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RISK MAPPING BASED ON RISK ASSESSMENT SEMI-QUANTITATIVE METHOD AS A MEANS FOR RESILIENCE STRENGTHENING SUPPORT IN TRANSCARPATHIA

ABSTRACT

The occurrence of natural and man-made hazards usually leads to the emergence of consequences that affect the living environment. Risk assessment as a process helps to comprehend risk. A risk assessment based on complex semi-qualitative approach to probability of hazard with specified consequences occurrence makes it possible to designate risk levels. In the Transcarpathian region the assessed risk levels distribution has been visualized on risk maps. Such risk maps as a form of risk communication may be used to support resilience strengthening regarding identified hazards and its impact on the society, infrastructure and environment. Based on conducted research, a risk assessment methodology and risk mapping methodology were proposed. Moreover, the usage of proposed methods was referenced to the resilience strengthening and its influence on the sustainable development of the Transcarpathian region. The proposed tool is a solution that is correlated to 30 innovations linking dedicated Disaster Risk Reduction with Sustainable Development Goals.

KEYWORDS

disaster risk reduction, sustainable development, risk matrix

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MAPOWANIE RYZYKA W OPARCIU O PÓŁILOŚCIOWĄ METODĘ OCENY RYZYKA JAKO WSPARCIE DLA WZMOCNIENIA ODPORNOŚCI NA ZAKARPACIU

ABSTRAKT

Występowanie zagrożeń naturalnych i spowodowanych działalnością człowieka prowadzi zazwyczaj do pojawienia się konsekwencji wpływających na środowisko życia. Ocena ryzyka jako proces pomaga zrozumieć ryzyko. Ocena ryzyka oparta na kompleksowym, półilościowym podejściu do prawdopodobieństwa wystąpienia zagrożenia o określonych konsekwencjach prowadzi do wyznaczenia poziomów ryzyka. W regionie Zakarpacia oceniony rozkład poziomów ryzyka został zwizualizowany na mapach ryzyka. Mapy ryzyka jako forma komunikacji o ryzyku mogą być zastosowane do wspierania wzmacniania odporności w odniesieniu do zidentyfikowanych zagrożeń i ich wpływu na społeczeństwo, infrastrukturę i środowisko. Na podstawie przeprowadzonych badań zaproponowano metodologię oceny ryzyka oraz metodologię tworzenia map ryzyka. Ponadto wykorzystanie proponowanych metod odniesiono do wzmocnienia odporności i jej wpływu na zrównoważony rozwój regionu Zakarpacia. Zaproponowane narzędzie jest rozwiązaniem będącym w korelacji z 30 innowacjami łączącymi dedykowaną redukcję ryzyka klęsk żywiołowych z Celami Zrównoważonego Rozwoju.

SŁOWA KLUCZOWE

redukcja ryzyka związanego z klęskami żywiołowymi, zrównoważony rozwój, matryca ryzyka

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1. INTRODUCTION

Transcarpathia is an Ukrainian region located in South-West part of the country at the crossroads of Slovakia, Hungary and Romania borders. Its geographical location determines its multiethnic structure and its Central European character with economic potential, especially tourism and recreation development, based on natural assets (Tisza River basin, Outer Eastern Carpathians) and a position in international transport networks [1,2,3,4]. The region is divided into following districts: Berehove, Velykyi Bereznyi, Vinogradov, Volovets, Irshawa, Mukachevo, Rachiv, Svaliava, Tiachiw, Uzhhorod, Khust, Mizhhirskii and Perechyn.

Focus on the Transcarpathian region was aimed at strengthening and improving disaster risk reduction (DRR) by implementing the ImProDiReT project founded by the Directorate General for European Civil Protection and Humanitarian Aid Operations (DG ECHO) [5]. Taking into consideration disaster risk and its reduction, the usage of risk mapping was suggested based on specified risk assessment methodology, which may be used as a preventive measure intended to strengthen the resilience of infrastructures, society or environment, and influence further the sustainable development in the region [6].

Based on UNISDR Global Assessment Report on Disaster Risk Reduction (2019), risk may be defined as the probability of a harmful effect occurring, as well as, the mathematical representation of the undesirable consequence of the occurred hazard [7]. The two-element combination of probability and severity of consequences determines the level of risk [8]. Risk can be estimated qualitatively (more general, descriptive) or quantitatively (more precise, based on index values). Risk assessment methodology used to assign the level of risk in Transcarpathia, based on two dimensions, is classified as semi-qualitative. This methodology includes a combination of numeric estimation and descriptive approaches [9]. The process of risk assessment consists of elements such as: risk identification, risk analysis, risk evaluation and risk treatment [10].

Further, the risk assessment result is visualized using the Geographic Information System (GIS). GIS is a system designed to "(…) capturing, storing, checking, and displaying data related to positions on Earth's surface". Since 1960s, when the definition of GIS was published [11], the use of GIS has become more widespread and serves as a common tool applied in different sectors [12].

Risk maps as a risk distribution visualization are an invaluable base for regional planning and hazard mitigation measures implemented by local authorities. The maps are a tool that allow communicating the level of risk with regional community representatives (decision-makers, residents, public services, non-governmental organizations) [13]. Resilience of the Transcarpathian region understood as an "ability to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard" [14] may be strengthened based on risk levels in individual parts of the region.

In the 2030 Agenda for Sustainable Development (SD) in United Nations Resolution adopted by the General Assembly on 25 September 2015, 17 Sustainable Development Goals (SDGs) were described. The Goals include the three dimensions of sustainable development (i.e. the economic, social and environmental dimensions) [15].

The proposed risk mapping methodology used as a resilience strengthening support might be linked to Goal 9 ("Build resilient infrastructures, promote inclusive and sustainable industrialization and foster innovation") and Goal 11 ("Make cities and human settlements inclusive, safe, resilient and sustainable"). Indirectly influencing: the development of resilient infrastructures (Goal 9.1), the protection of the cultural and natural heritage (Goal 11.4), and as a decision making support tool, helping to reduce the number of deaths/people affected (Goal 11.5).

Taking into account the above issues, the article comprises a summary and outline of the risk mapping methodology used in ImProDiReT project for Transcarpathia. To answer the question concerning the development of risk maps for Transcarpathia based on risk assessment methodology to support resilience strengthening, the following research hypotheses have been devised:

1. An assessment of risk probability and its consequences allows to assess the risk on different levels.
2. Risk maps enable the visualization of the risk assessment results.
3. Assessed and visualized risks help support the decision making process aimed at raising resilience.

2. MATERIALS AND METHODS

The proposed methodology is based on three steps: (1) risk assessment (RA), (2) risk mapping (RM), and (3) risk communication (RC) – use of risk map as form of a resilience strengthening support (Figure 1).

Risk identification is a basis for further risk analysis and allows defining the assessment context boundary [16,17]. Risk is closely correlated with the hazard. Finding out the extent to which a defined given phenomenon, event or situation hazards protects diverse values (e.g. life, health, property, environment) becomes possible thanks to assessing the value of risk [18]. Hazards identification begins the risk assessment process.

Hazards can be identified in many ways, e.g. by heuristic methods (brainstorming), interviews with people living in the study area, expert judgment and an analysis of statistical data concerning past hazards in a specific area.

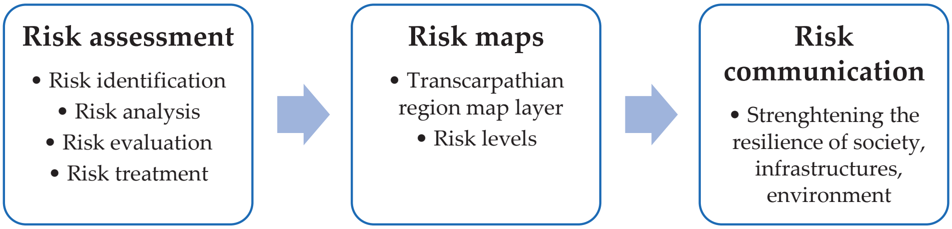

Fig. 1. Proposed methodology scheme
Source: own study.

The method for identifying and selecting hazards related to the Transcarpathian region was based on hazard identification procedure (HIP), which comprises the following steps: (1) designation of an expert group, (2) assigning hazards to specific areas (groups) by source of origin, and (3) hazards ranking by each expert individually. The basic list of hazards included 17 hazards divided into two groups (man-made hazards and natural hazards). Each expert assessed hazards by assigning the hierarchy of hazards ranging from 1 – as the less relevant up to 17 – being the most relevant. All points assigned by experts to each hazard were then summed up. Based on the scores hierarchy a list of hazards for further analysis was selected (chemical hazards, heavy snowfalls, heavy rains, black ice, drought, mudflow, landslide, flood).

Risk analysis

Risk analysis is a technique intended to evaluate the level of hazardous occurrences and helps to understand risks [19,20]. Risk analyses can be carried out in various aspects and with the use of different techniques, but its idea is based on determining the likelihood of hazard occurrence and the strength of its impact on the local society (effects / consequences) [21]. For the purposes of the analyses for defined hazards, it was assumed that the risk analysis will concern its two main attributes: (1) the likelihood that a hazard might occur and (2) the consequences of such a hazard. Data on probability and consequences were gathered in survey addressed to experts representing State Emergency Service in Transcarpathian region. The semi-quantitative method was used to assigned probability and consequences values.

Probability (P) values (classes from 1 to 5), which described frequency of previously selected hazards (Table 1), were estimated by experts from Transcarpathian districts [22].

Table 1. Classes of probability

Probability class (P)	Class description
1	Very rare events (> 100 years)
2	Low probability of occurrence (from 50 to 100 years)
3	Probable events (from 10 to 50 years)
4	Very probable events (from 1 to 10 years)
5	Events almost certain (often than once a year)

Source: own study based on [22].

A review of possible consequences (C) was carried out in the following categories: (1) number of dead people, (2) number of injured people, (3) number of evacuated people, (4) material (financial) losses, (5) losses in the environment, (6) disruption of functionality, (7) number of people affected by the disruption, and (8) duration of (local) critical infrastructure damage.

Consequences were estimated in categories related to life and health, infrastructure and environment. Specified classes of consequences were described and points were assigned to each class, according to the description contained in Table 2.

Table 2. Classes of consequences

Class of consequences	Points (C_n)	Name of class	Description
E	16	Disastrous	A large number of deaths. A large number of seriously injured. A large number of patients hospitalized. General and long-term displacement of the population. Extensive destruction. Impossibility of functioning of the community without significant external help. Great consequences on the environment and/or permanent damage. External financial assistance of considerable size is needed.

cont. Table 2.

Class of consequences	**Points (C_n)**	**Name of class**	**Description**
D	8	Big	Deaths and/or serious injuries to persons, some of them require hospitalization. Evacuation of people to designated places with the possibility of returning after 24 hours. Helping people in the evacuated place. Identification of destruction that requires routine repair. The functioning of the community with little inconvenience longer than a day. Larger consequences in the environment, but short-term or low consequences with a long-lasting consequence. Significant financial losses without external assistance. There is a need for specific resources to help people and to remove damage. A partially non-functioning community, some services are not available.
C	4	Average	A small number of wounded, no deaths. First aid is required. Some human movements occur (less than 24 hours). Some people need help. There is some destruction. Difficulties occur (not longer than 24 hours) in the functioning processes. Low environmental consequences with a short-term consequence. Small financial losses.
B	2	Small	No deaths or injuries. A small number of people displaced for a short period. Nobody in need of help or a small number of people needing help (does not apply to financial or material help). Small, practically meaningless destruction.

cont. Table 2.

Class of consequences	Points (C_n)	Name of class	Description
B	2	Small	No influence or very little consequence on the functioning of the local community. A virtually negligible consequence in the natural environment. Small financial losses.
A	1	Neglected	Discomfort. No human movements. No damage. Unimpeded functioning of people or impeded only to a small extent. Uninterrupted processes. No consequences on the environment.

Source: own study based on [22].

After expert estimation all categories were aggregated and the cumulative value of consequences for each hazard was calculated. To each consequence category a weight criterion was ascribed (Table 3).

Table 3. Categories of consequences

No.	Category of consequences	Weight criterion (a_n)	Percentage
1	Number of fatalities	$a_1 = 0.2$	20%
2	Number of injured people	$a_2 = 0.2$	20%
3	Number of evacuees	$a_3 = 0.1$	10%
4	Material losses	$a_4 = 0.1$	10%
5	Losses in the environment	$a_5 = 0.2$	20%
6	Disruption of functionality	$a_6 = 0.05$	5%
7	Number of people affected by the disruption	$a_7 = 0.05$	5%

cont. Table 3.

No.	Category of consequences	Weight criterion (a_n)	Percentage
8	Duration of (local) critical infrastructure damage	$a_8 = 0.1$	10%
	Total	$\mathbf{a_{sum} = 1}$	**100%**

Source: own study based on [22].

The cumulative value of the consequences (C) was calculated based on points assigned to consequences classes and each category weight criterion as follows:

$$C = \sum_{n=8} a_n \times C_n \tag{1}$$

where:
a_n – weight criterion
C_n – points assigned to consequences classes

The obtained value of cumulative consequences should be comprised by the classification of consequences defined by the ranges of achievable values (rounded up to the nearest above class of consequences according range of values presented in Table 4).

Table 4. Classes of consequences along with the quantitative range

Cumulative consequences value range (quantitative range)	Class of cumulative consequences	Ranked value of cumulative consequences (Cr)
< 1.00	A	1
1.01 – 2.00	B	2
2.01 – 4.00	C	4
4.01 – 8.00	D	8
> 8.00	E	16

Source: own study based on [22].

As a result of risk analysis (probability and consequences values estimation) a calculation was made of the value of risk for each selected hazard as follows:

$$R = f(P, Cr) \quad (2)$$

where:
P – probability
Cr – consequences values

Risk evaluation

Risk evaluation was carried out using the results of the risk analysis and its acceptance criteria. The evaluation relays on comparison of the estimated results were related to risk with the agreed criteria of risk acceptability. The outcome of risk evaluation is the determined level of risk expressed in risk matrix (Figure 2).

Consequences / Probability	A (1)	B (2)	C (4)	D (8)	E (16)
5	5	10	20	40	80
4	4	8	16	32	64
3	3	6	12	24	48
2	2	4	8	16	32
1	1	2	4	8	16

Legend
risk neglected
low risk
medium risk
big risk
catastrophic risk

Fig. 2. Risk matrix
Source: [23].

The risk acceptance levels presented in the risk matrix tool (Figure 2) were based on the adapted criteria (Table 5).

Table 5. Risk acceptance criteria and risk level criteria

Risk acceptance criteria	Risk levels	Risk level criteria
Unacceptable risk	Catastrophic risk	• the probability that a hazard might occur is defined as one of five classes 1–5, and at the same time it has disastrous consequences; • the probability of a hazard occurring is defined as class 4 or 5, and it has big (significant)consequences;
Unacceptable risk	Big risk	• the probability of a hazard occurring is defined as one of four classes 1–3, and at the same time it has big consequences; • the probability of a hazard occurring is determined to be at least very probable, and at the same time it has consequences in average class;
Acceptable risk	Medium risk	• the probability of a hazard occurring is defined as one of three classes 1–3, and at the same time it produces average class of consequences, • the probability of a hazard occurring is at least very probable, and at the same time it has small consequences, • the probability of a hazard occurring is defined as almost certain, and at the same time it produces negligible consequences,
Acceptable risk	Small risk	• the probability of a hazard occurring is defined in one of three classes 1–3, and at the same time it has small consequences,

cont. Table 5.

Risk acceptance criteria	Risk levels	Risk level criteria
Acceptable risk	Small risk	• the probability of a hazard occurring is defined in classes between 2–4, and at the same time it produces negligible consequences,
Acceptable risk	Negligible risk	• the probability of a hazard occurring is defined as very rare and at the same time it produces negligible consequences.

Source: own study based on [22].

Risk treatment

The distribution of risk levels assigned to each hazard helps in defining priorities aimed at ensuring the safety and resilience strengthening in considered areas.

In the first place, intervention is required in the areas where unacceptable risks have been assessed. In such a situation, measures meant to reduce risks to an acceptable level need to be undertaken. There are three directions to reduce the risk level: (1) by reducing the probability value, (2) by reducing the value of consequences, or (3) by reducing both values – probability and consequences.

The "upper" level of risk is never accepted and therefore in case of unacceptable risk, extraordinary and immediate measures should be undertaken to increase security. There is a need to introduce additional or new solutions, which cause the minimising of risk value to an acceptable level.

In cases where the value of the risk is at an acceptable level, it is considered that no additional extraordinary and immediate risk mitigation measures are necessary. Monitoring activities complied with applicable procedures should be are carried out on a continuous basis.

Risk mapping

Risk Mapping (RM) for the Transcarpathian region was based on the following elements to develop risk maps: (1) identification of necessary data, (2) choice of mapping form in relation to hazard and consequences, (3) assembling GIS data (spatial layer), (4) assembling data on risk levels, (5) digitalization of data on risk levels, and (6) visualization of risk levels. Free and open source QGIS software was used to develop risk maps.

Table 6. Risk mapping methodology elements

	RM element	Description
1	Identification of necessary data	In this stage necessary data was identified: risk of selected hazards data, Transcarpathian region/districts polygons in GIS applicable layer.
2	Choice of mapping form in relation to hazard and consequences	Based on information concerning selected hazards and risk assessments methodology used risk mapping form was selected.
3	Assembling GIS data (spatial layer)	Spatial layer representing Transcarpathian district polygons was compiled from an open source map (openstreetmap.org).
4	Assembling data on risk levels	Risk levels were assessed in the risk assessment process.
5	Digitalization of data on risk levels	Risk levels were added as an attribute to the already existing district polygons layers.
6	Visualization of risk levels	Based on risk levels the symbology of district polygons was visualized (negligible risk – blue, low risk – green, medium risk – rose, high risk – orange, catastrophic risk – red).

Source: own elaboration based on [22].

Risk communication

The proposed risk communication concept is based on risk assessments and visualization of its results through mapping. Awareness of hazards' risk is a crucial element of social, infrastructure or environment resilience strengthening. Risk and its distribution visualized through maps is a simple visual form enabling the exchange information concerning risk levels between regional/local government and other stakeholders representing different sectors (decision-makers, public administration, media, non-governmental organizations, local society representatives, etc.) [24, 25]. Based on risk mapping it is possible to map the communication channels regarding specified risks along with support measures undertaken to strengthen the ability to resist, absorb, accommodate, adapt to, transform and recover from consequences caused by hazards.

3. RESULTS

Based on the proposed methodology including hazard probability and consequence values assessment by experts in a survey (RA), and risk level visualization (RM), regions of Transcarpathia with an unacceptable risk value have been identified.

The Transcarpathian regions where the unacceptable risk value most often occurred are:

1. Uzhhorod – the levels of catastrophic risk were obtained for three hazards (Chemical hazards, Heavy rains, Flood).
2. Berehove, Mukachevo, Tiachiv – the level of catastrophic risk were obtained for two hazards (Heavy rains, Flood).
3. In Berehove and Tiachiv regions, the level of high risk, which is also deemed unacceptable, was obtained for Heavy snowfall. In the last region (Tiachiv) a high risk was also assumed for Landslide.

Hazards for which unacceptable risk values were obtained are:

1. Flood: Berehove, Vinogradov, Volovets, Irshawa, Mukachevo, Tiachiv, Uzhhorod, Khust, Velykyi Bereznyi, Svaliava and Perechyn.
2. Heavy rains: Berehove, Mukachevo, Tiachiv, Uzhhorod, Velykyi Bereznyi, Vinogradov, Volovets, Irshawa, Rachiv, Svaliava, Khust, Mizhhirskii and Perechyn.

Risk assessment results for each hazard are presented in Table 7.

Table 7. Risk assessment results for Transcarpathian districts

District	Chemical hazards	Heavy snowfalls	Heavy rains	Black ice	Drought	Mud-flow	Land-slide	Flood
Berehove	2	4	5	2	3	2	2	5
Velykyi Bereznyi	2	4	4	3	3	3	3	4
Vinogradov	2	3	4	2	3	3	3	5
Volovets	2	4	4	3	3	3	4	5
Irshawa	2	4	4	2	3	3	3	5
Mukachevo	2	3	5	2	3	2	2	5
Rachiv	2	4	4	4	3	3	4	3
Svaliava	5	4	4	2	3	3	4	4
Tiachiv	2	4	5	3	3	3	4	5
Uzhhorod	5	3	5	2	3	2	2	5
Khust	2	3	4	2	3	2	2	5
Mizhhirskii	2	4	4	4	3	3	4	3
Perechyn	2	4	4	3	3	3	4	4

Source: own study based on [23].

The assessed (obtained) risk levels for selected hazards have been visualized (Figure 3, Figure 4, Figure 5, Figure 6, Figure 7, Figure 8, Figure 9, Figure 10) according to the RM methodology described in 6th element in Table 6.

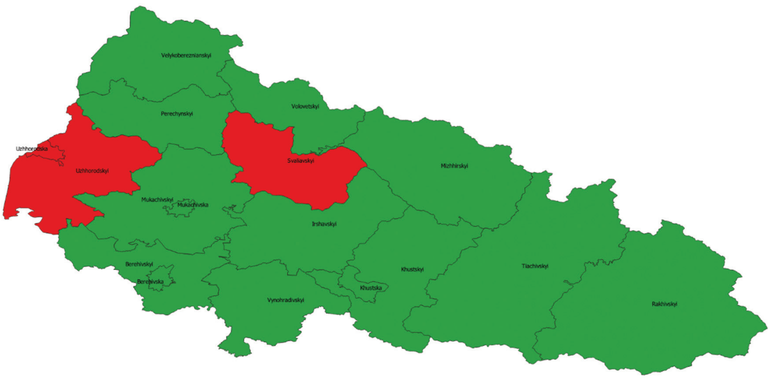

Fig. 3. Map showing the risk of chemical hazards in the Transcarpathian region
Source: own study based on [23].

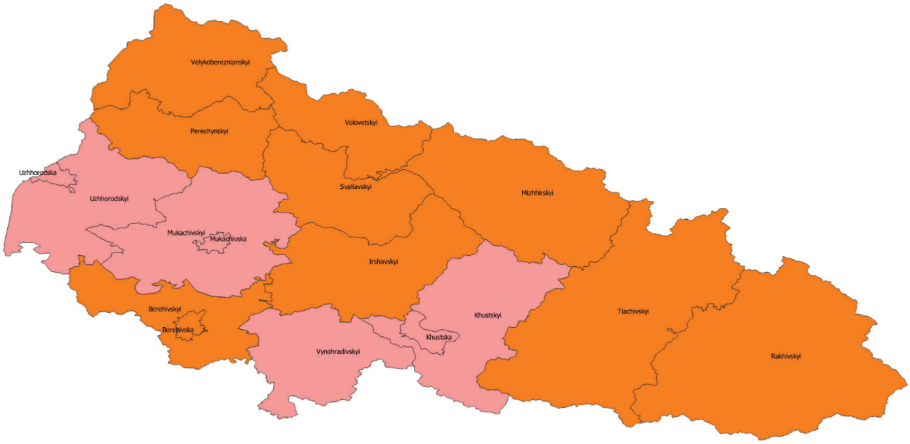

Fig. 4. Map showing the risk of heavy snowfall in the Transcarpathian region.
Source: own study based on [23].

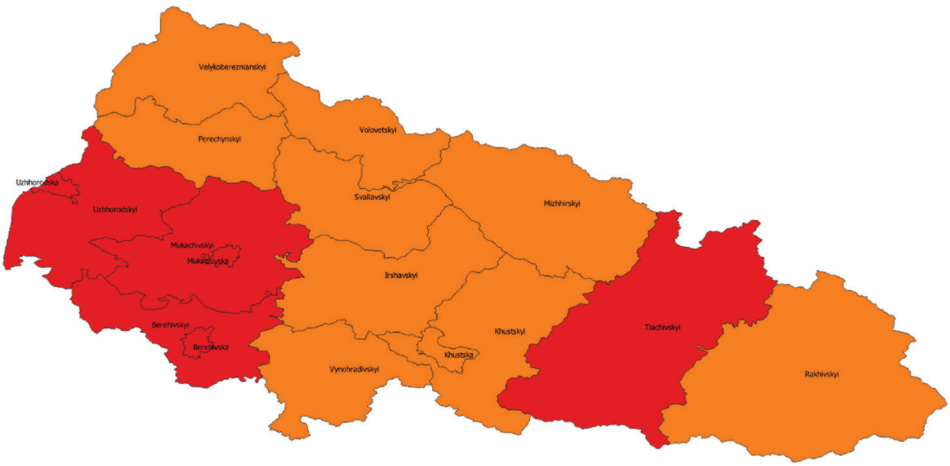

Fig. 5. Map showing the risk of heavy rainfall in the Transcarpathian region
Source: own study based on [23].

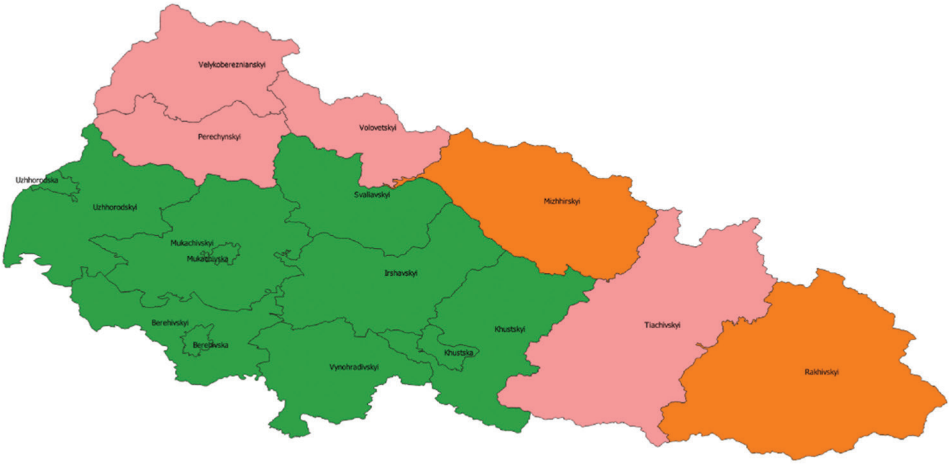

Fig. 6. Map showing the risk of black ice in the Transcarpathian region
Source: own study based on [23].

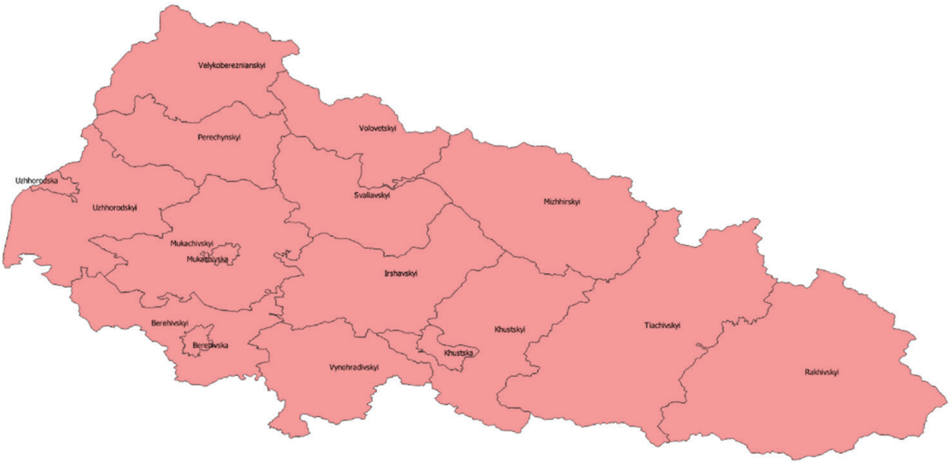

Fig. 7. Map showing the risk of drought in the Transcarpathian region
Source: own study based on [23].

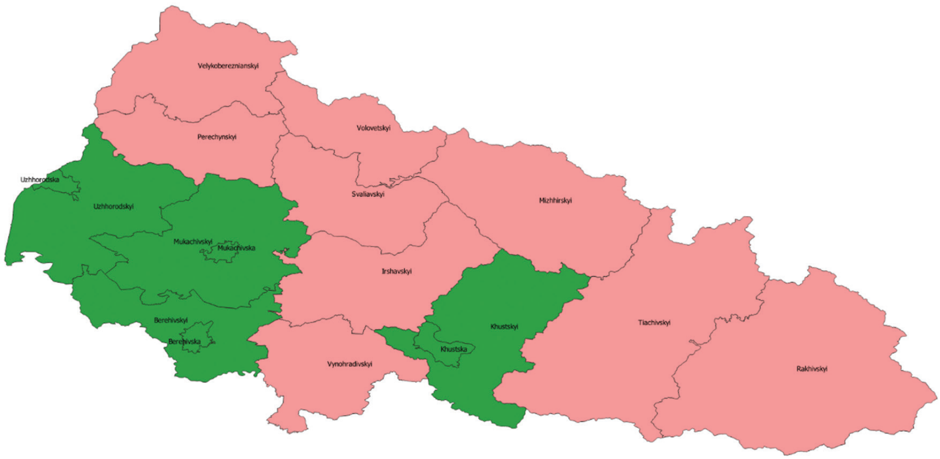

Fig. 8. Map showing the risk of mudflow in the Transcarpathian region
Source: own study based on [23].

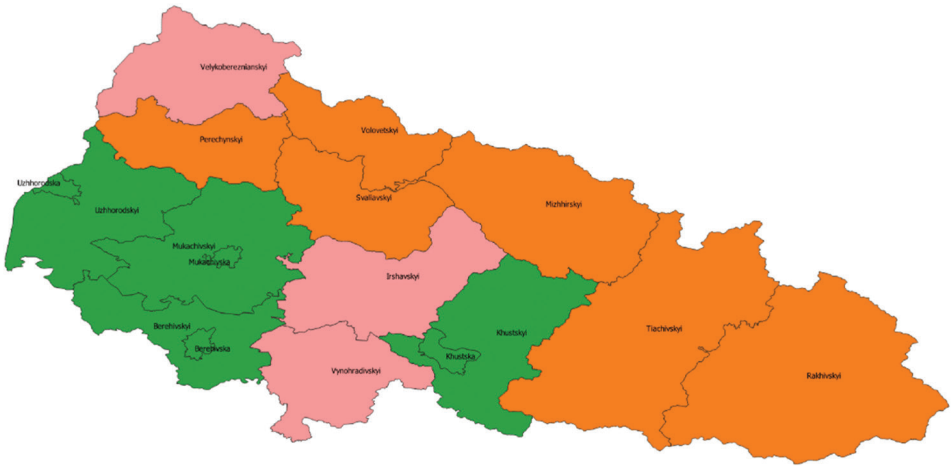

Fig. 9. Map showing the risk of landslides in the Transcarpathian region
Source: own study based on [23].

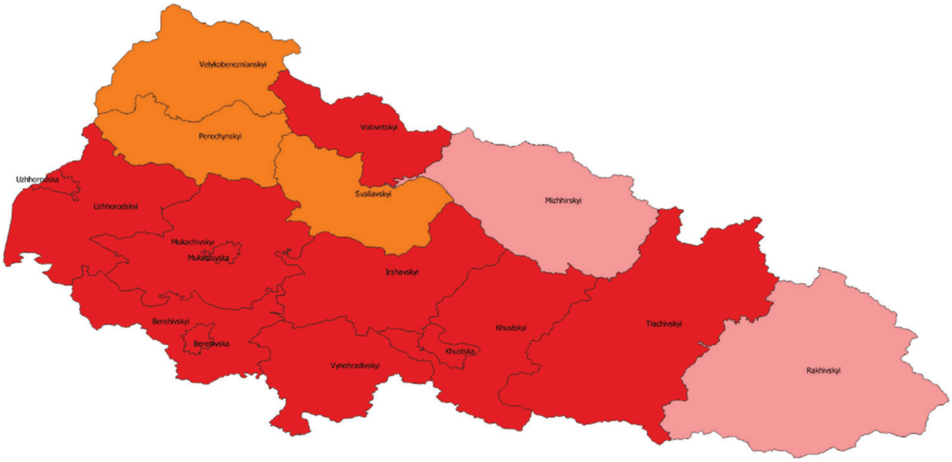

Fig. 10. Map showing the risk of flood in the Transcarpathian region
Source: own study based on [23].

4. DISCUSSION

As a spatial representation of risk assigned to hazardous events, risk maps are a simple measure that may be used to support decision-making process. Based on specified methods of risk assessment, maps represent the final results of complex risk analysis composed of hazard probability and consequences semi-qualitative assessment. Thanks to the established involvement of the Transcarpathian State Fire Service representatives, a survey concerning the hazard and its consequences was conducted.

Risk communication through a risk map offers a concise channel that can support justification of regulations enacted to strengthen the resilience of a region. Actions undertaken to strengthen resilience may be directed at: decreasing the probability of hazard occurrence, minimising the consequences of hazards, and both.

A risk matrix formed by a combination of probability and consequences delivers additional information concerning the directions from which a risk element should be considered.

It is important to emphasise the importance of spatial distribution of risk levels. Some of the risk treatment may be implemented merely in districts, where risk level has been considered to be unacceptable. That opportunity may lead to consistent measures in a sustainable manner.

The Transcarpathian region is an area where risk levels are diversified, which fact should be taken into consideration in regional development and safety strategies. Resilience of community, environment and infrastructure should be strengthened starting from the local level, but with strong cooperation at a regional and central administrative level. Risk maps allowed making certain observations. Risk mapping shows that the risk of drought is common for all districts, which is an opportunity to establish cooperation on a regional level with all Transcarpathian local authorities and other organizations interested in drought impact reduction. Furthermore, the risk of flood is assigned to the border district and that should lead to cross-border cooperation to reduce its probability and consequences. The Transcarpathian region and its geographical location on the national border with Slovakia, Hungary and Romania should be used as an opportunity to establish and streamline cross-border cooperation to strive at sustainable development.

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