Present Environment and Sustainable Development
Volume 16, number 2, 2022
DOI: https://doi.org/10.47743/pesd2022162021

Spatial study of soil erosion in the Republic of Moldova

Iurie BEJAN[1,2], Vitalie SOCHIRCĂ[2]*, Tatiana NAGACEVSCHI[2], Pavel ȚÎȚU[1,2]

[1]Institute of Ecology and Geography, Ministry of Education and Research, Chisinau, Republic of Moldova, ieg@ieg.md
[2]Moldova State University, Republic of Moldova

***Correspondence:** sochirca1970@gmail.com; Tel.: +373-68-44-77-53 (S.V.)

Keywords: land cadastre; agricultural lands; soil erosion; degree of erosion

Abstract: The study represents a detailed spatial analysis regarding soil erosion in the Republic of Moldova. The territory of the country (including the Transnistrian region), from the point of view of the administrative-territorial structure, is made up of 983 units. Thus, the analysis of eroded lands was carried out on administrative units at the level of villages, communes and cities, according to the data of the 2021 year from the Land Cadastre, developed by the *Agency for Land Relations and Cadastre of the Republic of Moldova*. The created database was later imported into a GIS (Geographical Information Systems) *program* and processed using ArcGIS software. The mapping and classification of the data regarding the proportion of eroded agricultural land (total; strongly, moderately and weakly eroded) allowed the identification of the most vulnerable areas to these processes - the Central Moldavian Plateau (Codrilor), the Ciuluc Hills, the Dniester Plateau etc. The frequency rate of agricultural land in total per country was 73.7%, including arable land constituted 54.9%. Of the entire agricultural area, 73.2% was monitored from the point of view of soil and geomorphological processes: approximately 1/3 of all agricultural land is affected by some degree of erosion, including 4.5% that are heavily eroded. The specific factors of soil erosion and the main consequences are evaluated, with an emphasis on the most affected regions.

1. Introduction

Soil erosion is the main factor of degradation of the soil cover – a chronic and primary problem in the Republic of Moldova, generated by the characteristics of the natural environment, by the very pronounced role of agriculture in the economy, by the exaggerated agricultural specialization in row crops, by the deficient „culture" of farmers in environment friendly practices, by the errors of post-soviet land privatization (excessive subdivision of land plots; delimitation of land quotas along the slope etc.), by the presence of indifferent and incapable authorities in this field etc.

The purpose of the investigation: mapping and classification of data relating to eroded agricultural lands (totally, strongly, moderately and slightly eroded) for identification of more affected and vulnerable areas, in order to change the land use.

2. Materials and Methods

The problem of soil erosion in the Republic of Moldova was addressed in numerous researches in the field of soil sciences, geography, having such concerns M. Zaslavskii, who dedicated to this problem about two decades (Заславский, 19666, 1987), I. Konstantinov, with investigations focused on soil protection (Константинов, 1987), V. Fedotov – on forestry improvement (Федотов, 1980), V. Voloșciuk – on the restoration of land affected by ravines (Волощук, 1986), I. Krupenikov – on linear erosion

(Крупеников and Добровольский, 2012), A. Ursu - on soil degradation and desertification (Ursu, 2000) and others, who deepened the elaborations on agrotechnical processes on eroded soils, their complex improvement, etc.

The territory of the Republic of Moldova (including the Transnistrian region), under the administrative-territorial report, is made up of 983 units (villages/communes; cities/municipalities), for which data on eroded lands were processed.

For the analysis of eroded lands, the data from the Land Cadastre of the Republic of Moldova (at the level of communes) for the year 2021, taken from *Agency for Land Relations and Cadastre*, were used (Cadastru funciar al Republicii Moldova, 2021). The created database was later imported into a GIS (Geographic Information Systems) *program* and processed using ArcGIS software. The Soil Map, scale 1: 200,000, developed by the "Nicolae Dimo" Institute of Paedology, Agrochemistry and Soil Protection from Chisinau was also used.

The degree of soil erosion is determined by the morphological study of the profile and its physical, physico-chemical, chemical, geochemical, etc. properties. The basic index in the morphological study is the thickness of the humiferous horizon, determined by comparing soil profiles with different degrees of erosion with the "standard". In assessing the degree of soil erosion, the following classification is used:

- slightly eroded soils: no more than ½ of horizon A is destroyed;
- moderately eroded soils: the entire A horizon is destroyed;
- heavily eroded soils: the B_1 horizon is also partially or fully destroyed.

Depending on the degree of erosion, the fertility of eroded soils decreases as follows: slightly eroded – with 20 %; moderately eroded – with 20-50 %; strongly eroded – with 50-80 % (*Eroziunea solului. Esența consecințele, minimalizarea și stabilirea procesului*, 2004).

3. Results and discussion

Factors favoring soil erosion

In general, this form of soil degradation is conditioned by some natural factors and the specifics of human activity. The natural environment of the Republic of Moldova is characterized by a set of natural factors that favor soil erosion: geomorphological conditions (uneven relief (Figure 1), especially in the sectors with high slopes), the torrential character of atmospheric precipitation, soil properties and its permeability, especially the low degree of soil resistance to erosion, the low degree of soil coverage with vegetation in the critical erosion season, etc., which, together, determine the erosivity potential of lands, especially agricultural ones. Thus, with the increase in the degree of fragmentation and the slope values, the potential for land erosivity also increases, the most vulnerable being agricultural land used as arable land, especially under row crops.

Following the processing of the data regarding the slope of all lands (with a total area of 33,843.5 km^2) on the relief units of the Republic of Moldova, we find an uneven distribution of slope lands (Figure 2 and Table 1). Land with a slope of 2º-6º has a greater spread (49.3%), followed by land with a slope of 0º-2º (31.6%), while land with a slope of more than 10º has only 3.7%. The geomorphological units with a more inclined relief are the Central Moldavian Plateau (Codrilor), with the lowest rate of land with a slope of 0º-2º (15.8%) and, respectively, the highest share of land with a slope of 6º-10º (31.3%) and over 10º (10.3%) (Bejan, 2010). A high degree of inclination is also found in the Ciulucs Hills, the Tigheci Hills, the Middle Cogâlnic Plateau. Namely, these relief units also have a higher frequency of eroded lands, as we will demonstrate below. On the other hand, the Lower Dniester Plain, the Cubolta Plain, the Lower Prut Plain have a flatter relief.

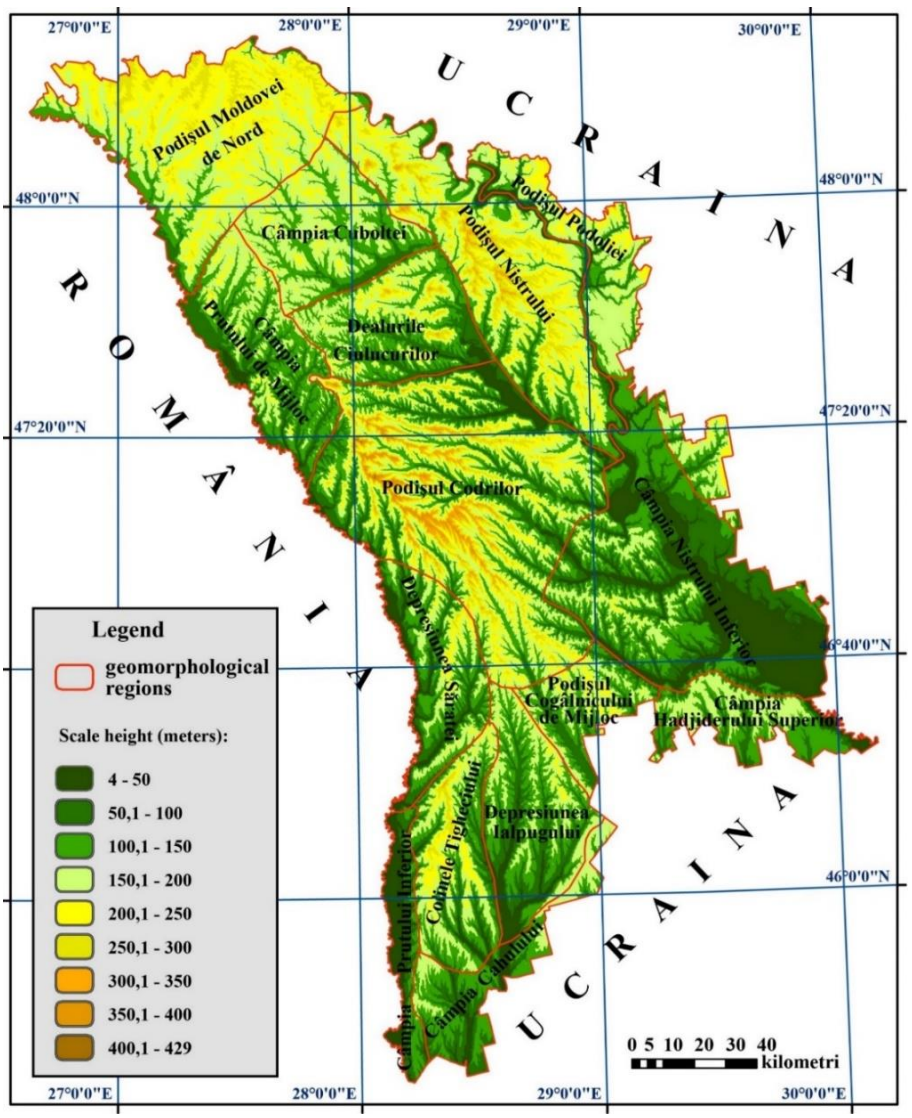


Figure 1. Physical map of the Republic of Moldova

Tabelul 1. Distribution of lands according to the degree of inclination on the relief units of the Republic of Moldova

Relief unit	Surface (km²)	0º-2º %	2º-6º %	6º-10º %	>10º %
Podişul Moldovei de Nord (Northern Moldavian Plateau)	3797,2	34,5	58,3	6,1	1,1
Câmpia Prutului de Mijloc (Middle Prut Plain)	1899,4	30,6	53,0	13,8	2,6
Câmpia Cuboltei (Cubolta Plain)	1830,9	32,7	62,1	5,1	0,1
Podişul Nistrului (Dniester Plateau)	3596,6	18,3	62,2	16,1	3,4
Podişul Podoliei (Podolian Upland / Plateau)	1289,6	43,5	38,6	11,3	6,6
Dealurile Ciulucurilor (Ciulucs Hills)	1751,0	21,4	56,8	18,5	3,2
Podişul Moldovei Centrale (Codrilor)	5945,8	15,8	42,6	31,3	10,3

Relief unit	Surface (km^2)	0º-2º %	2º-6º %	6º-10º %	>10º %
(Central Moldavian Plateau (Codrilor))					
Câmpia Nistrului Inferior (Lower Dniester Plain)	4981,6	51,5	35,2	11,2	2,1
Depresiunea Săratei (Sărata Lowland)	1529,3	32,1	46,6	16,6	4,7
Colinele Tigheciului (Tigheci Hills)	1286,1	23,5	55,8	18,6	2,1
Depresiunea Ialpugului (Ialpug Lowland)	1823,3	32,2	56,4	10,7	0,7
Podişul Cogâlnicului de Mijloc (Middle Cogâlnic Plateau)	927,5	23,6	55,7	18,8	1,9
Câmpia Hadjiderului Superior (Upper Hadjider Plain)	1071,5	48,2	43,3	7,9	0,5
Câmpia Cahulului (Cahul Plain)	1431,7	49,5	42,2	7,3	1,0
Câmpia Prutului Inferior (Lower Prut Plain)	682,0	60,5	29,8	8,3	1,5
TOTAL	33843,5	31,6	49,3	15,4	3,7

Source: Bejan, 2010

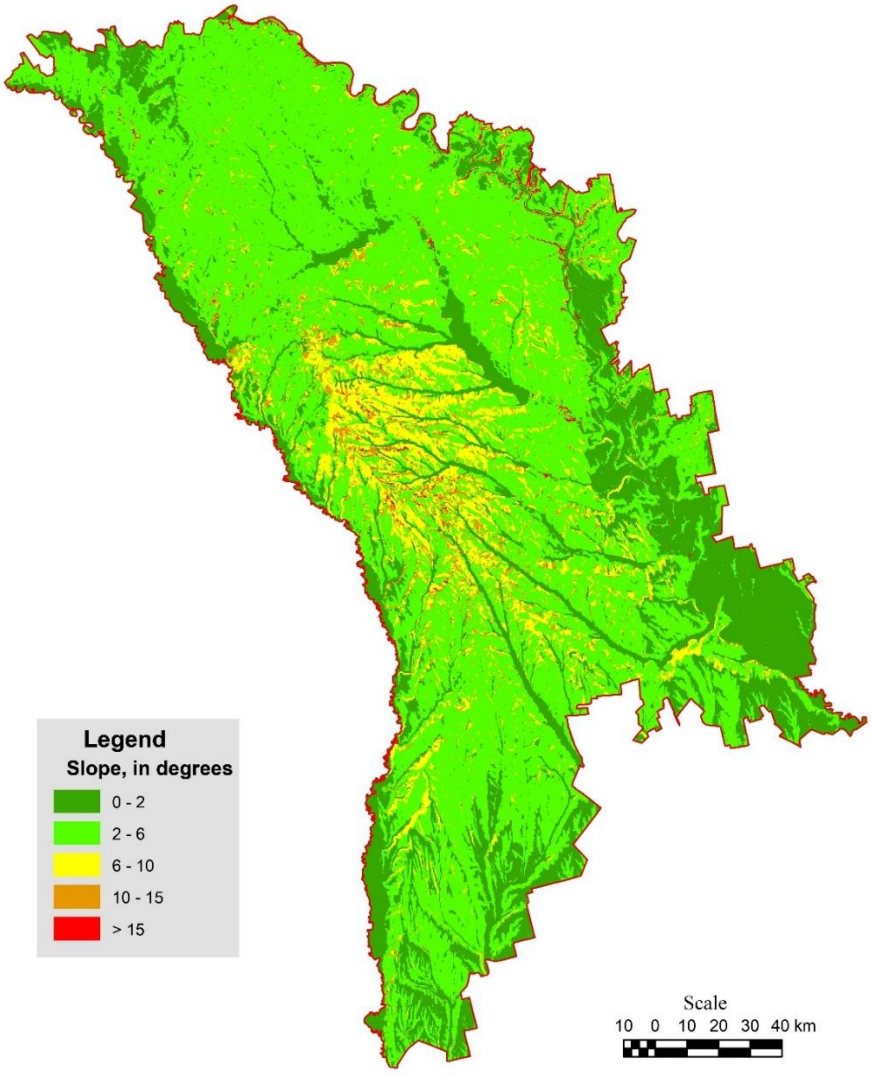


Figure 2. The Republic of Moldova: slope map

For the evaluation of the erosion resistance of soils and rocks, their global chemical composition is important, especially the content of silicon dioxide and aluminum and iron oxides. The influence of the underlying rocks on soil erosion is manifested in two ways. First of all, many chemical and physical properties of rocks in particular and, more importantly, their granulometric composition are inherited by the soil, to a large extent, and thereby exert their influence on its anti-erosion resistance.

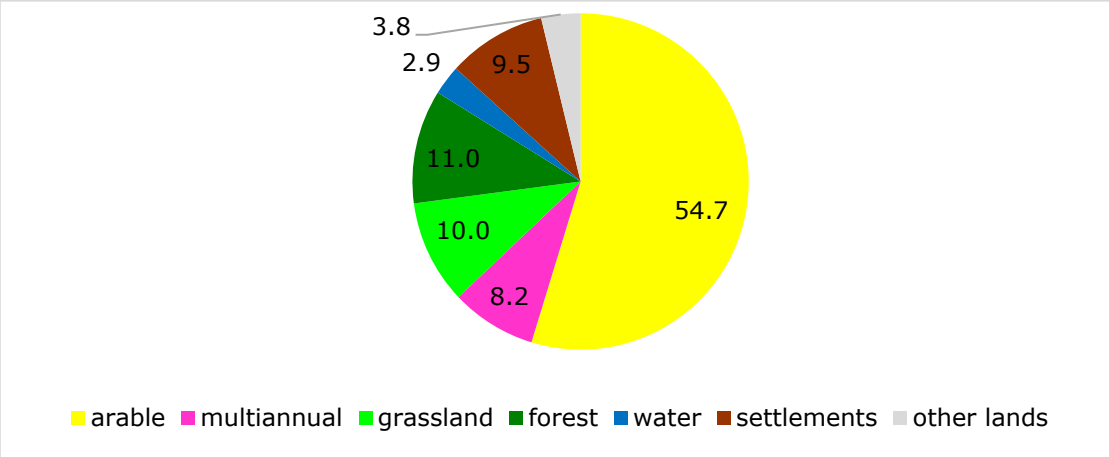
The territory of the Republic of Moldova is mainly covered by quaternary sediments of different age and genesis, especially loessoid deposits. The presence of these deposits increases from the north to the south of the country, where according to their properties (increased dust content, carbonatation and other) they approach the typical loess. The high content of coarse dust in the parent rocks determines the low anti-erosion resistance of the soils formed on loessoid deposits, especially of the typical weakly humic chernozems and carbonate chernozems, which are distinguished by the low content of physical clay (<0.01 mm) and fine clay (<0.001 mm) and a high dust (0.05-0.001 mm) content.

The soil's resistance to erosion depends on its physical, chemical and hydraulic properties. For a comprehensive evaluation of the anti-erosion resistance of the soil is necessary information about: the type and subtype of the soil; the degree of its erosion; the textural composition highlighting the fraction of fine clay (<0.001 mm) and the fraction of fine sand (0.01-0.05 mm); humus content; soil water permeability parameters; soil class by structure (Cerbari et al., 2012).

The soils of the Republic of Moldova have a different erosion resistance capacity, depending on certain particularities. Thus, depending on the genetic subdivisions of the soil, the most vulnerable to erosion processes is the carbonate chernozem, the more resistant being the typical chernozem, the other subtypes occupying an intermediate position. Cultivated forest soils (gray and brown) are little resistant to erosion processes. The granulometric composition plays an important role in the development of erosion processes: the most resistant are clayey, loamy-clayey, loamy soils, followed by loamy-sandy and sandy soils. Soils with a good granular structure break down into small and resistant particles, which are less subject to erosion compared to poorly structured soils. The humus content directly influences the soil resistance, while the carbonate content has the opposite effect. Therefore, in order to prevent and combat soil erosion, we must know the typology of soils, the granulometry and structure of the soil, the content of humus and carbonates and other properties (Ursu, 2000).

The main human activities that cause or accelerate erosion processes relate to land use:

- excessive capitalization of the land fund as agricultural land - about 63% of the total area is cultivated land - arable and perennial plantations (Figures 3 and 4);



Source: Cadastrul funciar al Republicii Moldova, 2021

Figure 3. The structure of the total land fund in the Republic of Moldova, 2020 year

- excessive use of agricultural land as arable land (54.9% of the total land fund), including land with an increased degree of inclination;
- the increased share of row crops on sloping land;
- abandonment of zonal anti-erosion crop rotations;
- the deforestation of the protective forest strips and the insufficiency of the drainage regularization strips on the slopes;
- soil work with deviations from the general direction of the level curves;
- the insufficiency of agro- and phytotechnical anti-erosion measures on sloping land;
- the errors of post-soviet land privatization (excessive parceling of agricultural land, which excluded the possibility of applying soil protection technologies; the delimitation of land quotas along the slope, which imposed tillage in the ”hill – valley” direction), etc.

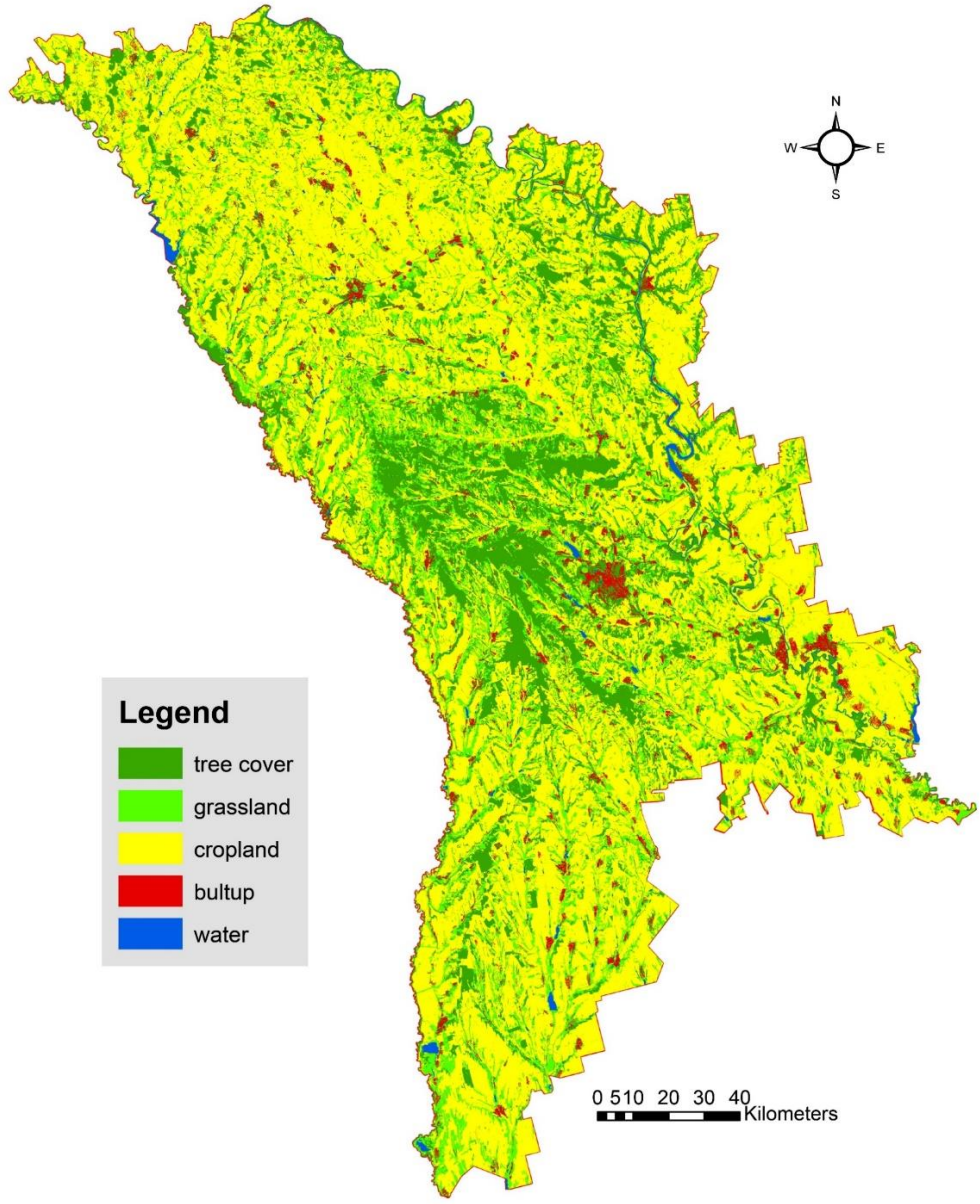


Figure 4. The Republic of Moldova: land cover map, 2020 year

The monitoring of erosion processes in the Republic of Moldova included 73.2% of the total agricultural area of the 983 administrative-territorial units (villages, communes,

cities, municipalities), at the level of 2021 year, for which the data were processed from the point of view soil and geomorphological processes (Figure 5).

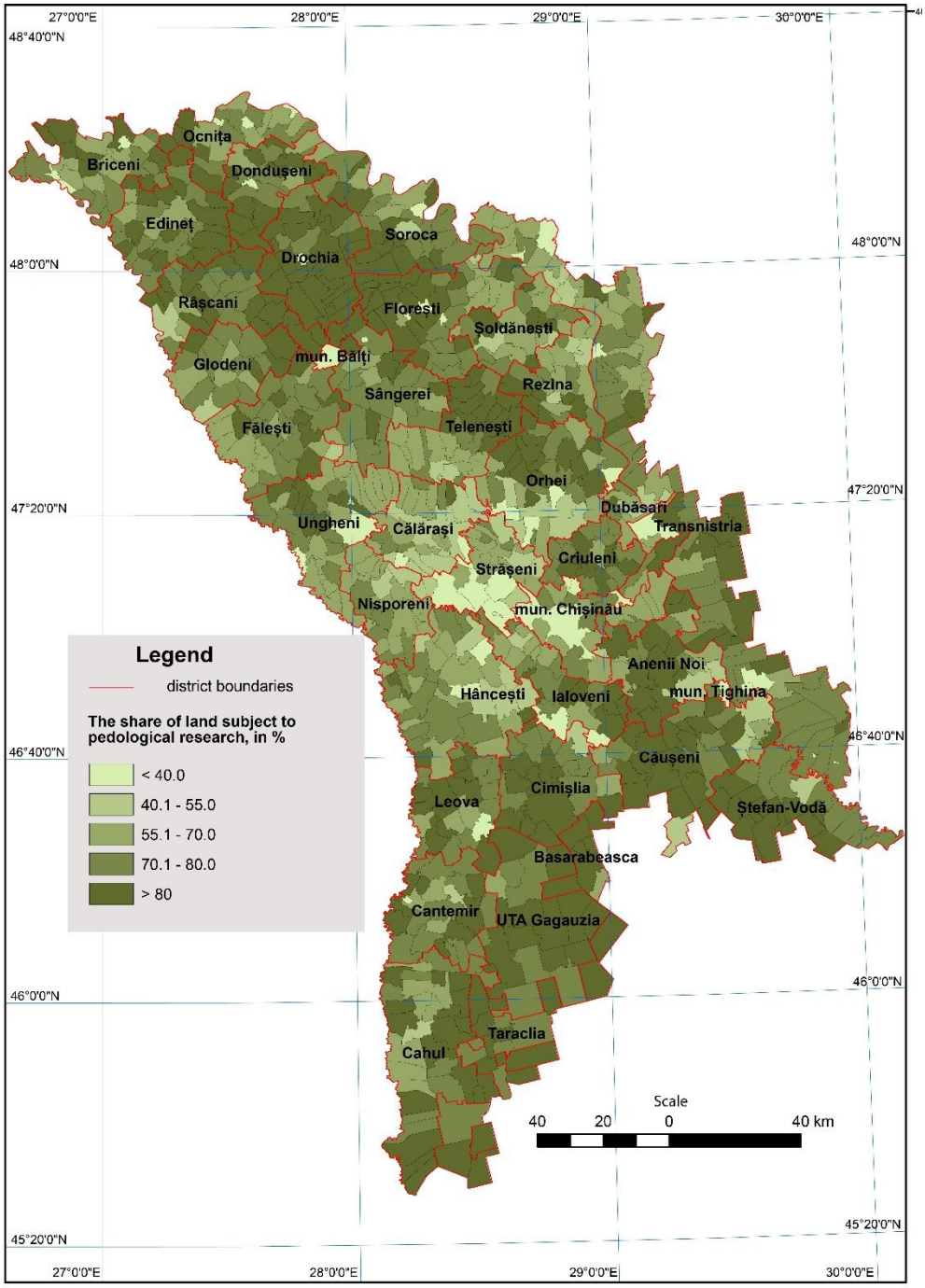


Figure 5. The Republic of Moldova: map of the share of soil monitored land, by commune, 2020 year

On the current Republic of Moldova territory, the agricultural use of land has always had very high shares in the total land fund, agriculture being the traditional basic activity of the population (Sochirca, 1999). In 2021 year, the frequency rate of agricultural land was 72.9%, including arable land constituted 54.7% of the total land fund, with certain spatial differentiations, having the largest presence in the north of the Moldavian Plateau (Cubolta Plain, Dniester Plateau), as well as in the Ialpug Lowland, the Lower Dniester Plain, and the lowest presence – in the Central Moldavian Plateau (Codrilor) (Figure 6).

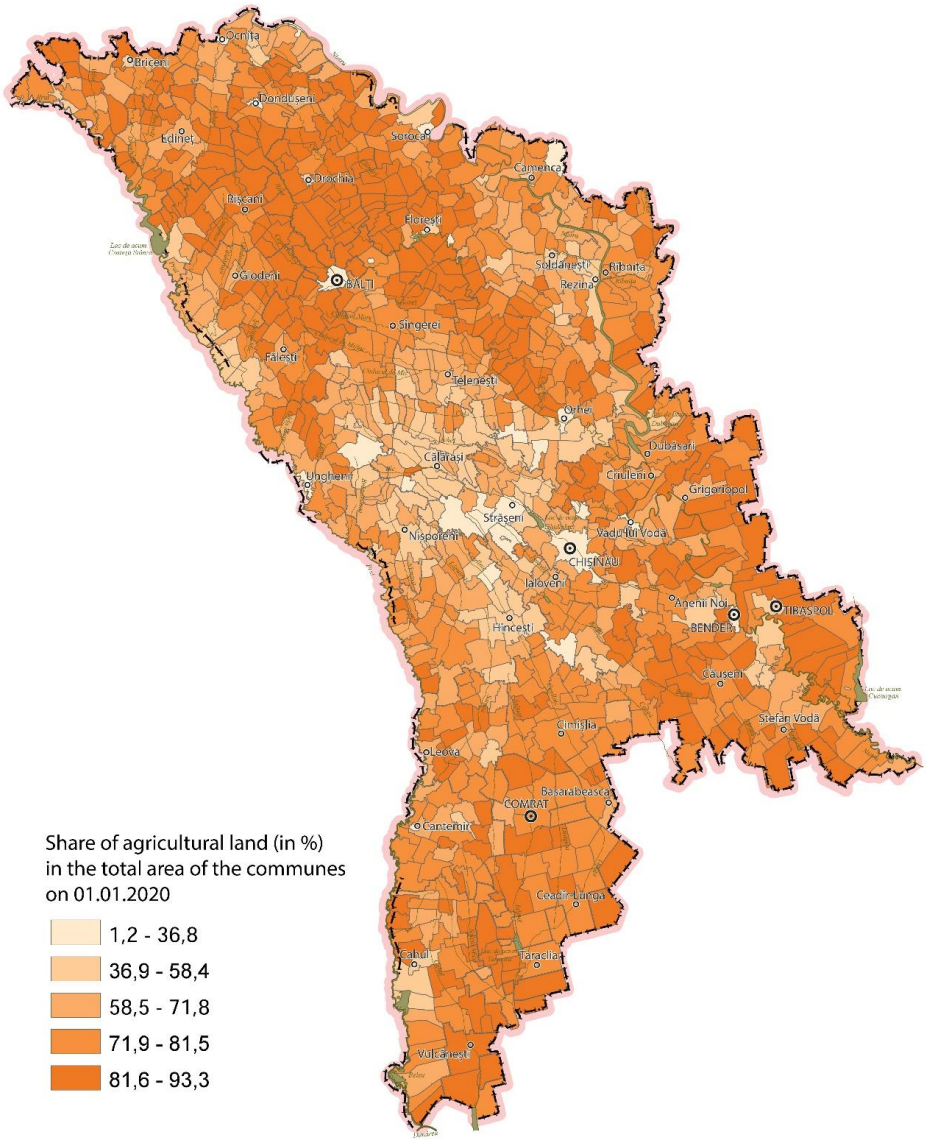


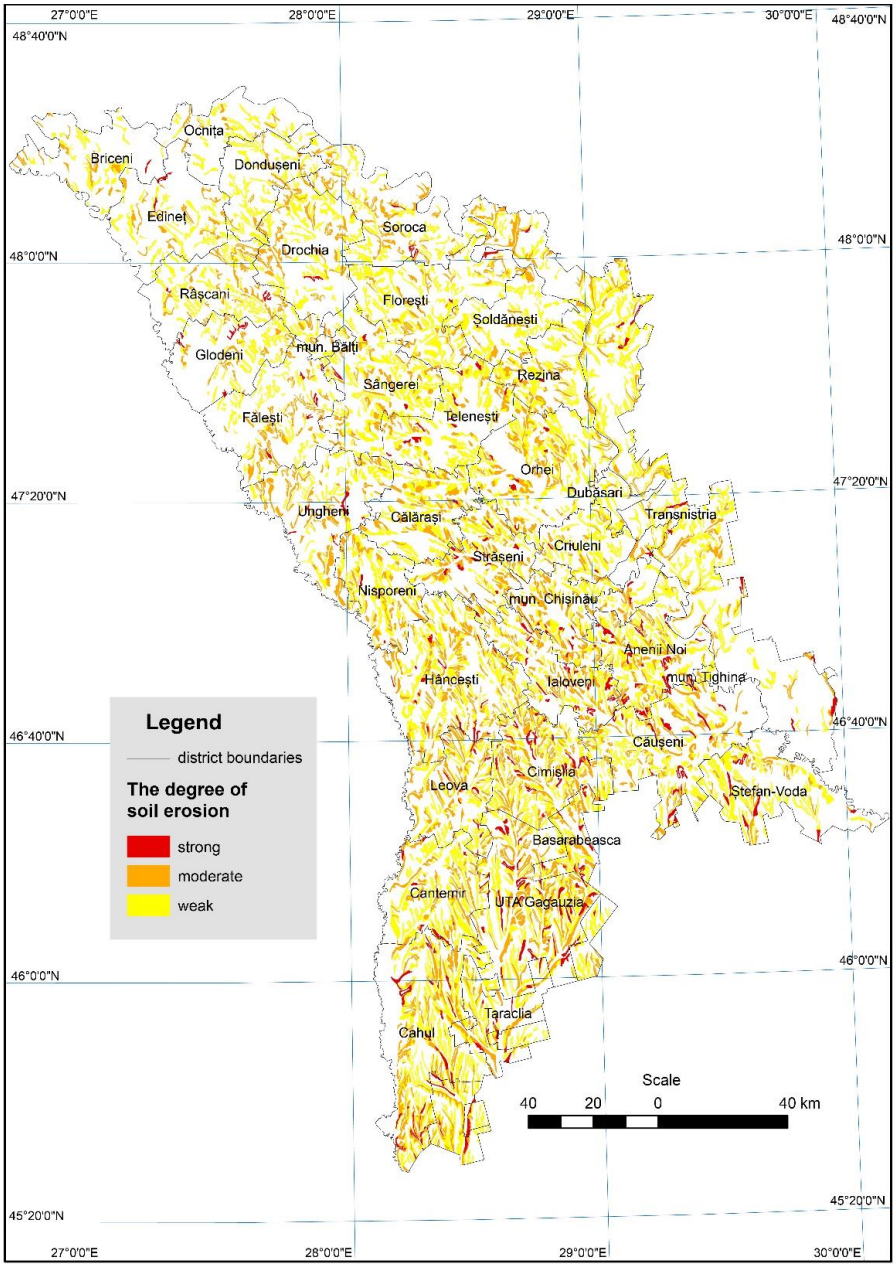
Figure 6. The Republic of Moldova: map of the share of agricultural land, by commune

Currently, approximately 55% of the country's total surface is at erosion risk (Figure 7). According to the data from the Land Cadastre for the period 1965-2021 (Bejan, 2010; Cadastrul funciar al Republicii Moldova, 2021; Ursu, 2000; Eroziunea solului. Esența consecințele, minimalizarea și stabilirea procesului, 2004), the surface of eroded land increased 1.7 times (from 594200 ha to 1015695 ha) (Figure 8 and Table 2). Annual losses of fertile soil from agricultural lands caused by erosion are estimated at 26 million tons, including humus – 700 thousand tons, nitrogen – 50 thousand tons, phosphorus – 34 thousand tons, potassium – 597 thousand tons (IPM, 2020).

Tabelul 2. Dynamics of eroded surfaces

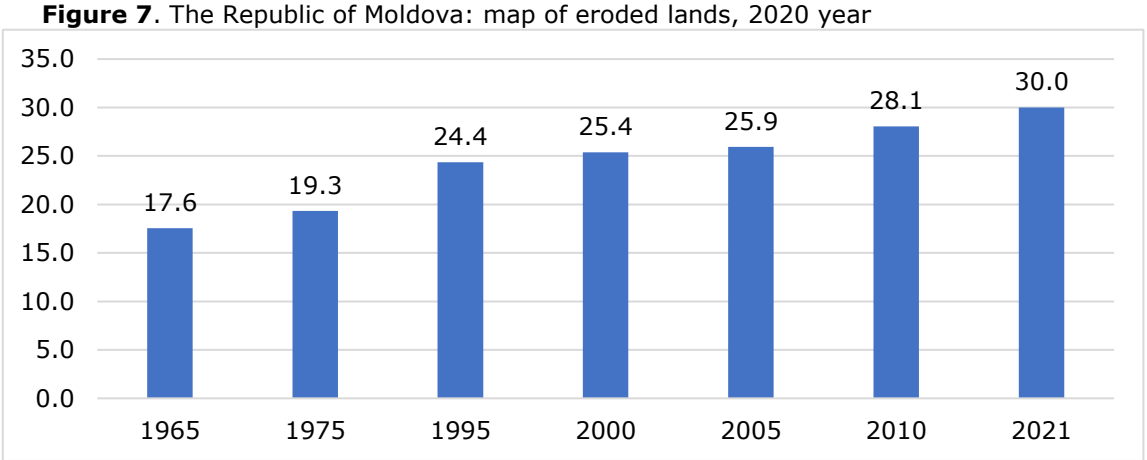
Year	1965	1975	1995	2000	2005	2010	2021
Total eroded land area, ha	594200	654400	824200	858600	877600	949468	1015695
% of the total area	17.6	19.3	24.4	25.4	25.9	28.1	30.0

Source: Bejan, 2010; Cadastrul funciar al Republicii Moldova, 2021; Ursu, 2000; Eroziunea solului. Esența consecințele, minimalizarea și stabilirea procesului, 2004



Source: soil map 1:200 000

Figure 7. The Republic of Moldova: map of eroded lands, 2020 year



Source: Bejan, 2010; Cadastrul funciar al Republicii Moldova, 2021; Ursu, 2000; Eroziunea solului. Esența consecințele, minimalizarea și stabilirea procesului, 2004

Figure 8. Share of eroded lands dynamics

At the district level, the most affected are Cimișlia, Basarabeasca and Telenești, all of which have a share of eroded land of over 40%, compared to the average value for the country of 31.6%. The lowest values are recorded in the Tighina municipality (5%), the Balti municipality (10%), the Dubăsari (14.9%), Briceni (19.4%) districts and those of the Transnistrian region (16.1%). About half of all agricultural lands (or about 30% of the country's territory) are affected by some degree of erosion, including 6.9% that are heavily eroded. In approximately 9% of the municipalities, the share of eroded land exceeds 50% of their surface. The highest values (over 70%) are registered in the communes of Crasnogorca (Transnistrian region) – 74.3%, Cornești (Ungheni district) – 73.3% and Nucăreni (Telenesti district) – 70.7%. These communes are mainly located in the Dniester Plateau, the peripheral area of the Central Moldavian Plateau (Codrilor) and the Tigheci Hills (Figure 9). The lowest values (below 1%) are recorded in the Camenca city and the Târnauca commune (Transnistrian region), the Mărculești (Floresti district) and Vadul lui Vodă (Chisinau municipality) cities.

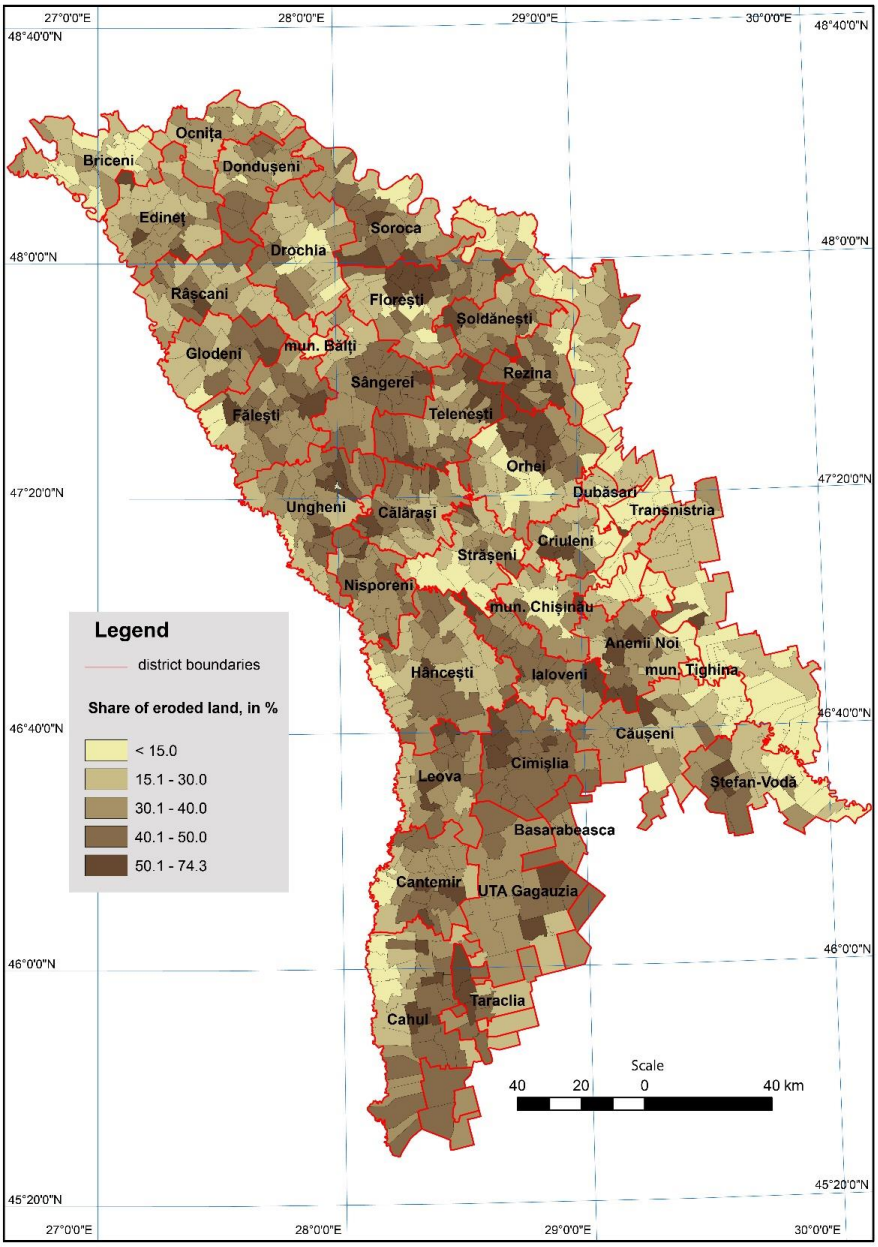


Figure 9. The Republic of Moldova: map of the share of eroded land per commune, 2021 year

Heavily eroded land constitutes 4.2% of the country's territory (or 6.9% of agricultural land), with a very uneven spatial distribution (Figure 10). The most affected are the lands in Nisporeni and Ungheni districts, where the form of erosion exceeds 8% of their surface. At the commune level, the maximum is in Cornești (Ungheni district). Heavily eroded lands are more common in the western, central and southern part of the Central Moldavian Plateau (Codrilor), in the Ciulucs Hills and in the Tigheci Hills, which have the most fragmented and inclined relief, but also an easily erodible geological substrate, with an alternation of clays, loams and sands.

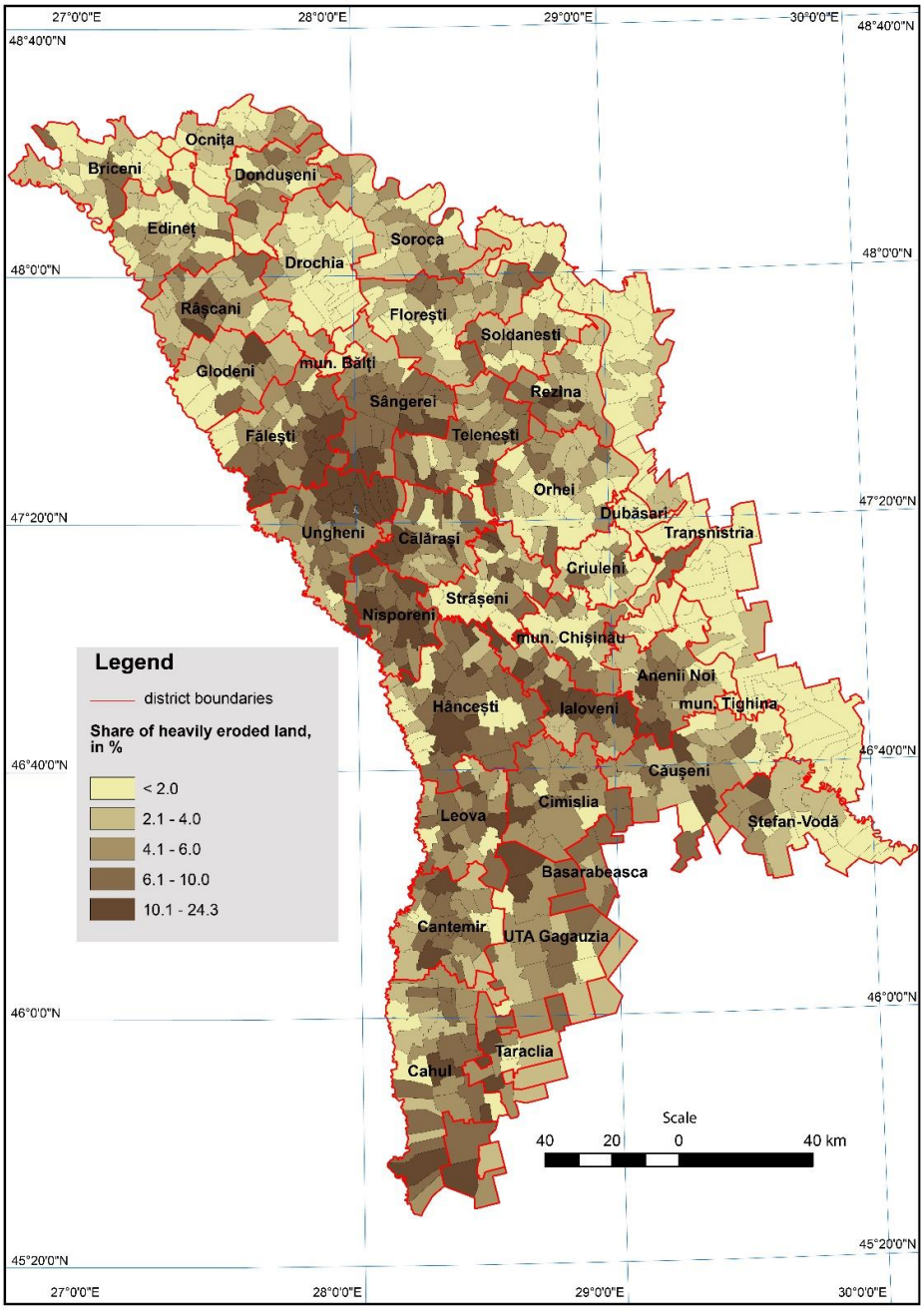


Figure 10. The Republic of Moldova: map of the share of heavily eroded land, by commune, 2021 year

On heavily eroded soils, it is necessary to cover with perennial grasses and use grass species resistant to drought and frost, capable of creating a closed and durable grassy carpet. Another effective measure to restore heavily eroded soils consists in the supply of earthy material with humic material from constructions, which has high qualities, is

quite homogeneous and is uncovered depending on the thickness of the dehumified layer. Covering with layers of 30 and 45 cm is a long-term measure of capital improvement or restoration. First of all, the restoration and growth of the eroded soil takes place due to the transposition of the humified mass on it (Cerbari, et al. 2012). Forest plantations are a component part of the set of soil protection actions against erosion and the rehabilitation of heavily eroded ones. This type of long-lasting protection, ecological and aesthetic, is the most effective. The degree of afforestation of the Republic of Moldova is very low, especially in the southern steppe zone and in the Bălților steppe. Therefore, if they are placed correctly, forest strips increase the soil protection index, as in the case of afforestation of ravines and lands affected by landslides (Ursu, 2000) .

4. Conclusions

- The surface of eroded land, in the Republic of Moldova, has expanded in the period 1965-2021 by about 1.7 times, from 594.2 thousand hectares to 1015.7 thousand hectares, and the expansion of eroded land is directly proportional to the increase in agricultural land on the slope;
- The most affected by erosion are the areas with a fragmented relief (with a slope over 6°), where row crops are intensively practiced (west of the Central Moldavian Plateau (Codrilor), Tigheci Hills, south of the Dniester Plateau, Ciulucs Hills);
- Among the most affected soil subtypes are the carbonate chernozems (44.2%), which have a low resistance to erosion due to the granulometric composition (light loamy texture), more widespread in the southeastern and southern parts of the country and leached/Luvic chernozems (31.6%), which have a less hydrostable structure;
- It is imperatively necessary to consolidate agricultural lands and implement the system of anti-erosion measures and procedures, which would contribute to reducing soil erosion below the maximum admissible limit of about 5 t of soil per hectare;
- We consider the National Afforestation and Reforestation Program justified, including from the perspective of covering eroded lands and those most vulnerable to erosion.

References

1. *Anuarul Inspectoratului pentru Protecția Mediului* (IPM) (2020) „Protecția mediului în Republica Moldova”; Chișinău: Pontos, 2021, p. 120.
2. Bejan, I. (2010) *Utilizarea terenurilor în Republica Moldova (monografie)*; Editura ASEM: Chisinau, 2010; 166 pp.
3. *Cadastrul funciar al Republicii Moldova (general) pentru anul 2021.* Agenția Relații Funciare și Cadastru. https://www.legis.md/cautare/getResults?doc_id=131752&lang =ro
4. Cerbari, V.; Andrieș, S. ; Popov, L. [et al.]. (2012) *Măsuri şi tehnologii de combatere a eroziunii solului*. Pontos: Chișinău, Republic of Moldova ; 80 p.
5. Ursu, A. (2000) *Degradarea solurilor și deșertificarea*. Chișinău, 59 p.
6. *Eroziunea solului. Esența consecințele, minimalizarea și stabilirea procesului.* (2004), Min. Agriculturii și Ind. Alimentare a Rep. Moldova. red. resp.: Dan Nor, trad.: D. Balteanschi. Pontos: Chișinău, Republic of Moldova ; 476 p.
7. Harta solurilor 1:200 000, https://geoportal.md/ro/default/map#lat=127543.470934 &lon=260665.251165&zoom=1
8. Sochircă, V. Studiul economico-geografic al sectorului particular al agriculturii Republicii Moldova. PhD thesis, Universitatea „Al. I. Cuza”, Iasi, Romania, 1999, 281 p.
9. Волощук, М.Д. (1986) Реконструкция склоновых земель, пораженных оврагами. Кишинёв: Картя Молдовеняскэ, 268 с.

10. Заславский, М.Н. (1987) Эрозиоведение. Основы противоэрозионного земледелия: [Учеб. для геогр. и почвовед. спец. вузов]. Москва: Высш. школа, 375 с.

11. Заславский, М.Н. (1966) Эрозия почв и земледелие на склонах. Кишинев, 491 с.

12. Константинов, И.С. (1987) Защита почв от эрозии при интенсивном земледелии. под ред. В. С. Федотова. – Кишинев: Штиинца, 240 с.

13. Крупеников, И.А. (2012) Добровольский, Г.П. Овраги, другие формы линейной эрозии и борьба с ними. Chişinău: Pontos, 83 p.

14. Федотов, В.С. (1980) Ливневая эрозия почв и лесомелиоративные меры борьбы с ней в Молдавии. Кишинев: Штиинца, 136 с.

© 2022 by the authors. Licensee UAIC, Iasi, Romania. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY-NC-ND) license (https://creativecommons.org/licenses/by-nc-nd/4.0).