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MONITORING OF DEGRADED SOILS IN THE REPUBLIC OF MOLDOVA: LANDSLIDES

Tamara LEAH

"Nicolae Dimo" Institute of Soil Science, Agrochemistry and Soil Protection,
100 Ialoveni Street, Chisinau - 2070, Republic of Moldova

Corresponding author email: tamaraleah09@gmail.com

Abstract

Landslides in Moldova presents a characteristic component of the landscape, the age of majority of them reach in the tens of thousands years. The total landslide area is about 750 thousand hectares, of which predominate the old stabilized slides, but there are about 84 thousand hectares of active landslides and ravines, mostly on the agricultural land. The paper examined the factors that lead to the formation of landslides - geological-structural, hydrogeological, geomorphologic, seismic, climatic, and anthropogenic. Quantitative data are presented on the dynamics of land areas with slides in a period of 45 years. Although some of them were set aside and forested, the affected area continue to rise: 1970-1975 – average growth is 18500 ha, 1976-1980 - 8800 ha, 1981-1985 - 23600 ha, 1986-1990 - 6200 ha, 1990-2015 - 4400 ha. Landslides after their essence present a very complicated phenomenon. Therefore, at first are presented brief information on the genesis and diversity. Classification of landslides into five groups according to the complexity is needs to be finalization of the reasons that the number of these is significantly larger. Overall, landslide monitoring needs to develop a special method of execution because according to its nature, diversity, duration of process, the landslides as research objects are not included in common system of ecopedological monitoring.

Key words*: degradation factors, erosion processes, landslides, monitoring, stabilization measures*.

INTRODUCTION

The main feature of landslides is the separation of soil masses with different volumes and their fall to lower places, accompanied by damage the all or partly the soil cover, which leads to loss of agricultural land, destruction of settlements, roads and other social objects. During landslides the rocks moves along the slopes rather large distances (up to 4 km). On steep slopes, especially when the soil is saturated with water, rocks moving at high speed causing massive disasters. Slopes occur in all regions of the world. They can be steep or line, fallow or cultivated and gives landscape variety and provide evidence about the relief's formation (Cruden, 2007).

Mass displacements are movements under the influence of gravity. Movements occur when pressure in the inside of rocks and soil grow or when friction decreases. Water is a main factor causing mass displacement. More abrupt movements are caused by heavy or prolonged rainfall or snowmelt that infiltrates the soil slopes, weakening the link between minerals.

Avalanches are landslides with high speed. They can be caused by vibrations caused by earthquakes or even by gunshots.

Falling rocks and soil subsidence occurs when water infiltrates in the cracks of rocks and then freezes. Landslide designates any sudden movement that takes place on a slope.

Land subsidence involves travel of fine materials, such as clay or shale. Sometimes they become so saturated with rainwater, that the slightest vibration can lead to the collapse of the slope (Андриеш et al., 2005).

Factors influencing landslides triggering may be natural - gravity, lithological construction and mode of rocks stratification, groundwater, seismic processes, etc. and artificial - drubbing and deforestation, location of economic and hydro technical objects without design project, terracing of slopes (Smolianikov et al., 2007).

Landslide processes in Moldova are favored by the geological structure of the territory, relief particularities, high seismicity of the territory, human activity. Erosion processes, landslides and other geodynamic and anthropogenic degradation have intensified significantly since the 60s-70s of last century (Krupenikov, 2004). Thus is emerged the need to study natural phenomena that lead to soil erosion and landslides. Analysis of the results showed that these processes were influenced by intensive agricultural practices - deep ploughing on the

slopes, immense irrigated areas, terracing of slopes, etc. (Dobrovolschi, 2004). Although the specialty literature sources on elucidating landslides are abundant, in them very little attention allotted to issues such as quantitative and qualitative assessment of their activities and monitoring of land affected by landslides as part of ecopedological monitoring.

MATERIALS AND METHODS

The methodological aspect was given preference on the quantitative indices (surfaces, ha), sliding scale processes during certain periods, related to action of concrete factors: destruction of slopes by old landslides, heavy rains in large quantities, seismic activities. The results are shown in dynamics for a period of 45 years under study. The information presented is necessary to assess the legalities of development processes which influence landslides, serves as a reference bases for further research and monitoring to protect land resources of Moldova.

RESULTS AND DISCUSSIONS

Landslide processes and their manifestation peculiarities in Moldova were studied over a period of 20 years (1970-1990), both as a phenomenon and as a process (after 1990 only surface, hectares). Landslide as a phenomenon is part of the geological environment of limited land area and the sliding surface on which basis without losing touch with its movement still is going to a new level, usually with a lower altitude. Landslide as a process shows a consecutive modification of composition, condition and characteristics of landslide, starting from its initiation and travelling to an another level, until the full termination, manifested by unrest of soils and rocks that compose it and producing new relief specific forms (Сергеева, 1986).

Investigation of landslide processes revealed that the slip is irreversible, initial restoration of the land to its initial stage is impossible.

Landslide classification. Study of landslides in Republic of Moldova has lead to several classifications development, taking into account certain specific features of their manifestation. Depending on the sliding base and the number of change position they differ: simple slides (single surface) and complex slides (with two or more sliding surfaces). Such landslides are distinguished by the surface of inclination, sliding surface depth and position (Table 1).

Table 1. Diversity of landslides

After the inclination of the sliding surface	
Landslides with small inclination	up to 5°
Landslides with moderate inclination	5°-10°
Landslides with high inclination	15°-45°
Landslides with very high inclination	over 45°
After the depth and position of the sliding surface	
Superficial landslides	up to la 1 m
Landslides with small deep	up to la 5 m
Landslides with moderate deep	up to 20 m
Landslides with high deep	over 20 m

Landslides that have formed in the past geological eras refer to ancient stabilized landslides, and those occurring due to actual anthropogenic erosion process - contemporary subsidence being activated and active landslides. Among contemporary slides was distinguished: moving landslides (active) temporarily or completely stabilized.

After morphology landslides differ: in the form of circus, frontal, glaciers, mudflows, and angular configurations.

After structure and movement mechanism in Moldova most often meet landslides: sliding, shearing, flow field with printing, and collapsed (Андриеш et al., 2005).

Despite the significant diversity of slopes affected by landslides, most of them are specific the some common features. Landslide processes occur more frequently in places where in the geological structure of the slope predominate relatively "weak", friable, stratified layers of the sandy-clayey Miocene and Pliocene rocks, which lead to the deformation of rocks, breaking and slipping them (Ткач, 1974 b).

The land of slide was divided into five groups (Smolianikov et. al., 2007), which differ according to the genesis and reclamation approaches concerning their practice value (Table 2).

Table 2. Grouping of sliding lands

Group	Landslide	Characteristics
I	Simple mono-genic	Slides with simple structure, with only one separation zone, the height of the rupture does not exceed 5 m.
II	Simple polygenic	Landslides, which passed several stages of development, the detach-ment are composed of overlapping fragments asymmetrical shape; some aquifers are related to inconsistent after thickness.
III	Moderate polygenic	Slides has several outbreaks slide interconnected events occurring at different times and covers the entire slope.
IV	Complex polygenic	Secondary slides on the stabilized slopes by insufficient measures to combat landslides.
V	Atrophic - industrial	Slides, which lands are fed with artificial industrial water due to technical defects.

The main factors that favor the formation of landslides in the Republic of Moldova are: highly fragmented relief, climate with frequent sudden change and intensive heavy precipitation, geological structure of the slopes, consisting of alternating sandy-loamy rock with physico - mechanical properties, that changes excessively, slow neotectonic (secular) and short term seismic vibration, human economic activity (Ткач, 1974 a).

Factors influencing the development of landslides are divided into: permanently active (geological structure and topography), that changing slowly (tectonic movements, specific regional climate) and those who are changing rapidly (weather and hydro-geological conditions).

Relief. Landslides are a geological process of forming the relief, which is manifested throughout the country and poses a constant danger. The highest quantity of landslides is attributed to relief items with absolute elevation 80-170 m (70.6-82.6%) - morphostructural relief of Drochia - Făleşti, Lower Prut, Comrat and Puhoi; 180-270 m (64.1-70.2%) – morpho-structural relief of Northern Moldova Plateau and Soroca; at the 130-220 m are located about 65.2% of landslides in the Codri morpho-structure (Smolianikov, et al., 1996).

Research has shown that location of the landslides on the slopes with diverse inclination and heights differs for geomorphologic areas. In the Northern Moldavian Plateau on the slopes with a height up to 30 m is triggered over 67% of landslides from the total quantity, with a height of 30-50 m - 31%, on slopes with a greater height - about 2% of landslides.

Geological rocks that form the slopes have a high variability of the mechanical (granulo-metric) composition of clay, dusty and sandy particle content in the vertical profile. On the many slides sectors was established location of moving landslides at the certain layers of sandy-clayey rocks that received the name - “main deformation horizon”. The content of rock dust and sand particles regulate humidity of higher and lower plasticity diapason, infiltration coefficient and shear strength indicator. High rainfall infiltration in depth of slope suddenly increases the hydrostatic pressure and hydrodynamic of groundwater and reduce stability of slope rocks. Clayey rocks of landslides, even with homogeneous structure, frequently disturbed by macro- and micro-cracks caused by earthquakes and neotectonic moves. In such areas during heavy rainfall periods occurs selectively swelling clays, leading to deformities and strength loss index of rocks about 10 times (Ткач, 1974 b).

Atmospheric precipitations are one of the most important factors influencing the intensity of the slip process. Under their influence are increasing humidity and pressure of swelling rocks, reducing resistance and stress, redistribution in sliding slopes.

In Moldova the rainfall are distributed unevenly from 560 mm in the north to 370 mm to south part. In high regions the rainfall increased approximately 60 mm at each 100 m of height. The most favorable conditions for landslides producing are create at fall abundant rainfall in the months of October to March, exceeding the annual average of 1.3 times. On the territory of Moldova is characteristic the presence of cyclical precipitation falls, which is 29-30 years and 45 years (Сергеева, 1986).

Very strong activations of slides are related to abnormal fall of precipitation, which exceeding the annual average in the year and rainfall during the cold period of 1.2-2.4 times, which fell during 3-5 of consecutive years.

In periods of significant rain falling (2-3 consecutive years) they exert a great influence on the groundwater level and therefore on the landslides. The years with the highest level of groundwater (1969-1970 and 1979-1980) are noted as years with a strong landslide activity.

In these years the total area of farmland affected by landslides reaches 10 thousand hectares and more, and the surface of most landslides was increased 2-3 times.

Geological and hydrogeological conditions. Landslides in Moldova are developing in platform conditions of geological formations with subhorizontal settlement of sedimentary rocks, sometimes complicated by destructive rupture. In the deepness of current depth of the hydrological network, at the territory construction participate rocks of different ages and lithology. These deposits are sinking slowly (inclination from 2 to 6 m per 1 km) in the direction of south - southeast.

The slopes destroyed by landslides on the agricultural land spread in the north and centre of Moldova are influenced by sandy-loamy deposits of Middle Sarmatia, that forming the lower and middle parts of the slope, above which to the watershed are placed deposits of Upper Sarmatia and Miocene period (Ткач, 1974 b). In the south part of the Dniester basin, the downstream parts of the slopes are formed by Middle Sarmatia deposits and above them are situated the Upper Sarmatia deposits. On the slopes of Prut River vicinity in their place downstream openings the Upper Sarmatia and Miocene deposits and, on the surface are located the Lower Pontus deposits.

Across of the all these deposits are spread: the diluvial - proluvial Quaternary deposits - on the slopes, the alluvial deposits - in the watersheds areas of the rivers Dniester and Prut and on the their plains, the accumulations of landslide rocks - within the boundaries of contemporary and old landslides (Ткач, 1974 b).

Significant manifestations of landslides are related also to earthquakes with intensity of about 7 degrees and more, taking place in Moldova every 30-40 years. Anthropogenic factors favoring landslides include construction works on the terraces (cutting off), quarries, excavations, downloading deposits parts of old landslides etc.

Geological, hydrological, physico-mechanical characteristics of sliding land is required for its use in environmental monitoring (frequency, manifestation, category dynamics by slipping, forecasting, and development of control measures). Joint complex influence of objective assessment of all factors will allow developing and implementing concrete measures on prevention of landslides, restoration and enhancement of degraded land. Complex objective assessment of all common factors will allow developing and implementing concrete measures on prevention of landslides, restoration and enhancement of degraded land.

Dynamic of sliding surfaces. Until 1970 the documentary evidence of the sliding surface was not executed. It had only approximated data that relatively characterized the slopes affection after selective investigation results. Since 1971 in the land balance began to appear the number of ravines and land sliding surface, which were listed on annual household land plans, allowing tracing dynamics of sliding surfaces on agricultural land. According to mapping materials and landslides cadastre the Moldovan territory is characterized by 16 thousand of active slides covering an area of 83.5 thousand ha, old slides - 721200 ha (or 21.7%) of territory, including 2.4% of contemporary active landslides. This data can be considered as the initial (basic) information for ecopedological monitoring.

The highest degree (60-80%) of territory damage by old landslides is recorded for the upper river valleys Ikel - Bic. The extent of damage territory decreases towards the southwest and its value is equal to 10. Territory damage from contemporary landslides is significantly lower; the maximum value is 10-15 and the minimum - 0.05-0.1. Unlike the old landslides, the contemporary slides affect local slopes in the form of isolated outbreaks.

The unfavorable combination of natural and anthropogenic factors, the sliding activation processes took place in the late of 70s and 80s of XIX century, then in 1906, 1912-1915, 1923, 1932, 1937, 1940-1941, 1948, 1963, 1966-1967, 1969-1970, 1973-1974, 1977, 1978-1980, 1981 (Ткач, 1974 a).

On the bases of land cadastre materials, situation on the 01.11.1971 summary evaluation of active landslides surface was conducted in the households. These were classified into eight groups of land after graduation growing, in percentage of relative damage expressed by landslides area per 100 ha of agricultural land. According to research, it was found that landslides are triggered inconsistent across the country. Their biggest

spread tends to plateaus and considerably fragmented lands with active neotectonic movements. At the 01.11.1971 the total area of active agricultural landslides constituted 19483 ha (without landslides of forestry fund), which constituted 0.62% (Cadastru funciar, 1971).
In the 1973 was estimated about 31.6 thousand ha of active landslides and ravines. Currently there are 16 thousand units of active slides covering an area of 84030 ha. The largest of them (over 70 thousand ha) are situated on the agricultural land. Ancient and old landslide area constitutes about 22% of Moldova territory. In activation periods the land areas affected by landslides reaches more 10 thousand ha annually, causing immense damage in the republic.
The dynamics of increasing landslides and gully areas in the republic was: 1970 - 21.2 thousand ha, 1980 - 48.6 thousand ha, 1990 - 79.3 thousand ha, 2015 - 84.0 thousand ha.
During period 1970-1990 the surface of landslides and ravens increased by 58.1 thousand ha or 2.9 thousand ha annually (Figure 1). The main factor of intensifying the land slipping process in this period was unreasonable terracing the slopes.

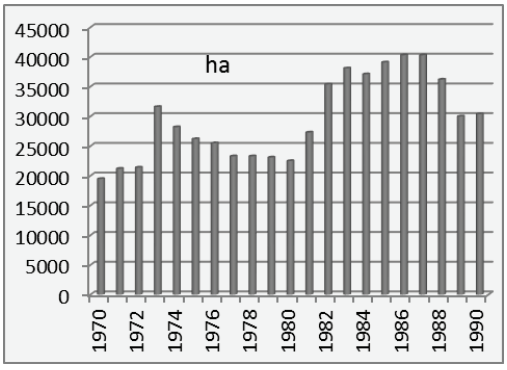

Figure 1. Dynamic of landslides areas in 1970-1990

During 45 years (1970-2015) as a result of human activity, landslides and gully area was increased by 62.8 thousand ha, increasing annually by 1.4 thousand hectares (Figure 2).
Currently a slip lies with every 200 ha of land and annual growth landslide areas are about 1000 ha. Considering that soil cover is completely damaged, only 20% of this area (200 ha) annual irreversible losses constitutes about 93 million Lei MD.

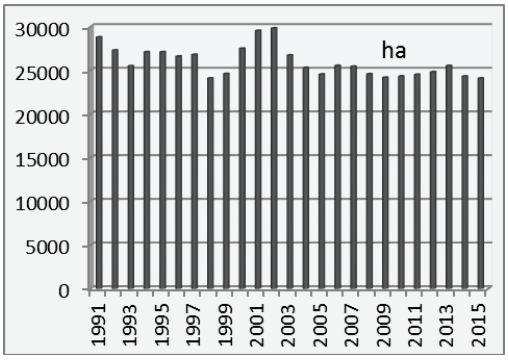

Figure 2. Dynamic of landslides areas in 1991-2015

In the land fund with agricultural destination of Moldova are highlighted 31.3 thousand ha of stabilized and semi-stabilized landslides with partially deformed soils and 39.6 thousand ha of active slides with completely destroyed soils. At the 01.01.2016 the total land area destroyed by landslides and ravines constituted 84.03 thousand ha, inclusive: ravines - 12031 ha, landslides - 24098 ha (Fişa cadastrală, 2016).
Landslides are a geological process of forming the relief, which is manifested throughout the country and poses a constant danger. From 15000 of landslides in recorded with a total area of 79 thousand ha, the 2300 of landslides occurs in localities and affecting over 12.5 thousand hectares of land occupied by various buildings.
Stabilization of landslides. The mechanism of landslides initiation is determined by following factors: the land resistance to deformation, the natural state of slope tension, the massive presence of water. Preventing landslides are possible if timely noticed and interpreted the specifics of these phenomena triggered by combating entry into the hazardous area of water, which through infiltration; increase groundwater reserves and favor the formation of sliding layer.
The main measures to prevent and combat landslides are:
- Construction channels that rapidly discharge rainwater;
- Land drainage through various methods;
- Capturing the coastal springs;
- Afforestation of affected or potentially damage land;
- Building fences, retaining walls, contrary banquets, etc;

- Consolidation of land by electro osmosis and heat treatment etc.

It is recommended for monitoring activities:

- Correctly identification the areas with high risk of erosion, for intervention with consolidation, stabilization, smoothing, shaping measures and other drainage works.
- Systematization the crops on arable land, choosing optimal land use category after land evaluation, use suitable agrosystem in order to prevent the negative effects of erosion.
- Monitoring of the erosion processes on the agricultural land using GIS technologies, expressed through the quality of accumulated biomass.
- To apply methodology for estimating the risk of erosion, given that each country uses a methodology for estimating the risk of erosion.
- Hydraulic works should be implemented at the incipient manifestation of the erosion process.

Capitalization of slippery surfaces is expensive, but more expensive is the abandonment of the affected areas. The easiest and most efficient way of capitalizing on slippery surfaces is afforestation with tree species rapidly increasing (willow, poplar, acacia), which will help them stabilization. At present require afforestation the 24.0 thousand ha of active landslides covering with damaged soils. Drainage work and other technical measures are needed where landslides threaten the destruction of communication lines, social and economic objects, settlements etc. and carried out under a special project.

CONCLUSIONS

For development of effective protective measures required knowledge of certain quantitative and qualitative characteristics of the factors forming slides over a long period. Preventing and combating landslide is possible only through research causal factors, minimize or remove their influence, conduct mapping and cadastre of affected land, monitoring establishment for predicting these processes. To forecast landslides is necessary implementation, function and updating the land with landslide risk, primarily in localities.

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