A COMPLEX ABIOTIC ENVIRONMENTAL FACTORS ANALYSIS FOR RISK ASSESSMENT FOR REPUBLIC OF MOLDOVA

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***Abstract**: This study aims to explore the geological and geomorphological factors, relief morphometry, soil cover, destructive processes affecting soils, hydrography, land vulnerability, and anthropogenic changes within the limits of the Republic of Moldova based on cadastral and other open source data from geodata.gov.md, satellite and orthophoto images. The research findings, conducted by the Institute of Ecology and Geography of the Moldova State University, are illustrated through thematic maps, which are included in the Atlas "Abiotic Environmental Factors and Ecological Security", published in 2023. The maps in the atlas are presented at scales ranging from 1:1,500,000 to 1:3,500,000, with each page enhanced by supporting diagrams, text, photographs, and graphs.*

***Key-words**: abiotic factors; cadastral data; soil maps; vulnerability; geomorphological processes*

1. Introduction

According to the Ecological Dictionary [1], abiotic factors, in the context of the environment, mean the totality of non-living parts of an ecosystem that shapes the environment (physical, chemical, meteorological). For risk assessment, abiotic environmental factors are often the main detrimental factors affecting agriculture.

The territory of Republic of Moldova is densely populated with over 90% of the countryside inhabited. This fact significantly increases the risk of disturbance of the regular climatic processes and their transformation into extreme ones. The excessive and uncontrolled increase of the anthropogenic pressure has conditioned, to a great extent, the obvious activation and the appearance of multiple phenomena and extreme processes. [2]

The notion of a risk cannot be consideredseparately from that of frequency and probability, from which it is naturally derived. Likewise, the notion of is further extended by the return time of an extreme event, which is commonly estimated by the probabilities of the occurrence of extreme events. Finally, the notion of risk is also defined by the spatial delimitation of the areas vulnerable to its manifestation.[3]

One of the initial endeavours to present and evaluate abiotic factors of the territory of the Republic of Moldova is the Atlas of the USSR of 1984 [4]. The geomorphological and geological maps in this atlas are produced at a scale of 1:16,000,000 and encompass the entire territory of the USSR. The temperature and precipitation maps are produced at a scale of 1:36,000,000 and are arranged into two maps per A3 page.

Research and complex analysis of abiotic environmental factors for risk assessment in the Republic of Moldova has been conducted at the Institute of Ecology and Geography for numerous years.

Among the outcomes of this work, it is noteworthy to mention the wall map "Republic of Moldova. Geomorphological conditions" [Fig.1], published in 2006. Itdemonstrates the geomorphological map, relief units, gully distribution frequency, landslide distribution frequency, influence of geological and geomorphological processes on relief formation, anthropogenic relief changes and geological and geomorphological objects protected by the state.

The thematic content of the maps was developed in the Laboratory of Dynamic Geomorphology utilizing both own materials and the Land Cadastre’s as of 1.01.2005. The text is presented in three languages: Romanian, Russian and English.

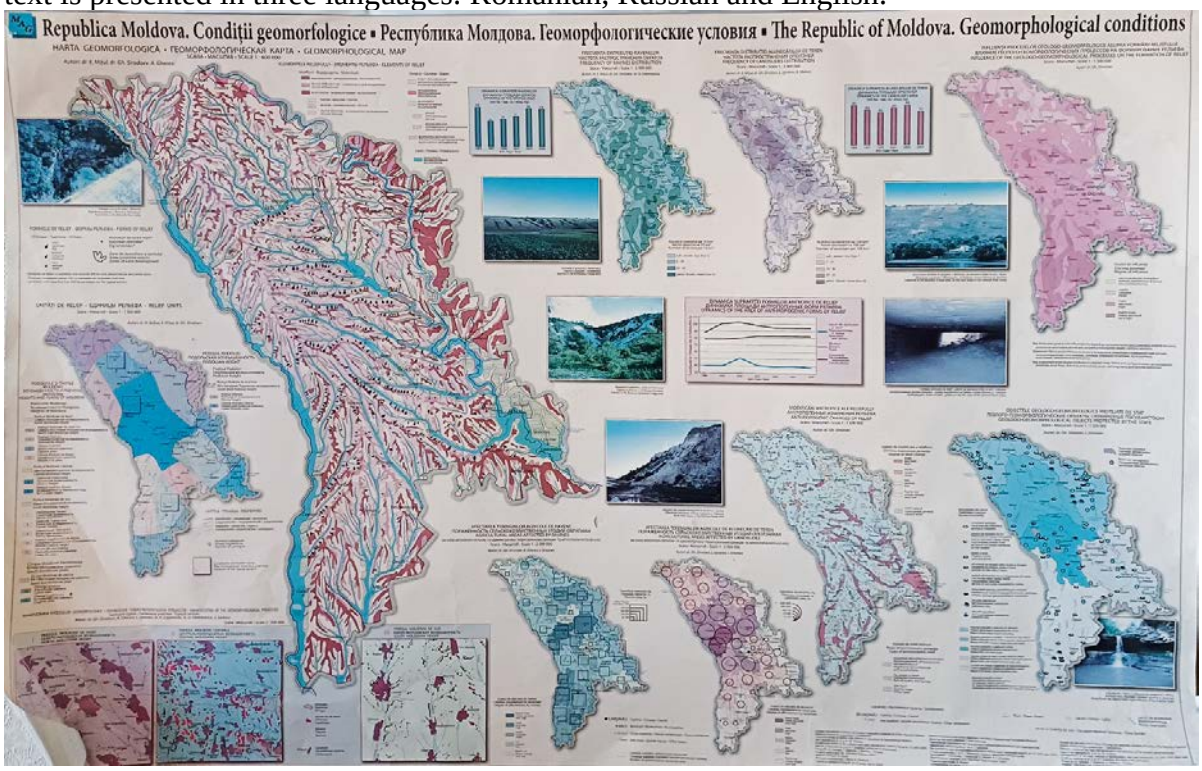


Fig. 1. Wall map "Republic of Moldova. Geomorphological conditions"

In 2013, the Atlas of Climatic resources of the Republic of Moldova [5] was developed. The Atlas contains information about spatio-temporal estimation of average temperatures and the amount of precipitation for different periods within the boundaries of the Republic of Moldova. The textual information is presented in two languages - Romanian and English.

Subsequently, in 2019, abiotic environmental factors were partially assessed in the atlas " Republic of Moldova: natural and anthropogenic risk factors" [6]. Two of the three sections of the atlas are dedicated to geomorphological and meteorological-climatic factors.

The publication of the Atlas "Climate Change and the Current State of Landscapes" [7] was necessitated by the accelerated pace of climate change, which significantly impacts the current state of landscapes. The Atlas is structured into six sections, four of which are dedicated to abiotic environmental factors: Average temperature in the period 1991-2020, Average precipitation in the period 1991-2020, Modeling of average temperatures in correlation with the reference period (1986-2005), and Modeling of precipitation in correlation with the reference period (1986-2020).

In addition to large-scale maps, the institute created and collected maps in atlases dedicated to abiotic conditions within the Dniester (2012) and Cubolta (2023) river basins. Additionally, in 2020, the Atlas "RegimulTermicșiPluviometric din SudulRepublicii Moldova" was published. The research for this atlas was conducted within the boundaries of Cahul district and the Zirnesti commune.

Having gathered a wealth of materials and experience in atlas development, the decision was made to update the maps of the Republic of Moldova, incorporating, among other things, the latest cadastral data.

The Atlas "Abiotic Environmental Factors and Ecological Security" [8] was developed based on the results obtained regarding the spatial modeling of abiotic environmental factors that influence the ecological security of the country. The atlas is structured in the following sections: Geological-morphological factors, Climatic conditions, Hydrography, Soil cover, and Landscapes.

2. Materials and Methods

The study was based on initial data collected from various organizations responsible for operational monitoring, including the Land Cadastre, INGEOCAD, and AGEOM. The atlas was created using Geographic Information Systems (GIS) software, such as ArcGIS and QGIS, as well as graphic editors like Adobe Illustrator and Adobe Photoshop.

To assess the vulnerability of territories to exogenous processes, we used the most recent cadastral data (2023), breaking them down at the level of administrative-territorial units. Three categories were identified as stabilizing factors: rate of afforestation (including also forest plantations, shrub plantations and protective forest belts), perennial plantations area (this category of land use includes orchards, vineyards, walnut, mulberry plantations, fruit and berry bushes, etc.) and meadows and pastures area, since, according to [DOUSA 2021] [9], the above-mentioned types of land use mitigate the development of erosion processes, and, to a lesser extent, landslides. The degree of anthropogenic transformation of the relief was assessed according to three cadastral categories that represent the territories with partially stabilized and stabilized character in this regard - roads; buildings and courtyards; streets and squares. The destructive exogenous processes affecting soil cover were estimated based on the notion that arable areas are considered to be the most susceptible, thus we took into account their normalized area plus analysed the most frequently met representations of these processes, namely landslides and ravines.

The above mentioned categories of cadastral data were mapped according to their normalized areas. The classification method and grading method for each one resulting in the vulnerability map is given in Table 1. [Jenks and Caspall 1971] [10] The visual method of standardized choropleth maps was used, estimating the share of corresponding areas in the

total area of the regions, thus using normalized data to exclude visual misinterpretations [Hallisey 2005] [11].

Table 1. Classification method and grading system applied for the cadastral data during the mapping process.

	Classification / Grading system				
Cadastral category	**Very low / 1**	**Low / 2**	**Moderate / 3**	**High /4**	**Very high / 5**
Landuse with a complex load on exogenous processes development					
Landslides	Less than 0.1 %	0.1-0.4%	0.4-1.0%	1.0-2.0%	More than 2.0%
Ravines	Less than 0.1 %	0.1-0.3%	0.3-0.5%	0.5-0.7%	More than 0.7%
Arable areas	Less than 40%	40-55%	55-60%	60-65%	More than 65%
Stabilizing factors					
Forested areas	Less than 8%	8 – 12%	12-21%	More than 21%	-
Meadows & pastures	Less than 5%	5-10%	10-15%	More than 15%	-
Perennial plantations	Less than 5%	5-7.5%	7.5-10%	10-14%	More than 14%
The types of anthropogenic modifications of the relief					
Roads	Less than 2%	2.0 – 2.5%	2.5-3.0%	3.0-3.5%	More than 3.5%
Constructions and courtyards	Less than 2%	2.0-3.0%	3.0-7.0%	7.0-10.0	More than 10.0%
Streets and squares	Less than 1%	1.0-1.5%	1.5-2.0%	2.0-2.5%	More than 2.5%

The slope represents a fundamental parameter in the geomorphological analysis of relief, being a key factor in the development of various geomorphological processes, particularly those related to slope movements. The slope map was derived from the numerical terrain model (NTM). During this phase of research, three distinct maps were created for the Republic of Moldova, each containing data on slope characteristics. Each map is delineated based on specific criteria aimed at illustrating particular parameters.

For the Soils map, we had used cadastral data and the soil classification system of the Republic of Moldova that was adopted by the National Soil Science Society of Moldova [Ursu, 2001] [13]. The basic principle of the Moldovan soil classification system consists in highlighting the naming of soils based on intrinsic properties, but also in using some horizon features for diagnostic purposes. The soil classification is based mainly on the traditional terms of the Dokuchaev’s genetic principle (Ursu, 1999) [14]. The entire taxonomic system is conditioned by the specificity of the parental material, the content of certain substances or the influence of pedogenetic processes.

3. Results and Discussions

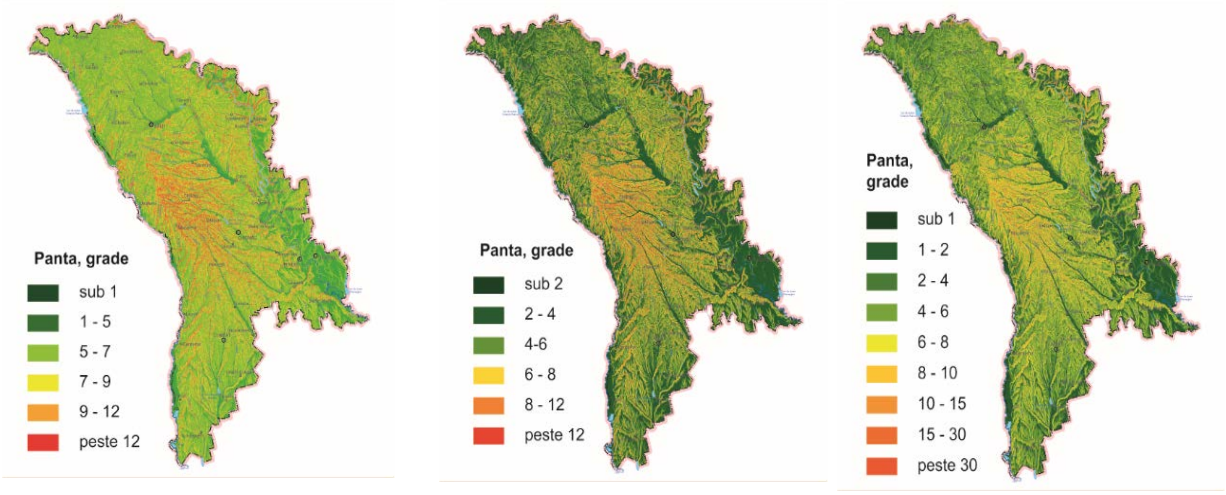
Among the most complex and important global problems, which influence or are caused by global environmental changes, are also characteristic for the Republic of Moldova, an important place is occupied by the problem of land surface modeling processes.In the Atlas "Abiotic Environmental Factors and Ecological Security" are analyzed the main abiotic factors that contribute to risk assessment analysis. Among them are morphometric parameters, soil, degree of afforestation, climate and human activity.

The first slope map (Figure 2a) is categorized into six slope classes, corresponding to intervals relevant to the evolution of landslide processes. The most extensive slopes are those with an inclination of less than 2°, accounting for 32.11% of the total surface area of the Republic. Slopes with inclinations ranging from 2° to 4° (29.80%) and from 4° to 6° (18.65%)

show nearly equal values, while slopes with inclinations between 6° and 8°, and between 8° and 12°, cover 7.96% and 7.71% of the area, respectively. Slopes exceeding 12° represent only 1.77% of the territory and are typically associated with collapsed slopes or the ledges of landslides.

The second map (Figure 2b) categorizes slopes into six classes, with intervals linked to the development of ravines. The most prevalent slopes are those with inclinations ranging from 1° to 5°, which occupy 58.01% of the total land area of the Republic. Slopes with inclinations between 0° and 1% (14.6%) and those between 5° and 7° (13.47%) display similar values. Slopes with inclinations between 7° and 9°, and between 9° and 12°, account for 7.33% and 4.42%, respectively. Slopes steeper than 12° comprise less than 2% of the total area, which similarly corresponds to collapsed slopes or landslide ledges, as noted in the first classification.

The third classification (Figure 2c) divides slopes into nine categories. The first category represents slopes with an inclination of up to 1°, corresponding to river meadows and slope peaks, covering 15.61% of the country's surface area. The second category, with slopes between 1° and 2°, follows closely with a share of 16.23%. These areas are particularly favourable for agricultural activities due to the negligible impact of exogenous degradation processes. Slopes with inclinations ranging from 2° to 4° constitute the largest category, covering 30.07% of the land area. These lands are minimally affected by gravitational degradation processes, making them highly suitable for agricultural use. However, for slopes steeper than 3°, it is imperative to implement anti-erosion measures, depending on both the degree of slope and the type of agricultural crops cultivated.



a) **b)** **c)**

Fig. 2 Slope Intervals used in assessment of a) Development, b) Ravine Development, c) Intervals Used in the Evolution of Collapse-Rolling Processes

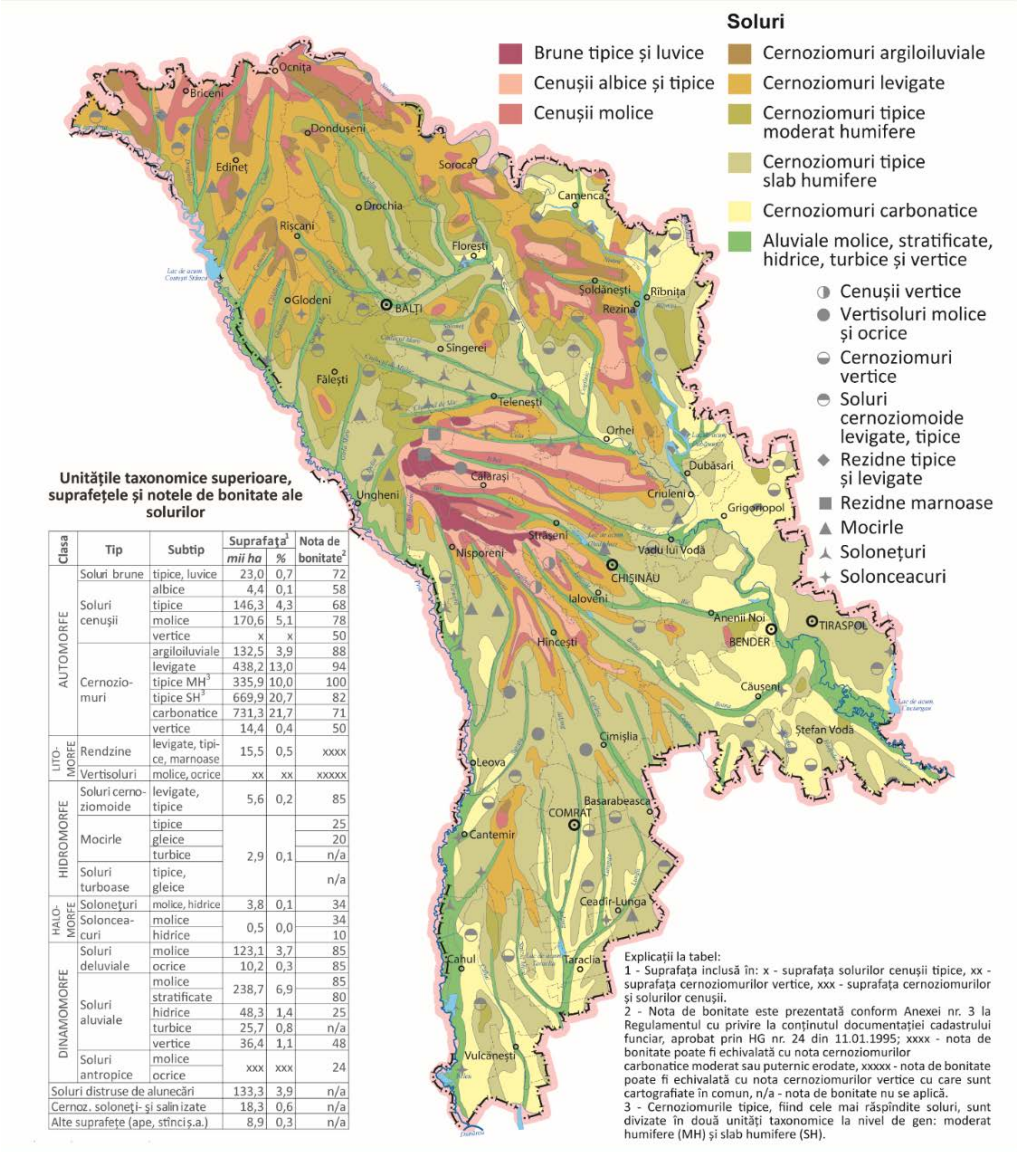
Slopes with inclinations between 4° and 6° cover 18.65% of the country's territory, while slopes between 6° and 8° occupy 10.03%. Anti-erosion protection measures are essential for these areas. Finally, slopes steeper than 7° are classified as highly eroded lands, for which the planting of perennial grasses is recommended. Slopes with inclinations between 8° and 10°, and between 10° and 15°, cover 5.16% and 3.75%, respectively. The smallest proportion is represented by slopes exceeding 15°.

The detailed slope categorization presented in this paper provides valuable information for identifying areas at risk due to geomorphic processes and for implementing appropriate land management strategies. The majority of the land area consists of gentle

slopes, with over 60% having inclinations less than 6°. These areas are generally suitable for agricultural activities, though slopes exceeding 3° require anti-erosion measures. Steeper slopes, particularly those above 7°, are prone to erosion and landslides, necessitating careful land use planning and protective measures.This comprehensive slope analysis serves as a crucial tool for sustainable land use planning, agricultural development, and natural hazard mitigation in the Republicof Moldova.

The soil cover of the Republic of Moldova comprises 5 classes, encompassing 13 genetic types with 36 subtypes (Figure 3). The comprehensive systematic classification of soils in the region includes more than 700 taxonomic units.

The higher taxonomic units are represented by multiple genus, species, and varieties, which exhibit variations in thickness (depth), texture, erosion degree, salinisation and solonetzisation, gleization, and other characteristics. This diversity amplifies the spatial variability of soil distribution, resulting in a heterogeneous appearance of the soil cover.



Unităţile taxonomice superioare, suprafeţele şi notele de bonitate ale solurilor

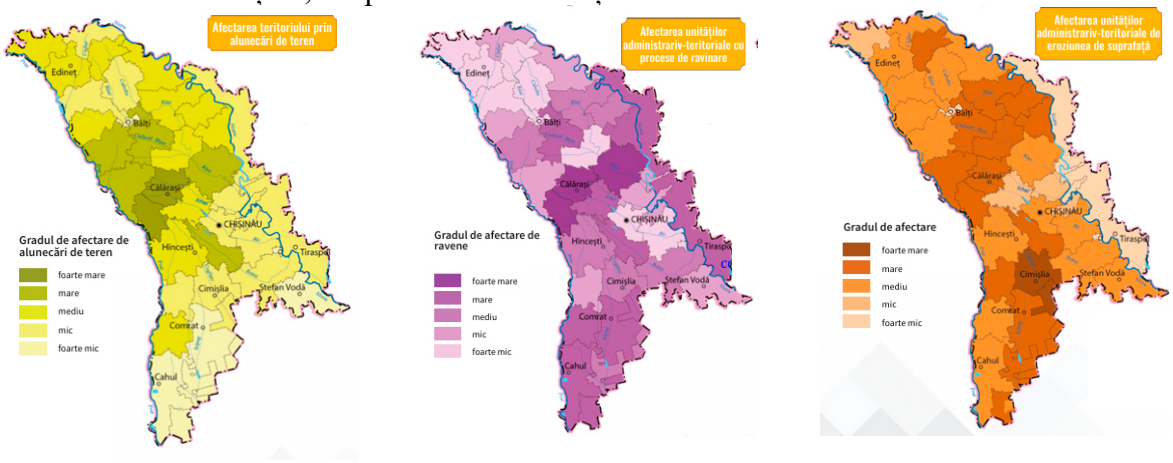
Clasa	Tip	Subtip	Suprafaţa[1] mii ha	Suprafaţa[1] %	Nota de bonitate[2]
AUTOMORFE	Soluri brune	tipice, luvice	23,0	0,7	72
	Soluri cenuşii	albice	4,4	0,1	58
		tipice	146,3	4,3	68
		molice	170,6	5,1	78
		vertice	x	x	50
	Cernozio-muri	argiloiluviale	132,5	3,9	88
		levigate	438,2	13,0	94
		tipice MH[3]	335,9	10,0	100
		tipice SH[3]	669,9	20,7	82
		carbonatice	731,3	21,7	71
		vertice	14,4	0,4	50
LITO-MORFE	Rendzine	levigate, tipice, marnoase	15,5	0,5	xxxx
	Vertisoluri	molice, ocrice	xx	xx	xxxxx
HIDROMORFE	Soluri cerno-ziomoide	levigate, tipice	5,6	0,2	85
	Mocirle	tipice	2,9	0,1	25
		gleice			20
		turbice			n/a
	Soluri turboase	tipice, gleice			n/a
HALO-MORFE	Soloneţuri	molice, hidrice	3,8	0,1	34
	Soloncea-curi	molice	0,5	0,0	34
		hidrice			10
DINAMOMORFE	Soluri deluviale	molice	123,1	3,7	85
		ocrice	10,2	0,3	85
	Soluri aluviale	molice	238,7	6,9	85
		stratificate			80
		hidrice	48,3	1,4	25
		turbice	25,7	0,8	n/a
		vertice	36,4	1,1	48
	Soluri antropice	molice	xxx	xxx	24
		ocrice			
Soluri distruse de alunecări			133,3	3,9	n/a
Cernoz. soloneţi- şi salinizate			18,3	0,6	n/a
Alte suprafeţe (ape, stînci,s.a.)			8,9	0,3	n/a

Explicaţii la tabel:
1 - Suprafaţa inclusă în: x - suprafaţa solurilor cenuşii tipice, xx - suprafaţa cernoziomurilor vertice, xxx - suprafaţa cernoziomurilor şi solurilor cenuşii.
2 - Nota de bonitate este prezentată conform Anexei nr. 3 la Regulamentul cu privire la conţinutul documentaţiei cadastrului funciar, aprobat prin HG nr. 24 din 11.01.1995; xxxx - nota de bonitate poate fi echivalată cu nota cernoziomurilor carbonatice moderat sau puternic erodate, xxxxx - nota de bonitate poate fi echivalată cu nota cernoziomurilor vertice cu care sunt cartografiate în comun, n/a - nota de bonitate nu se aplică.
3 - Cernoziomurile tipice, fiind cele mai răspîndite soluri, sunt divizate în două unităţi taxonomice la nivel de gen: moderat humifere (MH) şi slab humifere (SH).

Fig. 3 Soil map of the Republic of Moldova

The largest share of areas affected by landslides is observed in the district of Călărași (4.3%) and Nisporeni (3.2%), and the smallest - in other five districts (Bălți Municipality, Taraclia, Cahul, Ștefan-Vodă and ATU Gagauzia). Regarding the degree of ravine damage,

the largest areas are recorded in the regions of Orhei (1.34%) and Călărași (0.83%), and the smallest - in six districts (Bălți Municipality, AneniiNoi, Telenești, Râșcani, Dondușeni and Edineț). The territories most affected by surface erosion are observed in the central and southern part of the republic (Figure 4a, 4b, 4c). The most arable areas are located in Drochia (72%) and Florești (65%), and the least in the municipalities of Chișinău and Bălți, as well as in the districts of Strașeni, Nisporeni and Călărași.



a) b) c)

Fig.4 Affectation of the territory by geomorphological processes.
a. Landslides; b. Gullies; c. Surface erosion

Only four districts (11%) - Nisporeni, Calarasi, Hancesti and Straseni have relatively high afforestation. A third of the districts of the republic have low forests ratio (31%), another third - moderate (33%), and a quarter have a very low rate of forest plantations per unit area. The lowest normalized area of meadows and pastures is observed in Straseni district (4.3%) and Chisinau municipality (4.6%), the highest - in Sangerei, Ungheni and Falesti districts (17.2%, 15.0% and 16.6%, respectively). 14% of the districts have a very low degree of coverage by the perennial plantations, and only half of the total number of them have moderate and high areas of orchards, vineyards and other categories of perennial plantations. The districts of Nisporeni, Călărași and Ialoveni have the highest percentages in this regard, having 15.6%, 15.9% and, respectively, 18% of the total area covered with perennial plantations.

In the Republic of Moldova, a low share of roads is recorded, the minimum normalized area (1.94%) is observed in the Soroca district, and the maximum - in the Ialoveni district (3.85%). The average normalized share of roads in the republic is 2.71%. Approximately similar values are observed in the Cantemir, Orhei, Ungheni and AneniiNoi districts. 30% of the districts have a specific share of roads above the average for the republic, and 50% of the districts - respectively, below this average.

The maximum share of buildings and yards in the total area of the districts is recorded in Balti municipality (27.44%), in second place is Chisinau municipality with 20.94%. The minimum share is observed in Telenești district (1.25%). The average value for the republic is 3.96%, and approximately at this level are the districts of Transnistria (3.87%), Dubăsari (3.58%), Edineț (3.52%), Ialoveni (3.28%) and Șoldănești (3.19%).

Streets and squares occupy the largest share of the area in the region of Balti municipality (4.11%), in Chisinau municipality the share is slightly lower, 3.59%. The lowest percentage of coverage with streets and squares is observed in Cahul district (0.47%). The average value for the republic is very low – 1.56%. Half of the republic's districts have approximately average weight values, 22% - values below average, and 28% - above average.

4. Conclusions

The initial section of the Atlas "Abiotic Environmental Factors and Ecological Security" offers a detailed examination of the geomorphological parameters and pedological conditions across the entire territory of the Republic of Moldova. This analysis provides a comprehensive assessment of abiotic environmental factors pertinent to risk evaluation. It serves as a valuable resource for land management decision-making, further scientific inquiry, and the development of strategies to ameliorate the condition of degraded soils in the Republic of Moldova, thereby enhancing ecological security.

At the current stage of society's development, these laws are determined by the peculiarities of the interaction of endogenous and exogenous natural factors, as well as by the anthropogenic impact on the process of forming the noospheric space.

The quantitative and qualitative analysis of the factors taken into account are of great utility in various fields.Knowing the degree of impact and the intensity with which these factors act on the territories of our country can serve as a basis for activity in the agricultural, infrastructure and construction fields.

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