff, and recent alluvium, which constitute the young terraces, exhibit the greatest potential for hazard occurrence. When these geological units are situated on elevated terrains with steep slopes, the variety and frequency of hazards tend to increase.

Although the landforms of slopes, hollows, and valleys present a wide range of hazards, the risks have been mitigated due to the distance of villages from high-risk areas, the enclosure of gardens, their terraced configurations, and the density of tree cover. To further minimize the potential for risk escalation, it is essential to refrain from expanding settlements on these landforms designated for agricultural use.

Over the past ten years, the region has experienced a variety of natural hazards, including floods, rockfalls, landslides, and the erosion of riverbanks due to undercutting, all of which have resulted in significant human and economic losses. Consequently, it is imperative to restrict the development of residential areas and alter land use practices in high-risk zones, guided by lithological data and landform classifications, while taking into account regions susceptible to natural hazards.

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