DEBRIS FLOWS: Disasters, Risk, Forecast, Protection

Proceedings
of the 5th International Conference

Tbilisi, Georgia, 1-5 October 2018

Editors
S.S. Chernomorets, G.V. Gavardashvili

Publishing House “Universal”
Tbilisi   2018

СЕЛЕВЫЕ ПОТОКИ: катастрофы, риск, прогноз, защита

Труды
5-й Международной конференции

Тбилиси, Грузия, 1-5 октября 2018 г.

Ответственные редакторы
С.С. Черноморец, Г.В. Гавардашвили

Издательство Универсал
Тбилиси 2018

ღვარცოფები: კატასტროფები, რისკი, პროგნოზი, დაცვა

მე–5 საერთაშორისო კონფერენციის მასალები

თბილისი, საქართველო, 1–5 ოქტომბერი, 2018

რედაქტორები
ს.ს. ჩერნომორეც, გ.ვ. გავარდაშვილი

გამომცემლობა "უნივერსალი"
თბილისი 2018

УДК 551.311.8
ББК 26.823

Селевые потоки: катастрофы, риск, прогноз, защита. Труды 5-й Международной конференции. Тбилиси, Грузия, 1-5 октября 2018 г. – Отв. ред. С.С. Черноморец, Г.В. Гавардашвили. – Тбилиси: Универсал, 2018, 671 с.

Debris Flows: Disasters, Risk, Forecast, Protection. Proceedings of the 5th International Conference. Tbilisi, Georgia, 1-5 October 2018. – Ed. by S.S. Chernomorets, G.V. Gavardashvili. – Tbilisi: Publishing House “Universal”, 2018, 671 p.

ღვარცოფები: კატასტროფები, რისკი, პროგნოზი, დაცვა. მე–5 საერთაშორისო კონფერენციის მასალები. თბილისი, საქართველო, 1–5 ოქტომბერი, 2018. გამომცემლობა "უნივერსალი", თბილისი 2018, 671 გვ. პასუხისმგებელი რედაქტორები ს.ს. ჩერნომორეც, გ.ვ. გავარდაშვილი.

Ответственные редакторы С.С. Черноморец, Г.В. Гавардашвили
Edited by S.S. Chernomorets, G.V. Gavardashvili

Верстка: С.С. Черноморец, К.С. Висхаджиева, Е.А. Савернюк
Page-proofs: S.S. Chernomorets, K.S. Viskhadzhieva, E.A. Savernyuk

При создании логотипа конференции использован рисунок из книги С.М. Флейшмана «Селевые потоки» (Москва: Географгиз, 1951, с. 51).
Conference logo is based on a figure from S.M. Fleishman’s book on Debris Flows (Moscow: Geografgiz, 1951, p. 51).

ISBN 978-9941-26-283-8

System geoinformation approach to the study of mudflow processes

T.B. Chepurna

Ivano-Frankivsk National Technical University of Oil and Gas, Ivano-Frankivsk, Ukraine, tetti.chepurna@gmail.com

The article is devoted to the issue of the developing of system geoinformation approach to the study of mudflow processes development. Proposed methodology divided into next stages: setting a task, conceptualization, specification, observation, identification, experiments, implementation of the model, verification of the model, model research, optimization. A brief description of each stage is provided and an example of the application of this methodology is given on the example of Teresva River basin territory. Based on the complex influence of main factors of mudflow development, existing representations and actual data of mudflow phenomena, mudflow hazard areas are identified. The proposed system geoinformation approach to the study of mudflow processes allows to systematize research and analysis of the processes of mudflow formation with the use of the latest geoinformation technologies. Each stage of such a system makes it possible to comprehensively consider the spatial and temporal patterns of the distribution of mudflow phenomena and their activation.

mudflows, mudflow hazard, temporal factors, spatial factors, geoinformation approach

Системный геоинформационный подход к изучению селевых процессов

Т.Б. Чепурная

Ивано-Франковский национальный технический университет нефти и газа, Ивано-Франковск, Украина, tetti.chepurna@gmail.com

Статья посвящена проблеме разработки системного геоинформационного подхода к изучению развития селевых процессов. Предлагаемая методика исследования включает следующие этапы: постановка задачи, концептуализация, спецификация, наблюдение, идентификация, эксперименты, реализация модели, проверка модели, исследование модели, оптимизация. Приводится краткое описание каждого этапа и пример применения этой методологии для изучения бассейна реки Тересва. На основе анализа факторов развития селевых процессов, существующих представлений и фактических данных о селевых явлениях выделяются зоны селевой опасности. Предлагаемый системный геоинформационный подход к изучению селевых процессов позволяет систематизировать исследования и проводить анализ процессов селеформирования с использованием новейших геоинформационных технологий. Каждый этап такого системного подхода позволяет всесторонне рассмотреть пространственные и временные закономерности селепроявления и активизации селей.

сели, селевая опасность, временные факторы, пространственные факторы, геоинформационный подход

Introduction

Ukrainian Carpathians are divided into three mudflow hazardous areas: northeast, northwest, and southwest. The east area belongs to the basin of the Dniester River. The southeast mudflow area is located in the district of the Prut and Seret River basins. The southwest mudflow area covers the basin of the Tysa River. Within these basins, 390 mudflow streams were marked, which cover an area of 3 917.4 km^2 [*Kuzmenko, 2014*].

Mudflow basins of the Carpathians belong to the third and fourth categories of the present hazard of mudflow: medium and slightly hazardous. The amount of the material, removed by mudflows annually in the Carpathian region, reaches 500-2400 m^3/km^2.

Brief review of the problem

Last big mudflows were observed in 1998, 2001, 2008, and 2010. New researches prove that climate change will affect all ecosystems of the Carpathians, which in turn will lead to changes in the conditions of the development of mudflow processes [*Chepurna, 2017; Didovets, 2017; Shvidenko, 2017*]. Considering the climatic changes of recent decades, gradual displacement of climatic zones, and formation of the so-called “hybrid zones” [*Taylor, 2015*], activity of mudflow processes in the Carpathians may increase, that is the reason that the study of mudflow processes is a pressing issue at present.

The fundamental researches of mudflows include the works, written by the following authors: M. Aizenberg, I. Bogolyubova, B. Velichko, B. Vinohradov, M. Gogoshidze, B. Goldin, B. Ivanov, V. Perov, S. Chernomorets, I. Kherkheulidze, S. Fleishman, A. Sheko, P. Conssot, D. Wrachien, E. Gabet, R. Iverson, M. Cora, M. Jakob, T. Takahashi., E. Zic.

An important contribution to the study of mudflows have been made by following Ukrainian scientists: O. Adamenko, E. Kuzmenko, A. Oliferov, H. Rudko, Ye. Yakovlev. Further development of these studies is authored by O. Ivanik, O. Lukianets, I. Kovalchuk, M. Susidko, T. Chepurna and V. Shevchuk and they give a large attention to the use of modern geoinformation technologies when studying the mudflow processes.

In investigations dedicated towards mudflow issues, many authors refer to modern statistic and geoinformational methods [*Jakob and Hungr, 2005; Xu, 2008; Zic et al., 2015*]. Some methods and ideas from these researches were developed in current investigation.

The purpose of these studies is to establish the system geoinformation approach to the study of mudflow processes which should involves modern geoinformation technologies. Geoinformation technology should be used for acquisition, analysis, storage, visualisation and utilization of geospatial data of development of mudflows and connected processes.

Methods

Proposed system of geoinformation approach to the mudflow processes study involves the integration of research methods (observation, experimentation, simulation) with the use of geoinformation technologies.

The study process is proposed to be divided into eleven stages that are consistently changing or coinciding in time:

1. Setting a task - to solve certain problems associated with the development of mudflow processes, it is necessary to allocate in the system a finite number of properties or actions that are most important for the solution of the problem. The purpose of the stage is specification of the number of possible directions and aspects of the study of the mudflow phenomena development.

2. Conceptualization. The formulation of information and ideas about the investigated mudflow site or hazard area in the form of conceptual schemes is formulated, which subsequently form the basis of the database for the collection and systematization of attributive information for the creation of a geoinformation model. In the first place, the place of the mudflow site in the space and possible factors of influence on the formation of mudflows should be determined. Within the framework of the conceptual model, the characteristics of the functioning of the mudflow formation system are given in the form of a verbal description of

the spatial position and time dynamics of the components and their interactions, as well as in the form of charts, tables reflecting changes in quantitative indicators.

3. Specification - the purpose of the stage is to determine the composition of the required input variables of the future geographic information model, to determine the methods and units of measurement.

4. Observation - based on the results of the specification, field observations of the development of mudflow processes are planned and carried out, or existing data are used.

5. Identification is the establishment of functional relationships between the input variables: data on the mudflow manifestations and factors that determine them.

6. Experiments - if necessary, carry out for testing various hypotheses about the nature of the relationship between the processes of mudflow formation and factors.

7. Implementation of the model - is the calculation of spatial or temporal dynamics of the development of mudflow processes.

8. Verification of the model - to establish the adequacy of the model: compare the calculated curves of the dynamics of the state variables with the data of observation and overlay analysis of actual and empirically constructed maps (verification).

9. Model research - construction of models of dynamics and cartographic mapping, application of the developed geographic information model in solving adjacent issues and consideration of the possibility of application in other territories.

10. Optimization - among the external factors influencing the formation of mudflows, there are such, the introduction of new information on which can greatly optimize the built model.

11. Final synthesis - at this stage, a report is prepared, which evaluates the results and gives recommendations for full-scale optimization or predictive calculations.

Analysis

Next it will be shown the practical realization of the proposed system. Main stages are marked here, but it is not necessary to show them in such kind investigation.

Setting a task. The task of determining the risks from mudflows in Teresva River basin is given. The scale is regional. Result of the investigations should become a part of regional geoinformational model of risk assessment.

Conceptualization. Teresva is a river in Ukraine, within Tyachiv district of the Transcarpathian region. Right tributary of Tysa (Danube Basin). Length 56 km, area of the basin 1225 km². The valley to the village of Dubovy is predominantly V-shaped (width 100-400 m), in some sections gorges (width 30-40 m), below - a drawer, in width from 0,5 km to 2 km. The floodplain is often asymmetric, intermittent (the width varies from 50-200 m to 1.5 km), at the bottom it merges with the floodplain of Tysa. Generous winding, very branched out, rapidshare, there are waterfalls (in the upper reaches). The width of the river is 10-20 m to 90 m. The slope of the river is 6.1 m / km. Power mixed with predominance of rain; typical floods and mudflows during the year, sometimes very devastating. Shore on separate plots fortified. Teresva is formed by the merging of Mokryanka and Brusturyanka near the village of Ust-Chorna. The upper part of the Teresva basin lies among the southern slopes of Gorgan and the western part of Svydovets. Below the river crosses the Poloninsky Range, in the lower reaches the Upper Tysa Cavern. The main tributaries are Mokryanka, Krasnyi, Tereshkilka, Luzhanka, Vil'vchivka (right); Brusturyanka, Tychovets, Dubovets (left) [*Chis, 2011*].

The area of 85 mudflow basins is 173,01 km, 7,2% of the basin of Teresva. The length of 129 mudflow water streams is 142,248 km, 15% from total length.

3. *Specification*. To analyze data using geoinformation analysis methods, the information should be in the form of quantitative data and transferred to a database that is related to GIS, or indeed to the GIS attribution tables. In our example, we used MapInfo. Statistical processing was performed in Statistica.

4. *Observation*. These studies were conducted on the basis of the data previously entered in the cadastre. The date of the cadastre-catalog of mudflows of SE “Zahidukrgeologiya” (in a number of 117 marked mudflow phenomena, over a period of 1998 – 2018 years) were used

for the realization of analysis. The main statistics of mudflow phenomena in Teresva are shown in Table 1. Full-scale study of mudflow sites, profiles of mudflow watercourses can be conducted through Google Earth by laying the required layers (Fig.1). Some graphics can make better imagine about interaction of some factors (Fig. 2).

Table 1. Basic statistics of mudflows phenomena of Teresva river

Statistics	**Absolute altitude, m**	**Length of the cone, m**	**Width, m**	**Area, m^2**	**Power of proluvium, m**	**Volume of material, m^3**
Medium	653,3	56,8	52,0	1695,8	2,2	5,9
Median	628,6	50,0	40,0	1000,0	1,6	0,8
25th percentile	564,3	30,0	25,0	343,8	1,0	0,2
75th percentile	718,4	75,0	70,0	2275,0	3,0	4,2
Minimum value	380,0	10,0	3,0	15,0	0,5	0,0
Maximum value	1187,2	200,0	180,0	9000,0	8,0	200,0
Standard deviation	138,6	36,8	37,6	1923,2	1,7	20,9
Dispersion	19199,4	1350,4	1414,2	3698801,5	2,9	435,7
Asymmetry	1,2	1,4	1,2	1,7	1,5	8,2
Kurtosis	2,1	2,3	1,1	3,0	1,8	74,9
Number of Values	117,0	103,0	105,0	100,0	106,0	103,0

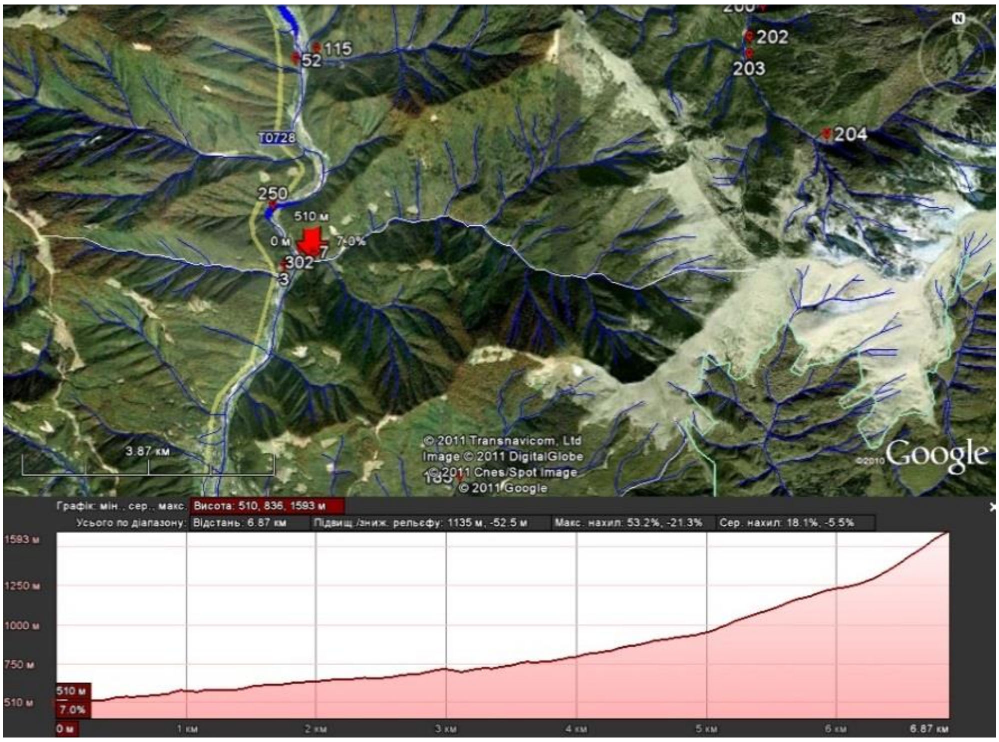


Fig. 1. Observation of mudflow basins in Google Earth

As for the time information, we graphically present the actual data for tracing the general dynamics of climatic factors in the region (Fig. 3).

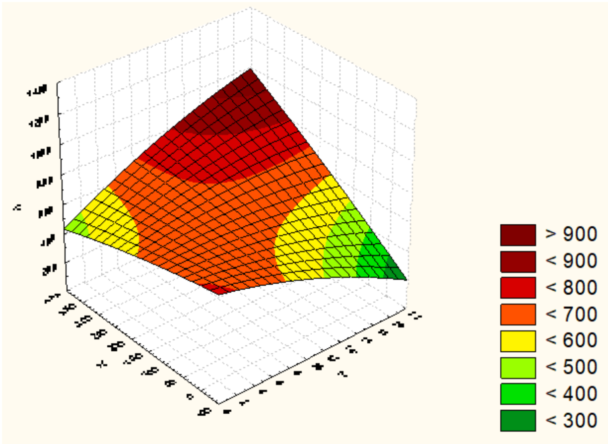
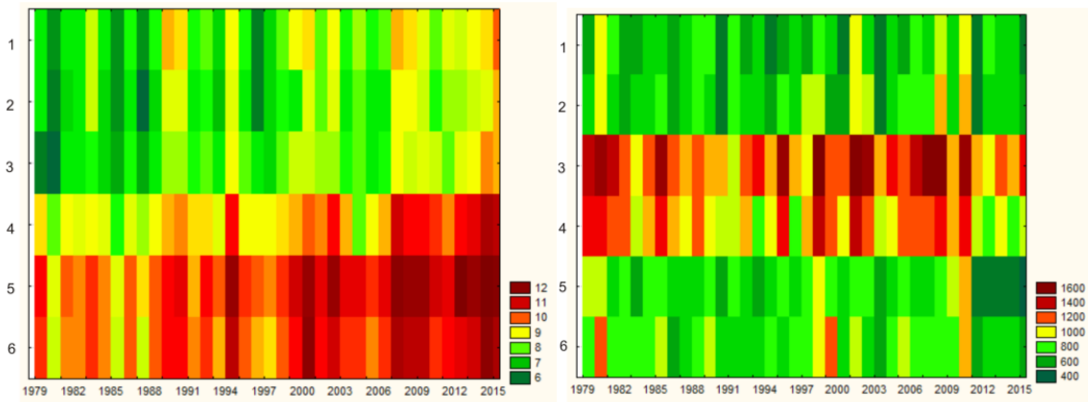


Fig. 2. 3D surface of factor characteristics “altitude” (Z), “slope angle” (Y), slope aspect (X) for Teresva river basin



a) b)

Fig. 3 The factual data of a) average annual temperature (°C) and b) total annual precipitation (mm) (for weather stations Ivano-Frankivsk (1), Kolomyya (2), Rakhiv (3), Khust (4), Beregovo (5), Uzhgorod (6))

5. *Identification*. A cartographic database was constructed and contained a cartographic layers of mudflows sites and factors which can affects the development of mudflows within the area, such as geological, geomorphological, technogenic, and landscape etc. The choice of factors should be made relative to the scale of the study area. The area under investigation is a regional scale, therefore some local factors are generalized.

6. *Experiments*. Here we use a large list of methods and types of analysis: as usual histogram correlation, cluster, factor, dispersion. The initial data can be factual data and secondary data, derived empirically or through overlay analysis in GIS.

A spatial analysis conducted with application of metrical overlay operations with the purpose to verify the existence of patterns between mudflow sites distribution and factors, which in cartographic relation are mapping points, linear and planar objects. As a result, values of the following factor characteristics can be calculated: altitude, angle of slope of surface, altitude of watershed, distances to the base of erosion, to the nearest landslide, to the tectonic fault, to the watershed or other. Searching of appropriate connection between the spatial distribution of mudflow sites and each of factors can be executed by the verification of accordance of distribution of factor characteristics values by the theoretical distributions using of different statistical criterions (Shapiro-Francia, Kolmogorov-Smirnov, Mann-Whitney tests, etc.) Widen descriptive analysis for mudflows study has been presented in article [*Chepurna, 2017*].

Here is an example of the use of factor analysis to prove the existence of an influence on the process of mudflow formation. For example, we will take three basic morphometric parameters: the altitude and angle of the slope where the mudflow was fixed, the altitude of the applicable watershed. The value of each potential predictor X_j is provided in the form of linear combinations of factors F_j and factor loadings a_{ij}, where $j = 1, 2, \ldots, m$, $m << k$.

$$X_j = \sum_{j=1}^{m} a_{ij} F_j. \quad (1)$$

m - number of factors. The mathematical model of the method is based on the logical assumption that the value of the set of interrelated characteristics produces a general result, in our case - the process of mudflow formation. As a result, we see that all factors are significant (Table 2). In the case of a large number of factors we use the Cattell criterion with the aim to select significant factor features.

Table 2. Results of factor analysis

Factor Loadings	
	Factor - 1
The altitude	0,960339
The angle of the slope	0,593659
The altitude of the applicable watershed	0,962475
Expl.Var	2,003577
Prp.Totl	0,667859

7. *Implementation of the model*. This stage involves analyzing the dynamics of mudflow processes, tracing existing rhythms and periodicity. In a part of the temporal analysis, the time series of the following factors can be selected: amount of precipitation, temperature, groundwater level, energy of earthquakes and Sunspot numbers. The source of all data was the Cadastre catalog of SE “Zahidukrgeologiya”, besides the Sunspot numbers, compiled by the US National Oceanic and Atmospheric Administration (monthly average daily sunspot number posted on WDC-SILSO, Royal Observatory of Belgium, Brussels). The presence of the trend and its character are studied; the presence of seasonal and cyclic components. The analysis of autocorrelation functions and periodograms allowed to define the basic rhythmic constituents in time series. Cross-correlation can identify an appropriate displacement between time series.

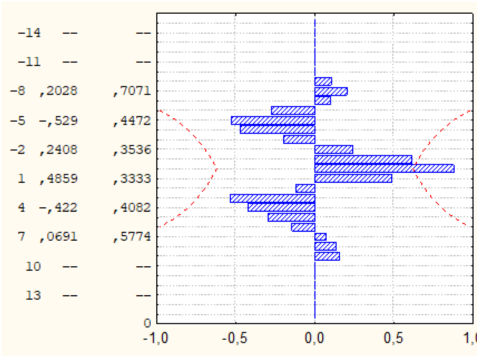
As an example, we present the results of the correlation analysis for periods of solar activity (Fig. 4). This research provided searching patterns between parameters relating to a specific time period of the solar cycle. The significance of the correlations is checked by the hit values in the confidence interval.

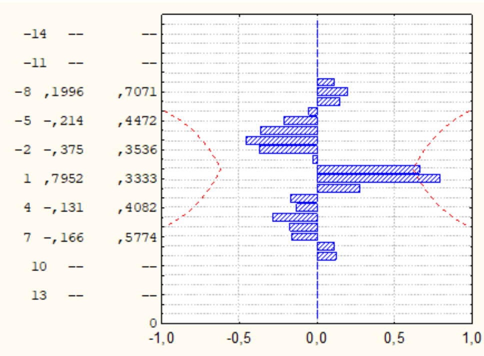
8. *Verification of the model*. At each stage of the above analysis, there are own validations and test criteria for tracking the correctness and verifying the results. At this stage, an integrated result is checked.

9. *Model research*.

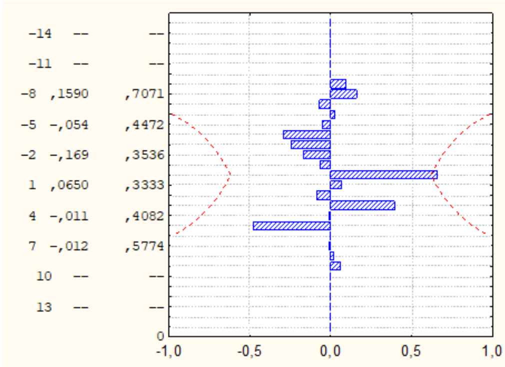
On the basis of the revealed regularities and periodicities it is possible to create time and spatial models of the development of mudflow phenomena, to simulate the development of the situation when changing the magnitude of the influence of factors, to build a variety of thematic maps, etc.

In many articles, scientists assume that the assessment of natural hazards should include information about the place and time of the phenomenon development, taking into account many factors of influence [*Bychenok, 2008; Cui, 2012; Fuchs, 2012; Kasianchuk, 2016; Kidyaeva, 2017*] In order to determine a generalized risk, it is proposed to calculate adjusted collective mudflow risk for the administrative-territorial units. Under the adjusted collective mudflow risk for an mudflow hazard area (region), one should understand the risk from mudflows, which takes into account: the average temporal probability of development of mudflows; the proportion of area of mudflow basin and total; the density of the population; and availability of the protective systems within the territory.





a) b)



c)

Fig. 4. Cross-correlogram for a series of a) average annual temperature of air and solar activity, b) The average annual air temperature and mudslide activity, c) the total annual rainfall and the activity of the mudflows for the period 1996-2005 (Rakhiv meteorological station)

The formula of the adjusted collective mudflow risk (persons per square km) for i area in t time) is

$$Rpr_{i,t} = \bar{P}_{i,t} \cdot N_i \cdot \frac{\sum_{n=1}^{k} S_i}{S_i^2} \cdot Z_i \quad (3),$$

where: $\bar{P}_{i,}$ - a mean value of mudflow hazard for the region *i* in *t* time; $\sum_{n=1}^{k} S$ - a total area of mudflow basins, km^2; S_i - an area of *i* region, km^2; N_i - an amount of population in *i* region, persons; Z_i - a coefficient that takes into account the presence of mudflow protective constructions [*Chepurna, 2017*].

The resulting map of adjusted collective mudflow risk is shown on Fig. 5.

As we see from the map, there is no significant threat to the territory from the development of mudflow processes. The maximum risk scores only 0,0115 persons for maximum peak activity of mudflows.

10. *Optimization*. Analyzing the new information and adding the new levels to time dynamics you can build current dynamics models and corresponding cartographic images.

11. *Final synthesis*. Secondary information obtained from the resulting models can be used in the comprehensive study of exogenous geological processes, control of the situation of the development of hazard.

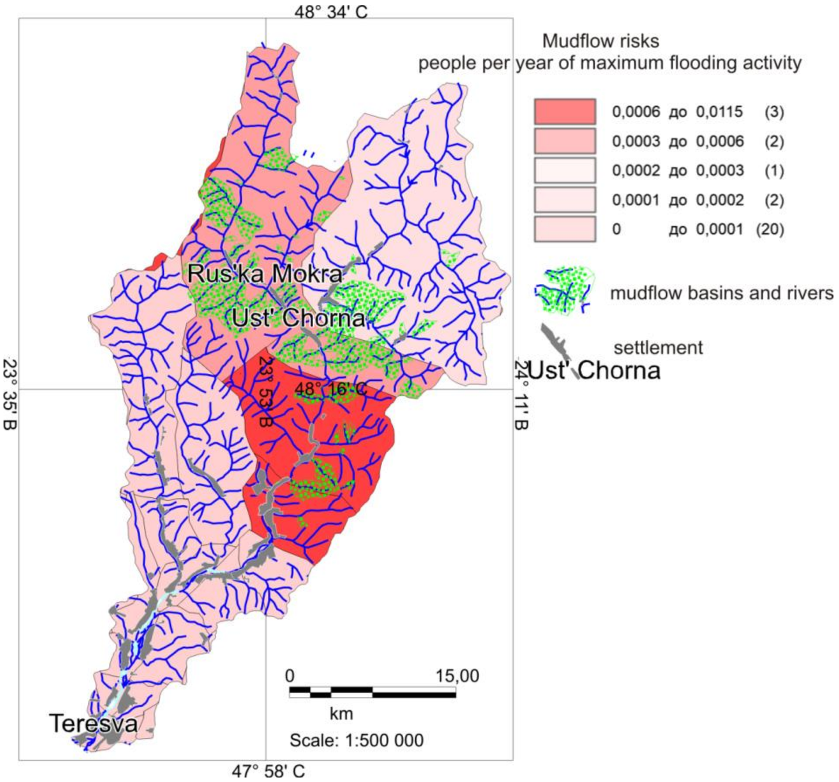


Fig. 5. Cartogram of adjusted collective mudflow risk assessment within the limits of administrative-territorial units (settlement and municipal advices) for river Teresva basin

Conclusions

The proposed system geoinformation approach to the study of mudflow processes allows to systematize research and analysis of the processes of mudflow formation with the use of the latest geoinformation technologies. Each stage of such a system makes it possible to comprehensively consider the spatial and temporal patterns of the distribution of mudflow phenomena and their activation. The multifaceted geoinformation analysis is an instrument of multilateral study of mudflows, the study of the complex influence of processes that affect formation. The considered system approach can be used not only for regional study, but also by applying new methods of analysis, in the study of local mudflow sites.

References

Bychenok M., Ivanyuta S., Yakovlyev, Ye. (2008). Risks of life in the natural and man-made environment. Institute for National Security Problems of Ukrainian Citizens and its Authorities. Kyiv, 160.

Kuzmenko E., Chepurna T. (2017) Prediction of the mudflow processes: monograph. Ivano-Frankivsk: IFNTUOG, - 254 p.

Chepurna T. (2017) Geoinformational prognostic model of mudflows hazard and mudflows risk for the territory of Ukrainian Carpathians. Contemporary Trends in Geoscience, 6(1). doi: 10.1515/ctg-2017-0005.

Chis T. V. and Kosinszki S., (2011). Geographical introductory characterization of the upper Tisa River basin (Romania-Ukraine), Transylvanian Review of Systematical and Ecological Research, Curtean-Bănăduc, 11, 1-14.

Chepurna T. (2017) Features of high-altitude distribution of mudflow sites in the Upper Tysa basins in Ukrainian Carpathians. Scientific Bulletin of the National Mining University №2, 118-127.

Cui P, Dang C, Zhuang J, Eds. (2012) Landslide-dammed lake at Tangjiashan, Sichuan province, China (triggered by the Wenchuan Earthquake, May 12, 2008): risk assessment, mitigation strategy, and lessons learned. Environ Earth Sci 65(4): 1055–1065.

Didovets I, Lobanova A, Bronstert A, Eds. (2017) Assessment of Climate Change Impacts on Water Resources in Three Representative Ukrainian Catchments Using Eco-Hydrological Modelling. Water (9). doi:10.3390/w9030204.

Fuchs S., Birkmann J., Glade T. (2012). Vulnerability assessment in natural hazard and risk analysis: current approaches and future challenges. Natural Hazards, 64(3): 1969–1975.

Jakob M., Hungr O., eds. (2005). Debris-Flow Hazards and Related Phenomena. Praxis-Springer, Berlin

Kasiyanchuk D., Kuzmenko E., Chepurna T., eds. (2016) Calculation of that environmental and geological landslide risk estimate. Eastern European Journal of Enterprise Technologies, 1(10): 18–25. doi:10.15587/1729-4061.2016.59687.

Kidyaeva V., Chernomorets S., Krylenko I., Wei F., Petrakov D., Su P., Yang H., Xiong J. (2017). Modeling potential scenarios of the Tangjiashan Lake outburst and risk assessment in the downstream valley. Frontiers of Earth Science, 11 (3): 579-591. doi 10.1007/s11707-017-0640-5.

Shvidenko A., Buksha I., Krakovska S., et al. (2017) Vulnerability of Ukrainian forests to climate change. Sustainability 9(7): 1152. https://doi.org/10.3390/su9071152.

Taylor S., Larson E., Harrison R. (2015). Hybrid Zones: Windows on Climate Change. Trends in Ecology and Evolution, 30: 398-406.

Xu J. (2008) A study on the integrated regional meteorological prognosis and warning model for geological hazards. Debris Flows: Disasters, Risk, Forecast, Protection: Intern. conf, Pyatigorsk, -. Pyatigorsk, Institut “Sevkavgiprovodkhoz”, 178-181.

Zic E., Arbanas Z., Bicani N. et al. (2015) A model of mudflow propagation downstream from the Grohovo landslide near the city of Rijeka (Croatia). Natural Hazards and Earth System Sciences. 15, 293–31.10.5194/nhess-15-293-2015.