

# Assessing and monitoring the risk of land degradation in Baragan Plain, Romania, using spectral mixture analysis and Landsat imagery

Iosif Vorovencii

Received: 6 November 2015 / Accepted: 21 June 2016 / Published online: 28 June 2016  
© Springer International Publishing Switzerland 2016

**Abstract** The fall of the communist regime in Romania at the end of 1989 and the ensuing transition to the market economy brought about many changes in the use of agricultural land. These changes combined with the action of climatic factors led, in most cases, to negative effects increasing the risk of degradation of agricultural land. This study aims to assess and monitor the risk of land degradation in Baragan Plain, Romania, for the period 1988–2011 using Landsat Thematic Mapper (TM) and Spectral Mixture Analysis (SMA). Each satellite image was classified through the Decision Tree Classifier (DTC) method; then, on the basis of certain threshold values, we obtained maps of land degradation and maps showing the passage from various classes of land use/land cover (LULC) to land degradation. The results indicate that during the intermediary periods there was an ascending and descending trend in the risk of land degradation determined by the interaction of climatic factors with the social-economic ones. For the entire period, the overall trend was ascending, the risk of land degradation increasing by around 4.60 % of the studied surface. Out of the climatic factors, high temperatures and, implicitly, drought were the most significant. The social-economic factors are the result of the changes which occurred after the fall of the communist regime, the most important being the fragmentation of

agricultural land and the destruction of the irrigation system.

**Keywords** Monitoring · Land degradation · Spectral mixture analysis · Landsat imagery · Fraction images

## Introduction

Land degradation has been acknowledged for a long time as a critical ecological and economic problem because of its impact on food safety and on the environment (Lu et al. 2007). In general, at the beginning, land degradation is a slow process, almost imperceptible and most often ignored by the population. As land degradation progresses, the rehabilitation becomes difficult and requires large investments for mitigation (Lu et al. 2007). The causes are different, the specialized literature (Barrow 1991; Johnson and Lewis 1995; Lu et al. 2007) quoting a series of factors including social-political changes, political instability, marginalization, poverty, land ownership problems, natural hazards, and population changes. Drought and climate change have also played an important role (Chehbouni et al. 2000). Land degradation affects 2 billion ha (22.5 %) of agricultural land, pastures, and forests (Al Dousari et al. 2000; Oldeman et al. 1990) throughout the world, located in over 110 countries with almost a billion inhabitants. The severe degradation is also the reason why 5–10 million ha of agricultural land disappear each year (Gao and Liu 2010).

---

I. Vorovencii (✉)  
Forest Management and Engineering Department, Transilvania  
University of Brasov, Faculty of Silviculture, Beethoven street nr.  
1, 500123 Brasov, Romania  
e-mail: iosif.vorovencii@unitbv.ro

In Romania, land degradation affects different categories of land located especially in the regions of Oltenia, Banat, Moldova, and Dobrogea (Vorovencii 2015). The economic and social transformations in Romania, mainly the agricultural reforms, led to changes in the land categories, particularly the transition from forest to agricultural land (Turubanova et al. 2015; Munteanu et al. 2016). A large part of these changes resulted in land degradation. The phenomenon of land degradation has different forms, intensities, and magnitudes, affecting especially the agricultural lands. Thus, on more than 12 million ha out of the 15 million ha of agricultural lands, the soils are under the influence of one or several degradation factors such as erosion, the increase of the salt content because of the higher groundwater level, acidification, chemical pollution (pesticides, fluorides, heavy metals, oil, etc.), and compaction (Sevastel et al. 2010). Almost 5.3 million ha of agricultural land are vulnerable to surface and depth erosion and to landslides (Sevastel et al. 2010). Every year, approximately 150 million tons of soil are lost, including around 1.5 million tons of humus, 0.4–0.5 million tons of nitrogen, a large amount of potassium, phosphorus, and various other nutrients in the soil (Sevastel et al. 2010).

Land degradation intensified, especially, after 1989 when over 4 million owners received plots of land of various sizes, configurations, fertility, location of crops in the field, etc. (Bălteanu et al. 2004). Among the negative effects of the agricultural reform in post-communism Romania, there were the excessive fragmentation of agricultural land, the degradation of the

market for agricultural products, and the degradation of land quality. These changes led to a new land use system which is less resistant and more vulnerable to extreme environmental disturbances (Ienciu et al. 2012; IGAR 2014).

The main objective of our research was to assess and monitor the risk of land degradation in Baragan Plain, Romania, using Landsat Thematic Mapper (TM) imagery and Spectral Mixture Analysis (SMA) for the period 1988–2011. The period under investigation is typical for former communist countries, such as Romania, where the fall of communism and the transition to the market economy brought about major changes in all aspects of the social and economic life. The specific research objectives are: (1) establishing the usability of SMA and Landsat imagery in analyzing the land degradation risk in the studied area, (2) identifying the trend for the studied period of the land degradation risk by monitoring the changes on the basis of multitemporal satellite images, and (3) analyzing the driving forces which increased the land degradation risk.

### Study area

The study area is located between 44° 06' 35" and 45° 19' 10" North latitude and between 26° 19' 24" and 27° 58' 58" East longitude. The area under investigation was of 1,032,125 ha. It includes Baragan Plain in the south-east of Romania (Fig. 1). It is a typical plain and it exhibits the best developed fields in the Romanian Plain.



**Fig. 1** Area location. The study area is delimited to the south and east by the Danube, to the north by the Buzau river, and partially by Calmatui Valley. A part of the western limit is an alignment which connects the localities Fundulea-Urziceni-Buzau

The minimum altitude is of 15–23 m (Ianca Valley) and the maximum altitude is of 91 m (Hagieni Plain). The average annual temperature ranges between 11 and 11.5° C. The average annual precipitation quantity is of 506.7 mm, specific for a moderately droughty pluviometric regime.

The values of the aridity index range between 0.7 and 0.8 in the western part of Baragan Plain and 0.6–0.8 in the eastern part, indicating a dry subhumid area. In the north-eastern extremity of Brăila Plain, the values of the aridity index are even lower, signaling a semiarid climate. For this reason, Baragan Plain covers two areas, namely the silvosteppe in the west and the steppe in the east. In the silvosteppe, we find open woods made up of quercine sites (oak stand) including species of grayish oak (*Quercus pedunculiflora*), oak (*Quercus robur*), Hungarian oak (*Quercus frainetto*), silver lime (*Tilia tomentosa*), and wild cherry (*Prunus avium*).

Agricultural lands include arable land (84 % of the total plain area), pastures and hayfields (4 %), vineyards, and orchards (1 %). Other land use categories are represented by built-up areas which cover around 6 % and include rural settlements, various constructions for industrial and agricultural activities, railways and road networks, etc. The natural and semi-natural vegetation is made up of 3.5 % forest and transitional woodland-shrubs, and around 1.5 % water body (IGAR 2014).

This area was investigated because it exemplifies many forms of land degradation caused by the concentrated action of social-economic and climatic factors. Prior to 1990, the agricultural lands were managed by agricultural production cooperatives, which implemented intensive agriculture. Today, land is very fragmented and many of the individual farms practice subsistence agriculture. The result is the conversion from agricultural land into other classes, such as abandoned land, most of them becoming increasingly prone to degradation. As for the type of property, 38 % of the surface of the agricultural land belongs to farmers, 35 % is rented, while leases represent only 8 % (IGAR 2014).

## Materials and methods

### Remote sensing and ancillary data

In this study, we used a time series of Landsat 5 TM satellite images acquired on 15 July 1988, 24 July 1994,

28 July 2007, and 8 August 2011. The images belong to path 182, and row 29 (Fig. 1) and were downloaded free of charge from <http://glovis.usgs.gov>. They have a 1T level of correction and were geo-referenced at Universal Transverse Mercator (UTM), datum WGS 84, zone 35 N. The spatial resolution of the multispectral bands is 30 m. For comparisons, the images were calibrated (Borşan and Voicu 2009; Tereşneu 2012) and the DN digital values were converted to reflectance.

Other ancillary data used for accuracy assessment and different interpretations included: topographic maps (1:50,000; 1:100,000), vegetation map (1:100,000), soils map (1:200,000; 1:500,000; 1:1000,000), the land erosion map (1:1000,000), geological maps (1:200,000), and hydrological maps (1:1000,000). We also found very useful the weather data from the meteorological stations in Baragan Plain and in the nearby area, collected from various reports. The statistical data were gathered from various statistics (National Institute of Statistics 2006; National Institute of Statistics 2010a; National Institute of Statistics 2010b; National Institute of Statistics 2015).

### Spectral mixture analysis

The remote sensing images acquired in arid and semiarid areas contain pixels made up of several components (vegetation, soil) offering mixed spectral information (Kaplan et al. 2014). Quantifying this information in thematic maps can be done using the SMA technique. This relies on the fact that the spectral information in each pixel is the result of the integration of the spectral signature resulting from the various land cover classes contained by the pixel. SMA allows us to obtain the proportions of the land cover elements which make up each pixel. In the specialized literature, many studies concerning the vegetation in arid and semiarid areas (Pech et al. 1986; Smith et al. 1990; Shoshany et al. 1996; Kaplan et al. 2014) used multispectral unmixing techniques in order to quantify the vegetation fraction as compared to the soil and rock fractions.

In this study, the basic linear model was chosen. The linear SMA implies that the specter measured by a sensor is a linear combination of the spectra of all the components within a pixel (Adams et al. 1995; Roberts et al. 1998). The mathematical

relationship which expresses the SMA model is (Lu and Weng 2004):

$$R_i = \sum_{k=1}^n f_k R_{ik} + \varepsilon_i \quad (1)$$

where  $i$  is the number of spectral bands used;  $k = 1, \dots, n$  represents the number of endmembers;  $R_i$  is the spectral reflectance of the pixel from the  $i$  band which contains one or several endmembers;  $f_k$  is the proportion of the endmember  $k$  within the pixel;  $R_{ik}$  is the spectral reflectance of the endmember  $k$  within the pixel in band  $i$ ; and  $\varepsilon_i$  is the error for band  $i$ . In order to solve  $f_k$ , it is necessary to satisfy the following conditions (Lu and Weng 2004): (1) the selected endmembers must be independent from each other, (2) the number of endmembers must be lower than the number of spectral bands used or equal to it, and (3) the selected spectral bands must not be strongly correlated.

To convert the Landsat TM data from highly correlated bands to an orthogonal subset, we can use the two most common transformations (Jensen 1996): (1) principal component analysis (PCA) and minimum noise fraction (MNF). In the MNF transform, the noise is separated from the data by using only the coherent portions, thus improving the results of the spectral processing (Lu and Weng 2004). The studies conducted (Small 2001; Lu et al. 2002; Small 2002; Wu and Murray 2003; Lu and Weng 2004) showed that using the MNF transform can improve the quality of fraction images. Consequently, the MNF transform was used in this study.

Endmember selection is an iterative process. Obtaining high-quality fraction images largely depends on selecting the most appropriate endmembers in the studied area. The characteristics of a study area and its scale are also important factors affecting the endmember selection. The selected endmembers must satisfy the following conditions (Brandt and Townsend 2006): (1) the patterns of fraction images coincide with the current conditions on the field; (2) the endmember fractions for the landscape components of interest are between 0 and 1, thus indicating that the selected endmembers contain the purest pixels; (3) the sum of endmember fractions for a pixel is one, showing that the set of endmembers adequately characterizes the details in the field; and (4) the band which illustrates the error presents a low root mean square (RMS) error for the components of interest in the analyzed landscape. The RMS values indicate the

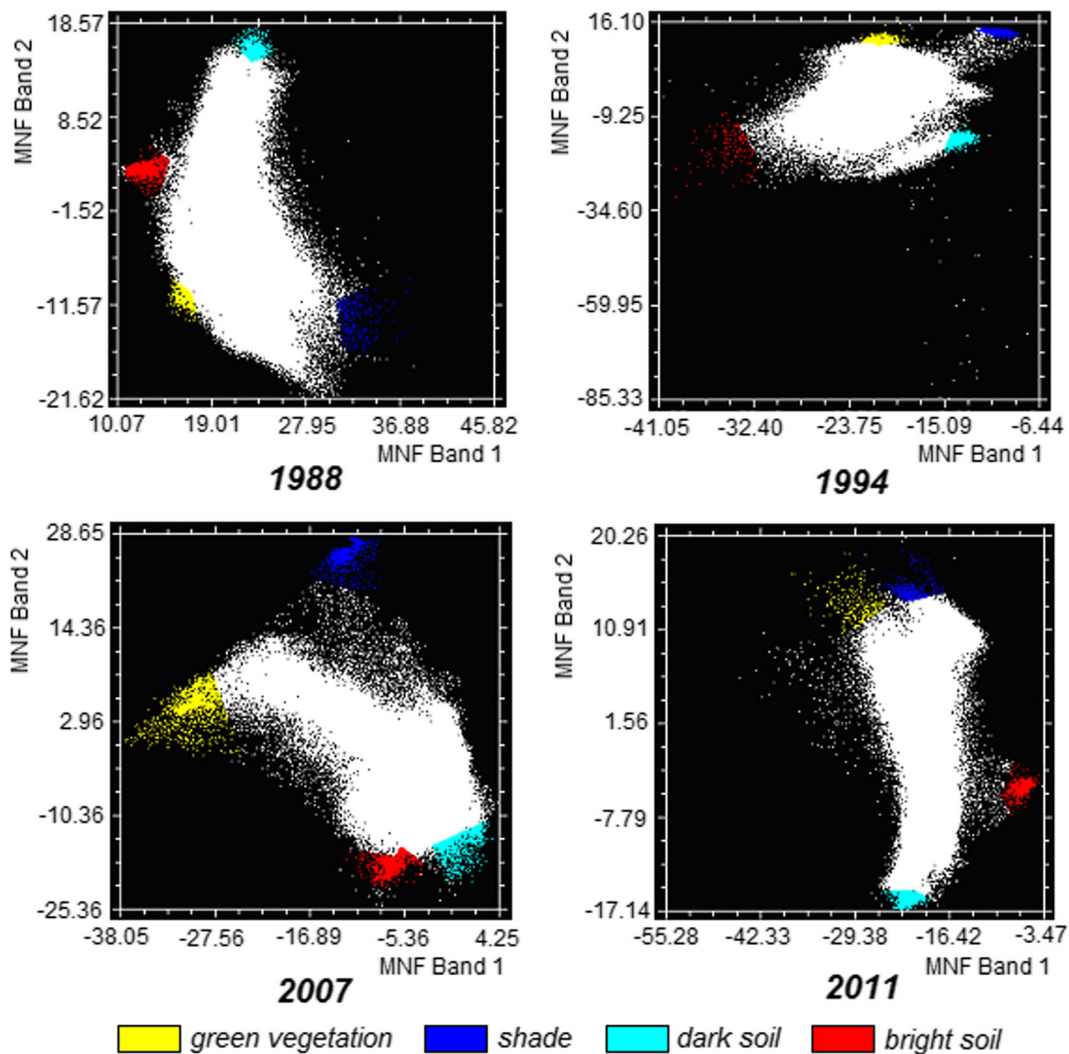
ability of the SMA model to explain the composition of each pixel.

In this study, the endmembers were collected from images (Fig. 2). The target endmembers were green vegetation (GV), shade (SHD), dark soil (DS), and bright soil (BS). The GV endmember was taken from forests and croplands. The SHD endmembers, although they were not physical material, were extracted from the deepest and clearest water body and represent the waters in the studied area, the shade surfaces in the area of low hills, and in the towns with the tall buildings. The DS endmember, extracted from bare soil, represents uncultivated fertile lands. The BS endmember, also extracted from bare soil, represents the degraded, eroded, dry land, without vegetation or with sparse vegetation.

Having selected an endmembers set, we performed SMA in order to determine the fraction of each endmember within each pixel. SMA produces a fraction image for each endmember and an image depicting RMS error by pixel. The mixed model we selected was assessed as proposed by Adams et al. (1995). First, we assessed the RMS image, as the final model selected displayed a very low RMS. Next, we assessed and interpreted the fraction images in terms of field context and spatial distribution. The examinations of fraction images allowed us to assess the spectral separability between the DS and BS endmembers. In the end, we examined the histograms of the fraction images in order to quantify the percentage of pixels which are not situated in the interval 0–100 %. In order to use only the pixels in the study area, we initially created a mask to cover the background and to exclude the pixels outside the contour. It was observed that the selected endmembers model around 95 % of the pixels in the examined interval. Out of these, the GV, SHD, DS, and BS fractions were normalized to fit within the range from 0 to 100 %. The normalization procedure was necessary because the pixels belonging to the different land use/land cover (LULC) classes were made up of green vegetation, shade, dark soil, and bright soil fractions endmembers.

#### Decision tree classifier

The classification of satellite images was performed by applying the Decision Tree Classifier (DTC) method. Although the chosen method was a nonparametric one, it has the potential to supply a set of decision rules based on physical properties (Roberts et al. 1998). The inputs in

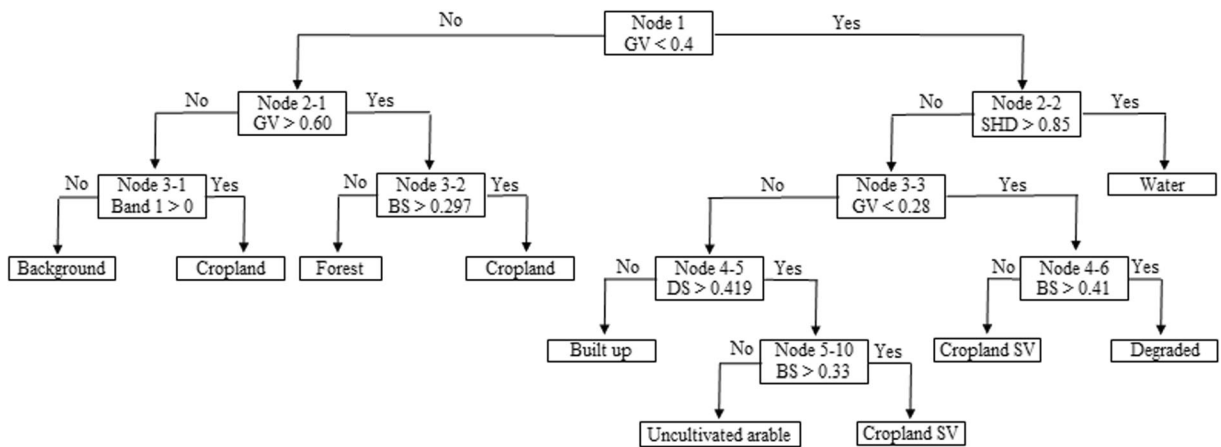


**Fig. 2** Endmembers collection from satellite images using the first two MNF bands

DTC represented endmember fractions. The DTC model consisted of: (1) a root, representing the first splitting rule with the maximum deviance; (2) a series of nodes representing the interval of the internal splits; and (3) a set of leaves illustrated by different LULC classes and terminal nodes. The model was examined in terms of residual mean deviance and the classification errors in the model which offers indications concerning the fraction images, whether they are representative or not.

In this study, the DTC was performed so as to understand the anatomy of the studied area in terms of its physical patterns (Fig. 3). The first decision rule occurred at the root node and relies on vegetation taking into account the fact that the greenery in the satellite images is the variable which leads to the largest

deviance measure. The classes with less vegetation are located on the right side of the DTC and include water, degraded, uncultivated arable land, built up, and cropland with sparse vegetation (cropland SV). The classes with plenty of vegetation are located on the left side of the DTC and consist of forest and cropland. The constituents of each class included in the DTC are presented in Table 1. The richer multiple paths in the right branch of the DTC are present because of the high heterogeneity and physical variability in the studied area. To that end, the multiple paths for certain classes reflect the higher variability in the composition of the classes, either natural (e.g., cropland SV) or artificial (e.g., built up). The agricultural land was split into three classes: cropland, cropland SV, and uncultivated arable.



**Fig. 3** The DTC schema for the 1988 image. The DTC includes 19 nodes with different decision rules spread on 5 levels

DTC was performed for the four images using different thresholds. These thresholds were determined based on a careful analysis of the images and of the conditions at the moment of acquiring the images and the environment conditions (Table 2). Then the accuracy was checked and the threshold values were adjusted according to the visual examination and accuracy assessment until a better accuracy assessment was achieved (over 85 %). The accuracy assessment of maps was performed using 80 stratified points and randomly for each class.

To highlight the conversion of the LULC classes from the analyzed period, the images classified using DTC were compared through crosstabulation. Thus, we obtained information “from 1988 to 2011” connected to the passage from various LULC classes in degraded land and we located the changes.

**Results and discussions**

Fraction images analysis and images classification

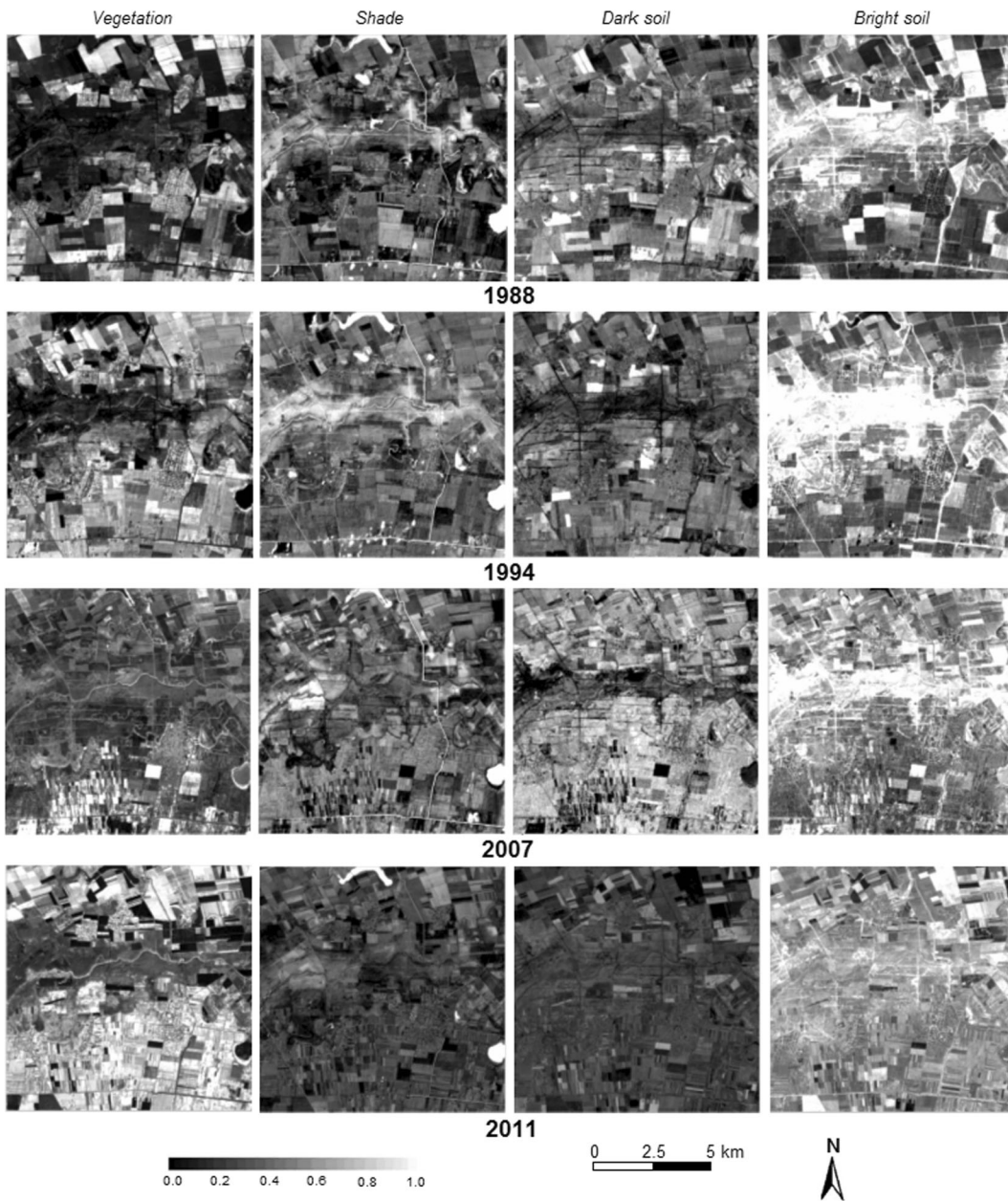
Fraction images are presented in Fig. 4. In the GV fraction image, forest and cropland are very bright. Vegetation structure, species composition, and density affect their fractions. Built up with high-density areas, uncultivated arable, cropland SV, and water appear in dark tone. Built up areas with low density appear in gray tone. The passage of areas from low to high GV fraction consists in the transition from high-density urban areas and bare land, with sparse vegetation, to low density urban areas and rich vegetation land. In the SHD fraction image, water appears very bright because of the high content of the shadow fraction. This is because the shade endmember was selected from clean deep water assuming that shadow and water have similar spectral

**Table 1** Description of LULC and its components in terms of fraction images

LULC classes	Description	SMA fraction
Cropland	Agricultural land with dense crops, dense grass/pasture	High vegetation, some bare soil
Cropland SV (cropland with sparse vegetation)	Agricultural land with sparse vegetation; pastures and hayfields with sparse vegetation	Medium and sparse vegetation, some shade, some dark soil, some bright soil
Uncultivated arable	Arable agricultural land, uncultivated	Very low vegetation, dark soil
Degraded	Degraded lands from different LULC classes	Very low vegetation, high bright soil
Forest	Forest, orchard, forest shelterbelts	High vegetation, some shade, low dark soil
Built up	Constructions (industrial, commercial, buildings), paved roads, parking lots	Some vegetation, some shade, low dark soil
Water	Lakes, streams	High shade

**Table 2** Threshold values used in Decision Tree Classifier

Image	Node 1	Node 2-1	Node 2-2	Node 3-2	Node 3-3	Node 4-5	Node 4-6	Node 5-10
1988	< 0.40	> 0.60	> 0.85	> 0.297	< 0.28	> 0.419	> 0.41	> 0.33
1994	< 0.55	> 0.56	> 0.80	> 0.192	< 0.36	> 0.4635	> 0.18	> 0.27
2007	< 0.26	> 0.22	> 0.827	>0.2353	< 0,24	> 0.7307	> 0.242	> 0.24
2011	< 0.43	> 0.50	> 0.82	>0.2663	< 0.40	> 0.624	> 0.27	> 0.29



**Fig. 4** Portions of fraction images for GV, SHD, DS, and BS. These portions resulted after the fraction images were clipped and include a part of Calmatui Valley

features. Built-up areas and forest appear in gray tone because of the average values of the shade fraction. Cropland and cropland SV have a darker tone which indicates a very low shade fraction. In the DS fraction image, forest, water, and cropland exhibit a dark tone. Uncultivated arable land appears in bright tone and degraded land in gray tone. In the BS fraction image, degraded land appears in white and built-up land is recorded in white with pixels in gray tone. In built-up areas, special residential areas, the fractions reflect the mixing result of their structure components, including buildings, trees, grass, and pavement. Cropland and forest appear in darker tone, the higher density of cultures determining the black tone. Clean waters appear in dark tone and muddled waters in gray tone. In the BS fraction image, the degraded lands around waters are very well highlighted.

Changes in the portion of endmembers occurred both on surfaces which passed from one class to another and on those without changes because of the climatic conditions, the different degree of the crops, and the forms of land degradation. The differences among the dates for acquiring the images must also be taken into consideration. The GV fraction fluctuated from one period to another, during the entire period it was reduced by 0.02 (Table 3). The loss of 0.32 of the GV fraction in 2007 as compared to 1994 due to land degradation led to an increase by 0.25 of the DS fraction. The DS fraction represents cropland with unsuccessful crops, sparse and very sparse, which underwent an ample degradation process in the period 1994–2007. The prolonged droughts and the lack of an irrigation system clearly stimulated the loss of the GV fraction during this period. Soil fraction increased with the conversion of cropland into cropland SV and bare land. In the period 1988–2011, the DS fraction increased by 0.14 which represents land subject to degradation. The constant size of the BS fraction during the entire studied period shows

that from 1988 onwards land degradation occurred in approximately the same locations which constituted real centers.

The RMS for every image was calculated in order to assess the performance of this model. The RMS over the images was less than 0.02 which suggests a generally good fit (Fig. 5). For the 2007 image, the RMS maximum value was 0.04 due to a strong variation in the soil reflectance caused by drought (Antofie et al. 2015).

The images classified by DTC are presented in Fig. 6. Cropland occupies the largest surface in the studied area, followed by cropland SV (Fig. 7). In the period 1988–2011, cropland increased by 6.65 %, cropland SV decreased by 31.70 %, and uncultivated arable and degraded land increased by 45.61 and 52.87 %, respectively. Forest decreased by 0.33 % as compared to the beginning of the period. Water presents no important fluctuations maintaining the 1988 values. Built-up land increased by 38.3 % due to the expansion of residential, commercial, and industrial areas, to building roads, parking spaces, etc. Out of all the years under analysis, the greatest variation in the surface covered by LULC classes was recorded in 2007. Thus, as compared to 1988, the cropland represents only 45.45 %, the cropland SV 167.31 %, the uncultivated arable land 227.42 %, and degraded land 202.07 %.

The overall accuracy of the classification of satellite images exceeds 85 % and is presented in Table 4. The more serious commission errors in the case of the classes of cropland, cropland SV, uncultivated arable land, and built-up land were due to the heterogeneity of the studied area, with certain classification confusions.

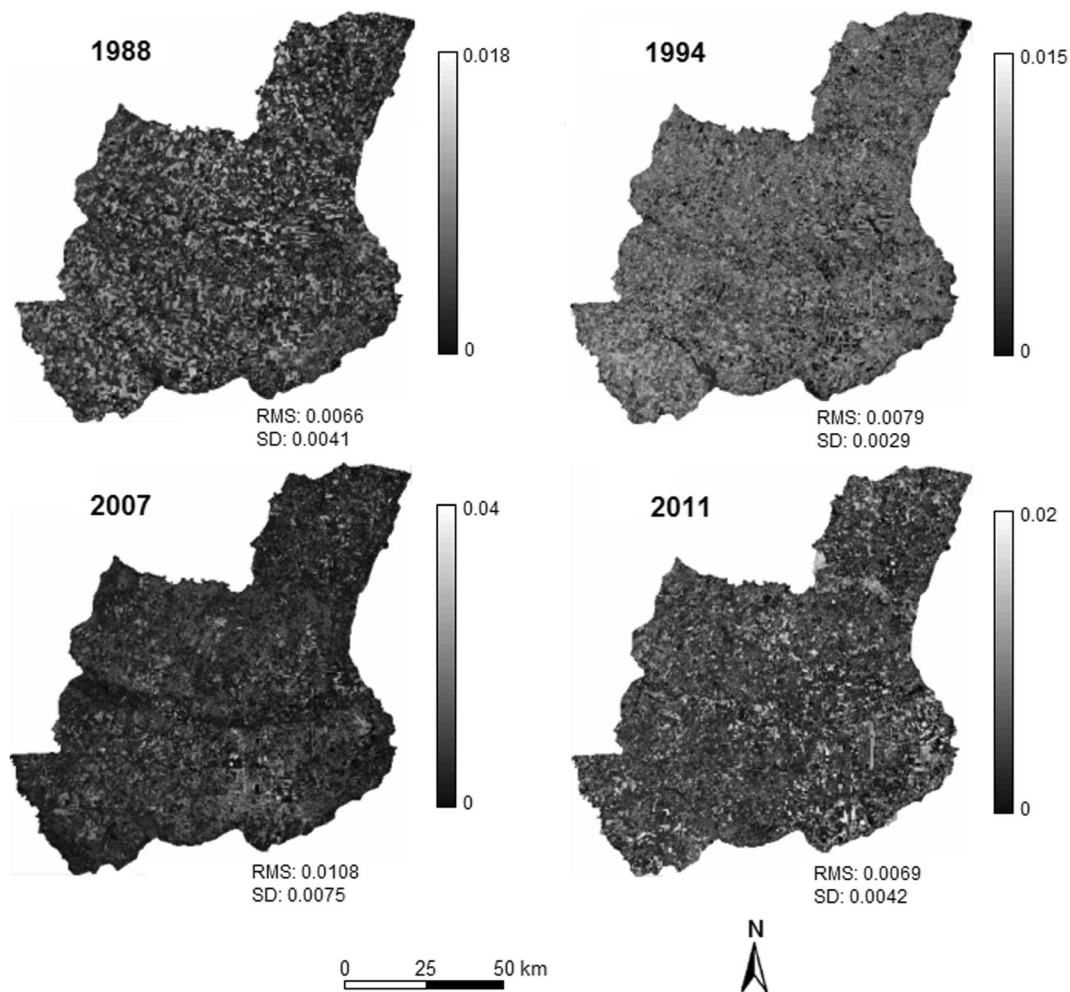
#### Identifying the risk of land degradation

The most frequent LULC changes over the period 1988–2011 were extensification of agriculture and intensification of agriculture. Extensification of

**Table 3** Mean endmember fractions and standard deviations for 1988, 1994, 2007, and 2011

Endmembers	1988		1994		2007		2011	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
GV	0.47	0.16	0.57	0.12	0.25	0.04	0.45	0.07
SHD	0.66	0.05	0.62	0.04	0.70	0.05	0.68	0.05
BS	0.35	0.05	0.23	0.03	0.24	0.02	0.28	0.02
DS	0.50	0.04	0.49	0.03	0.74	0.02	0.64	0.03



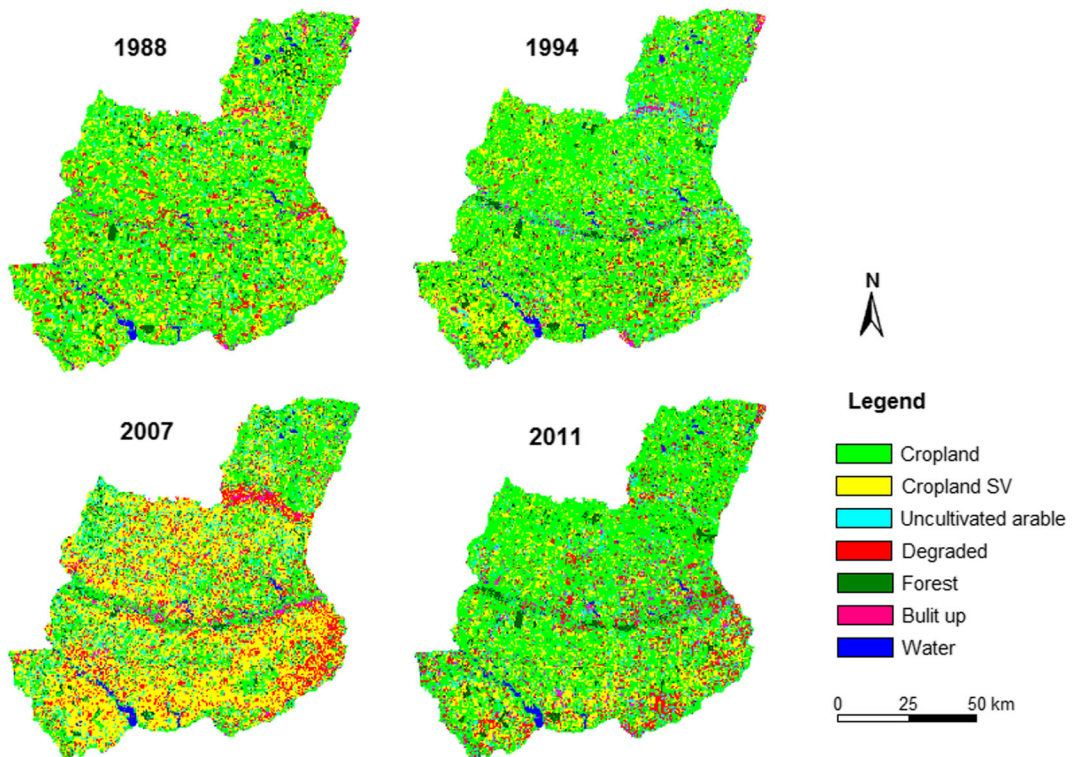


**Fig. 5** RMS images after performing the SMA model. For each image, we presented the root mean square (RMS) and the standard deviation (SD)

agriculture involved conversion from arable land and cropland into cropland SV, pastures, and heterogeneous agricultural surfaces. Intensification of agriculture means conversion from different LULC classes into agricultural land.

The results obtained by crosstabulation concerning the conversion of lands in the analyzed classes into degraded land are presented in Table 5 and Fig. 8. The data show that for the analyzed intermediary periods, there is a fluctuating trend of the surfaces affected by the land degradation risk. The most affected period was 1994–2007 when 122,559 ha (11.87 %) of the analyzed territory was subject to degradation risk. The result is in agreement with that signaled in other papers which are not based on remote sensing data, and which show that the risk of land degradation

occurs on 11.65 % of the surface (Vrînceanu 2011). The main cause is represented by the very high temperatures over this period, many years being considered extremely droughty (Fig. 9a). Nevertheless, the precipitations recorded in the analyzed period presented a slight increase due to the years 1997, 1999, and 2005 when the precipitations exceeded by far the annual average (Fig. 9b). They were very intense and led to bare soil, without vegetation, causing surface erosion. As a result, the climate changes can constitute a cause as well as a consequence (Marcu et al. 2011; Marcu and Marcu 2012) of the increased risk of soil degradation. The factors which led to the increase of land degradation risk in the period 1994–2007 diminished in the period 2007–2011, which is why during this latter period the land degraded surface decreased.

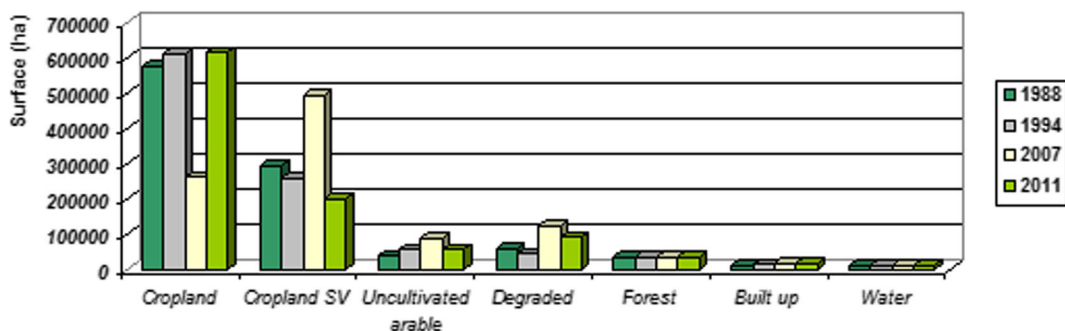


**Fig. 6** Images classified through DTC. The surface with the highest risk of land degradation was recorded in 2007 in Calmatui Valley, in the south-east of the studied area and sporadically on the entire surface

For the entire studied period, the results show that the land degradation risks increased by 4.60 %, that is from 45,238 ha affected in the period 1988–1994 to 92,720 ha subject to the risk in 2011. Consequently, in 2011, the land degradation risk was recorded on 8.98 % of the studied surface.

The land degradation risk affected all the analyzed classes. From the entire studied surface, the most affected is the agricultural land, namely cropland (4.49 %), cropland SV (2.84 %), and uncultivated arable land (0.31 %), which represents 85.03 % of the total area of

degraded land in 2011 (Table 5). Taking into consideration the entire agricultural land, in the period 1988–2011, there were changes on 78,836 ha (7.64 %). The results are similar to the ones signaled in other research papers based in statistical data not on remote sensing data, which show that in the period 1990–2006 changes occurred on 42,800 ha (4.83 %) (IGAR 2014). Given the very low degree of vegetation cover (2–25 %) on uncultivated arable land, any intervention was visible. Thus, the inadequate agricultural practices led to the accelerated degradation of the landscape accompanied



**Fig. 7** The distribution of the LULC class surfaces for the analyzed period after applying DTC

**Table 4** The accuracies obtained after the classification of the satellite images

LULC classes	1988		1994		2007		2011	
	Producers accuracy	Users accuracy	Producers accuracy	Users accuracy	Producers accuracy	Users accuracy	Producers accuracy	Users accuracy
Cropland	90.79	86.25	89.47	85.00	75.64	73.75	79.55	87.50
Cropland SV	91.30	78.75	86.59	88.75	74.71	81.25	87.34	86.25
Uncultivated arable	85.71	82.50	90.79	86.25	78.41	86.25	92.11	87.50
Degraded	76.92	87.50	79.31	86.25	80.00	85.00	87.18	85.00
Forest	97.44	95.00	97.37	92.50	98.63	90.00	97.47	96.25
Built up	68.48	78.75	81.93	85.00	95.77	85.00	87.65	88.75
Water	98.70	95.00	97.50	97.50	97.44	95.00	97.47	96.25
Overall accuracy	86.25		88.75		85.18		89.64	
Kappa statistics	0.8396		0.8688		0.8271		0.8792	

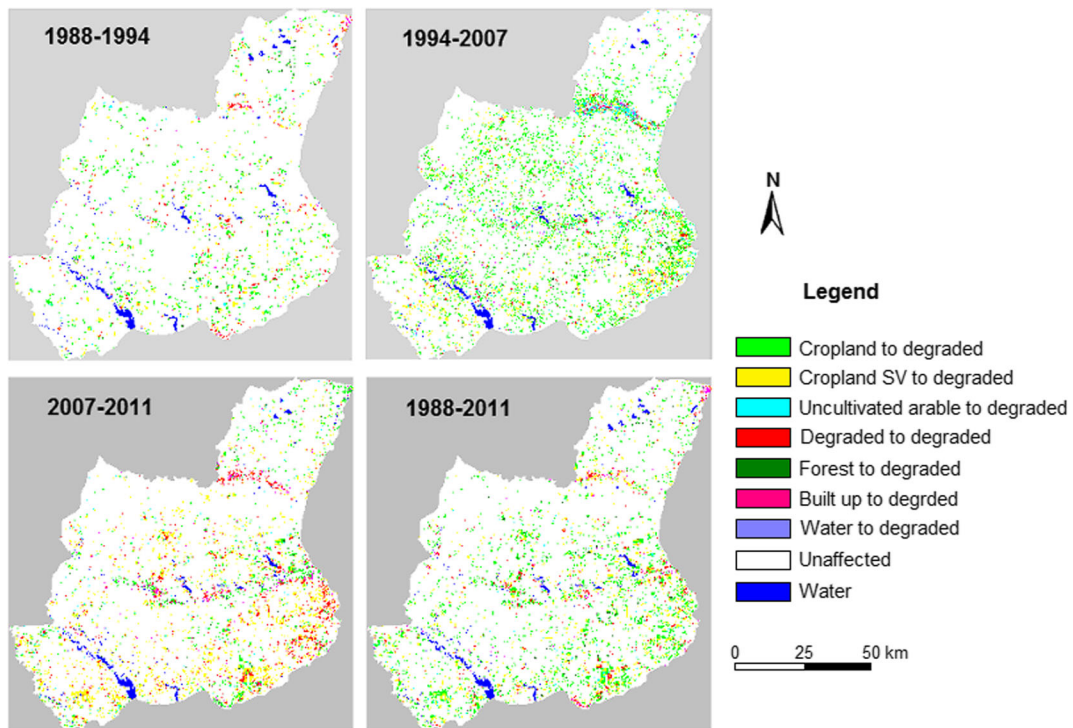
by destructuring, crusting, water and aeolian erosion, decrease of the nutrients reserve, secondary salinization, compaction, modification of chemical and biochemical circuits, etc.

The conversion from agricultural land (cropland, cropland SV, uncultivated arable) into degraded land, considered the most important change, determined certain processes which, in some locations, can become irreversible. Destructuring is the most important process of physical degradation in the studied area which is visible in the reduction or loss of the stability of soil structural aggregates caused by the mechanical pressure of agricultural machines, the kinetic pressure resulting from the impact of rain

drops, etc. This led to a change in porosity, water and air permeability, elasticity, etc. This specific change was facilitated by the soils in the area which contain a low amount of humus, by the alternation of periods with normal conditions with those of prolonged and excessive droughts, by the very high percentage of agricultural land. Thus, the specialized literature (Vrînceanu 2011) shows that, out of the entire surface of Baragan Plain, 0.1 % exhibits very reduced risk of destructuring, 32.9 % reduced risk, 56 % moderated risk, 6 % high risk, and 5 % very high risk. Some of these surfaces are included in the degraded class in this study, particularly in the cropland and uncultivated arable classes.

**Table 5** Conversion of land from the analyzed classes into the class of land with degradation risk

Conversion from LULC classes into degraded land	1988–1994			1994–2007			2007–2011			1988–2011		
	ha	% from		ha	% from		ha	% from		ha	% from	
		degraded	total surface		degraded	total surface		degraded	total surface		degraded	total surface
Cropland	21,342	47.18	2.07	67,436	55.02	6.53	19,748	21.30	1.91	46,358	50.00	4.49
Cropland SV	13,684	30.25	1.33	33,431	27.28	3.24	45,087	48.63	4.37	29,329	31.63	2.84
Uncultivated arable	1636	3.62	0.16	11,208	9.15	1.09	3652	3.94	0.35	3149	3.40	0.31
Degraded	5773	12.76	0.56	6926	5.65	0.67	18,509	19.96	1.79	9770	10.53	0.95
Forest	1373	3.03	0.13	1908	1.56	0.19	1744	1.88	0.17	1758	1.90	0.17
Built up	1067	2.36	0.10	1559	1.27	0.15	3686	3.97	0.36	2000	2.16	0.19
Water	363	0.80	0.03	91	0.07	–	294	0.32	0.03	354	0.38	0.03
Total	45,238	100.00	4.38	122,559	100.00	11.87	92,720	100.00	8.98	92,720	100.00	8.98

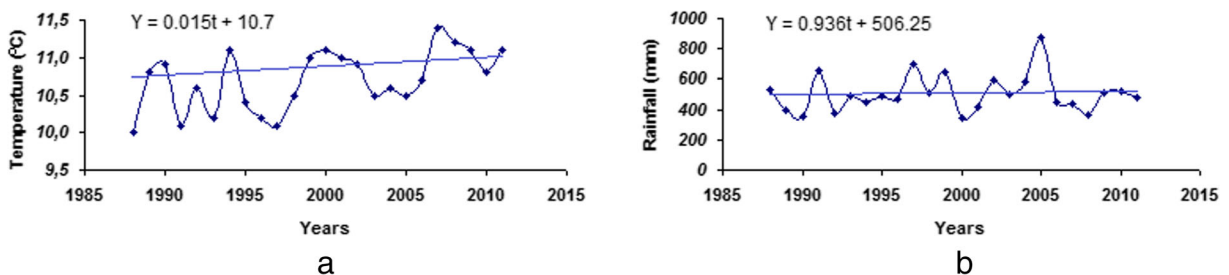


**Fig. 8** Conversion of LULC classes into land degradation risk class. In the period 1994–2007, the most affected classes were cropland and cropland SV

Incrustation, another physical process which occurred at the conversion from agricultural land into degraded, was characterized by the formation on the soil surface of a hard and compacted layer of 2–3 mm, sometimes even of 4–5 mm, with low permeability, with an apparently high density, difficult to permeate, and with very low porosity. Soil incrustation was caused by both physical and chemical factors as well anthropogenic ones. Among the physical and chemical factors, we can mention the granulometric composition and low content of humidified organic material, whereas the anthropogenic ones refer to the use of the land in agriculture. As far as incrustation is concerned, 2 % of the

soils in the studied area present a very low risk for this phenomena, 4 % low risk, 24 % moderated risk, 5 % high risk, and 65 % very high risk (Vrinceanu 2011). The soils that exhibit the highest risk are the ones formed on loess deposits and with a dusty texture. Incrustation occurs every year, especially in spring, but also in summer when precipitations alternate with increased temperatures.

The phenomenon of water erosion is quite infrequent due to the relief conditions in this area with no significant altitude difference. The conversion from cropland into degraded land because of this phenomenon is, however, encountered mainly along water valleys and



**Fig. 9** The evolution of the annual average temperature (a) and of the annual average precipitations (b) recorded in Baragan Plain according to the data from the meteorological stations for the period of 1988–2011

also in the northern part of Calarasi Plain. Aeolian erosion is present and determined, especially, by the existence of aeolian sand deposits, long droughts, and the absence of a vegetal cover to fix the soil. The soils which are very much affected by this process are psamic chernozems, psamosoils, and cambic-psamic soils. The emergence and development of this phenomenon were recorded on agricultural land where no cereals or vegetables were cultivated. In the case of cropland SV (pastures and hayfields with sparse vegetation), this phenomenon occurred more rarely. The affected locations are, in general, on the right side of Calmatui Valley and Ialomita Valley, but also grouped in the northern part of the studied area.

The decrease in the amount of organic material led to numerous significant modifications which determined the conversion of agricultural land into degraded. The way the soils were used, the intensive farming activities, and the small amounts of vegetal material incorporated into the soil resulted in the decrease of the humus reserve. As a result, the intake of nutrients necessary for plants diminished, the clay and colloidal substances migrated to the deeper layers, and the energy necessary for the soil microbial activity decreased. This situation affects over 65 % of all the pedological resources in the studied area (Vrinceanu 2011).

The degradation risk affected 0.17 % of the total surface of forests (Table 5). Because the forest in the area represents only 3.5 %, any intervention in the forest is visible. This was manifested by the loss of the regenerative capacity, the loss of the forest environment, the intensification of the wind speed leading to the occurrence of aeolian erosion and the increase of evapotranspiration at soil level, the intensification of the surface drainage and the reduction of the water quantities stored in the soil, the reduction of the thermal gradient in the atmosphere, and the reduction of snow accumulations in the cold season.

The waters were affected by the degradation process only on 0.03 % of the studied period (Table 5). Degradation occurred on the riverbeds and the valleys of waters and on the lands around lakes. Soil in the vicinity of these water bodies suffers from severe salinization. It is estimated that out of the total studied surface, land degradation caused by salinization affects 39,220 ha (Vrinceanu 2011).

The centers of degraded land expanded in the analyzed period by 0.39 % without a continuous ascending or descending trend, but with fluctuations determined

mainly by climatic factors and secondly by the social-economic ones (Table 5). The classified satellite images show that there are certain centers which remain from year to year but most surfaces subject to the degradation risk are spread in the studied area and vary from 1 year to the next. The most affected area is Calmatui Valley whose degradation is maintained annually (Fig. 10). Such centers were also identified in the Great Island of Brailei, on various surfaces where the soil fertility is very low.

The increase of the degradation risk for the agricultural land in Baragan Plain generally occurs on the edge of agricultural plots, close to former irrigation canals, in lands with erodisols, regosols, etc. The results obtained show that the extremely high risk occurs on lands with soils developed on the saliferous deposits in Calmatui Valley highlighted in the classified satellite images, especially in the period 1994–2007 (Fig. 10). Also, the extremely high risk of degradation was signaled on lands in Ianca Valley and in the central part of the Ialomita-Calmatui and Calmatui-Buzau-Siret interfluvial plains, around the salinized lake basins. In these areas, in the valley sectors frequently affected by floods or by advanced salinization, there is also the risk of overgrazing. A high risk was also exhibited, especially in the period 1994–2007, by lands developed on the aeolian sandy deposits in Marculesti Plain (Hagieni and Facaieni Plains), the northern part of Padina Plain, Mohreanu Plain, and the eastern part of Tataru Plain, as well as in the north of Ianca Plain.

#### Analysis of the driving forces in land degradation

The risk of land degradation in Baragan Plain is determined by a set of factors. In the general context of the social-political changes in the post-communist period as well as of the global warming, agricultural land use in Baragan Plain was influenced by a complex of proximate social-economic and climatic drivers in permanent interaction. These factors correlated with an excessive fragmentation of agricultural lands, and inadequate agricultural practices led to the increase of the vulnerability of this area.

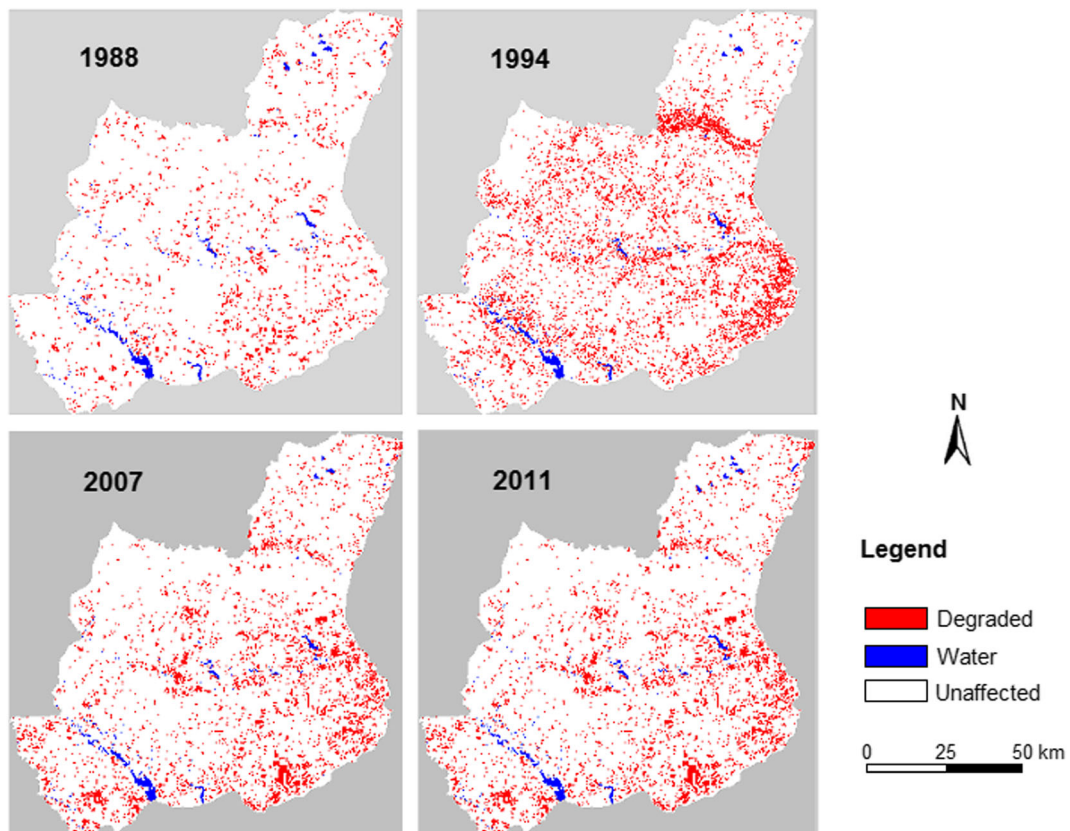
In Baragan Plain, over 86.2 % of the surface of arable agricultural land was managed by irrigation systems (947,600 ha), many of them being destroyed after 1990 or left in an advanced state of degradation. In 2010, only 6.9 % of the total surface of agricultural land equipped with irrigation systems were irrigated through

those systems (IGAR 2014). In the absence of irrigation systems, the agriculture in Baragan Plain depends on the climatic conditions which were very severe in that area because of the excessive and prolonged droughts in the period 1999–2002 and in 2007. The lack of irrigation systems resulted in soil crusting, land aridisation, the decrease in soil fertility, and soil salinization.

The climate drivers that lead to the increase of the land degradation risk are represented by climate changes and extreme climate phenomena (dryness, drought, strong winds, heavy snow, etc.). The lack of forest shelterbelts determined a higher frequency and intensity of these phenomena. Romania was one of the top countries in the world in the area of forest shelterbelts, and the plan to implement forest shelterbelts in Baragan in 1906, preceded by 29 years the “Roosevelt Plan” to implement forest shelterbelts in the plains in the west part of the United States (1935) and by 42 years the “Plan to transform nature” in the former Soviet Union from 1948. Because of a misguided policy, starting from 1962, most forest shelterbelts created, including in

Baragan Plain, were cut in order to create agricultural land, without taking into consideration their protection role.

The fragmentation of agricultural land led to the impossibility of practicing an intensive agriculture. In 2010, there were 188,812 agricultural farms in Baragan Plain. Out of them, 99 % were individual farms, with very small and small farms under 5 ha, covering 41 % of the agricultural land. The average surface of an individual farm was of 1.8 ha (National Institute of Statistics, 2010a; IGAR 2014). Out of them, 58 % were smaller than a hectare which made them ineligible for receiving direct payment/hectare. The rest of 1 % was made up of units with legal status using 58 % of the agricultural land, with an average surface of 347.9 ha (National Institute of Statistics, 2010b; IGAR 2014). They consisted of large and very large farms of over 100 or 1000 ha. In Baragan Plain, there are five of the largest farms in Romania with an area between 6000 and 35,000 ha. Four of these farms are owned by foreign investors (Portuguese, Lebanese, Danish, etc.).



**Fig. 10** The distribution of lands with degradation risk in the studied area in the period 1988–2011. The most affected surfaces were in the Calmatui Valley and in the south-eastern part of the studied area

Although by Law 247/2005 the agricultural lands were returned in full which made it possible to create large farms, and Law 312/2005 allowed foreign citizens to lease or to rent agricultural lands, the agricultural land in Baragan Plain remain fragmented. This makes it difficult to use new production technologies, to implement an efficient management and marketing system to increase productivity, and turn this sector into a competitive one (Sima et al. 2015). At the beginning of 2014, the Romanian market of agricultural land was liberalized by Law 17/2014 which meant that foreign citizens, natural persons from the European Union (EU), were permitted to buy agricultural land in Romania. In this context, the price of land increased and it is predicted that the lands will be merged in order to invest in and practice intensive agriculture.

Social-economic factors had a considerable influence on the risk of land degradation. The weak mechanization, the difficulties in implementing the new technologies, and the arbitrary fertilization of cultures are among the agricultural practices incompatible with an efficient agriculture. The decline in the value of the agricultural production, the low incomes and high costs for the farmers, as well as the small real prices led to, in most cases, land abandonment. The insufficient involvement of the local authorities in informing correctly and supporting the small farmers and the preferential distribution of funds for investments in agriculture resulted in the improper endowment of farmers. A part of the agricultural lands received through the land laws were not cultivated because of the lack of workforce, the aging rural population, and the lack of training of farmers. Thus, whole surfaces of agricultural land were converted to pastures affected by overgrazing. The infrastructure and the access to markets are weak, the centers for collecting the farmers' products are missing, and the distribution network for agricultural products is inefficient. All these social-economic drivers resulted in land abandonment and, implicitly, in a higher land degradation risk.

#### Measures for fighting against the land degradation risk

The measures for fighting against the land degradation risk can be aimed at reducing the effects of climatic and social-economic factors. The measures

in the first category include rebuilding the irrigation system which represents the most important tool in fighting against drought (Greșiță 2011; Greșiță 2013) and, implicitly, against the land degradation risk. It is the measure which involves the most consistent financial investment. The construction of the Siret-Baragan canal, designed and started in 1985, but abandoned after 1989, is considered vital for the agriculture in Baragan Plain, because it could ensure the irrigation of 700,000 ha. The canal should be 57 m wide at the water surface, 7 m deep, and 198 km long.

The great farmers could use their own money to irrigate the cropland, by digging deep wells, but the surface covered by such irrigation systems is very small, only a few tens of hectares. Consequently, many of these farmers submitted projects to obtain European funds for this enterprise. In the absence of the irrigation system in the case of small farmers, the pedologic drought can be attenuated by cultivating drought-tolerant species, breeds, and hybrids and through works meant to maintain soil humidity.

The implementation of a national system of forest shelterbelts, whose efficiency was verified in time, represents another very important measure. The measure includes at the same time planting new forest shelterbelts but also replanting the older ones using different species (*Robinia pseudacacia*, *Gleditsia triacanthos*, *Populus euramericana*, *Sophora japonica*, *Fraxinus americana*, *Elaeagnus angustifolia*, *Tamarix ramosissima*, *Ulmus pumila*, *Amorpha fruticosa*). Forest shelterbelts would allow the reduction of the wind effect, of evapotranspiration, reducing the air temperature in their vicinity by 1–4 °C, increasing the air humidity by 2–4 %, increasing the agricultural production in the protected areas by 20 %, etc. The implementation of forest shelterbelts is aggravated by the fact the lands on which they should be planted belong to private owners who fail to understand their usefulness.

The ecological reconstruction of degraded lands by forestation, where possible, can be performed by means of drought-tolerant tree species (*Q. pedunculiflora*, *Quercus pubescens*). In addition to this, solutions have to be identified for the forestation of the privately owned lands which are still not generated. This action has both a social and an ecological value. The ways of managing and nursing the forests in this area must also be reviewed in detail, and solutions must be identified which are

optimum from an economic, ecological, and social point of view (Iordache 2010). The rehabilitation of degraded grassland can be achieved by reducing grazing intensity to a sustainable level.

The biological rehabilitation can be applied in order to reduce soil salinity and to restore the deteriorated vegetal cover. This can be achieved by planting salt-tolerant crops such as beetroot, sunflower, and barley. Once these cultures become stabilized, we can expect the quantity of salts in the soil to decrease and a favorable environment for other cultures (Gao et Liu 2010). Also, we can use plantation of trees, shrubs (*E. angustifolia*, *Halimodendron halodendron*, *Hippophaë rhamnoides*, *T. ramosissima*), and salt-tolerant plants which, although they bring minimum economic benefits, they contribute to the absorption of the salt in the soil and reduce salinity. In addition, the vegetative protection can prevent the contamination of the adjacent lands from salt, thus avoiding the occurrence of bare land (Gao et Liu 2010). Salt-tolerant plants can be introduced in order to recover the pastures in the valleys of small rivers. Improving the structure of the salinized soil can be achieved also by applying gyps and phosphogypsum. Calmatui Valley, considered the relief unit with the highest percentage of salt in Romania, can undergo rectification works and its bed can be deepened and widened to improve the land's general drainage.

Encouraging the creation of associations or farms with surfaces of over 200 ha and their modernization would reduce the fragmentation of agricultural lands. Starting from 2015, the new Common Agricultural Policy stipulates granting an additional payment to stimulate land reparcelling in order to reduce the number of subsistence agricultural exploitations. Nowadays, after Romania's accession to the EU, the extension of land fragmentation is beginning to decrease and the average individual farm area increased. The accession to the EU and the implementation of its agricultural policies represent a step forward in the development of agricultural farms, the environment protection in this type of activity, and the adoption of measures and action plans that will lead to the sustainable use of natural resources. The need to use a combination of sustainable land management measures (agricultural practices which increase the productivity of non-irrigated

lands, the use of drought-tolerant seeds) and an intensive agriculture in the environments where they are efficient can satisfy the requests for market productivity, minimizing, at the same time, the impact on the environment.

As a complex system for monitoring the risk of land degradation, it is recommended to implement in Baragan Plain a pilot system using specific indicators concerning the soil, climate, vegetation, demographic pressure, and biodiversity. This system should be developed on a grid of  $4 \times 4$  km similar to the National System for Monitoring the Soil Quality built on a grid of  $16 \times 16$  km (Vrinceanu 2011).

## Conclusions

The interaction between climatic and social-economic factors plays an important role in the increase of the risk of land degradation in Baragan Plain. The prolonged droughts in the analyzed period, the lack of an irrigation system, and the excessive fragmentation of agricultural land are the main causes which determined the increase of land degradation risk. Out of these, land fragmentation was the cause for the entire period, even with significant effects towards its end. The climatic factors, especially drought, had different influences from year to year, which turned this factor into an essential one as it happened in 2007 when 122,559 ha were subject to land degradation risk.

The increase of the complexity of the climatic and social-economic factors which are at play in the case of the lands in Baragan Plain and the importance of cumulative impacts and the monitorization and accurate assessment of the condition and variation tendencies of the land degradation risk are essential to design efficient strategies for the management of the environment. As a result, adopting certain measures to reduce the land degradation risk which take into account the driving forces is more and more important. These measures must be adopted on the basis of sound studies both through determinations and terrestrial analyses and remote sensing which provides synoptic information on the condition of lands and surfaces affected by degradation risks. Such a study can be performed with the help of Landsat satellite images and by applying the SMA technique.



**Acknowledgments** The author thanks the United States Geological Survey (USGS) for providing the Landsat TM satellite images, and lecturer Raluca Sinu for her support with the English language. Also, the author would like to thank the two anonymous reviewers for their constructive observations and comments.

## References

- Adams, J. B., Sabol, D. E., Kapos, V., Filho, R. A., Roberts, D. A., Smith, M. O., et al. (1995). Classification of multispectral images based on fractions of endmembers: application to land cover change in the Brazilian Amazon. *Remote Sensing of Environment*, 52(2), 137–154.
- Al Dousari, A. M., Misak, R., & Shahid, S. (2000). Soil compaction and sealing in AL-Salmi area, western Kuwait. *Land Degradation and Development*, 11(5), 401–418.
- Antofie, T., Naumann, G., Spinoni, J., & Vogt, J. (2015). Estimating the water needed to end the drought or reduce the drought severity in the Carpathian region. *Hydrology and Earth System Sciences*, 19(1), 177–193.
- Bălțeanu, D., Popescu, M., & Urșanu, E. A. (2004). Land tenure and land relations in Romania. In V. Belenkiy (Ed.), *International encyclopedia of land tenure and land relations in the world* (pp. 357–453). New York: Edwin Mellen Press.
- Barrow, C. J. (1991). *Land degradation: development and breakdown of terrestrial environments*. Cambridge: Cambridge University Press.
- Borșan, T., & Voicu, G. E. (2009). *Geographic Information Systems*. Alba Iulia: “1 Decembrie 1918” University (in Romanian).
- Brandt, J. S., & Townsend, P. A. (2006). Land use–land cover conversion, regeneration and degradation in the high elevation Bolivian Andes. *Landscape Ecology*, 21(4), 607–623.
- Chehbouni, A., Goodrich, D., Moran, M., Watts, C., Kerr, Y., Dedieu, G., et al. (2000). A preliminary synthesis of major scientific results during the SALSA program. *Agricultural and Forest Meteorology*, 105(1–3), 311–323.
- Gao, J., & Liu, Y. (2010). Determination of land degradation causes in Tongyu County, Northeast China via land cover change detection. *International Journal of Applied Earth Observation and Geoinformation*, 12(1), 9–16.
- Greșiță, C. I. (2011). Expert system used for monitoring the behavior of hydrotechnical constructions. *REVCAD-Journal of Geodesy and Cadastre*, 11, 75–84.
- Greșiță, C. I. (2013). *Surveying methods to studying the behavior of dams*. Iași: Tehnopress Publishing House (in Romanian).
- IGAR (2014). Report on climate change effects for Baragan Plain. Romania.
- Iordache, E. (2010). *Accessibility of forests*. Brasov: Transilvania University Publishing House (in Romanian).
- Ienciu, I., Dimen, L., Ludusan, N., Grecea, C., Borșan, T., & Oprea, L. (2012). Dynamics of the rill and gully erosion using GIS technologies. *Journal of Environmental Protection and Ecology*, 13(1), 345–351.
- Jensen, J. R. (1996). *Introductory digital image processing: a remote sensing perspective* (2nd ed.). New Jersey: Prentice-Hall, Upper Saddle River.
- Johnson, D. L., & Lewis, L. A. (1995). *Land degradation: creation and destruction*. Oxford: Blackwell Publishers.
- Kaplan, S., Blumberg, D. G., Mamedov, E., & Orlovsky, L. (2014). Land-use change and land degradation in Turkmenistan in the post-Soviet era. *Journal of Arid Environments*, 103, 96–106.
- Lu, D., Mausel, P., Brondizio, E., & Moran, E. (2002). Assessment of atmospheric correction methods for Landsat TM data applicable to Amazon basin LBA research. *International Journal of Remote Sensing*, 23(13), 2651–2671.
- Lu, D., & Weng, Q. (2004). Spectral mixture analysis of the urban landscape in Indianapolis with Landsat ETM+ imagery. *Photogrammetric Engineering and Remote Sensing*, 70(9), 1053–1062.
- Lu, D., Batistella, M., Mausel, P., & Moran, E. (2007). Mapping and monitoring land degradation risks in the Western Brazilian Amazon using multitemporal Landsat TM/ETM+ images. *Land Degradation and Development*, 18(1), 41–54.
- Marcu, V., Bîlea, C., Gheorghîță, G., & Dolocan, C. (2011). Particular aspects of the rainfall regime in Vlasei Plains. *Bulletin of the Transilvania University of Brașov Series II: Forestry, Wood Industry, Agricultural Food. Engineering*, 4(53, 2), 53–58.
- Marcu, M., & Marcu, V. (2012). *Forest meteorology and climatology*. Brasov: Transilvania University Publishing House (in Romanian).
- Munteanu, C., Niță, M. D., Abrudan, I. V., & Radeloff, V. C. (2016). Historical forest management in Romania is imposing strong legacies on contemporary forests and their management. *Forest Ecology and Management*, 361, 179–193.
- National Institute of Statistics (2006). Farm structure survey 2005. Bucharest.
- National Institute of Statistics (2010a). General agricultural census 2010. Bucharest.
- National Institute of Statistics (2010b). Romanian statistical yearbooks 1990–2010. Bucharest.
- National Institute of Statistics (2015). TEMPO-Online database. <http://statistici.insse.ro/shop/?page=termeni&lang=en>. Accessed 20 June 2015.
- Oldeman, R. L., Hakkeling, R. T. A., & Sombroek, W. G. (1990). *World map of the status of human-induced soil degradation. An explanatory note*. Wageningen, Netherlands: International Soil Reference and Information Centre.
- Pech, R. P., Davis, A. W., Lamacraft, R. R., & Graetz, R. D. (1986). Calibration of LANDSAT data for sparsely vegetated semi-arid rangelands. *International Journal of Remote Sensing*, 7(12), 1729–1750.
- Roberts, D. A., Batista, G. T., Pereira, J. L. G., Waller, E. K., & Nelson, B. W. (1998). Change identification using multitemporal spectral mixture analysis: applications in eastern Amazonia. In R. S. Lunetta & C. D. Elvidge (Eds.), *Remote sensing change detection: environmental monitoring applications and methods* (pp. 137–161). Chelsea: Ann Arbor Press.
- Sevastel, M., Petrescu, N., Musat, M., Radu, A., & Sarbu, N. (2010). Soil erosion and conservation in Romania—some figures, facts and its impact on environment. *Annals. Food Science and Technology*, 11(1), 105–110.
- Shoshany, M., Golik, A., Degani, A., Lavee, H., & Gvirtzman, G. (1996). New evidence for sand transport direction along the coastline of Israel. *Journal of Coastal Research*, 12(1), 311–325.
- Sima, M., Popovici, E. A., Bălțeanu, D., Micu, D. M., Kucsicsa, G., Dragotă, et al. (2015). A farmer-based analysis of climate change adaptation options of agriculture in the Baragan Plain Romania. *Earth. Perspectives*, 2(1), 1–21.

- Small, C. (2001). Estimation of urban vegetation abundance by spectral mixture analysis. *International Journal of Remote Sensing*, 22(7), 1305–1334.
- Small, C. (2002). Multitemporal analysis of urban reflectance. *Remote Sensing of Environment*, 81(2–3), 427–442.
- Smith, M. O., Ustin, S. L., Adams, J. B., & Gillespie, A. R. (1990). Vegetation in deserts: I. A regional measure of abundance from multispectral images. *Remote Sensing of Environment*, 31(1), 1–26.
- Tereşneu, C. C. (2012). *Automatic data processing of geodetic data*. Brasov: Transilvania University Publishing House (in Romanian).
- Turubanova, S., Potapov, P., Krylov, A., Tyukavina, A., McCarty, J. L., Radeloff, V. C., et al. (2015). Using the Landsat data archive to assess long-term regional forest dynamics assessment in Eastern Europe, 1985–2012. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XL-7(W3), 531–537.
- Vorovencii, I. (2015). Assessing and monitoring the risk of desertification in Dobrogea, Romania, using Landsat data and decision tree classifier. *Environmental Monitoring and Assessment*, 187(4), Article 204.
- Vrînceanu, G. A. (2011). Research on the vulnerability of soils to the degradation processes—desertification in the Baragan Plain. PhD Thesis, University of Agronomic Sciences and Veterinary Medicine: Bucharest, 256 p.
- Wu, C., & Murray, A. (2003). Estimating impervious surface distribution by spectral mixture analysis. *Remote Sensing of Environment*, 84(4), 493–505.