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FEATURES OF HIGH-ALTITUDE DISTRIBUTION OF MUDFLOW SITES IN THE UPPER TYSA BASINS IN UKRAINIAN CARPATHIANS

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ОСОБЛИВОСТІ ВИСОТНОГО РОЗПОДІЛУ СЕЛЕВИХ ОСЕРЕДКІВ У БАСЕЙНАХ РІК ВЕРХНЬОЇ ТИСИ В УКРАЇНСЬКИХ КАРПАТАХ

Purpose. Establishment of regularities of the high-altitude and exposure distribution of mudflow sites in the basins of the rivers Teresva, Tereblya, Rika, Bila and Chorna Tysa, as well as connection between the landslide and mudflow processes.

Methodology. Digital terrain modeling of the basins of the rivers concerned. Spatial overlay analysis of distribution of mudflow sites, metric operations to obtain the data of the high-altitude and exposure positions and prevailing slope angles. Factor analysis identifying the direct and indirect effects of the high-altitude position of the mudflow potential sites onto mudflow formation, usage of the statistical criteria for significant characteristics selection. Graphical visualization of the influence of synthesis of the high-altitude position and slope angle onto the development of mudflows. Regression analysis of the regular connection availability between the mudflow and landslide processes.

Findings. Regularities of distribution of mudflow sites according to the factor characteristics: absolute altitude, slope angle, slope exposure and availability of landslides in the basins of the rivers concerned are identified.

Originality. The geoinformation modeling was used for the first time to identify the regularities of the mudflow development in relation to spatial factor characteristics for the basins of the rivers: predictor of the "absolute altitude" and revisers of the "slope angles" and "slope exposure". The histogram analysis of the high-altitude distribution of the mudflows and landslides in the basins of the rivers mentioned was used to determine the connection availability between their development and high-altitude position. Functional dependencies are presented in the form of linear and quadratic regression dependencies showing the relative contribution of the features and indicating the respective levels of significance.

Practical value. The determined regularities can be used to identify potential sites of mudflow in the basins of the rivers Teresva, Tereblya, Rika, Bila and Chorna Tysa at known values of altitudes, slope angles and slope exposures and occurrence of the landslide processes on some high-altitude areas. The regression dependencies may be considered when carrying out the mathematical and prognostic geoinformation modeling of the mudflow phenomena development according to the following algorithm: establishment of similar regression and functional dependencies between other factors of mudflow formation, their combination according to the regularities shown in the article, forecasting of the mudflow hazards based on the formed multifactor multiple model.

Keywords: *mudflow, geomorphological parameters, mudflow hazard, spatial factors, landslides, GIS*

Introduction. The Carpathians are divided into three mudflow hazardous areas: northeast, northwest, and southwest (Fig. 1). 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.

The 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. The last big mudflows were observed in 1998, 2001, 2008, and 2010. Considering the climatic changes of recent decades, gradual displacement of climatic zones, and formation of the so-called "hybrid zones" [1], activity of mudflow processes in the Carpathians may increase, because the geoinformation modeling and forecasting of mudflow processes are a pressing issue at present.

Analysis of recent research and publications. The fundamental research studies of mudflows include the works, written by the following authors: M. M. Eisenberg, I. V. Boholiubova, B. L. Velychko, B. F. Vinohradov, M. S. Hohoshydze, B. M. Goldin, B. M. Ivanov, V. F. Perov, I. I. Herheulidze, S. M. Fleishman, A. I. Sheko, P. Conssot, D. Wrachien, E. J. Gabet, R. M. Iverson, M. Cora, M. Jakob, T. Takahashi., and E. Zic.

An important contribution to the study of mudflows has been made by the following Ukrainian scientists: O. M. Adamenko, E. D. Kuzmenko, A. M. Oliferov, H. I. Rudko, Ye A. Yakovlev. Further development of these studies is authored by O. M. Ivanik, O. I. Lukianets, I. P. Kovalchuk, M. M. Susidko, and V. V. Shevchuk and they have paid much attention to the use of

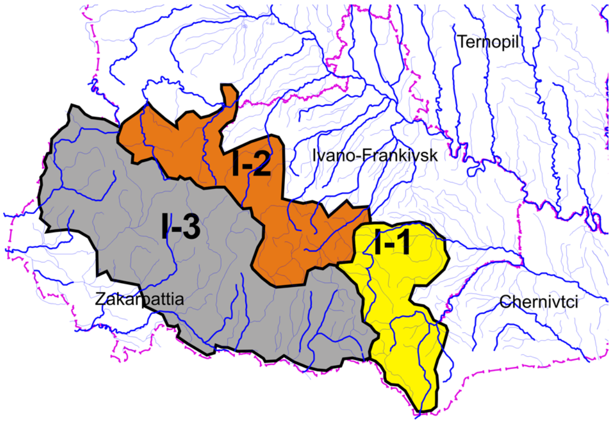

Fig. 1. Mudflow hazardous areas of the Carpathian region, I-1 – eastern (basin of Prut), I-2 – northeast (basin of the Dniester River), and I-3 – southeast (basin of the Tysa River)

modern geoinformation technologies when studying the mudflow processes.

The relevance of the study of mudflows is evidenced by the annual reports of international conferences and workshops, the latest of which is the "6th International Conference on Debris Flow Hazards Mitigation: Mechanics, Prediction and Assessment", held in Tsukuba in Japan in 2015.

The absence of activation of mudflow processes in the Carpathians for the period from 2011 to 2014 led to a reduction in the research on mudflows and publications on the subject respectively. Recent scientific works in this area were published by D. V. Kasiianchuk and I. P. Kovalchuk.

Unsolved aspects of the problem. The newest GIS technologies provide an opportunity to assess the multifactorial impact of environmental conditions onto the mudflow processes in the multi-year cross section. The modern prognostic systems, proposed for mudflow hazardous territories of the world, operate mostly in the areas considering the regional features that are peculiar only for them. The study of local regularities of mudflows allows improving these systems and getting of reliable results.

The predictive GIS model, proposed in the work [2], is an open system, the improvement of which is expected to be carried out by means of establishment and consideration of the new regularities of the factors influence onto the mudflow process in spatial and in temporal dimensions. When creating the aforementioned model, the grouped data files of the factor features were taken into consideration for the whole mudflow hazardous area. An issue arose to study the mudflow phenomena beyond the river basins and in order to do this, it was decided to use the geo-modeling mudflow formation within the basins of the rivers of Teresva, Tereblya, Rika, Bila and Chorna Tysa.

Objectives of the article. The objective of these studies is to establish the regularities of mudflow processes depending on their altitude and aspect within the basins of the rivers Teresva, Tereblya, Rika, Bila and Chorna Tysa.

In order to achieve this objective, the following tasks were solved:

- search for the latest methods of spatial analysis and modeling in GIS when studying mudflow processes;
- formation and supplement of the database of registered mudflows;
- GIS modeling of the relief of the river basins with addition of the values of altitudes and expositions of slopes to the database;
- factor analysis in order to find stochastic connection between spatial factors and mudflow processes;
- quantitative histogram analysis of altitude of mudflow position and mudflow streams belonging to the slopes of certain aspects;
- search for the connection between the development of mudflows and landslides with elements of overlay and histogram analysis.

The research was made for the eastern part of the territory of Transcarpathia within the basins of the rivers Rika, Teresva, Tereblya, Chorna and Bila Tysa (Fig. 2). The maps at scale 1:100 000 were used for construction of a digital elevation model. The area of the study is 4,222 km^2.

Presentation of the main research materials. The main factors of development of mudflows include tectonics, geomorphological, geological, hydrological conditions, modern exogenous geological processes, soil and vegetation cover, and human activities.

When selecting the complex of factors for the mudflow process modeling, it is important to consider the mudflow process genesis. When carrying out the spatial analysis, the mudflows of rainy genesis were taken into account. This choice is caused by the fact that this type of mudflows occurs in the Carpathian region most frequently (in 99 % of cases). According to the scheme of the territory zoning of the mudflow hazard, the chosen territory belongs to the zone of predominant development of "warm" water and mudslide mudflows.

After the mudflow activity peaks in the Carpathian region in 1998, 2001, 2008, and 2010, there were not many mudflows during the period from 2010 to 2014. The November flooding in the basin of the Verkhnia Tysa River in 2015, when one and half month rain fell during three days causing the mudflow processes activation. The cases of rainy and snow-rainy genesis mudflows were recorded in the Rakhiv district near the villages of Kostylivka and Bilyn.

The data from the cadastre of mudflows of the "Zahidukrheolohiia" SE, results of the field geological and geomorphological observations in the mudflow areas, and stock materials of the region were used for the analysis.

The work [3] profoundly describes the process of selecting the relevant factors and factor features (quantitative measures of factors reflection) at the regional prognostic modeling of mudflow formation. Simultaneously, the question of structuring influence of factors by searching for their specific hierarchy arises. It is logical that the altitude of the area is a determining factor since it has a direct impact on all other natural conditions of the territory in the multi-year cross section. Let us fol-

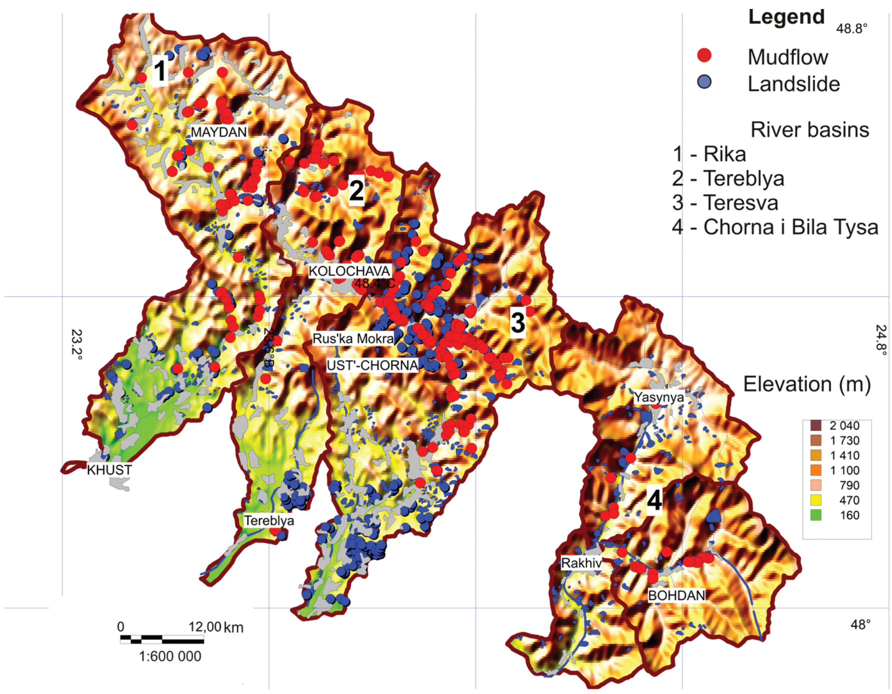

Fig. 2. Model of relief of the research area with landslides and mudflows

low empirically the impact of the altitude on the development of mudflows in the complex of other factors through factor analysis by the principal components method.

The value of each potential predictor (mudflow factor feature, altitude, angle of slope, altitude of watershed, the average annual amount of precipitation, distances to the road, to the river, to the forest, to the settlement, to the landslides, to the tectonic faults, to the watershed, affection of lithofacies and tectonic zones by mudflows) X_i is provided in the form of linear combinations of factors F_j and factor loadings a_{ij} where. $j = 1, 2, ...m, m \ll k$.

$$X_i = \sum_{j=1}^{m} a_{ij} F_j, \qquad (1)$$

where m is the number of factors.

The mathematical model of the method is based on the logical assumption that the value of the set of interrelated characteristics produce a general result, in our case it is the process of mudflow formation. To select the significant factor features, we use the Cattell criterion. According to the schedule in Fig. 3, factors 1–5 were selected; the factor loadings are given in Table 1. The discovered connection between factor 1 and factor characteristic of "altitude" is the largest among all other factors. In addition to the above-stated, the high value of the correlation is observed for other characteristics of the altitude – "altitude of the watershed", which further proves the significant impact of altitude on the development of mudflow processes. We can conclude that there is a complex influence according to the "predictor-corrector" system, where the altitude is a predictor while other factor characteristics are identified with strong correlations – correctors. The contribution of factor 1 to the general variance is the biggest and sufficient (0.26) since the revealed strong connections between factor characteristics and factors 3, 5 (variances of 0.11, 0.07, respectively) are less important, but scientifically interesting (important by Cattell criterion) and require further study.

For the purpose of redistribution of the dispersion, a procedure of factor rotation was performed using the Varimax normalized method, which maximizes the variation of squares of loadings for each factor that leads to increase in the large and reduction of the small values of the factor loadings. After the procedure of rotation, the obtained aggregates are no longer the main components but they are generalized factors. The matrix of the factor loadings after the rotation is listed in Table 2. The procedure of rotation of axes confirmed a significant impact of the above mentioned factor features, the factor loading of which remained significant. Simultaneously with the strong connections identified previously, new

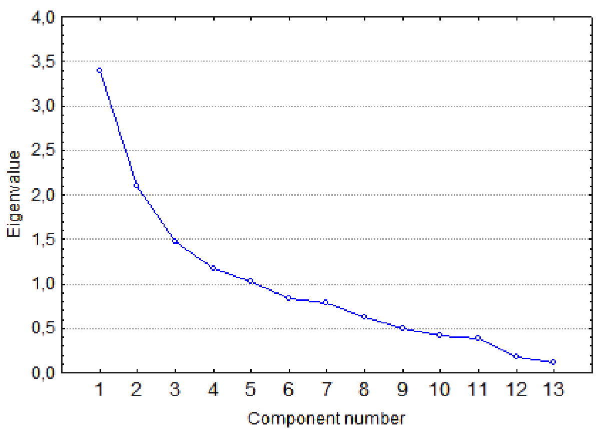

Fig. 3. Cattell's scree plot

Table 1

The matrix of factor loadings (factor analysis without rotation of the axes)

Factor characteristic	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Altitude	**–0.862576**	0.124923	–0.210226	–0.079788	0.061311
The angle of slope	–0.076945	0.444725	0.136490	–0.623666	0.129498
The distance to the road	–0.606169	0.463988	–0.085587	0.047351	0.089731
The distance to the river	0.024753	0.478660	0.248430	–0.528499	0.315227
The distance to the forest	0.555062	–0.364523	0.113179	–0.310920	–0.026898
The distance to the settlement	–0.507841	0.533246	–0.081431	0.352309	–0.120377
The distance to the landslide	–0.068292	0.158477	0.113787	–0.323066	**–0.876507**
The distance to the tectonic fault	–0.271787	–0.497131	–0.380582	–0.210868	0.295874
The distance to the watershed	–0.291968	–0.187106	**0.866542**	0.126017	0.099282
Altitude of the watershed	**–0.726569**	–0.140990	0.552816	0.100987	0.039446
The average annual precipitation	0.579194	–0.127753	0.311753	0.152379	0.048947
Infestation of lithofacies zone	–0.541007	–0.566128	–0.005836	–0.231751	–0.098958
Infestation of tectonic zone	–0.622615	–0.595674	–0.067834	–0.150377	–0.095651
The contribution in the general variance	0.260884	0.161062	0.112879	0.090164	0.079363

Table 2

The matrix of factor loadings (factor analysis with rotation of the axes)

Factor characteristic	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Altitude	**0.729036**	0.505943	0.088082	0.136814	–0.003607
The angle of slope	0.086063	–0.029979	–0.021417	**0.773131**	0.146844
The distance to the road	**0.738806**	0.050933	0.078310	0.213513	–0.014010
The distance to the river	0.030494	–0.176597	0.067304	**0.794944**	–0.039287
The distance to the forest	–0.731154	0.013416	–0.092956	0.070703	0.052622
The distance to the settlement	**0.796640**	–0.179015	0.074343	–0.073856	0.099169
The distance to the landslide	0.019540	0.021381	–0.016539	0.048664	**0.954925**
The distance to the tectonic fault	–0.051021	0.675524	–0.181652	–0.017876	–0.324968
The distance to the watershed	–0.067424	0.008747	**0.943861**	0.028044	–0.024577
Altitude of the watershed	0.346545	0.323061	**0.800065**	0.005636	0.023309
The average annual precipitation	–0.527168	–0.395355	0.125184	–0.126195	–0.093717
Infestation of lithofacies zone	0.011065	**0.777503**	0.231746	–0.086898	0.104086
Infestation of tectonic zone	0.093656	**0.827868**	0.224189	–0.172493	0.068479
The contribution in the general variance	0.205332	0.179254	0.132072	0.104705	0.082989

pairs of factor characteristics “altitude” appear – “distance to the road” – “distance to the settlement”, which form a group of technogenic factors; “infestation of lithofacies zone” – “infestation of tectonic zone”, a group of parameters of the linear infestation of mudflow watercourses appeared. These groups are artificial and there is no sense to explore them. In contrast, the pair “distance to the river” – “slope angle” fully reflects the geomorphological peculiarity of the Earth’s surface, describes the impact of the slope angle of the Earth’s surface on mudflow processes, including some belonging to the basin.

Logically, the factor variable “distance to the watershed” is a derivative of the factor characteristic of “altitude” and “altitude of the watershed,” it explains its strong factor loading, but the “distance to landslide” as a quantitative measure of the presence of landslides in mudflow basins is completely an independent characteristic. The connection between the mudflows and landslides for mountainous areas was studied in the works [4, 5] where the physics effects in accordance with local geomorphological features are described in detail. Let us consider the existence of such paragenesis to the study area for every river basin separately.

In order to observe the altitude position of mudflows in GIS, the elevation models for the basins of the rivers Teresva, Tereblya, Rika, Chorna and Bila Tysa were constructed. When analyzing the digital elevation models, except the altitudes of mudflow sites, the values of slope angles and aspect were taken. The data were analyzed using statistical apparatus.

The histogram analysis showed that more than half recorded mudflows in the basin of the Teresva River were observed at an altitude of 500–800 meters above the sea level.

The interval of 25–75 percentile in Table 3 reflects the height of 564–718 meters and can be considered the most favorable for the mudflow processes.

The combined effects of altitude and slope angles can be observed in Fig. 4, *a*, which showed the surfaces constructed with the help of the method of weighted distances. The parameters of summary regression of the factor characteristics of "altitude", "slope angle", "slope exposition" are given in Table 4. These values can be used for modeling the process of the mudflow formation under the scheme: predictor (altitude) – correctors (slope angle, slope exposition).

Table 4 shows the standardized regression beta coefficients and ordinary regression B coefficient. The beta coefficients were obtained during the previous standardization of variables for the mean value of 0 and a standard deviation of 1. The value of the beta coefficient makes it possible to compare the relative contribution of the independent variable (altitude) in the prediction of dependent one (slope angle). As we can see, *p*-level is significant, indicating the current pattern. We will explain how the slope angle of surface directly and indirectly affects the mudflow development. The steeper the slope is, the more intensive is the surface runoff and the less is infiltration of moisture into the thickness of the soil that forms liquid component of the mudflow during heavy rain. The intensity of erosion exponentially increases with the increase in the slope angle. This is explained by the fact that with the increase in the gradient, the kinetic energy of precipitation remains constant, but the transport accelerates towards the foot. The power of the soil profile on the slope varies regularly according to the relative altitude and the slope. Typically, soil thickness is less on elevated flat-angle areas as a result of erosion and gravitational movement of the material, and it is gradually increasing due to its accumulation towards the lower areas with little bias. It explains the formation of mudflows on very small slope angles where there is detrital material available. The amount of the solar energy also depends on the slope, because it determines the angle of sunlight on the Earth's surface. Increasing the slope in the direction of receipt of sunlight increases the angle of incidence and the amount of the energy that the surface receives. This determines the microclimate features of the potential mudflow site, in particular – temperature, evapotranspiration and moisture of the upper soil layers. The peculiarity of the vegetation cover cumulatively reflects all the above mentioned characteristics, because they directly or indirectly have an effect on the edaphic factors such as water and temperature regime of soil, mechanical composition of the root layer, the content of nutrients, etc. The effect of vegetation on mudflow forming processes is described in detail in the work [6].

The next parameter of relief, which is closely associated with the angle of the slope, is the slope exposition. In the case of mudflow forming processes, both factors are correctors. Formation of mudflows in the basin of the Teresva River on the slopes of some aspect can be seen in Fig. 5.

Most of mudflow streams are on the slopes of the north-east (20 % of amount of mudflows) and north (21 %) aspects. Interpretation of the aspect in predicting of mudflows can be carried out in several ways because it describes: the direction of the flow lines and the very direction of mudflow streams; orientation of areas in relation to the flow of sunlight, i.e. the amount of solar radiation that is received by the Earth's surface and that affects moistening. It is known that in the northern hemisphere, the slopes of the southern aspect are better heated than the northern ones. In addition, due to higher evapotranspiration, the southern slopes are drier than the northern ones. The amount of solar radiation di-

Table 3

Basic statistics of values arrays of altitude position of landslides and mudflow sites in the river basins

	Teresva		Tereblya		Rika		Chorna and Bila Tysa	
	Mudflow	Landslide	Mudflow	Landslide	Mudflow	Landslide	Mudflow	Landslide
Average	653.3	759.23	756.0	694.05	505.87	681.94	616.18	988.74
Median	628.6	720.00	759.8	720.00	490.72	720.00	609.77	920.00
25th percentile	564.3	480.00	699.9	440.00	406.74	400.00	542.44	760.00
75th percentile	718.4	960.00	820.5	880.00	595.01	870.00	648.34	1160.00
Minimum	380.0	240.00	281.4	240.00	277.95	240.00	481.46	400.00
Maximum	1187.2	1680.00	1108.6	1480.00	915.50	1480.00	930.70	1680.00
Standard deviation	138.6	315.45	130.2	273.40	132.71	277.68	92.41	276.99
Variance	19 199	99 508.81	16 942.9	74 747.63	17611	77 105.17	8539	76 722.97
Number	117	426	82	121	97	124	44	119

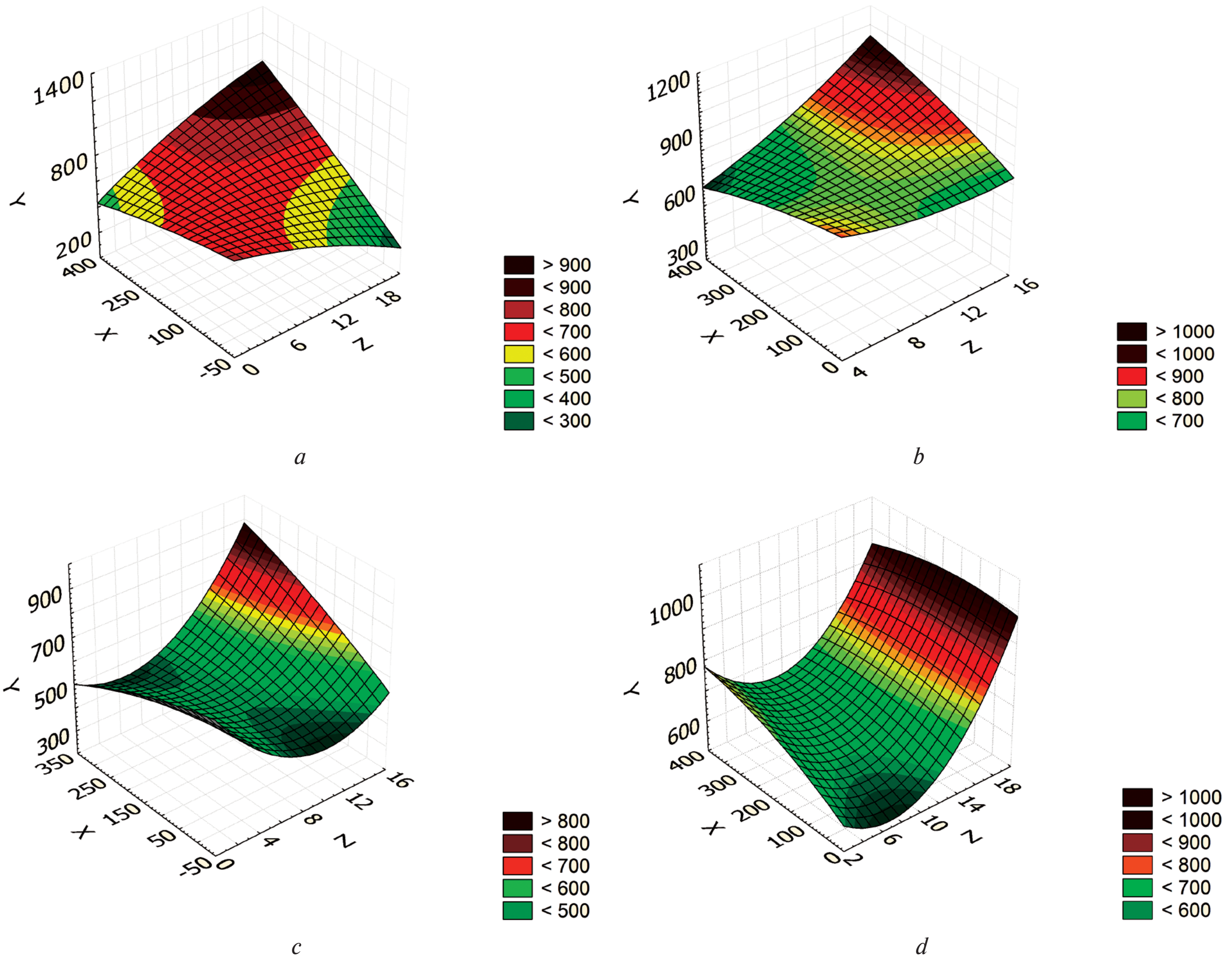

Fig. 4. 3D surface of factor characteristics of "altitude" (Z), "slope angle" (Y), slope aspect (X) for the river basins: a – Teresva; b – Tereblya; c – Rika; d – Chorna and Bila Tysa (color scale in accordance with the absolute altitude values, m

rectly determines the intensity of development of plants and their biological productivity. These laws stipulate the local features of soils and vegetation that affect the intensity of mudflows. This is explained by the fact that the sun falls on the eastern slopes in the cool morning hours and it is spent on heating of surface and western slopes are lighted in the afternoon when the surface was already heated. As a result, the western slopes are slightly warmer and less wet than the eastern ones. In addition, since the northern and north-eastern slopes are wetter, the landslide processes develop on them [7]. All of the foregoing explains the presence of more favorable conditions for the formation of mudflows on the slopes of the northern and north-eastern aspects.

The spatial overlay analysis in GIS showed that 30 out of 114 partial mudflow basin of the Teresva River have landslides, which is 26 % of the amount. To trace the presence of connection between the mudflow and landslides, a pairwise histogram analysis was made. The distribution of values of altitude of mudflow tends to the normal law of distribution (K–Sd = 0.103719 at $p < 0.20$). The distribution of mudflows and landslides by altitude is shown in Fig. 6, *a*, from which we can see that the interval of values of altitudes of landslides contains the values of the altitudes of the mudflows, i. e. in the upper parts of the partial basins, where the mudflows were observed and landslides were recorded, which could be potential sources of sediments and vice versa – mudflows could be activators of the landslides at lower altitudes. The existence of such connection was proven statistically using the Mann-Whitney test, the results of which are shown in Fig. 6, *a*, *p*-value indicates a level of dependency of two samples of mudflows and landslides.

As for the mudflows in the basin of the Tereblya River, most of them are fixed at altitudes of 600–900 meters above the sea level, which indicates more alpine conditions of their development. 25–75 percentiles include a range of altitudes from 700 to 820 m. Mudflows are recorded mainly in the upper part of the river because the lower part of the catchment area is a plateau, dissected by river valleys into separate slopes with wide flat or dome-shaped peaks that do not promote the development of mudflow processes. The angles of the slopes in relation to absolute marks are shown in Fig. 4, *b*. 28 % of the mudflow basins have a northeastern prevailing aspect (Fig. 5).

The water regime of the Tereblya river which is higher than the reservoir, as wells as other rivers of this area, is characterized by frequent floods throughout the year, but the maximum expenditure is usually formed at

Table 4

Results of regression analysis of variables of factor characteristics: altitude, slope angle, slope aspect

River	Number of values	Parameters of regression							
				Beta	St.dev.B	B	St.dev ad.B	t	*p*-level
Teresva	117/115	Displacement				7.365178	0.946899	7.778206	0.000000
		Slope angle		0.117115	0.066061	0.002465	0.001390	1.772820	0.077605
		Displacement				104.5262	30.28824	3.451049	0.000666
		Slope aspect		0.208607	0.065056	0.1426	0.04447	3.206601	0.001538
		Formula	Linear	$Z = 571.9577 + 4.253 * x + 0.2867 * y$					
			Quadratic	$Z = 704.1714 - 8.1118 * x - 0.5011 * y - 0.4702 * x * x + 0.109 * x * y - 0.0004 * y * y$					
Tereblya	82/80	Displacement				3.129497	1.671996	1.871714	0.064901
		Slope angle		0.330958	0.105503	0.006681	0.002130	3.136964	0.002389
		Displacement				223.6784	56.33151	3.970751	0.000156
		Slope aspect		–0.002324	0.111803	–0.0015	0.07175	–0.020790	0.0983465
		Formula	Linear	$Z = 650.5054 + 16.6598 * x - 0.0678 * y$					
			Quadratic	$Z = 964.6239 - 33.1931 * x - 0.8406 * y + 1.1808 * x * x + 0.1153 * x * y - 0.0006 * y * y$					
Rika	97/95	Displacement				4.561705	1.314898	3.469247	0.000786
		Slope angle		0.213463	0.100233	0.005249	0.002465	2.129671	0.035784
		Displacement				153.1314	34.88268	4.389897	0.000029
		Slope aspect		0.068099	0.102360	0.0435	0.06539	0.665293	0.507475
		Formula	Linear	$Z = 432.0582 + 8.7697 * x + 0.1165 * y$					
			Quadratic	$Z = 740.4248 - 61.6104 * x - 0.4622 * y + 3.2586 * x * x + 0.0952 * x * y - 0.0006 * y * y$					
Bila and Chorna Tysa	44/42	Displacement				–1.71026	3.731386	–0.458343	0.0648864
		Slope angle		0.391194	0.135692	0.01676	0.005812	2.882959	0.005972
		Displacement				116.7383	127.0126	0.919108	0.0362834
		Slope aspect		0.052289	0.147240	0.0703	0.1978	0.355124	0.0724120
		Formula	Linear	$Z = 528.0335 + 10.0235 * x + 0.1167 * y$					
			Quadratic	$Z = 643.3894 - 35.4176 * x + 0.8771 * y + 2.6262 * x * x - 0.0325 * x * y - 0.0008 * y * y$					

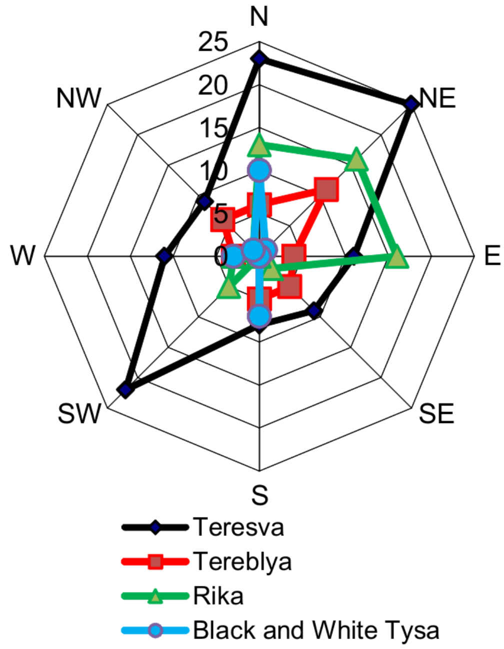

Fig. 5. Distribution of values of altitudes of landslides and mudflows for the rivers

snowmelt, which activates the landslide and mudflow processes that are characterized by a special mutual connection, whose presence is shown in a histogram in Fig. 6, *b*. Distribution of the variables of the altitudes of the mudflows tends to normal: K–Sd = 0.128 with $p < 0.15$. 18 out of 42 partial mudflow basins include landslides, which is 43 %. The connection is checked statistically using the Mann-Whitney criterion. The result is shown in Fig. 6, *b* and it allows concluding that there is dependence between the samples of the altitudes of landslides and mudflows.

Comparing the altitudes of mudflows in the basins of other rivers that are discussed in this article, mudflows in the basin of the Rika River develops at lower altitudes – half of all listed in the cadastre mudflows were in the basin at an altitude of 400–600 m. The development of mudflows at lower altitudes can be explained by the presence of the considerable slope angles (Fig. 4, *c*), except the favorable complex of effects of local meteorological, geological and tectonic conditions. Mudflows are mainly of mudslide nature. The slopes, on which the mudflows were recorded, mostly have northern, north-eastern, and eastern aspects (Fig. 5). Fig. 6, *c* shows the high-altitude position of landslides and mudflows in the river basin. The high-altitude areas, where landslides develop, contain areas with mudflow processes. It can

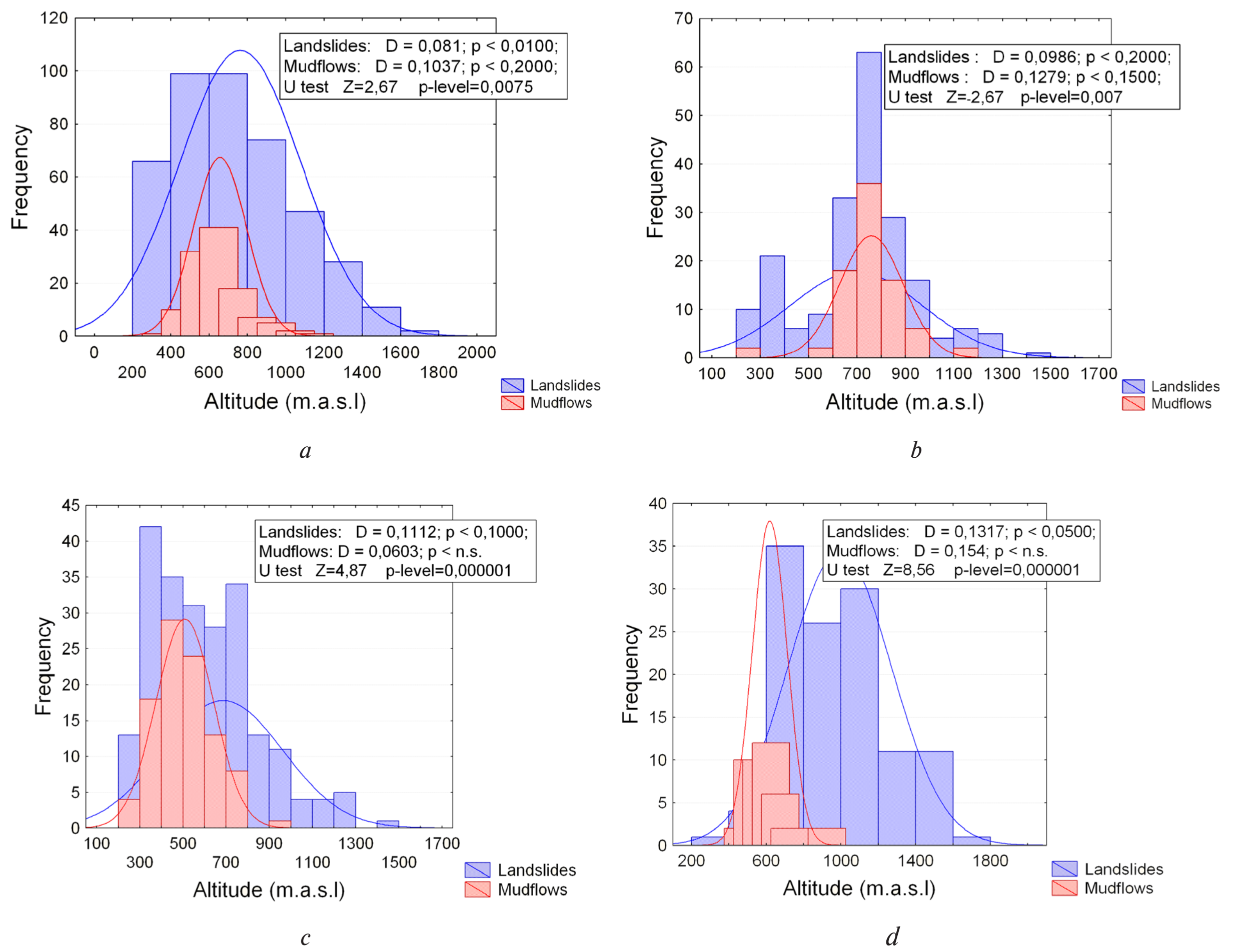

Fig. 6. Distribution of values of absolute altitudes of the landslides and mudflows for the rivers: a – Teresva; b – Tereblya; c – Rika; d – Chorna and Bila

be seen from the histogram with the p-levels and test values of normality of samples and their interdependence. Work [7] explains the interdependence of mudflows and landslides due to formation of the so-called "soils that lost coupling", while there occurs the process of formation of loosely-sediments, moving due to the altitude difference on a slope, excessive moisture, and changes the center of gravity. This process can begin from the formation of a landslide (landslide body or part of it further forms a solid component of mudflow) and from mudflow process that gives rise to the development of landslides.

Most of the mudflow manifestations in the basins of the rivers of Bila and Chorna Tysa are characterized by the altitudes in the range from 500 to 700 m, where the surface is composed of aeration products of flysch sand-clay sediments. At the altitudes above 900 m, there are meadow soils, generally with the admixture of gravel and rocks that promotes the formation of water-rock mudflows. 10 out of 22 slopes with mudflows streams have northern aspect, which is reflected in the chart in Fig. 5. Fig. 6, *d* shows that the vast majority of the landslides that have been recorded in the partial basins have altitudes higher than the altitudes where mudflows have been recorded at the same time. The available theoretical assumptions about the connection between landslides and mudflows in the basins of the rivers of Teresva, Tereblya, Rika, Bila and Chorna Tysa have been proven empirically by the analysis of their high-altitude location by the histogram. The identified regularities can be used for identifying potential mudflow sites with known values of altitudes, slope angles, slope aspect, and availability of landslide processes in certain high-altitude areas, which allows assuming that landslides were used as a source of loosely-clastic material for mudflows. To determine the existence of statistical dependence between the samples of the altitudes of mudflows and landslides as in previous cases, the criterion of Mann-Utni, which showed that the hypothesis of the existence of dependency between the samples should be taken into account, was used.

Research conclusions and recommendations for further research in this area.

1. The prognostic information systems based on GIS allow modeling mudflow processes and predicting their development effectively. The openness of such systems provides the possibility of continuous addition of the spatial and temporal information and taking into account the new regularities of the factor impact. The introduction of the factor characteristic of "altitude" in the system led to the appearance of the issue of indirect reflection of its influence through another characteristic. Verification of this hypothesis was performed with the help of the factor analysis, which denied allegations of duplication of influence. The question of structuring the influence on mudflow formation by hierarchy of factor characteristics in matrix of factor loadings was solved simultaneously.

2. To optimize the usage of the prognostic model of mudflow hazard, previously presented by the authors, it is proposed to primarily define the potential mudflow sites (by altitude division), for which the mudflow hazard will be calculated.

The results of the research presented in this article make it possible to trace the influence of high-altitude position of the mudflow sites with the help of the predictor-corrector system in complex of the factor characteristics of "slope angle", "slope exposition". The functional dependency is reflected in the form of linear and quadratic regressions and the standardized regressive beta coefficients are given. The regularities that were identified should be considered in mathematical and prognostic geoinformational modeling of mudflow processes development for the basins of the rivers Teresva, Tereblya, Rika, Bila and Chorna Tysa. The algorithm of using the results is the following: establishment of similar regression and functional dependencies between the factors of mudflow formation, combining them with the regularities given in this article, and forecasting a mudflow hazard formation based on the presented multiple multifactorial model.

3. The available theoretical assumptions about the connection between landslides and mudflows in the basins of the rivers Teresva, Tereblya, Rika, Chorna and Bila Tysa are proven empirically by the histogram analysis of their high-altitude location. The identified regularities can be used for identifying of potential mudflow sites with known values of altitudes, slope angles, slope aspect, and availability of the landslide processes in certain high-altitude areas.

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Мета. Встановлення закономірностей у висотному та експозиційному розподілі селевих осередків – у басейнах рік Тересви, Тереблі, Ріки, Білої та Чорної Тиси та зв'язків між зсувними й селевими явищами.

Методика. Цифрове моделювання рельєфу басейнів указаних рік. Просторовий оверлейний аналіз розподілу осередків селесходження, картометричні операції отримання даних про висотне та експозиційне положення, переважаючі кути ухилу. Факторний аналіз з метою виявлення безпосереднього та опосередкованого впливу висотного положення потенційного селевого осередку на процес селеутворення, використання статистичних критеріїв відбору вагомих ознак. Графічна візуалізація впливу синтезу висотного положення й кута ухилу на розвиток селів. Регресійний аналіз наявності закономірного зв'язку між селями та зсувами.

Результати. Виявлені закономірності розподілу селевих осередків відповідно до її факторних ознак: абсолютної висоти, кута ухилу, експозиції схилу та наявності зсувів у басейнах вищевказаних рік.

Наукова новизна. Уперше для басейнів рік шляхом геоінформаційного моделювання виявлені закономірності розвитку селепроявів відносно просторових факторних ознак: предиктора „абсолютної висоти“ та коректорів „кутів ухилів“ і „експозицій схилу“. Уперше шляхом гістограмного аналізу даних висотного розподілу селів і зсувів у басейнах цих рік установлено наявність взаємозв'язку між їх розвитком за висотним положенням. Функціональні закономірності наведено у вигляді лінійних і квадратичних регресійних залежностей з відображенням відносного внеску ознак, із зазначенням відповідних рівнів значимості.

Практична значимість. Встановлені закономірності можуть бути використані для виявлення потенційних селевих осередків у басейнах рік Тересви, Тереблі, Ріки, Білої та Чорної Тиси, за відомих значень висот, кутів нахилу, експозиції схилів та наявності зсувних процесів. Регресійні залежності можуть ураховуватись при математичному й прогностичному геоінформаційному моделюванні розвитку селевих явищ за наступним алгоритмом: встановлення аналогічних регресійних і функціональних залежностей між факторами селеформування; комплексування їх за приведеними у даній статті закономірностями; прогнозування селенебезпеки на основі утвореної мультифакторної множинної моделі.

Ключові слова: *селі, геоморфологічні параметри, селева небезпека, просторові фактори, зсуви, ГІС*

Цель. Установление закономерностей в высотном и экспозиционном разделе селевых очагов – в бассейнах рек Тересвы, Теребли, Реки, Белой и Черной Тисы и связей между сдвижными и селевыми явлениями.

Методика. Цифровое моделирование рельефа бассейнов указанных рек. Пространственный оверлейный анализ распределения селевых очагов, картометрические операции получения данных о высотном и экспозиционном положении, преобладающих углов наклона. Факторный анализ с целью выявления непосредственного и косвенного влияния высотного положения потенциального селевого очага на процесс селеформирования, использование статистических критериев отбора значимых признаков. Графическая визуализация влияния синтеза высотного положения и угла наклона на развитие селей. Регрессионный анализ наличия закономерной связи между селями и оползнями.

Результаты. Выявлены закономерности распределения селевых очагов в соответствии с ее факторными признаками: абсолютной высотой, углом наклона, экспозицией склона и наличием оползней в бассейнах вышеуказанных рек.

Научная новизна. Впервые для бассейнов рек путем геоинформационного моделирования выявлены закономерности развития селепроявлений относительно пространственных факторных признаков: предиктора „абсолютной высоты“ и корректоров „углов наклона“ и „экспозиций склона“. Впервые путем гистограммного анализа данных высотного распределения селей и оползней в бассейнах этих рек установлено наличие взаимосвязи между их развитием по высотному положению. Функциональные закономерности приведены в виде линейных и квадратичных регрессионных зависимостей с отображением относительного вклада признаков, с указанием соответствующих уровней значимости.

Практическая значимость. Установленные закономерности могут быть использованы для выявления потенциальных селевых очагов в бассейнах рек Тересвы, Теребли, Рики, Белой и Черной Тисы, при известных значениях высот, углов наклона, экспозиции склонов и наличия оползневых процессов. Регрессионные зависимости могут учитываться при математическом и прогностическом геоинформационном моделировании развития селевых явлений по следующему алгоритму: установление аналогичных регрессионных и функциональных зависимостей между факторами селеформирования; комплексирования их с приведенными в данной статье закономерностями; прогнозирования селеопасности на основе созданной мультифакторной множественной модели.

Ключевые слова: *сели, геоморфологические параметры, селевая опасность, пространственные факторы, оползни, ГИС*

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