GEOGRAFICKÝ ČASOPIS / GEOGRAPHICAL JOURNAL 76 (2024) 4, 355-375
DOI: https://doi.org/10.31577/geogrcas.2024.76.3.19

IDENTIFICATION OF MUDFLOW–PRONE AREAS IN THE SHAKHIMARDAN TOURIST AND RECREATION ZONE USING MULTI–CRITERIA ANALYSIS AND GIS

Odiljon Tobirov*, Doniyor Muminov*, Khidoyatkhan Abdinazarova*, Azamatjon Khoshimov*, Husniddin Nazarov*, Gayratjon Berdiyev*

* Kokand State Pedagogical Institute, Department of Geography and Basics of Economic Knowledge, Kokand, Uzbekistan, tobirovodiljon4@gmail.com

Identification of mudflow-prone areas in the Shakhimardan tourist and recreation zone using multi-criteria analysis and GIS

Mudflow-prone zones in the Shakhimardan Tourist Recreation Zone in Uzbekistan were identified using a multi-criteria evaluation method based on a Geographic Information System. By considering a number of variables, including aspect, curvature, soil type, elevation, slope, average annual rainfall, normalised vegetation difference index and flow accumulation, this study sought to identify possible mudflow hazard areas. GIS was combined with the Analytical Hierarchy Process within a multi-criteria decision making framework to provide a thorough assessment of potential hazard areas. The study found that the eastern part of the studied area is more susceptible to mudflows due to its unique geographical location and hydrological conditions. The Shakhimardan Tourist-Recreation Zone can benefit from the findings of this study in terms of land use planning, risk mitigation and management, which will increase the safety of visitors.

Key words: tourism, mudflow, mudflow risk, Geographic Information System, Multi-Criteria Decision Making, Analytical Hierarchy Process, Shakhimardan, Uzbekistan

INTRODUCTION

In the Republic of Uzbekistan, a number of measures are gradually being implemented to develop the tourism sector as one of the strategic sectors of the national economy, ensuring intensive development of regions, creating new jobs, raising the income and living standards of the population, and increasing the investment attractiveness of the country. According to the 35th objective of the Development Strategy of the New Uzbekistan for 2022 – 2026, within the framework of the programme "Travelling in Uzbekistan", the number of domestic tourists should be at least 12 million, and the number of foreign tourists should be 9 million. Ensuring safe travel conditions is a priority in the state's tourism development strategies. In 61% of cases, mudslides cause material and social damage. In 17% of cases, they also cause human casualties. Therefore, there is an urgent need to record, assess, monitor and forecast natural and man-made phenomena and processes, i.e. the main factors influencing not only human life, but also the entire information structure of the tourism industry.

One of the most dangerous risks of natural hazards in Uzbekistan is mudslides (Dergacheva et al. 2021), because mountainous areas, where types of tourism and recreation of natural nature are widely developed, are prone to complex relief conditions and weak soil protective cover of vegetation during periods of intense rainfall (90%), melting of snow cover (about 4%), and breakthrough of platinum and snow debris, glacial bridges (Akhmedov and Salyamova 2018). This causes significant damage to tourism facilities.

Tourism has always been recognised as an industry that brings new opportunities and economic development to the region (Nigmatov and Tobirov 2021). Several factors affect tourism positively and negatively (Ferreira et al. 2021, Chen et al. 2023 and Biardeau and Sahli 2024). One such factor is flash mudflow (Tsai and Chen 2011 and Ye et al. 2022). A flash mudflow is a short-lived strong flow of muddy or slushy water mixed with mudstone that flows out of mountain valleys, streams, and gullies with great destructive power. The main causes of flash mudflows are heavy rainfall, intensive snowmelt, overflow of high mountain lakes, and mudflows caused by dam failures due to anomalous water level rise, including volcanic eruptions and earthquakes (Chepurna et al. 2017).

Mudflows are widespread in mountainous regions (Petrakov et al. 2020), and 9% of the mudflows occurring in Central Asia are located in Uzbekistan (Dergacheva et al. 2021). Although mudflows mainly occur from March to August, 30 – 36% of all mudflows occur in April and May (Akhmedov and Salyamova 2018 and Dergacheva et al. 2021).

In Uzbekistan, the area of basins with the formation and destructive effects of mudflows is 53,770 km^2, which is 12% of the country's territory (Akhmedov and Salyamova 2018). Mudflows occur mainly in the lands of the republic bordering Kyrgyzstan and Tajikistan (Akhmedov and Salyamova 2018). For example, on 8 July 1998, the most destructive mudflow in Central Asia in the past 100 years occurred in the Shakhimardan exclave, a tourist and recreational area in the territory of Kyrgyzstan in Uzbekistan (World Bank Group 2022).

By relying on accurate calculations of scientifically based mudflow indicators, it is possible to predict mudflows in advance and to reduce, mitigate and minimise the damage caused by the resulting mudflows. Mudflows in the region are driven by persistent rainfall and a sharp rise in air temperature. Rainfall of 15 – 30 mm lasting 12 hours or more can cause severe flash mudflows (Shaazizov 2021).

In recent years, hundreds of mudflows have been observed in the country. Most of the observed mudflows in the period 1987 – 2020 were recorded in mountainous areas, i. e. 19% in Namangan, 16% in Fergana, 13% in Surkhandarya, 12% in Tashkent, and 11% in the Kashkadarya region (Dergacheva et al. 2021 and World Bank Group 2022).

In Uzbekistan, the mudflows recorded in the years 2010 – 2020 were analysed on the basis of the Uzgidromet data, and it was found that a total of 672 mudflows were observed in these years. When most mudflows were observed in 2012, 2019 and 2020, this number exceeded 100. About 40% of the 672 recorded mudflows occurred in the Fergana and Surkhandarya regions (Tab. 1).

In 2020, the maximum daily precipitation during the transition period of mudflows ranged from 15 mm to 43 mm, and the duration of precipitation was mainly 2 – 3 hours. Heavy precipitation falling within a short period of time caused the formation of mudflows in mountainous and sub-mountainous areas.

In Central Asia, the climate is distinctly continental, dry in the mountains and rainy in the valleys, and mudflows occur from March to August. However, most mudflows occur in spring, from April to May, during the period of highest humidity in the region. In the period 2010 – 2020, the mudflow activity on the territory of Uzbekistan was recorded in March – May (more than 100 mudflows were observed). It was observed that 19.05% of the generated mudflows occurred in March, 26.49% in April and 28.13% in May (Tab. 2).

Tab. 1. Mudflows that occurred in the territory of the Republic of Uzbekistan as a result of rainfall during the years 2010 – 2020 (by region*)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total	%
Andijan	-	-	6	-	-	-	1	-	4	-	-	11	1.64
Bukhara	-	-	2	-	-	-	-	-	-	-	-	2	0.30
Jizzakh	4	10	25	4	2	4	3	1	-	13	10	76	11.31
Kashkadaryo	-	-	26	-	-	2	2	3	23	32	10	98	14.58
Navoi	-	5	4	1	-	-	-	-	3	6	3	22	3.27
Namangan	6	1	-	-	-	-	6	4	10	8	25	60	8.93
Samarkand	13	5	28	11	2	4	1	2	4	-	3	73	10.86
Surkhandarya	9	1	7	1	-	4	6	-	8	54	43	133	19.79
Tashkent	2	-	3	3	1	2	10	4	8	10	20	63	9.38
Fergana	14	12	32	5	2	12	18	5	15	14	5	134	19.94
Total	48	34	133	25	7	28	47	19	75	137	119	672	100

*Mudflows were not observed in the Syrdarya and Khorezm regions of the Republic of Karakalpakstan. Source: Uzgidromet.

Tab. 2. Mudflows occurred in the territory of the Republic of Uzbekistan during 2010 – 2020 (in months)

Year/month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Total
2010	-	3	4	13	9	15	3	-	1	-	-	-	48
2011	-	-	-	-	13	16	5	-	-	-	-	-	34
2012	-	9	14	41	40	25	3	1	-	-	-	-	133
2013	2	10	-	3	-	3	1	6	-	-	-	-	25
2014	-	-	1	2	2	1	-	-	-	-	1	-	7
2015	-	-	-	1	6	14	5	-	-	-	2	-	28
2016	-	-	-	4	26	1	10	6	-	-	-	-	47
2017	-	-	6	9	1	2	1	-	-	-	-	-	19
2018	2	1	1	63	8	-	-	-	-	-	-	-	75
2019	-	19	98	1	18	1	-	-	-	-	-	-	137
2020	-	-	4	41	66	1	5	2	-	-	-	-	119
Total	4	42	128	178	189	79	33	15	1	0	3	0	672

Source: Uzhydromet.

Therefore, mudflows must be taken into account to ensure the stability of the tourism industry. Due to their geographical location, it is advisable to conduct a comprehensive assessment of tourism risks in areas that may be affected by mudflows. This will facilitate faster recovery of tourism facilities from natural disasters and simultaneously reduce the damage caused by natural disasters.

The aim of this paper is to use Geographic Information System (GIS)-based Multi-Criteria Decision Making (MCDM) and Analytical Hierarchy Process (AHP) to assess and manage mudflow-prone areas in the Shakhimardan Tourist Recreational Zone in Uzbekistan. The integration of these methodologies aims to provide a comprehensive understanding of the factors influencing the occurrence of mudflows and to facilitate effective decision making for risk mitigation and management in the region.

While the use of AHP combined with GIS for the assessment and management of mudflow-prone areas is not entirely new, our study contributes to the existing literature (Hussain et al. 2021, Shah and Shah 2023 and Sari et al. 2024) in several significant ways:

Integration of multiple factors: Our study considers a comprehensive set of eight factors influencing mudflow occurrence, including elevation, slope, rainfall, Normalised Difference Vegetation Index (NDVI), aspect, curvature, soil type and flow accumulation. By integrating these factors within a GIS-MCDM-AHP framework, we provide a holistic understanding of mudflow susceptibility.

Localised analysis: Focusing on the Shakhimardan Tourist Recreation Zone, we provide a localised analysis of mudflow risk. This allows for tailored risk assessment and management strategies specific to the unique geographical and hydrological conditions of the study area.

Detailed methodological approach: Our study provides a detailed methodological approach, outlining the steps involved in data preparation, factor analysis, AHP weighting and vulnerability mapping. This transparency enhances the reproducibility and applicability of our findings.

Consistency assessment: We perform a consistency assessment of the pairwise comparisons used in the AHP analysis to ensure the reliability of the weighting process. This rigorous validation step strengthens the credibility of our results.

Practical implications: The practical implications of our research extend to land -use planning, disaster preparedness and resource allocation in mudflow-prone regions. By identifying high-risk areas and prioritising mitigation measures, our study contributes to increasing community resilience and reducing the socio-economic impacts of mudflows.

STUDY AREA

Shahimardon is an exclave located in the eastern part of Uzbekistan, in the Fergana district of the Fergana region. The area of the enclave is 90 sq km and the population is more than 10,000 (91% are Uzbeks, 9% are Kyrgyzs). An exclave of Uzbekistan, surrounded by Kyrgyzstan, is located in the Pamir-Olai mountains. This name means "king of people" in Persian. The Shahimardonsoy river flows through the exclave. There are two villages in the exclave named Shahimardon and Yordon.

It is located in a valley on the northern slopes of the Ala Mountains at an altitude of about 1 550 m a.s.l.. The highest points of the exclave are peaks Almalik 2 841 m, Chivirgan 2 465 m a.s.l., and Qizil-Gaza 2 568 m a.s.l. The Kozdibel Mountains lie to the west of the village of Shohimardon.

Several rivers flow through the exclave, the largest being Koksu, Oqsu and Shohimardonsoy. After the Koksu joins the Oqsu near the village park, the Shohimardonsoy begins, which flows down to Margilan. The main source of the rivers are glaciers in Kyrgyzstan. The flow of Oqsu starts from the glaciers of Northern Alauddin, Archa-Bashy and Western Karakazyk. At the beginning the river is called Alauddin, after Alauddin comes together with Archa-Bashy stream it gets the name Oqsu. Dugoba stream joins it in Yordon village.

Minimum temperature in January -23.0 °C and the highest temperature in July +42.0 °C. The average amount of precipitation in the form of rain and snow is 350-400 mm. The average temperature in July is 22 °C, in January from -3 to 3 °C.

Triplophysa ferganaensis, a fish endemic to the Shohimardonsoy River, lives in the waters of the Shohimardonsoy. The mountains are covered with forests. Most of the flat land is used for agriculture.

The Shakhimardan Tourist and Recreational Zone is located in the southern part of the Fergana region of Uzbekistan (Fig. 1). The total area of the zone is 90 km^2. The surface landscapes of Shakhimardan are diverse. In particular, low and high mountains and valleys cut by rivers can be found along the plains. The absolute altitude of the region ranges from 1 324 m a.s.l. in the northern and central parts to 2 825 m a.s.l. in the eastern, southern and western parts.

According to the information from the World Database of the International Standard of Soil Classification System approved by the International Union of Soil Science (https://soilgrids.org/), in the Shakhimardan area there are moderately developed soils (Calsisols), black soils (Chernozems), chestnut soils (Kashtonozems), (Leptosols) and poorly developed soils (Regosols). The most common soil types in the Shakhimardan region are chestnut soils and weakly thick or stony soils, which occupy an area of 2 163.53 ha (46.0%) and 1 622.18 ha (34.5%) respectively. The least common soil types were soils with secondary carbonate accumulation on 0.07 ha and poorly developed soils on 128.17 ha (2.7%).

Data from the Environmental Systems Research Institute (ESRI) show that the land use and land cover (LULC) types in the area are watershed, trees, cropland, developed land, barren wasteland and pasture. Pasture occupies the largest area of all other land types with 4 078.95 ha (86.55%), followed by built-up land with 494.76 ha (10.50%) and 81.12 ha (1.72%), and bare land without vegetation occupies a large area.

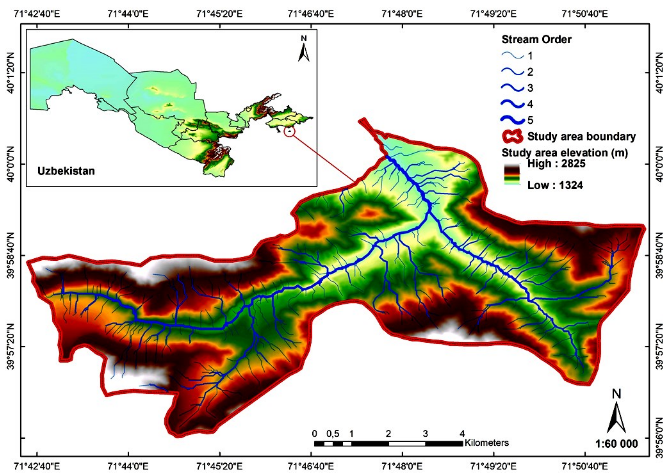

Fig. 1. Location map of the research area

Several recent studies have used a combination of GIS-based techniques (Chepurna et al. 2017). Multi-criteria decision analysis (MCDA) and analytical hierarchy process (AHP) were used to identify and map mudflow-prone areas (Danumah et al. 2016 and Mujib et al. 2021).

MCDM has been recognised as an important method for evaluating complex decision problems involving incommensurable data or criteria, such as identifying and mapping mudflow-prone areas using multiple factors (Abdelkarim et al. 2020 and Allafta and Opp 2021), and the AHP is a multi-criteria method used for decision making (Das and Gupta 2021). Based on the above, GIS-based multi-criteria decision analysis (GIS-MCDA) and AHP were used to identify mudflow-prone areas in the Shakhimardan tourist recreation zone. Eight factors influencing mudflow occurrence were considered: elevation, slope, precipitation, Normalised Difference Vegetation Index (NDVI), aspect, curvature, soil type and runoff. Data on the impact indicators were collected from various sources (Tab. 3).

Tab. 3. Types and sources of data used to map mudflow risk areas

Type of data	Source
DEM 30m (Copernicus DEM – GLO-30)	TanDEM-X mission - https://download.geoservice.dlr.de/TDM30_EDEM/
Sentinel 2A satellite image (10 m spatial resolution)	Downloaded from Copernicus Open Access Hub https://scihub.copernicus.eu/ (Retrieved 27 May 2023)
World Soil Groups World Reference Base (WRB)	International soil classification system standard approved by the International Union of Soil Sciences. https://soilgrids.org/
Rainfall (2010–2020)	Forecast of World Energy Sources (POWER) https://power.larc.nasa.gov/

Source: Compiled by the authors.

On 8 July 1998, the deadliest glacier lake outburst flood (GLOF) in Central Asia for at least the last 100 years occurred in the Shakhimardan catchment, Kyrgyzstan. However, most of the >100 victims were killed in the Uzbek enclave of Shakhimardan, i.e. in the downstream part of this transboundary catchment. No alerts were issued between the two countries. In addition, political tensions have prevented access to the site and a detailed assessment of the disaster has not yet been possible. Due to political tensions, and despite the fact that the "Shakhimardan event" was the deadliest GLOF in Central Asia in the last 100 years (no reliable data exist for earlier periods), the disaster has not been studied in detail and all conclusions, although very vague, have been drawn on the basis of the post-event report prepared after helicopter reconnaissance (Petrakov et al. 2020).

METHODS AND DATA

An integration of GIS-based multi-criteria decision making (MCDM) and analytic hierarchy process (AHP) was used to identify and map mudflow-prone areas in the study area (Kasiyanchuk et al. 2015). Spatial data layers of eight factors influencing mudflow occurrence, including elevation (El), slope (Sl), rainfall (Rf), normalised difference vegetation index (NDVI), aspect (As), curvature (Cu), soil type (St), and flow accumulation (FA) data were created in raster format using GIS and remote sensing methods (Gaprindashvili et al. 2021).

Muddy mudflows are widespread in the lowlands, while rocky and rocky mudflows dominate in the mountains (Yancey et al. 2013 and Nabiyev et al. 2019). The slope of the Earth's surface controls the rate of surface water flow. As the slope decreases, the rate of surface water flow decreases, reducing the amount of water on the ground and the likelihood of debris flows (Movasat and Tomac 2020). It is important to consider rainfall as a factor in mudflow risk analysis. Heavy and prolonged rainfall is the most important factor in mudflow occurrence (Bai et al. 2014, Rosi et al. 2016 and Mamadjanova et al. 2018). Flow accumulation is one of the most important indicators for determining areas at risk of mudflows (Kazakis et al. 2015).

Research has mainly focused on factors directly related to mudflow susceptibility. While lithological conditions and land use/cover may indirectly influence mudflow occurrence by influencing factors such as soil erosion and surface runoff, the researchers may have chosen to prioritise factors more directly related to mudflow processes, such as elevation, slope, precipitation, vegetation index, aspect, curvature, soil type and flow accumulation.

All raster factor maps were reclassified to an overall measurement scale of 1 (very low) to 5 (very high) using the Reclassify tool of the Spatial Analyst Tools. After reclassifying the mudflow control factor maps, the AHP model was used to assign the relative influence of each factor. The final mudflow susceptibility map of the study area was obtained by overlaying four mudflow control spatial layers using the weight overlay method in ArcGIS.

As far as methods used to generate and reclassify mudflow control factor maps, the factors to be considered in mudflow susceptibility mapping using MCDM are not defined, and there are no general guidelines for factor selection. For this study, eight factors closely related to mudflows were selected based on previous studies (Zelepukina et al. 2020), data availability, researchers' conclusions (Mussina et al. 2023), and the natural structure of the study area. The factors considered in this study and the methods used to process and produce each factor map are described below.

The digital elevation model (DEM) map of the study area was reclassified into five mudflow susceptibility classes and scaled to 10 m spatial resolution to generate an elevation factor map. Slope, curvature and aspect maps were produced directly from the DEM map of the study area using the slope and landform tools in the spatial analysis tools of the ArcGIS environment.

A flow map was produced from a DEM map of the area. First, a flow direction map was created from the DEM map, and then a stream accumulation raster map was created from the flow direction map. Flow direction and flow accumulation calculations were performed using the hydrology tools Fill, Flow Direction and Flow Accumulation in the spatial analysis tools of ArcGIS.

The 2010 – 2020 precipitation record from the World Energy Outlook (POWER) website was used to create the precipitation factor map for the study area. Precipitation was interpolated in ArcGIS10.8 using the interpolation (IDW) method at 10m resolution and extracted along the study area boundary to create a continuous precipitation map of the area.

The Normalised Difference Vegetation Index (NDVI) map of the area was developed from Sentinel 2A satellite imagery. Images as of May 27, 2023, downloaded from the European Copernicus Open Access Center Service website. The

NDVI map was generated from the Sentinel 2A satellite image using ArcGIS 10.8 software by applying the equation 1:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}} = \frac{\mathrm{Band8} - \mathrm{Bad4}}{\mathrm{Band8} + \mathrm{Band4}}, \qquad 1)$$

where NDVI is the Normalised Difference Vegetation Index, NIR is the spectral reflectance of the surface in the near infrared band (band 8 in the Sentinel 2A satellite image) and RED is the spectral reflectance of the surface in the red band (band 4 in the Sentinel 2A satellite image).

Soil type information was downloaded from the World Soil Groups – World Reference Base (WRB) platform of the International Soil Classification System (https://soilgrids.org/) approved by the International Union of Soil Science. Downloaded data were extracted within the survey boundary using *Spatial Analyst Tools→ Extraction→Extract* by mask commands using ArcGIS 10.8 software.

Once all the mudflow control factors were produced in raster format, they were reclassified into five common measurement scales from 1 (very low susceptibility to mudflow) to 5 (very high susceptibility to mudflow) and reclassified to the same spatial resolution (10 m). A higher classification value (5) corresponds to areas more prone to mudflows, while a lower value (1) corresponds to areas less prone to mudflows. As there is no general scale for the reclassification of mudflow control factors, the classes of all factors were determined based on the evaluation of previous studies and the local conditions of the study area (van Westen 2013 and Natsvlishvili et al. 2022).

The Analytic Hierarchy Process (*AHP*) proposed by (Russo and Camanho 2015 and Stofkova et al. 2022) is the most widely used and effective method in the MCDM process to determine the relative importance of each criterion or factor considered in a study. Various previous studies (Abdelkarim et al. 2020, Ajibade et al. 2021 and Karymbalis et al. 2021) have used this method to weigh each mudflow control factor and identify and map mudflow susceptible areas. The factors used to map mudflow susceptibility using multi-criteria decision making were weighted based on the local physical characteristics of the study area and the assessments of previous studies. As suggested by (Russo and Camanho 2015 and Stofkova et al. 2022), the following step-by-step procedure was used to assign relative weights to each mudflow-controlling factor used in this study.

– Based on the relative importance, a value ranging from 1 to 9 was assigned to each factor to construct the pairwise comparison matrix (Tab. 4). According to the scale, 1 indicates equal importance and 9 indicates extreme importance.

– Next, a normalised pairwise comparison matrix table (Tab. 5) was created by dividing each value in the column by the sum of the columns in the pairwise comparison matrix.

– In the third step, the weight of each factor was calculated (Tab. 5) by dividing the sum of each row in the normalised pairwise comparison matrix table by the number of factors (eight in this study).

Tab. 4. Pairwise comparison matrix for selected mudflow control factors

Number of factors	1	2	3	4	5	6	7	8
Symbol of factor	El	As	Rf	Cu	Sl	St	NDVI	FA
El	1	2	3	2	2	3	4	5
As	1/2	1	3	2	2	3	4	6
Rf	1/3	1/3	1	2	2	3	3	4
Cu	1/2	1/2	1/2	1	2	4	3	5
Sl	1/2	1/2	1/2	1/2	1	3	4	5
St	1/3	1/3	1/3	1/4	1/3	1	3	3
NDVI	1/4	1/4	1/3	1/3	1/4	1/3	1	3
FA	1/5	1/6	1/4	1/5	1/5	1/3	1/3	1

Note: Elevation (El), slope (Sl), rainfall (Rf), normalized difference vegetation index (NDVI), aspect (As), curvature (Cu), soil type (St), flow accumulation (FA).
Source: Compiled by the authors.

Table 5 shows the final criterion effect for each mudflow control factor, which reflects the estimated relative influence of each factor on mudflow occurrence in the study area: altitude (24.5%), slope (12.0%), rainfall (14.3%), normalised vegetation difference index (4.7%), aspect (20.7%), curvature (14.2%), soil type (6.8%) and flow accumulation (2.8%).

After calculating the weights for each mudflow controlling factor, a consistency check was performed using the following equations to check whether the comparison was correct or consistent. The consistency index (CI) was calculated using the following equation (Eq. 2), as described in (Štofkova et al. 2022, Russo and Camanho 2015).

$$CI = \frac{\lambda_{max} - n}{n - 1}, \qquad 2)$$

where CI is the consistency index, n is the number of factors compared in the matrix, and λ_{max} is the highest eigenvalue in the pairwise comparison matrix.

Tab. 5. Normalized pairwise comparison matrix and calculated criteria weight for each factor

Factor number	1	2	3	4	5	6	7	8	Sum	CW	CW %
Symbol of factor	El	As	Rf	Cu	Sl	St	NDVI	FA			
El	0.28	0.39	0.34	0.24	0.20	0.17	0.18	0.16	3.62	0.24	24.5%
As	0.14	0.20	0.34	0.24	0.20	0.17	0.18	0.19	5.08	0.21	20.7%
Rf	0.09	0.07	0.11	0.24	0.20	0.17	0.13	0.13	8.92	0.14	14.3%
Cu	0.14	0.10	0.06	0.12	0.20	0.23	0.13	0.16	8.28	0.14	14.2%
Sl	0.14	0.10	0.06	0.06	0.10	0.17	0.18	0.16	9.78	0.12	12.0%
St	0.09	0.07	0.04	0.03	0.03	0.06	0.13	0.09	17.67	0.07	6.8%
NDVI	0.07	0.05	0.04	0.04	0.03	0.02	0.04	0.09	22.33	0.05	4.7%
FA	0.06	0.03	0.03	0.02	0.02	0.02	0.01	0.03	32.00	0.03	2.8%

Source: Compiled by the authors. Note: Elevation (El), slope (Sl), rainfall (Rf), normalized difference vegetation index (NDVI), aspect (As), curvature (Cu), soil type (St), flow accumulation (FA), criteria weight (CW).

As suggested by (Russo and Camanho 2015 and Stofkova et al. 2022), the maximum eigenvalue (λ_{max}) of the comparison matrix was calculated using the following procedure (Tab. 6).

– multiplying each value in the column (in the matrix table, which is not normalised) by the criterion weight,

– calculating the weighted sum by adding the values in the rows,

– calculating the ratio of each weighted sum to the respective criteria weight, and

– averaging the ratio of the weighted sum to the criteria weight.

Finally, the consistency ratio (CR) was calculated using the following equation (Eq. 3) proposed by (Russo and Camanho 2015 and Stofkova et al. 2022) to verify the consistency of the comparisons.

$$CR = \frac{CI}{RI} , \qquad 3)$$

where CR is the consistency ratio, CI is the consistency index, and RI is a random index that varies according to the number of factors in a pairwise comparison matrix. If the CR is less than 0.10, the pairwise comparison matrix has an acceptable consistency. Otherwise, if the CR is greater than or equal to 0.10, it means that the pairwise comparison has insufficient consistency, and the comparison process must be repeated until the value of the CR is below 0.10 (Stofkova et al. 2022).

Tab. 6. Calculated consistency of pairwise comparison (CR = 0.09)

Factor number	1	2	3	4	5	6	7	8	Sum	WSV	WSV/CW
Symbol of factor	El	As	Rf	Cu	Sl	St	NDVI	FA			
El	0.24	0.41	0.43	0.28	0.24	0.20	0.19	0.14	2.15	0.24	8.77
As	0.12	0.21	0.43	0.28	0.24	0.20	0.19	0.17	1.84	0.21	8.93
Rf	0.08	0.07	0.14	0.28	0.24	0.20	0.14	0.11	1.28	0.14	8.92
Cu	0.12	0.10	0.07	0.14	0.24	0.27	0.14	0.14	1.23	0.14	8.70
Sl	0.12	0.10	0.07	0.07	0.12	0.20	0.19	0.14	1.02	0.12	8.52
St	0.08	0.07	0.05	0.04	0.04	0.07	0.14	0.08	0.23	0.07	3.44
NDVI	0.06	0.05	0.05	0.05	0.03	0.02	0.05	0.08	0.21	0.05	4.39
FA	0.05	0.03	0.04	0.03	0.02	0.02	0.02	0.03	0.15	0.03	5.23

Note: Elevation (El), slope (Sl), rainfall (Rf), normalized difference vegetation index (NDVI), aspect (As), curvature (Cu), soil type (St), flow accumulation (FA), weighted sum value (WSV), criteria weight (CW).
Source: Compiled by the authors.

The primary focus of the study was to determine the relative importance of the factors using the Analytic Hierarchy Process (AHP) rather than to assess multicollinearity.

Mudflow susceptibility map production method. After the preparation and reclassification of each mudflow controlling factor to a common measurement scale of 1 (very low) to 5 (very high) using ArcGIS software, and the weighting of the factors using the AHP approach, the spatial layers were integrated and overlapped together in the Spatial Analyst extension of the ArcGIS environment using the weighted overlay technique by applying equation (4) to derive a mudflow susceptibility map of the study area.

$$FS = \sum_{i=0}^{n} x_i * w_i \;, \qquad 4)$$

where FS is the mudflow susceptibility, n is the number of decision criteria, x_i is a particular normalised criterion, and w_i is the weight of the criterion. The values of the raster layers were multiplied by their weight/percentage influence obtained from the AHP analysis, and the results were added to produce the output raster map of mudflow susceptibility.

RESULTS

Analysis of factors

Eight mudflow control factors were used in this study: elevation, slope, precipitation, normalised vegetation difference index, aspect, curvature and soil type. The flow factors were used to identify and map mudflow prone areas within the study area. By examining and analysing these factors, the spatial distribution of mudflow susceptibility in the study area was determined and mapped. A more detailed analysis of each factor is given below.

One of the natural factors influencing the occurrence, development and spread of mudflows is the elevation of the area above sea level. As elevation increases, so does the amount of precipitation. The flow of water in rivers and streams increased, as did the number of herring ponds. Absolute altitude also affects rainfall patterns. For example, as people move from the lowlands to the mountains, the amount of snow and hail increases. In the lowlands, most of the rain fell in March. On the mountain slopes it was in April and in the mountains in May. It is clear that with increasing altitude, the number of debris flows caused by melting snow and glaciers increases somewhat. The altitude of the Shakhimardan region, which is the subject of this study, is 1 324 – 2 825 m above sea level. Considering this, the elevation of Shakhimardan region in terms of susceptibility to mudflows (Fig. 2a and Tab. 7) was evaluated as follows: 2 801 – 3 000 was very high, 2 401 – 2 800 was high, 2 001 – 2 400 was moderate, 1 601 – 2 000 was low, and 1 324 – 1 600 was very low (Karpov et al. 1976).

As the Shakhimardan region is mountainous, the slopes are rather high (Fig. 2e). The influence of the slope of the area on the mudflow risk (Tab. 7) was evaluated as very low from 0 to 5.0, low from 5.1 to 15.0, moderate from 15.1 to 30.0, high from 30.1 to 45.0, and very high from 45.1 to 60.0° (Karpov et al. 1976 and Xiao et al. 2020).

Rainfall. Rainfall in the Shakhimardan area varied from 656 mm to 726 mm. Based on the average annual rainfall, the Shakhimardan region has (656 – 670 mm), (671 – 685 mm), (686 – 700 mm), (701 – 715 mm) and (716 – 726 mm) rainfall. were classified as very low, low, moderate, high and very high for mudflow risk, respectively (Fig. 2b and Tab. 7).

Normalised Difference Vegetation Index (NDVI) is an index that represents the density of vegetation in an area and is one of the factors used to determine susceptibility. The role of plants in mudflows is significant. They have a significant influence on the characteristics and mode of flow of liquid and thick mudflows. Some of the precipitation was stored in the plants for a certain period of time. The absorption of water into the soil is accelerated by plant roots. Leaves and other debris in trees hold large amounts of water. In some places they can hold more than six times their weight in moisture. Vegetation is a natural barrier to mudflow. Trees and bushes significantly reduce the force and speed of a mudflow. High vegetation density reduces the velocity of streams and mudflows (Li et al. 2024). The NDVI values for the Shakhimardan area ranged from -0.281 to 0.140, 0.141 to 0.180, 0.181 to 0.270, 0.271 to 0.360, and 0.361 to 0.740, and areas were classified as very high, high, medium, low, and very low for mudflow, respectively (Fig. 2f and Tab. 7).

Curvature determines the morphology of the surface topography of an area or represents a change in relief forms in a particular direction (Siviglia and Cantelli 2005 and Ohlmacher 2007). A positive landform value indicates a convex surface, a negative value indicates a concave surface, a zero value indicates a flat surface, and a flat landform is highly susceptible to mudflow, followed by concave and convex landforms (Fig. 2d and Tab. 7).

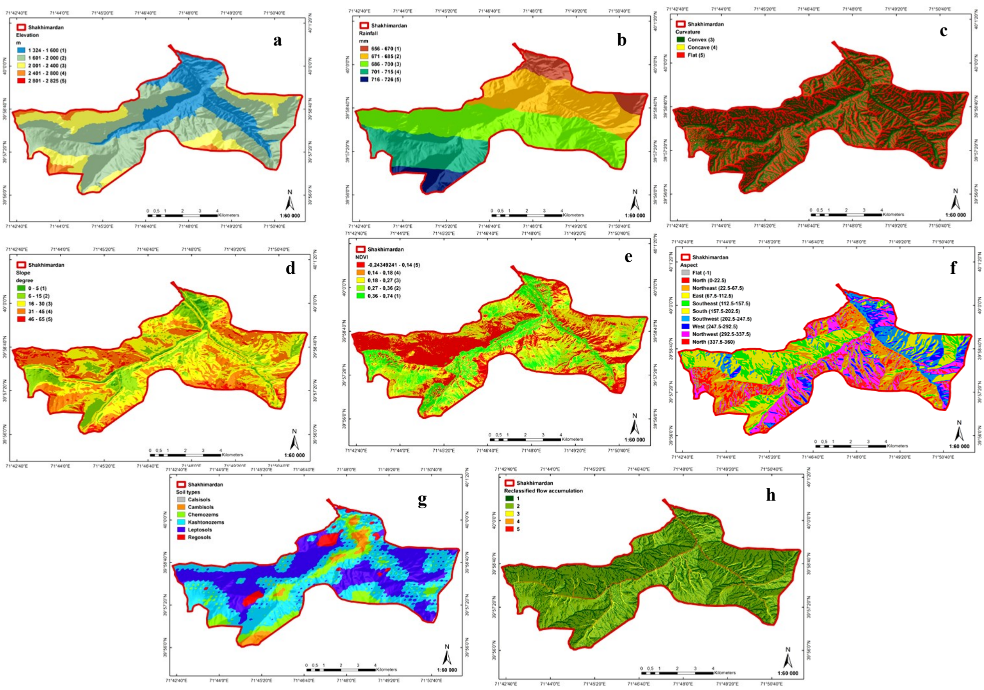

Fig. 2. Evaluation of Shakhimardan region according to the degree of susceptibility to mudflow

a – elevation, b – average annual rainfall, c – curvature, d – slope, e – normalized difference index of vegetation, f – aspect, g – soil types, h – flow accumulation.

Tab. 7. Mudflow factors, their classification criteria, levels, and values

Factor	Class	Mudflow susceptibility
Elevation (El – m a.s.l.)	2 801 – 3 000	Very high
	2 401 – 2 800	High
	2 001 – 2 400	Average
	1 601 – 2 000	Low
	1 324 – 1 600	Very low
Slope (Sl – grades)	45 – 60	Very high
	30 – 45	High
	15 – 30	Average
	5 – 15	Low
	0 – 5	Very low
Rainfall (Rf – mm)	716 – 726	Very high
	701 – 715	High
	686 – 700	Average
	671 – 685	Low
	656 – 670	Very low
Normalized Difference Vegetation Index (NDVI)	-0.121 – 0.140	Very high
	0.141 – 0.180	High
	0.181 – 0.270	Average
	0.271 – 0.360	Low
	0.361 – 0.740	Very low
Curvature (Cu)	Concave	Average
	Flat	Very high
	Convex	High
Flow accumulation (FA – pixel)	9 093 – 59 450	Very low
	934 – 9 092	Very high
	234 – 933	High
	1 – 233	Average
	0	Low
Soil type (St)	Leptosols/Regosols	Very high
	Kashtonozems	High
	Chernozems	Average
	Cambisols	Low
	Calsisols	Very low
Aspect (As)	Southern, South-Eastern, South-Western	Very high
	Western	High
	North-Eastern, Nort-Western	Average
	Eastern	Low
	Northern	Very low

Source: Compiled by the authors as a result of literature analysis.

In this study, flow accumulation in the area was assessed at five levels (Fig. 2i and Tab. 7). These included very high (1 – 233), high (234 – 933), medium (924 – 9 092) and low (9 093 – 59 450) and very low (0).

The role of soil type in mudflow formation is particularly important. Soil erosion has not been uniform. For example, red and mountain meadow soils are more resistant to erosion. Degradation of forest and chestnut soils was moderate. Saline and grey soils eroded rapidly. This is why most of Uzbekistan's soils are muddy. Soils with large amounts of clay become porous when wet, water infiltration into the ground decreases, and surface runoff increases (Ekawati et al. 2020, Widjaja 2019). According Saidov (1971), the soil types in the Shakhimardan area were classified into five secondary carbonate soils (Calcisols): very low, moderately developed soils (Cambisols), black soils (Chernozems), medium, chestnut soils (Kashtonozems), weakly thick or stony soils (Leptosols). Poorly developed soils (Regosols) were classified as very high (Fig. 2h and Tab. 7).

The location of mountains, i.e. their aspect, is one of the factors influencing the risk of mudflows. In Uzbekistan, for example, more rain falls on the western slopes of southern mountains than on the eastern slopes. Mudflows occur more frequently on the southern slopes of mountains than on the northern slopes, and their regimes are different. The southern slopes of mountains receive more sunlight and the weathering process increases. Soil erosion on the southern slopes of the mountains is 1.5 – 2 times higher than on the northern slopes (Fig. 2g and Tab. 7).

Analysis of AHP results

The Analytical Hierarchy Process (AHP) was used to determine the relative importance of each factor in mudflow susceptibility. Pairwise comparisons were made and weights were assigned to each factor based on its influence. Values from 1 to 9 were assigned to each factor to construct the pairwise comparison matrix, reflecting their relative importance. A normalised pairwise comparison matrix was generated and weights were calculated for each factor based on the sum of the normalised values. Consistency indices were calculated to ensure the reliability of the pairwise comparisons. The consistency ratio was calculated to check the consistency of the comparisons, with values below 0.10 considered acceptable.

Analysis of the final mudflow susceptibility map

The integration of GIS-MCDM-AHP facilitated the development of a comprehensive mudflow susceptibility map for the study area. Thematic maps of the eight mudflow control factors were integrated using the weighted overlay technique, considering their respective weights derived from the AHP analysis. The study area was classified into low, medium and high susceptibility zones based on the integrated spatial data and weighted factors.

DISCUSSION

After the reclassification of each mudflow control factor (Figs. 3a – 3i), an AHP analysis was performed to determine the relative influence or impact of the mudflow control factors. A pairwise comparison matrix (Bartl and Ramík 2022) was developed (Tab. 4), the normalisation of the pairwise comparisons and the effects of the factors were calculated (Tab. 5), and a consistency check of the comparison was performed according to the procedures recommended by Stofkova et al. (2022) – Tab. 6.

The concordance index (CI=0.127) was calculated using equation 4 and the robustness ratio (CR=0.09) was calculated using equation 5. The calculated maximum value (λ_{max}=8.93) and the number of factors (n=8) were used to calculate the CI. A random index (RI) of 0.71 was used to calculate the CR. The random index (RI) varies with the number of factors and is 0.71 for eight factors according to different authors. The calculated value of the correlation coefficient (CR) is 0.09 (9%), which is less than 0.1 (10%). Therefore it is acceptable to use the comparison for the weighted coating. The mudflow susceptibility map of the Shakhimardan region was developed by integrating thematic maps of the eight mudflow control factors, as shown in Figure 4. The study area was classified as low (2), medium (3) or high (4) according to the degree of mudflow susceptibility. Less than too percent (1.8 = 1.62 km²) of the total study area was classified as low, 68.3 percent (61.47 km²) as medium and 29.9 percent (26.91 km²) as high.

As far as the Shahimardan district, the available information is difficult to obtain from the relevant organisations. Previously published research materials also do not include such data. With this in mind, we would like to emphasise that our research is primarily for the safety of tourists, and we would like tourists and their service providers to pay close attention to flood-prone areas, especially in May and September.

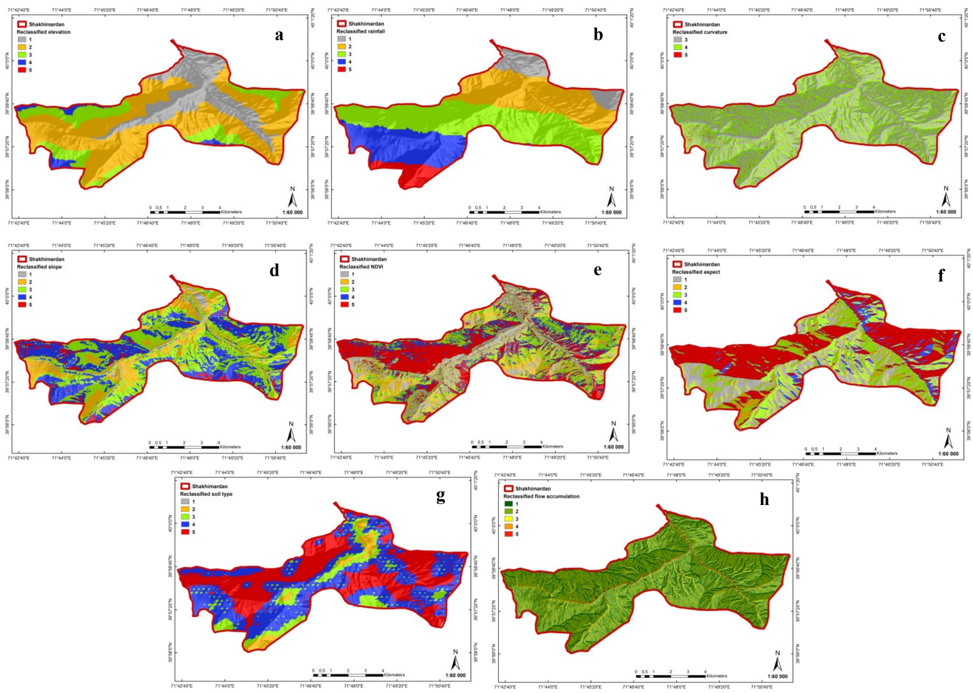

Fig. 3. Reclassification map of factors controlling mudflow

a – elevation, b – average annual rainfall, c – curvature, d – slope, e– normalized difference index of vegetation, f – aspect, g – soil types, h – flow accumulation.

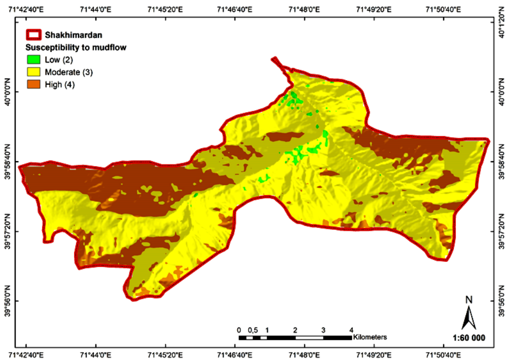

Fig. 4. Mudflow suscetibility map

The lack of monitoring stations in the region to collect real-time data on rainfall, soil moisture and river flow has made it difficult to understand flood flows and dynamics. To address these data limitations, it is necessary to improve monitoring networks, strengthen data quality assurance procedures and integrate multidisciplinary approaches that include geological, hydrological and socio-economic factors. It is also important to encourage collaboration between researchers, local authorities and communities. By addressing these issues, stakeholders can improve the authority, validity and reliability of empirical data used for flood risk assessment and mitigation in the Shakhimardan area.

CONCLUSION

This study highlights the importance of integrating GIS-based MCDM and AHP for the identification and management of mudflow-prone areas. The combined approach not only improves the accuracy of mudflow risk assessment, but also provides a systematic and comprehensive framework for effective decision making.

The GIS-MCDM-AHP integration proved valuable in considering multiple factors and criteria, allowing for a more nuanced understanding of the dynamic nature of mudflow hazards. By incorporating spatial data and multiple decision criteria, this approach allows for a more realistic representation of the complex interplay of factors influencing mudflow events.

In addition, AHP helps to prioritise criteria and facilitates the identification of key variables in the decision-making process. This structured methodology assists decision-makers in allocating resources and implementing targeted mitigation strategies in high-risk areas.

This study found that the eastern part of Shakhimardan Tourist Recreational Zone is most prone to mudflows due to its unique geographical location and hydrological conditions. It contributed to the accounting, assessment, monitoring and forecasting of natural and man-made phenomena and processes that influence human life activities and the overall information structure of the tourism industry.

Practically, the results of this research have implications for land-use planning, disaster preparedness and resource allocation in mudflow-prone regions. The integration of GIS-MCDM-AHP provides a powerful tool for policy makers and land managers to make informed decisions that mitigate the impact of mudflows and contribute to overall community resilience.

We also thank the Environmental System Research Institute for permission to download the land use and land cover map. We thank the NASA Langley Research Center (LaRC) POWER Project, funded by the NASA Earth Sciences/Applied Sciences Program, for providing free downloads of the precipitation data. We thank the ISRIC World Soil Grid website (SoilGrids.org) for providing free downloads of digital soil data. We also thank the Hydrometeorological Service Agency under the Ministry of Ecology, Environmental Protection and Climate Change of the Republic of Uzbekistan for their cooperation in providing the necessary information.

REFERENCES

ABDELKARIM, A., AL-ALOLA, S. S., ALOGAYELL, H. M., MOHAMED, S. A., ALKADI, I. I., ISMAIL, I. Y. (2020). Integration of GIS-based multicriteria decision analysis and analytic hierarchy process to assess flood hazard on the Al-Shamal Train Pathway in Al-Qurayyat region, Kingdom of Saudi Arabia. *Water*, 12, 1702. DOI: https://doi.org/ 10.3390/w12061702

AJIBADE, F. O., AJIBADE, T. F., IDOWU, T. E., NWOGWU, N. A., ADELODUN, B., LASISI, K. H., OPAFOLA, O. T., AJALA, O. A., FADUGBA, O. G., ADEWUMI, J. R. (2021). Flood-prone area mapping using GIS-based analytical hierarchy frameworks for Ibadan city, Nigeria. *Journal of Multi-Criteria Decision Analysis*, 28, 283-295. DOI: https://doi.org/10.1002/mcda.1759

AKHMEDOV, M. A., SALYAMOVA, K. D. (2018). Mudflows in Uzbekistan. *Journal of Civil Protection*, 2, 214-223. DOI: https://doi.org/10.33408/2519-237X.2018.2-2.214

ALLAFTA, H., OPP, C. (2021). GIS-based multi-criteria analysis for flood prone areas mapping in the trans-boundary Shatt Al-Arab basin, Iraq-Iran. *Geomatics, Natural Hazards and Risk*, 12, 2087-2116. DOI: https://doi.org/10.1080/19475705.2021.1955755

BAI, S., WANG, J., THIEBES, B., CHENG, C., YANG, Y. (2014). Analysis of the relationship of landslide occurrence with rainfall: A case study of Wudu County, China. *Arabian Journal of Geosciences*, 7, 1277-1285. DOI: https://doi.org/10.1007/s12517-013-0939-9

BARTL, D., RAMÍK, J. (2022). A new algorithm for computing priority vector of pairwise comparisons matrix with fuzzy elements. *Information Sciences*, 615, 103-117. DOI: https://doi.org/10.1016/j.ins.2022.10.030

BIARDEAU, L. T., SAHLI, M. (2024). Investigating the non-linear impacts of seven types of natural disasters on inbound tourism: Insights from the EM-DAT database. *Tourism Economics*, 30, 900-923. DOI: https://doi.org/10.1177/13548166241229319

CHEN, L., YANG, H., HUANG, H., CHANG, M., WANG, X., HAN, D., LIU, S., XIAO, Y., YAO, D., XIANG, X., YANG, Q. (2023). How do natural and socio-economic factors influence the sustainable development of the ecological environment in the World Natural Heritage Sites? Evidence from the Jiuzhaigou, China. *Journal of Cleaner Production*. 428, 20. DOI: https://doi.org/10.1016/j.jclepro.2023.139238

CHEPURNA, T. B., KUZMENKO, E. D., CHEPURNYJ, I. V. (2017). Geoinformational prognostic model of mudflows hazard and mudflows risk for the territory of Ukrainian Carpathians. Contemporary *Trends in Geoscience*, 6, 57-69. DOI: https://doi.org/ 10.1515/ctg-2017-0005

DANUMAH, J. H., ODAI, S. N., SALEY, B. M., SZARZYNSKI, J., THIEL, M., KWAKU, A., KOUAME, F. K., AKPA, L. Y. (2016). Flood risk assessment and mapping in Abidjan district using multi-criteria analysis (AHP) model and geoinformation techniques, (cote d'ivoire). *Geoenvironmental Disasters*, 3, 1-13. DOI: https:// doi.org/10.1186/s40677-016-0044-y

DAS, S., GUPTA, A. (2021). Multi-criteria decision based geospatial mapping of flood susceptibility and temporal hydro-geomorphic changes in the Subarnarekha basin, India. *Geoscience Frontiers*, 12, 101206. DOI: https://doi.org/10.1016/j.gsf.2021.101206

DERGACHEVA, I., KLIMOV, S., KHAMDAMOVA, G., RAXIMOV, Q., APAKHUJA-YEVA, T. (2021). Mudflow hazard in the foothill and mountainous regions of Uzbekistan. *E3S Web Conferences*, 263, 02019. DOI: https://doi.org/10.1051/e3sconf/202126302019

EKAWATI, J., HARDIMAN, G., PANDELAKI, E. E. (2020). Analysis of GIS-based disaster risk and land use changes in the impacted area of mudflow disaster Lapindo. IOP *Conferences Series: Earth and Environmental Science*, 409, 012032. DOI: https://doi.org/10.1088/1755-1315/409/1/012032

FERREIRA, F. A., CASTRO, C., GOMES, A. S. (2021). Positive and negative social-cultural, economic and environmental impacts of tourism on residents. In de Carvalho, J. V., Rocha, Á., Liberato, P., Peña, A., eds. *Advances in tourism, technology and systems, smart innovation, systems and technologies*. Singapore (Springer), pp. 288-298. DOI: https://doi.org/10.1007/978-981-33-4256-9_26

HUSSAIN, M., TAYYAB, M., ZHANG, J., SHAH, A. A., ULLAH, K., MEHMOOD, U., AL-SHAIBAH, B. (2021). Gis-based multi-criteria approach for flood vulnerability assessment and mapping in district Shangla: Khyber Pakhtunkhwa, Pakistan. *Sustainability*, 13(6), 3126. DOI: https://doi.org/10.3390/su13063126

KARPOV, P. M., PUSHKARENKO, V. P., UMAROV, A.YU., KHODZHAEV, SH. K. (1976). *Mudflow phenomena in Uzbekistan*. Tashkent ("Fan").

KARYMBALIS, E., ANDREOU, M., BATZAKIS, D.-V., TSANAKAS, K., KARALIS, S. (2021). Integration of GIS-based multicriteria decision analysis and analytic hierarchy process for flood-hazard assessment in the Megalo Rema River Catchment (East Attica, Greece). *Sustainability*, 13, 10232. DOI: https://doi.org/10.3390/su131810232

KASIYANCHUK, D., CHEPURNYI, I., CHEPURNA, T., HURSKA, N. (2015). Methodology of quantitative forecasting risk assessments of exogenous geological processes using GIS technology. Presented at the 14th EAGE International Conference on Geoinformatics – Theoretical and Applied Aspects, May 2015, European Association of Geoscientists & Engineers, pp. 1-5. DOI: https://doi.org/10.3997/2214-4609.201412408

KAZAKIS, N., KOUGIAS, I., PATSIALIS, T. (2015). Assessment of flood hazard areas at a regional scale using an index-based approach and analytical hierarchy process: Application in Rhodope–Evros region, Greece. *Science of the Total Environment*, 538, 555-563. DOI: https://doi.org/10.1016/j.scitotenv.2015.08.055

LI, M., WANG, H., CHEN, J., ZHENG, K. (2024). Assessing landslide susceptibility based on the random forest model and multi-source heterogeneous data. *Ecological Indicators*, 158, 111600. DOI: https://doi.org/10.1016/j.ecolind.2024.111600

MAMADJANOVA, G., WILD, S., WALZ, M. A., LECKEBUSCH, G. C. (2018). The role of synoptic processes in mudflow formation in the piedmont areas of Uzbekistan. *Natural Hazards and Earth System Sciences*, 18, 2893-2919. DOI: https://doi.org/10.5194/nhess-18-2893-2018

MOVASAT, M., TOMAC, I. (2020). Evaluation and remediation of post-wildfire slope stability. In *2nd International Conference on Energy Geotechnics (ICEGT 2020) 205, 04007, La Jolla, California, USA, September 20-23, 2020.* DOI: https://doi.org/10.1051/e3sconf/ 202020504007

MUJIB, M. A., APRIYANTO, B., KURNIANTO, F. A., IKHSAN, F. A., NURDIN, E. A., PANGASTUTI, E. I., ASTUTIK, S. (2021). Assessment of flood hazard mapping based on analytical hierarchy process (AHP) and GIS: Application in Kencong district, Jember Regency, Indonesia. *Geosfera Indonesia*, 6, 353-376. DOI: https://doi.org/10.19184/geosi.v6i3.21668

MUSSINA, A., RAIMBEKOVA, Z., SHAHGEDANOVA, M., BARANDUN, M., NARBAYEVA, K., ABDULLAYEVA, A., NYSSANBAYEVA, A. (2023). Mountain resilience: A tool for mudflow risk management in the Ile Alatau Mountains, Kazakhstan. *Mountain Research and Development*, 43, D1-D10. DOI: https://doi.org/10.1659/MRD-JOURNAL-D-22-00004

NABIYEV, G., TARIKHAZER, S., KULIYEVA, S., MARDANOV, I., ALIYEVA, S. (2019). Formation characteristics of the mudflow process in Azerbaijan and the division into districts of territory based on risk level (on the example of the Greater Caucasus). *Applied Ecology and Environmental Research*, 17, 5275-5291. DOI: https://doi.org/10.15666/aeer/1702_52755291

NATSVLISHVILI, L., JORJIASHVILI, N., KOCHORADZE, V. (2022). Development of a PostGIS-based method for creating risk maps of natural disasters using the example of Georgia. *Geodesy and Cartography*, 48, 70-77. DOI: https://doi.org/10.3846/gac.2022.14791

NIGMATOV, A., TOBIROV, O. (2021). Scientific and theoretical foundations of the concepts of tourism, geography and geographical tourism. *American Journal of Interdisciplinary Research and Innovation*, 3, 1-10. DOI: https://doi.org/10.37547/tajiir/Volume03Issue03-01

OHLMACHER, G. C. (2007). Plan curvature and landslide probability in regions dominated by earth flows and earth slides. *Engineering Geology*, 91, 117-134. DOI: https://doi.org/10.1016/j.enggeo.2007.01.005

PETRAKOV, D. A., CHERNOMORETS, S. S., VISKHADZHIEVA, K. S., DOKUKIN, M. D., SAVERNYUK, E. A., PETROV, M. A., EROKHIN, S. A., TUTUBALINA, O. V., GLAZYRIN, G. E., SHPUNTOVA, A. M., STOFFEL, M. (2020). Putting the poorly documented 1998 GLOF disaster in Shakhimardan River valley (Alay Range, Kyrgyzstan/Uzbekistan) into perspective. *Science of Total Environment*, 724, 138287. DOI: https://doi.org/10.1016/j.scitotenv.2020.138287

ROSI, A., PETERNEL, T., JEMEC-AUFLIČ, M., KOMAC, M., SEGONI, S., CASAGLI, N. (2016). Rainfall thresholds for rainfall-induced landslides in Slovenia. *Landslides*, 13, 1571-1577. DOI: https://doi.org/10.1007/s10346-016-0733-3

RUSSO, R. de F.S.M., CAMANHO, R. (2015). Criteria in AHP: A systematic review of literature. *Procedia Computer Science*, 55, 1123-1132. DOI: https://doi.org/10.1016/j.procs.2015.07.081

SAIDOV A. (1971). *Mudflow events in Uzbekistan*. Tashkent (FAN" publishing house of Uzbekistan).

SARI, D. N., ANNA, A. N., TARYONO, T., MAULANA, M. F., KHUMAEROH, D. N. F. 2(024). Detection of flood hazard potential zones by using analytical hierarchy process in Tuntang Watershed area, Indonesia. *Geographia Technica*, 19, 61-78. DOI: https://doi.org/10.21163/GT_2024.191.05

SHAAZIZOV, F. (2021). Assessment of damage during the formation and passage of mudflows in the Tashkent region. *E3S Web Conference*, 264, 03042. DOI: https://doi.org/10.1051/e3sconf/202126403042

SHAH, R. K., SHAH, R. K. (2023). GIS-based flood susceptibility analysis using multi-parametric approach of analytical hierarchy process in Majuli Island, Assam, India. *Sustainable Water Resources Management*, 9, 139. DOI: https://doi.org/10.1007/s40899-023-00924-0

SIVIGLIA, A., CANTELLI, A. (2005). Effect of bottom curvature on mudflow dynamics: Theory and experiments. *Water Resources Research*, 41, 1-17. DOI: https://doi.org/10.1029/ 2005WR004475

STOFKOVA, J., KREJNUS, M., STOFKOVA, K. R., MALEGA, P., BINASOVA, V. (2022). Use of the analytic hierarchy process and selected methods in the managerial decision-making process in the context of sustainable development. *Sustainability*, 14, 11546. DOI: https://doi.org/10.3390/su141811546

TSAI, C.-H., CHEN, C.-W. (2011). The establishment of a rapid natural disaster risk assessment model for the tourism industry. *Tourism Management*, 32, 1, 158-171. DOI: https://doi.org/10.1016/j.tourman.2010.05.015

van WESTEN, C. J. (2013). 3.10 remote sensing and GIS for natural hazards assessment and disaster risk management. In Shroder, J. F., ed. *Treatise on geomorphology*. San

Diego (Academic Press), pp. 259-298. DOI: https://doi.org/10.1016/B978-0-12-374739-6.00051-8
WIDJAJA, B. (2019). Landslide and mudflow behaviour case study in Indonesia: Rheology approach. *IPTEK Journal of Proceedings Series*, 3, 93-97. DOI: https://doi.org/10.12962/j23546026.y2019i3.5849
WORLD BANK GROUP (2022). *Strengthening hydromet and multi-hazard early warning services in Uzbekistan: A road map*. Washington, DC. (World Bank). DOI: https://doi.org/10.1596/38057
XIAO, L., ZHANG, Y., GE, T., WANG, C., WEI, M. (2020). Analysis, assessment and early warning of mudflow disasters along the Shigatse Section of the China – Nepal Highway. *Open Geosciences*, 12, 44-58. DOI: https://doi.org/10.1515/geo-2020-0004
YANCEY, T. E., MUSTOE, G. E., LEOPOLD, E. B., HEIZLER, M. T. (2013). Mudflow disturbance in latest Miocene forests in Lewis County, Washington. *PALAIOS*, 28, 343-358.
YE, X., WEN, J., ZHU, Z., SUN, R. (2022). Natural disaster risk assessment in tourist areas based on multi scenario analysis. *Earth Science Informatics*, 15, 659-670. DOI: https://doi.org/10.1007/s12145-020-00518-w
ZELEPUKINA, E. S., GAVRILKINA, S. A., PRYAKHINA, G. V. (2020). An application of GIS technologies for identifying the potential foci of occurrence of hazardous hydrological phenomena (by the example of mountains of Southern Siberia). In *Proceedings of the international conference InterCarto, InterGIS*, Moscow (Lomonosov Moscow State University), pp. 212-223. DOI: https://doi.org/10.35595/2414-9179-2020-2-26-212-223

Odiljon T o b i r o v, Doniyor M u m i n o v, Khidoyatkhan A b d i n a z a r o v a, Azamatjon K h o s h i m o v, Husniddin N a z a r o v, Gayratjon B e r d i y e v

IDENTIFIKÁCIA OBLASTÍ OHROZENÝCH BAHENNÝMI TOKMI V TURISTICKEJ A REKREAČNEJ ZÓNE SHAKHIMARDAN POMOCOU MULTIKRITERIÁLNEJ ANALÝZY A GIS

Cieľom tohto príspevku je použiť multikritériové rozhodovanie (MCDM) založené na geografickom informačnom systéme (GIS) a analytickom hierarchickom procese (AHP) na posúdenie a riadenie oblastí ohrozených bahennými tokmi v turistickej rekreačnej zóne Shakhimardan v Uzbekistane. Cieľom integrácie týchto metodík je poskytnúť komplexné pochopenie faktorov ovplyvňujúcich výskyt bahenných tokov a uľahčiť efektívne rozhodovanie na zmiernenie a riadenie rizík v regióne.

Skúmaná oblasť Shakhimardan je exkláva Uzbekistanu obklopená Batkenskou oblasťou Kirgizska, Kadamjayský okres, vo východnej časti Strednej Ázie. Jeho hornatý reliéf bez výrazných prírodných nížin je súčasťou pohoria Alay. Je jednou zo štyroch uzbeckých exkláv v Kirgizsku, ďalšími sú Sokh, Chon-Qora (Qalacha) a Jani-Ayil. S rozlohou 90 km^2 je druhou najväčšou po exkláve Sokh s rozlohou 325 km^2. Nachádza sa v údolí na severných svahoch pohoria Alay v nadmorskej výške približne 1 550 m. Najvyššími bodmi exklávy sú vrcholy Almalik 2 841 m, Chivirgan 2 465 m a Qizil-Gaza 2 568 m. Západne od obce Shohimardon sa rozprestiera pohorie Kozdibel. Exklávou preteká niekoľko riek, z ktorých najväčšie sú Koksu, Oqsu a Shohimardonsoy. Po tom, ako sa Koksu pri dedinskom parku spojí s Oqsu, vzniká Shohimardonsoy tečúci do Margilanu. Hlavným zdrojom riek sú ľadovce v Kirgizsku. Minimálna teplota v januári je -23,0 °C. Najvyššia teplota v júli je 42,0 °C. Priemerné množstvo zrážok vo forme dažďa a snehu je 350 – 400 mm. Priemerná teplota v júli je 22 °C, v januári -3 až 3 °C.

Hoci použitie analytického hierarchického procesu (AHP) v kombinácii s geografickým informačným systémom (GIS) na hodnotenie a riadenie oblastí náchylných na bahenné toky nie je úplne nové, naša štúdia prispieva k existujúcej literatúre niekoľkými významnými spôsobmi: integráciou viacerých faktorov, lokalizovanou analýzou, podrobným metodickým prístupom, hodnotením konzistentnosti a praktickými dôsledkami výskumu, ktoré sa rozširujú na plánovanie využívania pôdy, pripravenosť na katastrofy a prideľovanie zdrojov v oblastiach náchylných na bahenné toky. Identifikáciou vysokorizikových oblastí a stanovením priorít zmierňujúcich opatrení naša štúdia prispieva k zvýšeniu odolnosti komunít a zníženiu sociálno-ekonomických dôsledkov bahenných tokov.

Štúdia zdôrazňuje význam integrácie MCDM založeného na GIS a AHP pre identifikáciu a riadenie oblastí náchylných na bahenné toky. Kombinovaný prístup nielenže zlepšuje presnosť hodnotenia rizika bahenných tokov, ale poskytuje aj systematický a komplexný rámec pre efektívne rozhodovanie. Integrácia GIS-MCDM-AHP sa ukázala ako cenná pri zohľadňovaní viacerých faktorov a kritérií, čo umožnilo diferencovanejšie pochopenie dynamickej povahy nebezpečenstva bahenných tokov. Začlenením priestorových údajov a viacerých rozhodovacích kritérií tento prístup umožňuje realistickejšie znázorniť komplexnú súhru faktorov ovplyvňujúcich udalosti spojené s bahennými tokmi.

Okrem toho AHP pomáha stanoviť priority kritérií a uľahčuje identifikáciu kľúčových premenných v rozhodovacom procese. Táto štruktúrovaná metodika pomáha rozhodovacím orgánom pri prideľovaní zdrojov a realizácii cielených stratégií zmierňovania následkov vo vysokorizikových oblastiach. Výsledky tohto výskumu majú praktický význam pre územné plánovanie, pripravenosť na katastrofy a prideľovanie zdrojov v regiónoch ohrozených bahennými tokmi. Integrácia GIS-MCDM-AHP poskytuje účinný nástroj pre tvorcov politík a správcov pôdy na prijímanie informovaných rozhodnutí, ktoré zmierňujú vplyv bahenných tokov a prispievajú k celkovej odolnosti komunity.

Article first received: January 2024
Article accepted: June 2024