SOIL EROSION ESTIMATION FOR SECAŞELOR PLATEAU, ROMANIA, USING THE E_{30} MODEL AND LANDSAT IMAGERY

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***Abstract**: At present, increasingly large areas are affected by surface and deep erosion as well as landslides. In this paper we will estimate soil erosion in the case of Secaşelor Plateau using the E_{30} model and Landsat imagery for the period 1986–2011. As a result of applying the E_{30} model we were able to draw soil erosion maps reclassified into the following erosion classes: absence, low, moderate, high and extreme. The results show that low soil erosion increased by 18.79% in the analyzed period, while for the moderate class the increase was of 1.3% for the period 1986-1994, after which, in the interval 1994-2011, it decreased by 4.54%. In the high erosion class the surface decreased by 15.5%, and in the extreme erosion class by 1.89%. Soil erosion in Secaşelor Plateau was triggered and maintained by both anthropogenic and climatic causes.*

***Keywords:** E_{30} model, Landsat imagery, NDVI, soil erosion.*

1. Introduction

Soil erosion and land degradation raise serious problems in many countries worldwide. These important problems have economic, political, social and environment implications due to both on-site and off-site damages [8, 9]. Various human activities, such as constructions, mining, agriculture, deforestation, can disturb land surfaces and finally lead to soil erosion. This phenomenon is stronger in the case of cultivated land than in that of uncultivated one.

The evaluation of the soil erosion represents one of the most important problems in land management. Due to the complexity of the variables involved in erosion, measuring and estimating the amount of eroded soil is a difficult task. In order to estimate the average annual loss of soil we applied different models divided into two main classes: empirical models and physically-based models. The class of empirical models includes: Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE), Modified Universal Soil Loss Equation (MUSLE), Chemical Runoff and Erosion from Agricultural Management Systems (CREAMS), and Agricultural Nonpoint Source Model (AGNPS). The class of physically-based erosion models comprises: Water Erosion Prediction Project (WEPP), Limburg Soil Erosion Model (LISEN), European Soil Erosion Model (EUROSEM), and Revised Morgan, Morgan and Finney Model (RMMF). The advantage of the physically-based models consists in the ease with which they can combine with physically-based hydrological models. The description and the complete list of the soil erosion models can be found in [1].

At present, the most frequently used soil erosion models are USLE and RUSLE, but they require a set of detailed data concerning the soil, rainfall, land cover, slope, and land management. In developing countries these data are not always available or require much money, time and effort to obtain. For this we can use empirical models like the E_{30} model which is based on the Digital Terrain Model (DTM) and on the Normalized Difference Vegetation Index (NDVI) obtained from satellite images.

The main objective of this study was to estimate the soil erosion in Secaşelor Plateau, Romania, during the period 1986–2011, using the E_{30} model. The specific objectives were: (1) to estimate the quantity of eroded soil for the years 1986, 1994 and 2011; (2) to draft erosion maps for each erosion class considering the analysis of land degradation in the studied area; (3) to analyze the causes of land degradation.

2. Materials and methods

2.1. Studied area

The studied area is located between 23°34'06" and 24°13'24" East longitude and between 45°46'09" and 45°11'56" North latitude and has a surface of 122725 ha (Figure 1). It is represented by Secaşelor Plateau situated in the south-east part of the Transylvanian Plateau, and from an administrative point of view it overlaps with the territory of the Alba and Sibiu counties. The minimal altitude is of 200 m while the maximum is 635 m. The energy of the relief ranges between 50 and 150 m and its fragmentation density between 1.3 and 4.1 km/km^2 [7]. The slopes, which are predominant in the area, have 15°–30°. The source of the torrential watersheds of Secaşul Mic, Secaşul Mare and the morphostructural declivities displays values of over 55° (15%). The values between 5° and 10° (20%) are recorded at the base of slopes and decrease under 5° (10%) in the floodplain and on the bridges of terraces to the right of Secaşul Mic [7]. From a morphological point of view Secaşelor Plateau exhibits an evolved relief, materialized in the levelling surfaces Amnaş and Secaşelor, to which we can add a structural relief and the diversity of forms corresponding to slope processes.

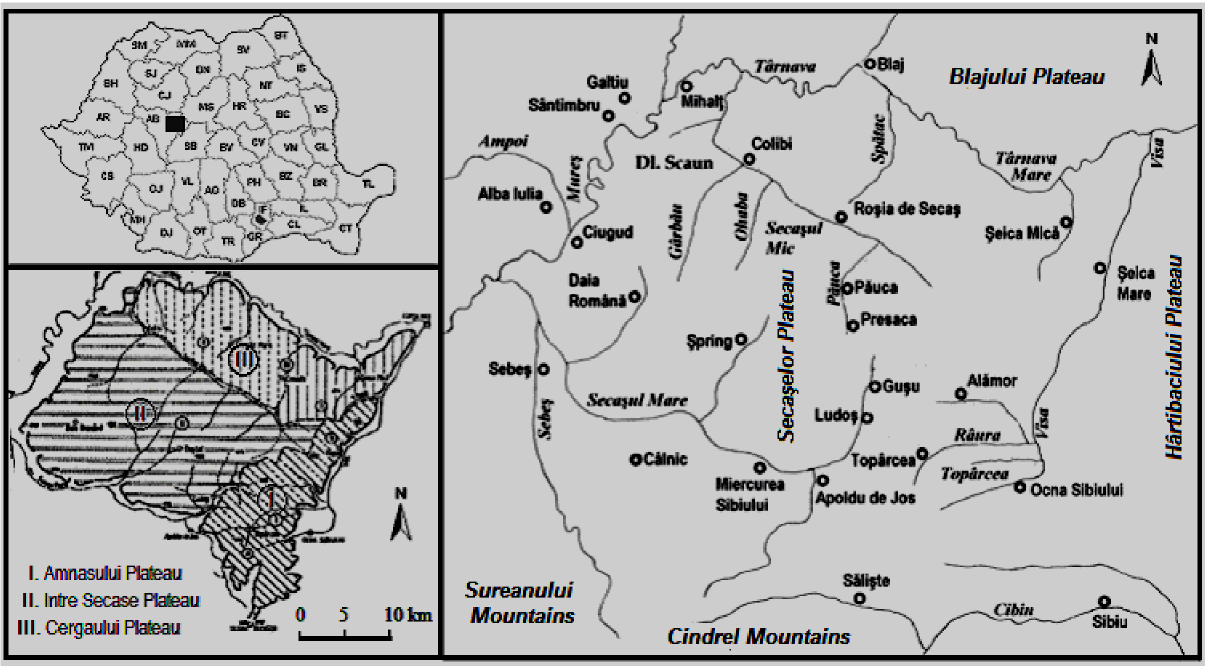

Fig. 1. The location of the studied surface. Secaşelor Plateau includes Amnaşului Plateau, Intre Secaşe Plateau and Cergăului Plateau

Forests cover 12.3% of the surface and are represented by beech forests, Irish oak and beech forests, Irish oak forests, Turkey oak forests, Hungarian oak forests, and mixtures of oak trees. The arable land occupies 64%, followed by pastures and hayfields on 19.2%, vineyards and orchards on 2%, and human settlements on 2.5% [7]. Soils are represented by luvic chernozems, pseudorendzines, chernozemoid soils and eumezobasic brown soils. Secaşelor Plateau is crossed by several rivers among which the most important are Secaşul Mare and Secaşul Mic. From a climatic point of view, the studied area belongs to the temperate-continental climate, with a multiannual average of precipitation of 550–600 mm.

2.2. Materials

We used three frames clipped from Landsat 5 TM images acquired on 18.09.1986, 08.09.1994, and 22.08.2011. They are part of path 184 row 28 and have a spatial resolution of 30 m. The images were clipped so that Secaşelor Plateau is in the middle. The correction level of the images is 1T and they were georeferenced in the Universal Transvese Mercator (UTM), projection system zone 35 N, datum WGS 84. The Digital Terrain Model (DTM) we used is of the type Shuttle Radar Topography Mission (SRTM) with a spatial resolution of 1 arcsec (30 m) (Figure 2). It was projected in the projection system of the satellite images, going from geographic coordinates to metrical coordinates, and the clipping took place along the same contour line. The reference data consisted in topographical plans with level curves (1:50000), soil map (1:2400000), soil erosion map (1:500000), and vegetation map (1:500000).

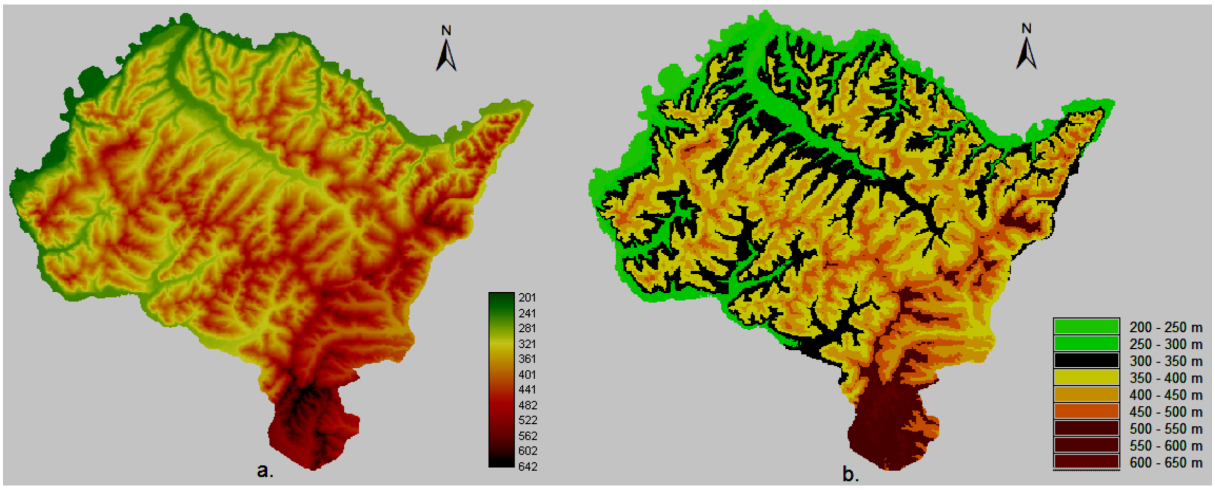

Fig. 2. The digital model of the land in the studied area according to:
a. the altitude (in meters); b. altitude categories every 50 meters

2.3. Methods

We had to calibrate the Landsat 5 TM images because we used a series of satellite images acquired in different years. The calibration was performed for each individual band using the ENVI 5.3 software, taking into consideration the type of sensor, the date the images were acquired and the sun elevation. The atmospheric corrections were applied using the Cost Model.

In order to estimate the soil erosion we used the equation proposed by [3]:

$$E = E_{30}(S / S_{30})^{0.9} \quad (1)$$

where: E – rate of annual soil erosion (t ·ha^{-1} year^{-1}); S – gradient of the point under consideration (%); S_{30} – tan (30^o); E_{30} – the rate of soil erosion that occurs on a slope of 30^o obtained using the following relationship [3]:

$$E_{30} = \exp\left[\left(\frac{LogE_{\min} - LogE_{\max}}{NDVI_{\max} - NDVI_{\min}}\right)\cdot\left(NDVI - NDVI_{\min}\right) + LogE_{\max}\right] \quad (2)$$

The maximum and minimal values of soil erosion were obtained using the research about the studied area. In this respect E_{min} was considered 0.1 t ha^{-1} year^{-1} and E_{max} 5 t ha^{-1} year^{-1}.

NDVI was calculated on the basis of satellite images using red (R) and near infrared (NIR) bands [4] using the equation below:

$$NDVI = \frac{NIR - R}{NIR + R} \quad (3)$$

To avoid the negative values of the NDVI and to handle more easily the digital data, the NDVI values obtained after processing the Landsat images were re-scaled with the following relationship:

$$NDVI = \left[\left(\frac{NIR - R}{NIR + R}\right) + 1\right] \times 100 \quad (4)$$

DTM was used to determine the slope (gradient of the point under consideration), by processing it in order to obtain a percentage slope map (Figure 3).

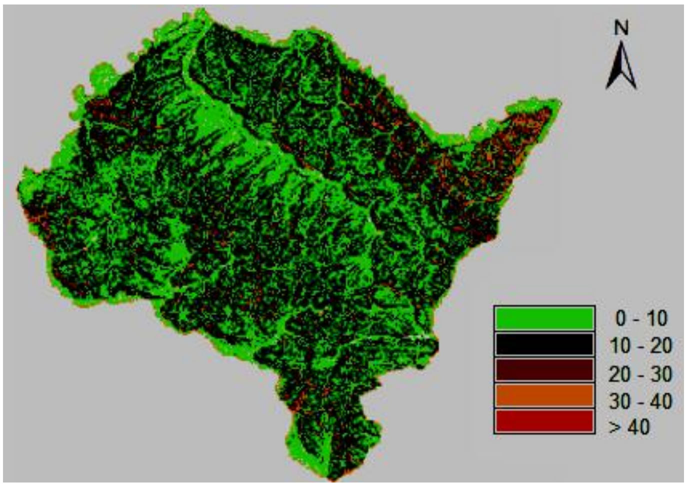

Fig. 3. Slope map reclassified, derived from DTM (in percentages)

The images obtained after the E_{30} model was applied were then reclassified according to the criteria formulated by the Research Institute for Pedology and Agrochemistry [5] in the following erosion classes: (1) absence (< 1 t ha^{-1} year^{-1}); (2) low (1–8 t ha^{-1} year^{-1}); (3) moderate (8–16 t ha^{-1} year^{-1}); (4) high (16–30 t ha^{-1} year^{-1}); (5) extreme (>30 t ha^{-1} ·year^{-1}).

3. Results and discussions

The results obtained by applying the E_{30} model are presented in Figure 4. The estimated quantity of eroded soil is different, depending on the land slope [2] and the degree of vegetation coverage at the date the satellite images were acquired.

The surface and deep erosion, associated with landslides, are frequently encountered processes in the studied area. Such phenomena were identified in the east and north-east of the plateau, around the villages of Soroştin, Cenade, Haşag, Hedel, Alămor. In the southern part, in the middle of the slopes from the watersheds of Secaşul Mare, we identified erosion and landslides near the villages of Boz, Cut, Draşov (Figure 4).

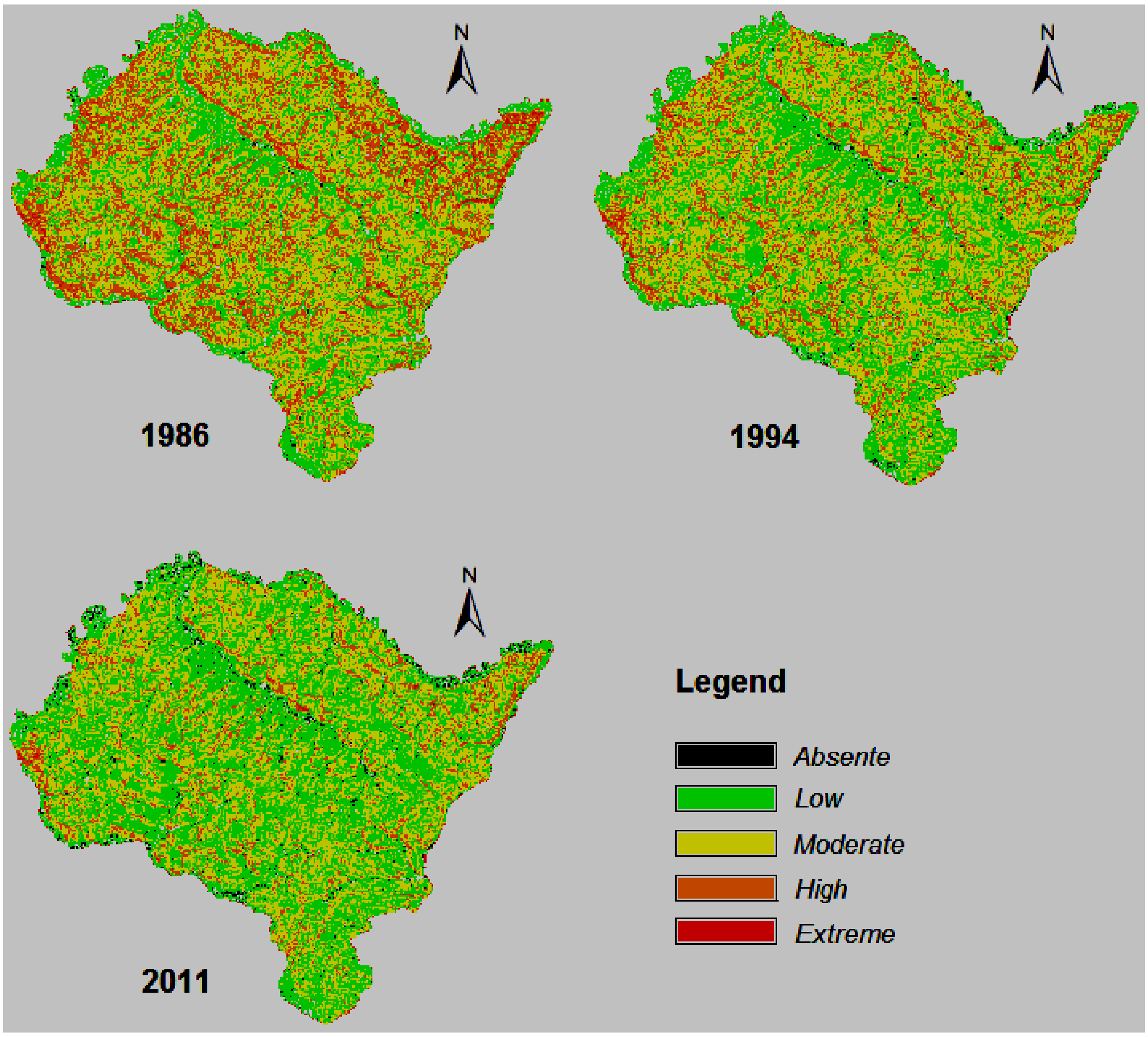

Fig. 4. Maps which present the classes of soil erosion in Secaşelor Plateau, obtained by applying the E_{30} model

Generally, we noticed that the surfaces affected by erosion are arranged on a Gaussian curve, with left side or right side asymmetry, the largest surface, for the years 1986 and 1994, being classified in the moderate class of erosion risk (Figure 5). The results obtained show an increase of the surface in the low erosion class from 28.31% in 1986 to 36.91% in 1994 and to 47.10% in 2011. For the surfaces in the moderate erosion class we noticed a slight increase in 1994 (46.18%) as compared to 1986 (44.88%), then a decrease in 2011 (41.64%). The surfaces in the high and extreme erosion classes also decreased in the interval 1986–2011.

Thus, the surface in the high erosion class decreased from 23.76% in 1986 to 8.26% in 2011. In the case of the extreme erosion class, the surface decreased from 2.78% in 1986, to 1.36% in 1994 and to 0.89% in 2011.

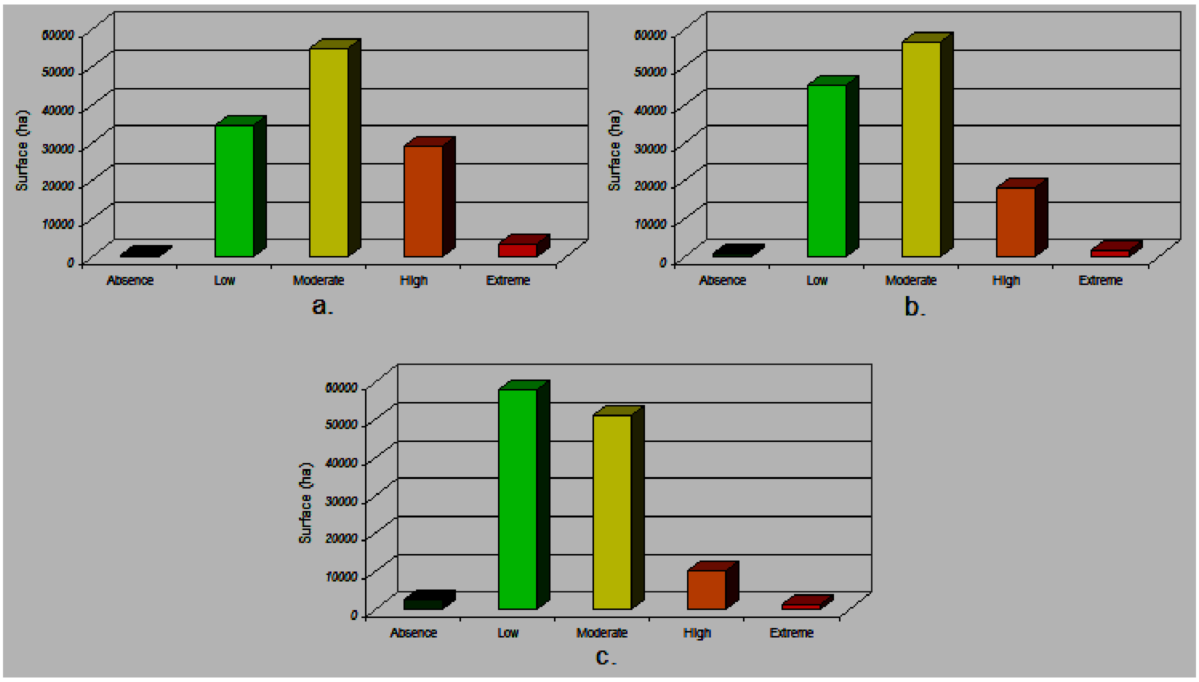

Fig. 5. The distribution of surfaces in erosion classes: a. 1986; b. 1994; c. 2011

Consequently, during the studied period, we noticed that the high and extreme erosion surfaces were reduced but there was an increase of the surfaces in the low erosion class. This means that new surfaces vulnerable to surface and deep erosion might be affected. This could prove a questionable observation considering the fact that the research, for 2011, was based on an image acquired in August and not in September like in the case of 1986 and 1994, despite the preprocessing of images. The low erosion surfaces are located mainly in the floodplains of Târnava Mare (to the left towards Secaşelor Plateau), Secaşul Mic and Secaşul Mare (to the right towards Secaşelor Plateau) where the slope is less steep (Figure 2, 3 and 4).

The classified images from 1994 and 2011 show a considerable decrease in the erosion process in the north-eastern part of the studied area. This decrease can be explained by the reduction of the activity of the carbon black factory in Copşa Mică which polluted the vegetation cover and the soil with heavy metals thus causing bare land. The reduction in vegetation pollution and bare land in Copşa Mică is highlighted in other studies as well [6, 10].

In the east and south-east of Secaşelor Plateau, because of the almost total lack of forests and of the sporadic presence of protection cultures, the slopes exhibit a high morphodynamic potential. In this context, the high relief energy (80–150 m) and the high declivity, with slopes ranging from 25^o to 35^o, we could notice regressive erosion. Also, the high torrential fragmentation in the origin areas, of around 2.5–3.5 km/km^2, represents another factor which determined regressive erosion as well as superficial and deep landslides and mud torrents. Deep landslides were identified in Miercurea Sibiului (Dealul Viilor) and in Apoldul de Jos (Dealul Potca, Coasta Lupului). These are caused by the clay and marl fluidization, by summer floods which determined strong erosion dislocating and transporting the soil, or by the emersion of certain alignments of river sources.

Weaker surface erosion was identified in all the images of slightly inclined surfaces, on monolateral terraces and in Secaşului Floodplain where we can find human settlements, ways of communication and cultivated agricultural land. In these areas, the erosion is weaker, except for the riverbed sectors dominated by lateral erosion and the formation of steep banks of up to 2 m. It is the case of the minor riverbed of Secaşul Mare at the intersection with Apold river, to the east of Miercurea Sibiului and at Cunţa. The lateral erosion into banks higher than 2–5 m was identified on the Apoldului river, on the right bank of the Gârbova river, on the Rodului river and at Cunţa.

The surfaces with high and extreme erosion are spread throughout the entire studied area under the form of nuclei (Figure 4). Thus, we can mention Râpa Roşie (Red Ravine), with a relief energy of 150 m and declivities of 50–70^o, and sometimes even 90^o. The complexity of torrential formations present here encompasses a distance of 800 m, continuing on around 500 m with those in Râpa Lancrămului (Lancrăm Ravine). Another identified nucleus is the Mesteaca riverbed where both banks of the Mestecii river have high relief energies. Thus, the left bank has a relief energy of 50–100 m and slopes of 45–75^o, whereas the right bank (Dealul Rupturilor) has a relief energy of 50–70 m and declivities of 15–35^o. The lengths of the ravines in this riverbed range between 600 and 800 m, and its depth is of 5–8 m. High and extreme erosion nuclei can be found in Râura riverbed as well, with a relief energy of 80–100 m and slopes of 50–70^o. Here the precipitations in rainy years transformed rivulets into ravines whose depth is of 10–15 m.

The causes of soil erosion and landslides are both anthropogenic and climatic. Among the anthropogenic ones we can enumerate deforestations, turning the soil, overgrazing, excessive fragmentation of land after 1989, expansion of the arable land on the slopes of 15–20^o. The forests were logged irrationally and illegally so that today we can only find them sporadically between Secaşe, in the Amnaşului Plateau and at the basis of mountain slopes. The reduction of areas covered by forests by deforestation and illegal logging predisposed the soil and the substratum in certain areas to erosion and landslides. Thus, the land has degraded, including the one covered by pastures, cultivated with cereal (*Poa compressa*, *Festuca sulcata* and *Festuca rubra*). The destabilization of the slopes was caused in certain areas also by the diggings performed at the basis of slopes in order to obtain construction material. This explains the formation of several surface quarries on the southern slope of Apoldului Hill, to the west of Apoldu de Sus and on Dobârca Valley.

The climatic causes are represented by torrential precipitations in the hot season, the May-August period. From this point of view, the erosion was intensified by the rains of 1971, 1975, 1984, 1993, 1991, 1998, 2000, which, at the same time, reactivated the landslides in Cenade, Soroşin, Boz, Cut, Alămor. Such nuclei were identified sporadically in all of the images and are part of the extreme erosion class.

4. Conclusions

The results obtained for the period 1986–2011 show that around 41–46% of the studied period is classified in the moderate erosion class. Secaşul Mare riverbed displays dense signs of degradation which are in various stages of evolution caused by the action of both anthropogenic and natural factors. They present various sizes and intensities which can eventually lead to high and extreme erosion unless the necessary measures are adopted. In order to mitigate the degradations caused by surface and deep erosion, and by landslides there is a need to implement territorial management and planning works in the areas affected by intense degradation as well as on the larger surfaces which might be affected by various forms of erosion.

Monitoring, evaluating and improving erosion phenomena must lead to the implementation of a rational management system of the studied area. This is why a series of measures should be devised to combat soil erosion and its expansion. Such measures should include, for example, delimitation of improvement perimeters in which the intervention should take into consideration the local specificities; ecological reconstruction of certain areas; rational management by avoiding the continuous fragmentation of agricultural land; earthwork in order to reduce the slope; reforestation of areas of origin affected by landslides; grass coverage of slopes. Also, we need to perform torrential management works, to build sewage systems and to perform surface or deep drainage in areas with excess humidity, river capture, riverbank consolidation, etc. For this purpose, the use of Landsat satellite images and of DTM can represent an alternative in identifying, evaluating and monitoring land affected by degradation.

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