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THE INFLUENCE OF GIS TECHNOLOGY IN RECLAMATION SOLUTIONS FOR SLOPING LAND AFFECTED BY EROSION

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Abstract

The study was performed on a catchment area of approx. 150 ha, mainly for agricultural use, with steep slopes, with intense erosion and associated processes. The arrangement proposal was made after establishing the erosion risk, the degrees of intensity and the spatial distribution of this process. In order to determine the average annual soil loss and then the alluvial influx, the U.O.R. (Homogeneous Relief Units) procedure was chosen: for each U.O.R. the ROMSEM equation was applied successively, adapted for our country by acad. M. Moţoc. In this approach, the GIS technique was used by using Geo-Graph software, by creating spatial bases and processing by overlay technique (7 information layers were created). The attribute database was created taking into account all the factors involved in the erosion process, the parameters characterizing the climate, the relief, the soil, the land use, the technologies of agricultural exploitation, etc. The main purpose of the paper is to demonstrate that the complex action of monitoring and management of lands affected by various degradation processes can only be done correctly within a Geographic Information System - GIS.

***Key words**: Database, erosion, GIS, landscaping, reclamation.*

INTRODUCTION

Soil erosion is one form of soil degradation along with soil compaction, low organic matter, and loss of soil structure, poor internal drainage, salinization, and soil acidity problems. These other forms of soil degradation, serious in themselves, usually contribute to accelerated soil erosion.

Soil erosion may be a slow process that continues relatively unnoticed, or it may occur at an alarming rate causing serious loss of topsoil. The loss of soil from farmland may be reflected in reduced crop production potential, lower surface water quality and damaged drainage networks, (Haidu I. et al., 2012).

Water erosion's complex hierarchy of processes mean that erosion by water operates over a wide range of spatial scales. Rainsplash redistribution and the initiation of microrills and rills occur at a scale of millimeters. Rill erosion on agricultural hillslopes operates at a scale of meters to tens of meters, while gully erosion can occur on a scale of hundreds of meters, or even kilometers.

The offsite impacts of erosion can affect very large areas, sometimes hundreds or even thousands of square kilometres (Iacobescu O. et al., 2012).

Soil erosion has a range of environmental impacts, including loss of organic matter and nutrients, reduction of crop productivity, and downstream water quality degradation (Berghoff et al., 2014).

Effective control of soil erosion is a critical component of natural resource management when the aim is to achieve sustainable agriculture and acceptable ecosystem integrity (Bilaşco et al., 2018).

Soil conservation on sloping land is carried out through complex measures and works, some of which fully manage water runoffs or intercept and drain water under controlled conditions. They are sized according to hydrological and hydraulic criteria (Arnaudova et al., 2020)

Other measures or works ensure better land coverage and by increasing the ability to infiltrate the soil, prevent erosion. The effect of the set of measures must be assessed, both in terms of water and soil conservation.

In this context, however, it is important that the testing of soil conservation measures, planned for a given territory, is carried out on the basis of average annual soil losses, since their size conditions the level of soil fertility and agricultural production (Irimuș I. et al., 2017).

The planner land reclamation needs to determine the level of soil losses - current and

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probable ones - after the application of the proposed set of measures. Successive tests must find the combination of measures and works that bring highest anti-erosion and economic efficiency.

Soil erosion control is intended to secure and conserve agricultural land in particular and other social-economic objectives in general, and is called 'conservation works'.

Long-standing practice and scientific study of soil conservation on slopes showed that erosion can be contained if a set of anti-erosion measures is applied, both for preventive purposes and for the improvement of already degraded land (Biali et al., 2020). Taking into account the large area of land that need anti-erosion facilities in Romania (approx. 5.3 million ha), at the rate at which such arrangements have been carried out so far (on approx. 42% of the need), in the future, special financial efforts are required to extend them.

MATERIALS AND METHODS

In Romania, by complying with the structure of USLE equation, but changing the denomination and the determining method of the terms, the formula for computing the soil loss due to surface hydric erosion was used through the form of ROMSEM model-Romanian Soil Erosion Model (Moţoc M., 2002):

$$E = K \cdot S \cdot C \cdot C_s \cdot L^{0,3} \cdot i^n \quad (1)$$

where:

E - the annual soil loss per hectare by means of sheet erosion (t/ha·year);

K - regional erosion (rain erosion) soil loss per rain aggressiveness areas determined based on the rain aggressiveness index $H \cdot I_{15}$; is determined by means of elements extracted from rainfall recorder charts related to torrential rain that generate erosion: H - the quantity of precipitations fallen during the torrential rain (mm); I_{15} - average intensity per 15 minutes of the rain torrential core (mm/ minute).

In this context, the pluvial aggressiveness is expressed through the pluvial aggressiveness coefficient and defines, concomitantly, the erosiveness of rain and the impact on the eroded soil.

The Romanian pluvial aggressiveness zoning map was developed based on the average multiannual values.

L^m - length in the flowing (slope) direction, (m); m = 0.3 for L > 100 m; m = 0.4 for L < 100 m.

i^n - average gradient in the flowing direction, (%); n = 1.4.

S - correction factor for soil erosiveness (non-dimensional).

C - influence factor of purposes, crops and soil works (non-dimensional).

C_s - influence factor of soil protection and preservation actions and works (non-dimensional).

In our project we gave special importance to the "relief" parameter. The relief conditions are characterized by two factors: the length of the slope in the flowing direction (L) and the land gradient (i).

In USLE model, these factors are reunited (Li) and represent the topographic factor. The length of the slope index is defined as the horizontal distance measured from the point of origin of the superficial flow up to one of the following points (Wischmeier and Smith, 1978):

- the point where the slope decreases and the deposit process begins;
- the point where the flow reaches a well-defined channel.

The land gradient factor (i) reflects the influence of the land gradient on the hydric erosion process.

The length of slope factor (L) can be determined through the following formula:

$$L = \left(\frac{\lambda}{22,14}\right)^m \quad (2)$$

where:

λ - length of slope (in horizontal projection), (m);

22.14 - length of the standard plot for the control of flow on versants, (m) or (76.2 ft);

m - exponent depending on the land gradient.

By considering the ratio β between erosion in the culverts (through the water currents) and between culverts (caused mainly by the impact of rain drops), the exponent *m* can be determined by means of the following formula (Renard K.G. et al., 1996):

$$m = \frac{\beta}{1+\beta} \quad (3)$$

According to Renard K.G. et al., 1996:

$$\beta = \left[\frac{\frac{\sin\theta}{0,0896}}{3,0 \cdot \sin\theta^{0,8} + 0,56} \right] \quad (4)$$

where θ is the land gradient (radians).

According to researches (Williams J. et al., 1990 and Renard K.G. et al., 1996) the factor (i) which characterizes the size of the land gradient, can be determined through the following formula:

$$i = 10,8 \sin\theta + 0,03; \text{ for } i < 9\% \quad (5)$$

$$i = \left(\frac{\sin\theta}{0,0896} \right)^{0,6}; \text{ for } i \geq 9\% \quad (6)$$

where i is the gradient value (%).

Based on the above, it results the opportunity of determining a single topographic factor Li:

$$Li = \left(\frac{\lambda}{22,14} \right)^{m} (10,8 \cdot \sin\theta + 0,03); \text{ for } i < 9\% \quad (7)$$

$$Li = \left(\frac{\lambda}{22,14} \right)^{m} \left(\frac{\sin\theta}{0,0896} \right)^{0,6}; \text{ for } i \geq 9\% \quad (8)$$

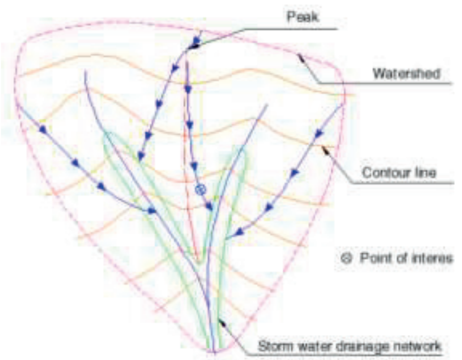

Figure 1. Determination of parameter "length of flow on versants" in model USLE

The flowing/draining directions of the reviewed water catchment area were also laid out by means of the land raster form alphanumeric model. Under this procedure, the draining network of the reviewed area has an arborescent structure, with maximum ramification at source pixel level, where the concentration manner of drainage towards the closing pixel depends on the confluence positioning. By transiting it pixel by pixel, the flow from upstream towards downstream was represented by means of irregular lines, with lengths reduced at the confluence points. In the distributed flowing model, the integration computation organizing manner is based on the determination of associated draining local directions, and the other topographic information was used in particular in order to partially verify the accuracy thereof.

The water flow from a hydrographic unit takes place by means of a complex of paths that unite the high-altitude points with the closing point of the watershed (Haidu I. et al., 2012).

Thus, in the catchment area, one can see the source type pixels - to which no other pixel is drained, the confluence pixels - where at least two upstream pixels are drained, and the closing pixel - passed by all draining paths of the basin (Moore I.D. et al., 1992).

The raster representation considered that the current pixel can be drained based on one of the eight possible directions (Figure 2a), depending on the positioning of the lowest altitude adjacent pixel (Figure 2b). When analysing the vicinities of the central pixel, in order to determine the draining direction thereof (Figure 2c and Figure 2d), the altitude of diagonal ones are reconsidered in order to maintain the same distance from the reference pixel (Burrough P.A., 1988).

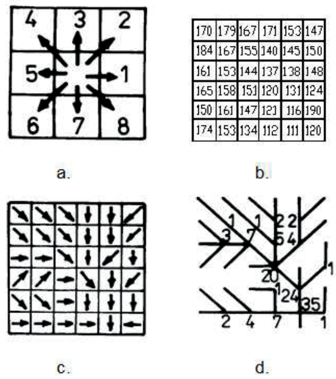

Figure 2. Analysis of versant flow based on GIS raster method:
a) determination of the flowing direction based on one of the eight potential directions;
b) representation of the land surface in raster model (average quotas);
c) flowing directions related to the grid of (b);
d) flowing concentration grid equivalent with (c) and (d)

Research method proposed in the GIS application algorithm

The estimation of average annual soil loss non slopes longer than 400 m by water erosion is based on soil loss accumulation throughout the hill-valley route (highlighted in a land survey), taking into account its constituent landforms.

Assuming that the average amounts of soil reaching the bottom of a slope need to be calculated, on which the following landforms exist: plateau, plateau top (upper/upstream of the plateau), terrace, terrace top (upper/upstream part of the terrace), for the purpose stated, the following steps shall be taken:

a) To calculate the specific average soil loss on the plateau, depending on its elements (L, i, C, Cs, S). Note that a small percentage of the eroded material is deposited in negative landforms (if they exist) or is retained by the vegetation at the slope bottom, as suspension sediments (As) or most of the other types of sediments (Ar).

b) To calculate the specific average loss for the plateau top, which depending on length, tilt, soil, crop, etc. can have much higher values than those on the plateau (generally the tops have small lengths but steep slopes, with low infiltration and short concentration time).

c) To sum up the specific average soil loss at the bottom of the plateau with the loss at the top of the plateau. From this value, the estimated percentage of sediments retained on slope is subtracted, resulting specific average loss from plateau top.

The remaining solid material runs down by draining and accumulates with the rest of terrace soil loss. The value obtained is corrected by removing deposits on slopes, obtaining the specific average loss at the bottom of the terrace.

d) To calculate with the known formula the soil volume on terrace top and to add the soil volume on the terrace. From this value, subtracting the estimated loss due to microrelief and vegetation, the specific average amount of solid material deposited at the base of the slope is obtained.

The more knowledge on erosion alongside the complex slopes and relation between suspended load and pushed load of silts along waterways, the more accurate the results achieved.

For additional insight, mostly within large territories and with a wide variety of geomorphological conditions, soil and slope use, we recommend the implementation of the Technique of Geographical Information Systems (Cochrane et al., 1999).

Estimation of sheet erosion is based on the method developed by acad. M. Motoc (1980), using the calculation relationship (eq. 1).

Land surveys were used to estimate sheet erosion at 1:5000 scale, with relatively homogeneous units in terms of use, slope and slope width. For each relatively homogeneous unit, erosion in t/ha per year is calculated, depending on unit area and then erosion in t/ha.

When summing up erosion of all relatively homogeneous units, the erosion in the entire river basin studied, t/year, is determined.

The measurement unit of sheet erosion is be converted from t/year into m3/year, taking into account the average volumetric weight of the eroded material.

The following chart (Figure 3) presents the organization of operations needed to estimate sheet erosion, in a territory or river basin.

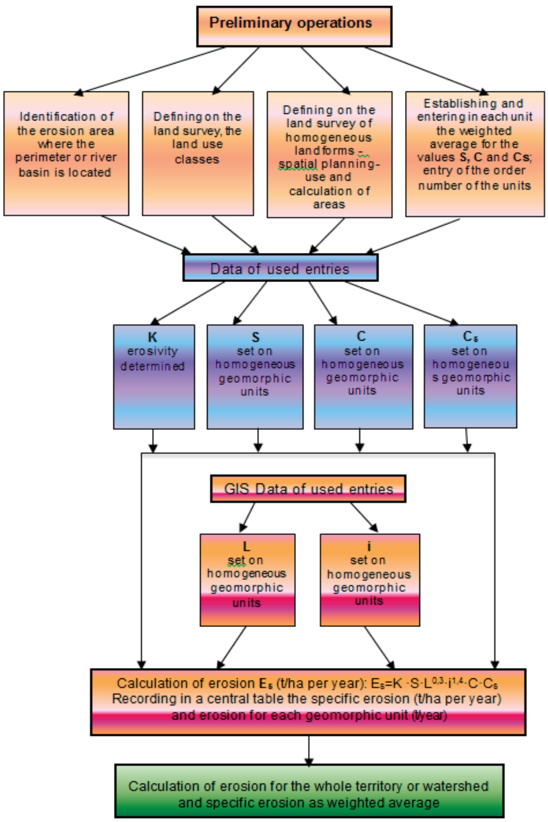

Figure 3. Organising operations to estimate sheet erosion

RESULTS AND DISCUSSIONS

In our project, the geo-referenced data is represented in the form of layers, fact that enables the analysis of spatial variables and the distribution of entities on the analyzed surfaces, and the overall analysis of acquired information, which implies the concomitant approach of several layers, was enables by the "*overlay*" technique (Biali, 2002).
The application used a Romanian GIS-type software, Geo - Graph, intended for work operations with digital maps and database interrogations with ROMSEM Model.

Research area

The study area is located in the Nicolina river basin (Figure 4), in the lower third of the Bahlui basin, in the vicinity of Iași municipality, being delimited as follows:
- north of the Bahlui river meadow - Iași city;
- east of the Bahlui river basin - Repedea mini-basin;
- east of the Rebricea and Vasluieț river basins;
- west of the Bahlui river basin - Pârâul Mare mini-basin.

The territory of the Nicolina river basin is in administrative terms part of the commune of Miroslava (Iași), having the following limits:
- to the east the Uricani agricultural land
- to the west the Uricani agricultural land
- to the north the Miroslava agricultural land
- to the south Cornești commune

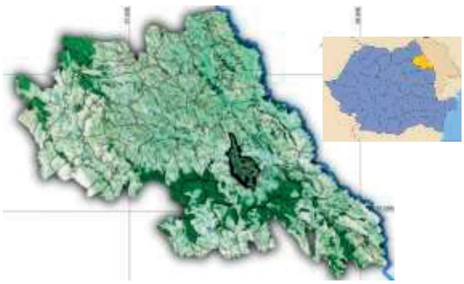

Figure 4. Nicolina river basin, in the lower third of the Bahlui basin, in the area of Iași municipality

Geomorphological data

The studied area is part of the Central Moldavian Plateau. The researched territory is located in the transitional region from the Jijia-Bahlui depression to the high peak of the Central Moldavian Plateau. Consistent valleys: this category includes Nicolina valley with the approximate orientation in the NW-SE direction, with generally open slopes, with a convex profile, and in slippery areas, undulating with an average slope value of 8-12°, (Niacsu L., 2012).

The area under study is 142.70 ha. Following the vectorization from the initial situation plan, it was found that the arable predominates in a percentage of 47.5% equivalent to 67.8 ha, followed by hay 9.9%, pasture 17.4%, orchard 17.1%, the remaining 8.1% being unproductive (gully). The graphical results are presented in the Figure 5.

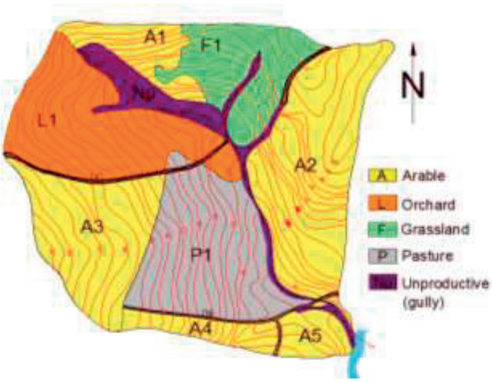

Figure 5. Inventory of use categories (vector)

Climatic data

For the climatic characterization of the studied area, the meteorological data obtained by the Iasi resorts were used. The average annual temperature is 9.6°C, average rainfall 517.8 mm. The average period of frost-free interval is 181 days. The soil is covered with snow for about 60 days, and the average annual thickness is 28 cm in the mentioned period. At Iași resort, there is a deficit of total annual precipitation of 21.2 mm starting in July, August. The microclimate of sunny slopes, which retain less moisture, is often observed the effect of more pronounced drought.

Pedological studies

The lands within the reception area of Ursului Valley (Nicolina Hydrographic Basin) are characterized by a wide range of soils subjected to degradation processes, of different shapes and intensities expressed by sheet erosion, depth and landslide processes (Niacșu L. et al., 2015). The soil type is chernozem in different leaching stages. The studied surface includes

the following pedo-amelioration groups (Figure 6), presented briefly:
Group I: Slightly eroded soils. Requires regular cultivation and fertilization. It includes semi-group IA with soil units: US 6.
Soils have good fertility. Hydrological class B/C and C. Erodability coefficient 0.6-0.7.
Group II: Moderately eroded soils. It comprises the US 2,3,4,10,15 moderately-eroded heavily - leached chernozem soil unit. They are located on slopes of 6-12%. Stable structural elements, erosion-resistant soils. Hydrological class C/D. Erodability coefficient 0.6-0.8.
Group III: Moderately to heavily eroded soils. Includes soil unit US 19 medium heavily-leached, heavily-eroded chernozem. Soil permeability is poorly moderate, infiltration coefficient is $1 \cdot 10^5$cm/s. Hydrological class C and D. Erodability coefficient: 0.7-0.8.
Group IV: Excessively eroded soils in the cornice area. It comprises the US 20 soil unit. The texture varies widely from light, medium and fine. The infiltration coefficient is between 10-4-10-5. Erodibility coefficient 1.0-1.1.

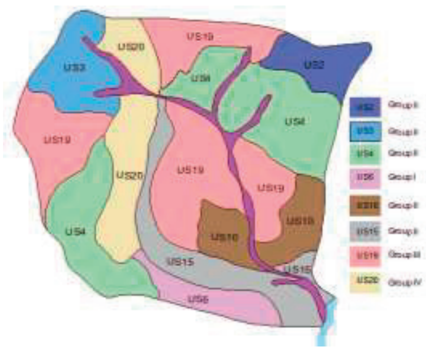

Figure 6. Soil mapping (vector)

Hydrological and hydrogeological studies
Hydrographic regime is characterized mainly by pluvial supply with high waters in spring and floods in summer and autumn. Winter runoff is low, high turbidity due to heavy erosion. Under loessoid deposits, the groundwater is found at a depth of 8-10 m, under the marly clayey deposits on slopes, from 4 to 6 m, and under the deposits of saliferous marls, the canvas varies. On some slopes it is found at 1-2 m and in some areas at 0.6-1.0. On eroded slopes 1-4 m, in meadows, it varies from 0.8 to 1.8 m depth. Following field studies and research, the presence of captive water bodies has been reported, which greatly influences the extent of erosion and landslides.
Proposals for Land Reclamation
Development proposals were made according to results obtained for sheet erosion. Much importance is given to drainage/drainage network/on basin surface, the network obtained by using GIS.
In the GIS application, based on the criteria imposed by maximum lengths and direction, 39 homogeneous relief units (H.R.U.) resulted. Based on equations 2, 6, 8 the parameters length and slope were determined. The graphical results are presented in the Figure 7.

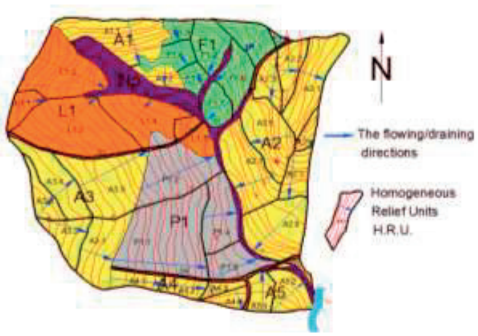

Figure 7. The flowing/draining directions of the reviewed water catchment area (H.R.U)

Based on sheet erosion results in GIS application were proposed the following anti-erosion culture systems on slopes:
a) Cover crops cultivated in the general direction of the level curves, meaning all agricultural crops shall be placed alongside level curve direction on all land with slope under 8%. We proposed this cultivation system on the following homogeneous relief units (H.R.U.): $A_{3.4}$, $A_{4.3}$, $A_{4.4}$, $A_{5.2}$, $A_{5.3}$ (Figure 8).
b) Cover crops cultivated in strips consisting of dividing slope into strips oriented along level curves and growing alternately crops that provide different anti-erosion protection In general, strip width depends on land slope, topsoil type, rainfall characteristics and volume, plants being cultivated etc.
Calculation of strip width (L) cultivated with various plants can be made mainly based on the criterion of critical erosion (tolerable or admissible), according to the equation:

$$L^{0.3} = \frac{E_{cr}}{K \cdot i^{1.4} \cdot S \cdot C \cdot Cs} \quad (9)$$

The interpretation of abbreviations is presented in eq. 1.

In STAS 8390/1980, the following equation is given to calculate cultivated strip width (D):

$D = 10^{2.22} - 0.03 \cdot i$, (10)

for erosion-resistant soils;

$D = 10^{2.15} - 0.03 \cdot i$, (11)

for medium erosion-resistant soils;

$D = 10^{2.05} - 0.03 \cdot i$, (12)

for poorly erosion-resistant soils;

where i is the land slope (%).

Since calculations always show variable strip widths (for the same slope) which depend on cover crop type (each with different roughness, draining coefficients, etc.), for proper exploitation and rotation of crops, approximately equal strip widths will be chosen so that sowers can operate on them.

The calculations in the GIS application resulted in strip lengths between 80 and 280 m.

We proposed the anti-erosion strip system for the following homogeneous relief units (H.R.U.): $A_{1.2}$, $A_{1.3}$, $A_{2.3}$, $A_{2.4}$, $A_{2.5}$.

c) Buffer strip cultivation system is intended to divide the slope (designed for slopes from 12 to 25%) in strips cultivated with the same crop, and interspersed with narrow strips (4-10 m wide) cultivated with grass. According to STAS 8390/1980 we used the following equation to calculate the distance of placing grass strips on tillable land:

$D = C_1 \cdot E_{critic}^2 \cdot i^{-0.28}$ (13)

where:

D is the distance between two consecutive grass strips (m);

C_1 = 2.90 on topsoil thicker than 0.60 m, formed on loessial sediments.

E - admissible erosion value 4.0...7.0 t/ha per year;

i - land slope (%).

Grass or buffer strip system is proposed for the following plots: $A_{2.2}$, $A_{2.8}$, $A_{3.1}$, $A_{4.2}$.

d) Terrace cultivation system

In areas with high climatic aggression, light soils, long slopes and with a high percentage of hoes, the anti-erosion systems presented above are not enough to contain erosion and keep it within permissible limits, and in such cases the terrace cultivation is promoted. It leads to land slope alteration, soil erosion containment, topsoil changes and higher agricultural production.

We proposed terrace cultivation for the following homogeneous relief units (H.R.U.): $A_{1.1}$, $A_{2.1}$, $A_{2.6}$, $A_{2.7}$, $A_{3.2}$, $A_{3.3}$, $A_{3.5}$, $A_{4.1}$, $A_{5.1}$. The graphical results are presented in the Figure 8.

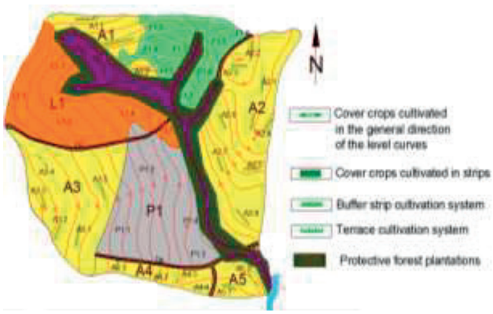

Figure 8. The flowing/draining directions of the reviewed water catchment area (H.R.U)

In the studied river basin, through the application of GIS, anti-erosion works on arable surfaces were proposed. The assessment of the positive effect can be done by determining the anti-erosion efficacy.

The effectiveness of the anti-erosion effect is:

$E_A = E_a^* - E_a^{**}$ (14)

where:

E_a^* - alluvial effluence before arrangement;

E_a^{**} - alluvial effluent after arrangement.

$E_A = 1978.02 - 600.69 = 1377.33$ (m^3/an)

Calculate: K_a - coefficient of anti-erosion effectiveness.

$K_a = \frac{E_A}{E_a^*} \cdot 100$ (%) (15)

$K_a = \frac{1377.33}{1978.02} \cdot 100 = 69.63$ %

Because the value of the anti-erosion efficiency coefficient is considerable (K_a = 69.63%), so that it can be concluded that the efficiency of the anti-erosion works in the river basin is significant.

CONCLUSIONS

In the studied catchment area, due to natural and anthropogenic factors, which have contributed to the appearance and development of soil degradation processes through sheet erosion and landslides, it is found that agricultural production on slopes decreased year by year, taking its economic toll on the region.

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Annual crop losses, due to sheet erosion, arable land disuse by expanding landslides and deep erosion, led to substantial annual losses taking its economic toll in the region.

In the current situation, 2-3 cm of the fertile topsoil layer is washed off annually, which leads to a decrease, year by year, of the soil production potential. Soil loss on slopes of the studied area (with slopes of 8-22%) amounts to 16-42 t/ha every year.

The land management measures proposed by this project aim to increase the fertility of soils affected by erosion, by improving the soil water storage and chemical characteristics. The objectives of these measures are: managing water runoffs from slopes (Figure 8) restoring disused lands affected by landslides, higher agricultural produce.

This paper presents partial results from a large project of monitoring and management of erosion processes on agricultural slopes and the choice of optimal solutions for the development of these lands.

It is known that the monitoring and management operations of a territory involve a considerable volume of data and means of processing and analysis. In this context, the correct establishment of the land arrangements affected by erosion degradation processes acquires a special importance both for the agricultural owners and for the decision-makers in the field of agricultural management.

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