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# Applying the change vector analysis technique to assess the desertification risk in the south-west of Romania in the period 1984–2011

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**Abstract** The desertification risk affects around 40% of the agricultural land in various regions of Romania. The purpose of this study is to analyse the risk of desertification in the south-west of Romania in the period 1984–2011 using the change vector analysis (CVA) technique and Landsat thematic mapper (TM) satellite images. CVA was applied to combinations of normalised difference vegetation index (NDVI)-albedo, NDVI-bare soil index (BI) and tasselled cap greenness (TCG)-tasselled cap brightness (TCB). The combination NDVI-albedo proved to be the best in assessing the desertification risk, with an overall accuracy of 87.67%, identifying a desertification risk on 25.16% of the studied period. The classification of the maps was performed for the following classes: desertification risk, re-growing and persistence. Four degrees of desertification risk and re-growing were used: low, medium, high and extreme. Using the combination NDVI-albedo, 0.53% of the analysed surface was assessed as having an extreme degree of desertification risk, 3.93% a high degree, 8.72% a medium degree and 11.98% a low degree. The driving forces behind the risk of desertification are both anthropogenic and climatic causes. The anthropogenic causes include the destruction of the irrigation system, deforestation, the destruction of the forest

shelterbelts, the fragmentation of agricultural land and its inefficient management. Climatic causes refer to increase of temperatures, frequent and prolonged droughts and decline of the amount of precipitation.

## Introduction

### Background

Presently, desertification affects 110 countries on all continents with a population that exceeds one billion inhabitants, the annual cost of desertification being estimated at around 42 billion dollars (Marinică 2006; Marinică and Marinică 2014). Among these countries, there are also five member states of the European Union. At a global level, according to the data supplied by the United Nations Convention to Combat Desertification (UNCCD), a third of the Earth's surface is covered by arid land. Out of the arid land used in agriculture, 3.6 billion ha (70%) is affected by a medium to high degree of degradation risk (Marinică and Marinică 2014). Each year, 24 billion t of agricultural land is lost because of erosion. Moreover, each year, approximately 5% of the value of the world's agricultural production, that is, 340 billion euro, is lost because of desertification and drought, agricultural land being turned into non-cultivable land.

Romania is one of the countries with areas affected by desertification risk. These are the result of frequent,

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long and pronounced droughts, caused mainly not only by climatic imbalances, but also by the reduction of the surface area occupied by forests in regions with plains and low hills. In Romania, over 7 million ha (29.36% of the country's surface) is affected by desertification risk. Out of the entire agricultural surface, around 40% is located in areas with desertification risk, the most exposed regions being in the south of the Romanian Plain, the region of Dobrogea, the south of Moldova and of the Western Plain.

The south-west of Romania is the most affected area, displaying aridisation tendencies, as acknowledged by the Romanian state starting from 1977. Here, the aridisation processes are intense, especially in the area called 'the Oltenian Sahara'. The largest surface affected is situated in the county of Dolj, bordered by Calafat, Poiana Mare, Sadova, Bechet, Dabuleni and the Danube, with a surface of 104,600 ha. The area is already covered by sand, is arid and has desertification tendencies. The only Museum of Sand in Europe, spreading over 12 ha, is located in this area. The area is covered by white sand which was left unmanaged by the communist regime in order to perform comparisons between cultures from managed land and those from unmanaged land. In the Dabuleni area, the land is sandy and the specialists estimate that each year, over 1000 ha will be covered by sand.

Land desertification is a complex area of scientific research in which remote sensing is used regularly with good results. The desertification process was analysed in regional-scale studies using images with average spatial resolution of the types Landsat multispectral scanner (MSS), thematic mapper (TM) and enhanced thematic mapper plus (ETM+) (Mason et al. 2008; Xu et al. 2009; Qi et al. 2011; Karnieli et al. 2014), as well as AVHRR and MODIS coarse resolution imagery (Runnstrom 2003; Mason et al. 2008; John et al. 2009; Karnieli et al. 2014). On the basis of different biophysical indicators (vegetation indices, albedo, fractional cover etc.), quantitative and qualitative assessments were performed which allowed classification according to desertification risk degrees (Xu et al. 2009; Qi et al. 2011; Karnieli et al. 2014).

The main purpose of the study is to analyse the desertification risk in the south-west of Romania during the period 1984–2011 by applying the change vector analysis (CVA) technique to indices and components derived from Landsat 5 TM satellite images. The specific objectives are as follows: (1) to apply CVA to normalised difference

vegetation index (NDVI)-albedo, NDVI-bare soil index (BI) and tasselled cap greenness (TCG)-tasselled cap brightness (TCB) combinations, in order to establish which is the most suitable to analyse the desertification risk in the studied area; (2) to analyse the desertification risk for the period 1984–2011 and (3) to analyse the driving forces that led to the desertification risk.

## Studied period

The period studied (1984–2011) is characterised by important changes brought about by the fall of the communist regime in Romania in 1989, which triggered major economic and social changes. After 1989, as a market economy was adopted and private property was emphasised, a series of land laws were adopted that radically changed the management of agricultural land (Popa 2003; Popa and Nita 2013). By restitution to the former owners, agricultural lands were fragmented in 0.5–10-ha lots, thus destroying the intensive agriculture practiced on large surface areas of hundreds, or even thousands, of hectares through the former agricultural production cooperatives. Consequently, the irrigation systems were abandoned, then, they disintegrated which led to an inefficient management of lands in the area. Also, most of the agricultural lands cultivated before 1989 were abandoned. The lack of an irrigation system and rising temperatures led to an acceleration of the aridisation process in the south-west of Romania. Another reason was deforestation on large surface areas in the studied area and also upstream of it, in the hill and mountain areas (Huber 2008). In addition to these anthropogenic actions, climatic factors also contributed through major and prolonged droughts during the years 1991–1993, 2000–2002, and in 2007. Thus, without neglecting the importance of the period prior to 1989, the post-1989 period is considered as being the most suitable for an analysis of the desertification risk in the south-west of Romania. For comparison purposes, the period under investigation also includes several years from before 1989.

## Materials and methods

### Study area

The studied area is located in the south-west of Romania and represents part of the region called Oltenia (Fig. 1). This is situated between 22° 23′ 15″ and 24° 38′ 49″ east
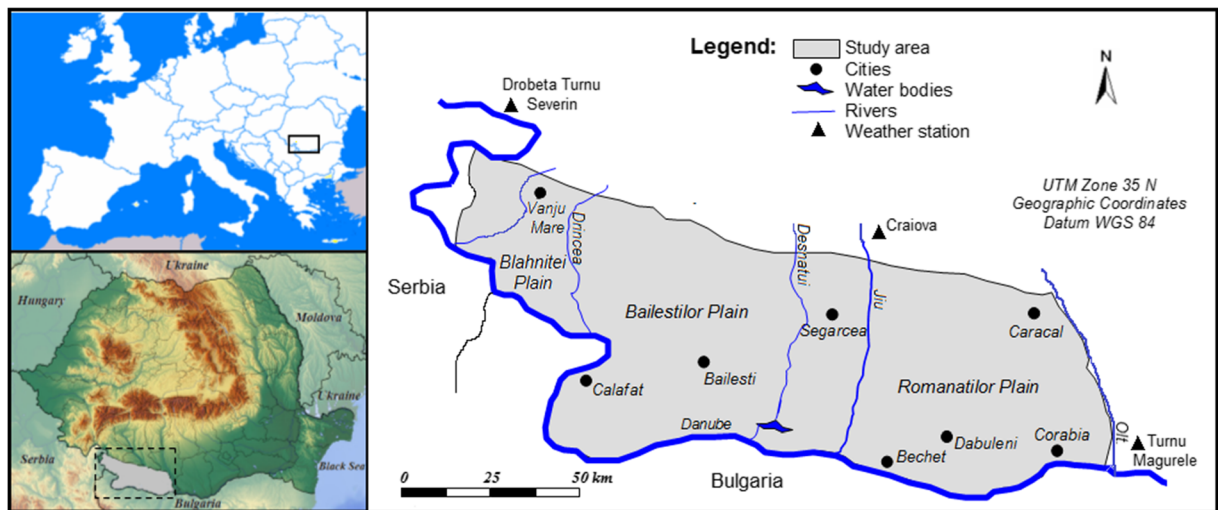
**Fig. 1** The location of the research. The studied area includes the Romanati Plain, Bailesti Plain, Blahnita Plain and a small part in the south of the Getic Plateau. To the east, the studied area approaches the Olt River

longitude and between 43° 40′ 08″ and 44° 29′ 53″ north latitude. The studied surface is of 853,716 ha from three counties (Mehedinti, Dolj and Olt). Its altitude ranges from 25 m in the Danube floodplain to 240 m in the Getic Plateau. This difference in altitude determines a difference in the quantity of average annual precipitation and in average annual temperature. Thus, in the southern part, the average annual rainfall is around 563 mm/year and the average annual temperature rises above 11.5 °C (WorldClim-global climate data 2015). In the northern part, towards the Getic Plateau, precipitation is around 640 mm/year and the average annual temperature decreases below 11 °C. The increase of the average annual temperatures and the decrease of the quantity of average annual precipitation over the last three decades led, in many cases, to the drying of the vegetation layer and even of some forest species (Prăvălie et al. 2013). According to the climatic regionalisation, southern Oltenia falls in the transitional temperate-continental climate with Mediterranean influences. Air humidity is 78–80%, and the mean annual potential evapotranspiration is over 700 mm/year (Sandu et al. 2008).

About 14% (116,300 ha) of the studied surface is covered by sandy-texture soil overlapping sand deposits (Pedology and Agrochemistry Research Institute 2013). A feature specific for the landscape is the presence of sand dunes to the north of the Danube and to the east of Jiu River, with these deposits reaching a thickness of 20 m in the areas Dabuleni and Leu-Rotunda (Prăvălie et al. 2014). The soils in the area have a sandy texture,

represented mainly by Cambic chernozem spread along the Danube area, and psamosoils, which cover large surface areas, especially to the east of Jiu River.

The vegetation is specific to flat land and consists of Hungarian oak (*Querqus frainetto*), Turkey oak (*Querqus cerris*), downy oak (*Querqus pubescens*), Tatar maple (*Acer tataricum*), pedunculate oak (*Querqus pedunculiflora*) and field maple (*Acer campestre*). The sand deposits are covered by forests of fake acacia (*Robinia pseudoacacia*) as one can encounter in the west of the town of Dabuleni and of Leu-Rotunda Plain, in the central-western part of Baileşti Plain.

Materials used

In the study, two frames clipped from a time series of Landsat 5 TM satellite images acquired on 12 September 1984 and 23 September 2011 were used. These are part of path 184, rows 29 and 30. The images were downloaded from the Internet at no cost, from the US Geological Survey (USGS) site (http://glovis.usgs.gov). The spatial resolution of multispectral bands is of 30 m. They have a 1-T level of correction and were geo-referenced at Universal Transverse Mercator (UTM), datum WGS 84, zone 35 N.

The reference data used in the assessment of the products obtained after the images were processed are as follows: the soil map (1:1,000,000), the land erosion map (1:1,000,000), the vegetation map (1:100,000), the radiation distribution map (1:100,000) and the drought

risk map (1:1,000,000). Meteorological data for monthly and annual averaged temperature and rainfall was used; it was collected from different reports, weather stations and the Romanian Meteorological Institute. In addition, social and economic census data of the study area were collected from local statistical yearbooks (General Agricultural Census 2010; National Institute of Statistics 2015).

## Methods used

### Image pre-processing

Relative radiometric normalisation (RRN) was carried out for the 1984 image, and the 2011 image represented the reference image. The automatic scattergram-controlled regression (ASCR) proposed by Eldvige et al. (1995) was the RRN method used. Applying the ASCR method entailed identifying the 'no-change' pixel set, i.e. all the pixels which occupy the core of the water and land data clusters visible in red-near-infrared scattergrams. The set of identified no-change pixels allowed us to calculate, through regression, the gain and offset values. These values were used afterwards in the normalisation of the subject image in order to match the reference image. In Eldvige et al. (1995), the procedure is described in detail.

### Indices, components and albedo calculation

The desertification risk can depend on the regional and local features of the ecosystems (including aridity, parental material, micro-relief and non-photosynthetic vegetation) recorded differently by certain indicators. Given the complexity of the studied area, more indices and components were used in applying the CVA technique.

In order to identify the desertification risk, the specialised literature shows that there is a well-defined relationship between NDVI and biomass productivity (Jensen 2007; Purkis and Klemas 2011). The decline of primary productivity is a reliable indicator of the decrease in or destruction of the biological productivity, particularly in semi-arid and arid areas (Li et al. 2004; Wessels et al. 2004; Yengoh et al. 2014). NDVI is also corroborated with various vegetation parameters, such as green biomass, chlorophyll concentration, leaf area index, foliar loss and damage, photosynthetic activity and phenology (Zaady et al. 2007). The reduction of the NDVI values shows negative changes which, in arid and semi-arid areas, indicate increase of the desertification risk. NDVI was calculated according to reflectance that is measured in near infrared ($NIR$) and the red band ($R$) with the following formula (Rouse et al. 1974):

$$NDVI = \frac{NIR - R}{NIR + R} \tag{1}$$

The brightness index ($BI$) is used very frequently in desertification studies. BI was calculated through a linear combination of spectral reflectance in green ($G$), red ($R$) and near-infrared ($NIR$) bands. Several brightness indices can be found in the literature; in this study, BI was calculated using the following relationship (Ahmed and Ahmad 2013):

$$BI = \frac{G^2 + R^2 + NIR^2}{60} \tag{2}$$

In the case of Landsat images, $G$ is band 2, $R$ is band 3 and $NIR$ is band 4.

Albedo is a physical indicator used frequently in the analysis of desertification, which is influenced by land surface conditions such as soil moisture, soil brightness and vegetation coverage. The visible change of the land surface conditions, because of the albedo increase, can show an increase of desertification risk. In the case of the semi-arid areas, this albedo increase leads to the loss of the radiation energy absorbed by the earth's surface and the convective overturning is reduced. In this study, albedo was calculated on the basis of radiometrically normalised Landsat TM images, using the following formula:

$$Albedo = 0.356\alpha_1 + 0.130\alpha_3 + 0.373\alpha_4$$
$$+ 0.085\alpha_5 + 0.072\alpha_7 - 0.0018 \tag{3}$$

where $\alpha_1$, $\alpha_3$, $\alpha_4$, $\alpha_5$, $\alpha_7$ are narrow-band albedos for the bands 1, 3, 4, 5 and 7 of Landsat TM.

The tasselled cap (TC) transformation rotates the Landsat data so that 95% or more of the total variability is expressed in the first two bands, TCB and TCG (Lillesand and Kiefer 2000). TCB is defined on the direction of variation of soil reflectance, and TCG is strongly related to the amount of green vegetation present in the area (Siwe and Koch 2008). These components are widely used in the analysis of changes, because landscape changes are linked to changes in brightness and greenness, which in turn depend on soil features and the amount of vegetation. The TCG and TCB components were calculated for the 1984 and 2011 images from non-thermal bands using coefficients for

Landsat 5 TM at-satellite reflectance from the ERDAS Imagine program. The use of these two components, in this study, was based on their direct relation to the physical features of the landscape (Teresneu 2012).

*Change vector analysis*

CVA is a rule-based change detection technique that analyses the magnitude and direction of changes in the spectral space among satellite images acquired at different dates (Lambin and Strahler 1994; Parmenter et al. 2003). The CVA technique is an effective tool to research land cover change dynamics and to monitor ecosystems. In the current study, CVA was applied to the following pairs of indices and components: NDVI-albedo, NDVI-BI and TCG-TCB. They were chosen to represent changes in vegetation and bare land, including sandy lands.

The magnitude ($\Delta M$) of the changes between date 1 and date 2 was calculated based on the following relationship (Idrisi Kilimanjaro Tutorial 2003):

$$\Delta M_{band1\_band2}$$
$$= \sqrt{(date2band1 - date1band1)^2 + (date2band2 - date1band2)^2}$$

(4)

The values of the magnitude were used to determine the degrees of desertification risk and of re-growing in the studied area. On the basis of the average ($m$) and standard deviation ($s$) in the magnitude images, the length of the vector taken into consideration in delimiting the degrees of desertification risk and of re-growing was calculated. In determining the length of the vector, magnitude values above 3.5 $s$, as compared to the average, were considered as outliers. For the studied area, four degrees of desertification risk and of re-growing were set: low, medium, high and extreme (Table 1).

The direction of changes ($\alpha$) is the angle between the two vectors, which defines the quadrant, and it shows the change from the pixel measured on date 1 to the corresponding pixel measured on date 2. Change directions were determined using each pair of indices and components at date 1 and date 2, applying the following relationship (Idrisi Kilimanjaro Tutorial 2003):

$$tg\alpha_{band1\_band2} = \frac{date2band2 - date1band2}{date2band1 - date1band1}$$

(5)

The analysis took into consideration two bands for each combination and resulted in four major classes that

**Table 1** Definition of the grade of the desertification risk and re-growing

| Grade of risk desertification | NDVI-albedo | NDVI-BI | TCG-TCB |
|---|---|---|---|
| Low (< 25%) | 0.0000–0.1468 | 0.0000–0.1471 | 0.0000–0.1793 |
| Medium (25–50%) | 0.1468–0.2937 | 0.1471–0.2943 | 0.1793–0.3587 |
| High (50–75%) | 0.2937–0.4405 | 0.2943–0.4414 | 0.3587–0.5380 |
| Extreme (> 75%) | 0.4405–0.5874 | 0.4414–0.5586 | 0.5380–0.7173 |

show the direction of changes. The first class, which corresponds to the first quadrant (0°–90°), indicates an increase of both components, and the third, which corresponds to the third quadrant (180°–270°), shows a decrease of both components. In this study, it was considered that the situation on these quadrants, for all the chosen combinations, represents persistence and they are grouped in one single class. In the second class, which corresponds to the second quadrant (90°–180°), and in the fourth class, specific to the fourth quadrant (270°–360°), one of the components is positive and the other one is negative. In the second quadrant, the areas with desertification risk were taken into consideration, while in the fourth quadrant, the areas with re-growing were considered. The description of signification of each class and quadrant, respectively, for all the indices and components is presented in Table 2.

The results were validated based on the error matrix (Table 3) using reference data. The ground truth consisted in 100 equalised random points for each class. The visual interpretation method discussed in the literature (Cohen et al. 1998) was used in certain cases to develop reference data for error matrices (Siwe and Koch 2008). For desertification risk, the areas without vegetation or with scarce vegetation or with bare or almost bare land, which presents a desertification risk, were taken into consideration; in the re-growing category, surface areas with vegetation regeneration were considered, and in the persistence category, surface areas without changes were all identified based on reference data. The points were labelled in the three classes by comparison and visual interpretation.

The change direction and magnitude values were cross-tabulated and classified into 16 classes for all the combinations of indices and components. Then, all the classes specific for the persistence category in the two quadrants

**Table 2**  Possible change direction classes based on indices and components and related types of change

NDVI-albedo

| Classes | Albedo | NDVI | Description | Signification |
|---|---|---|---|---|
| Class 1 | + | + | Vegetation loss | Persistence |
| Class 2 | + | − | Bare soil expansion | Desertification |
| Class 3 | − | − | Vegetation gain | Persistence |
| Class 4 | − | + | Chlorophyll increase | Re-growing |

NDVI-BI

| Classes | BI | NDVI | Description | Signification |
|---|---|---|---|---|
| Class 1 | + | + | Decrease of wetness | Persistence |
| Class 2 | + | − | Bare soil expansion | Desertification |
| Class 3 | − | − | Increase of wetness | Persistence |
| Class 4 | − | + | Chlorophyll increase | Re-growing |

TCG-TCB

| Classes | TCB | TCG | Description | Signification |
|---|---|---|---|---|
| Class 1 | + | + | Decrease of vegetation | Persistence |
| Class 2 | + | − | Bare soil expansion | Desertification |
| Class 3 | − | − | Increase of vegetation | Persistence |
| Class 4 | − | + | Chlorophyll increase | Re-growing |

**Table 3**  Error matrix for the studied combinations in the period 1984–2011

| Reference classes | Classification classes | | | Total | User's accuracy |
|---|---|---|---|---|---|
| | Persistence | Re-growing | Desertification risk | | |
| NDVI-Albedo | | | | | |
| Persistence | 90 | 6 | 4 | 100 | 90.00 |
| Re-growing | 2 | 88 | 10 | 100 | 88.00 |
| Desertification risk | 3 | 12 | 85 | 100 | 85.00 |
| Total | 95 | 106 | 99 | 300 | |
| Producer's accuracy | 94.74 | 83.02 | 85.86 | | |
| Overall accuracy 87.67% | | | | | |
| NDVI-BI | | | | | |
| Persistence | 89 | 6 | 5 | 100 | 89.00 |
| Re-growing | 8 | 84 | 8 | 100 | 84.00 |
| Desertification risk | 6 | 11 | 83 | 100 | 83.00 |
| Total | 103 | 101 | 96 | 300 | |
| Producer's accuracy | 86.41 | 83.17 | 86.46 | | |
| Overall accuracy 85.33% | | | | | |
| TCG-TCB | | | | | |
| Persistence | 87 | 7 | 6 | 100 | 87.00 |
| Re-growing | 8 | 79 | 13 | 100 | 79.00 |
| Desertification risk | 5 | 19 | 76 | 100 | 76.00 |
| Total | 100 | 105 | 95 | 300 | |
| Producer's accuracy | 87.00 | 75.24 | 80.00 | | |
| Overall accuracy 80.67% | | | | | |

were grouped into a single one, in the end resulting only in nine classes (four for the desertification risk category, four for the re-growing category and one for the persistence category). For each degree of desertification risk and re-growing, as well as for persistence, the surface areas and percentages that they occupy were calculated.

## Results and discussion

The analysis of the desertification risk

### NDVI-albedo

Cross-tabulation of the change direction and magnitude allowed us to obtain maps that show, for the period 1984–2011 and for each combination, the distribution of the affected areas (Fig. 2). The CVA technique applied to the NDVI-albedo combination returned the highest accuracy (87.67%) (Table 3) and overall kappa statistics of 0.8150 (Table 4). The surface areas affected by the desertification risk calculated by applying CVA were estimated at 214,778 ha (25.16%). According to the degree of desertification risk, the estimates were as follows (Fig. 3a): 0.53% extreme desertification, 3.93% high desertification, 8.72% medium desertification and 11.98% low desertification.

The results obtained show that emissivity and albedo are closely linked to NDVI for the vegetated fraction of the landscape. In locations with desertification risk, the decrease in NDVI values is linked directly to the reduction of primary productivity, photosynthetic activity and the loss of the vegetative apparatus, which is also indicated in other studies (Zaady et al. 2007). It is also concluded that the decrease in NDVI values triggered changes in the vegetation phenology and the loss of radiation energy absorbed on the surface of the earth, which led to an increase in albedo values. The soils in the studied area also contributed to the increase in the desertification risk, and they have made the relation between NDVI and albedo substantially different. Thus, Cambic chernozem soils in the areas affected by desertification risk caused an increase in surface temperatures from sandy areas that reached even 60–70 °C on summer days.
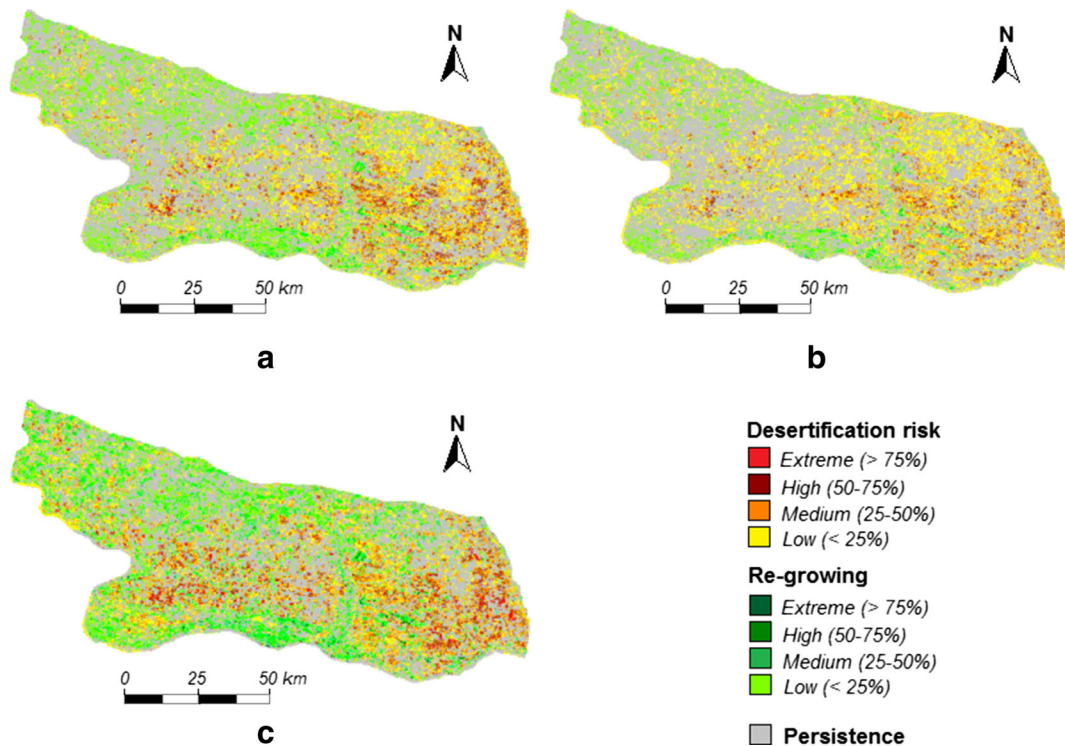


Fig. 2 Maps obtained after cross-tabulation that render surface areas according to the degrees of the desertification risk, re-growing and persistence. **a** NDVI-albedo. **b** NDVI-BI. **c** TCG-TCB.

The surface areas most affected by desertification risk are located in the Romanati Plain and in the south of the Bailesti Plain, bordering the Danube floodplain

**Table 4** Kappa statistics for the analysed classes and combinations

| Classes | NDVI-albedo | NDVI-BI | TCG-TCB |
|---|---|---|---|
| Persistence | 0.8537 | 0.8325 | 0.8050 |
| Re-growing | 0.8144 | 0.7588 | 0.6769 |
| Desertification risk | 0.7761 | 0.7500 | 0.6488 |
| Overall kappa statistics | 0.8150 | 0.7800 | 0.7100 |

The areas with extreme risk are small isolated islands, identified in the sandy area to the north of Dabuleni, to the east of Jiu River, in the Romanati Plain and to the north of the villages Tunarii Noi and Piscul Nou. During periods with high temperatures, these become intense-
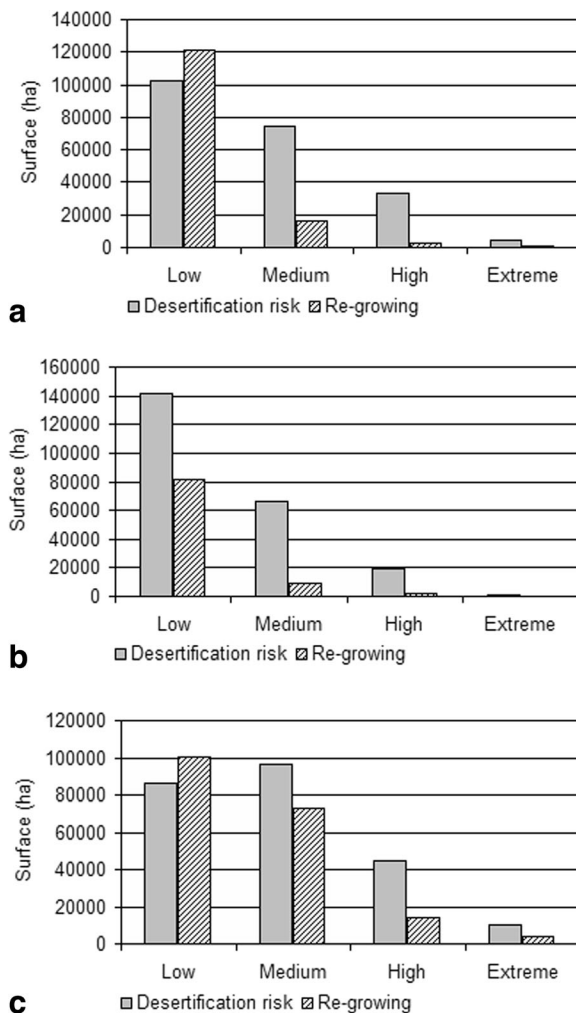
**Fig. 3** Distribution of the surface areas according to their degree of desertification risk and re-growing for the combinations **a** NDVI-albedo, **b** NDVI-BI and **c** TCG-TCB

heat islands. The marked desertification process in these areas is characterised by the lack of vegetation; the existence of a lithological substratum, which favours wind erosion; and the presence of sand deposits. These deposits from the valleys of the Danube and Jiu River are the result of wind erosion and require permanent monitoring and constant work to cover them with forest vegetation so as to counter the action of the wind (Prăvălie et al. 2014). In the last decades, many of the sand deposits were reactivated as a result of the inefficient management of the local forest ecosystems. This was caused by illegal clear cuttings, by inefficient policies of local authorities in managing and protecting forests, and by the lack of viable strategies for stabilising the sands.

According to re-growing degrees, surface areas are distributed following a decreasing curve (Fig. 3). NDVI-albedo combination was estimated at 0.06% out of the entire analysed surface area in the extreme re-growing degree case, and 0.36% in the high re-growing degree case. The re-growing process in the studied area is very weak and discontinuous and is unsupported by the environmental conditions, as shown by the very small surface areas with high and extreme degrees. Most surface areas with re-growing are classified as low and medium, which shows a weak evolution towards correcting the situation in the studied area.

Surface areas estimated in the case of low re-growing degree for the NDVI-albedo combination are larger than those estimated in the case of low desertification risk. For the persistence category, out of the entire studied area, 58.42% was estimated (Fig. 4). These surface areas are spread throughout the entire area, alternating with surface areas affected by desertification risk, and they are characterised by vegetation gain and vegetation loss (Fig. 2).

The results obtained are in accordance with those specified in literature (Karnieli et al. 2014; Ma et al.
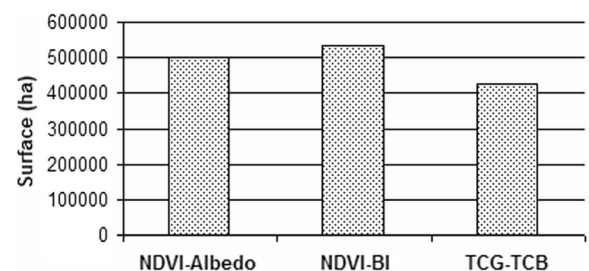
**Fig. 4** The distribution of surface areas with persistence identified by each combination after applying the CVA technique

2011) that used the same methodology. In other studies (Xu et al. 2009), NDVI and albedo indicators were used as well as the moving standard deviation index (MSDI) in assessing desertification in the Ordos Plateau, China, applying the decision tree classifier (DTC) method. The results have shown that desertification has expanded in some locations of the Ordos Plateau, but the general trend from 1980 to 2000 consisted of the reduction of desertification. Another study (Lamchin et al. 2017) has used NDVI, albedo indicators and other variables for desertification risk analysis. They found that more than 15% of the total land area in Hogno Khaan, Mongolia, suffered from severe desertification in 2011, increasing from 7% in 1990.

### NDVI-BI

CVA technique applied to the NDVI-BI combination led to obtaining an overall accuracy of 85.33%. Similar accuracies obtained by applying the CVA technique to the NDVI-albedo and NDVI-BI combinations can be explained by the higher values of the correlation coefficients between albedo and BI. For 1984, the correlation coefficient between albedo and BI is 0.86, while for 2011, it is 0.92, which shows that the two indices worked similarly.

The surface area estimated as being affected by desertification risk after applying CVA to the NDVI-BI combination was 229,142 ha (26.84%). Out of the total analysed surface, 0.16% is affected by an extreme desertification risk, 2.27% by a high desertification risk and 7.79% by a medium desertification risk (Fig. 3b).

For the low desertification risk, out of all the combinations, NDVI-BI highlights the larger surface (16.62%). This is because the analysed area is a complex one, with a lot of agricultural land with cultures in different development stages, with various species and different densities, among other factors, at the moment of acquiring the satellite images. This means that it is possible that NDVI-BI might have recorded partially cultivated agricultural lands as uncultivated lands. Also, BI gave a clearer picture of shrubs and other small plants that are photosynthetically inactive, resulting in low reflectance in near-infrared (Escadafal and Huete 1991), to the north of the rivers Jiu and Olt. In addition, BI helped reduce the effect of vegetation and emphasised the various categories of reactivated sands. This is because the sand deposits in the area are covered by sandy-texture soils that led to an increase in BI

values. The reactivated sand caused by wind erosion and the sand in the valleys of rivers in the area and of the Danube cannot be separated.

Regarding surfaces with re-growing, NDVI-BI estimated only 0.03% of the entire studied surface area, for the extreme degree, and almost 0.20% for the high re-growing degree (Fig. 3b). In the persistence class, the NDVI-BI combination estimated 62.33% of the studied surface area (Fig. 4) and it is characterised by an increase of wetness and a decrease of wetness. These surfaces are mainly concentrated in the northern part of the Bailesti Plain, the north-west of the analysed area; isolated, under the form of islands; and spread throughout the entire area. On these surfaces, no changes were estimated for the period 1984–2011; they are characterised by a fragile stability, and a part of them can be exposed at any moment to desertification risk. It is the case for surfaces located close to the already affected areas and those bordering agricultural lots, unpaved access roads, abandoned irrigation canals etc.

The results obtained are close to those in the literature. Dawelbait and Morari (2011) used CVA applied to bright soil (BS) and bright vegetation (BV) components, after applying the spectral mixture analysis (SMA) for obtaining endmembers. Results show that CVA applied to components that render uncovered soil and vegetation allows for obtaining information on vegetation cover and soil surface type and identifying risk areas. Also, CVA was applied to the sand and vegetation fractions from SMA to stratify and analyse desertification processes in north Kordofan state, Sudan (Khiry 2007). The study showed that by applying this method, during 1988–2003, there was an increase in the re-growing surface area and a decrease of the desertification risk as compared to the first period. Becerril-Piña et al. (2015) used CVA applied to SAVI, instead of NDVI, and BI indices for the assessment of desertification in the centre part of Mexico. In another study, Becerril-Piña et al. (2016) have applied CVA to NDVI and BI indices and albedo for identifying areas at risk of desertification in Mexico, in addition to monitoring changes in the degree or direction of desertification. Results have shown that in the semi-arid area of Querétaro state, 48.3% of the land use corresponds to agricultural lands, 2.7% of the studied area does not present any desertification degree and 49% of the surface is affected by the following desertification degrees: 5.5% extreme, 10.9% severe, 18.9% moderate and 13.7% low (Becerril-Piña et al. 2016).

*TCG-TCB*

The overall accuracy obtained after applying the CVA technique in the case of the TCG-TCB combination was of 80.67%. The lower value of overall accuracy for this combination, as compared to the others, can be ascribed to a weaker correlation between BI and TCB and less to that between albedo and TCB.

The correlation between NDVI and TCG proved high for both 1984 (0.96) and 2011 (0.92). Thus, the difference was made by the component that renders uncovered soil, namely, TCB and albedo and BI, respectively, in the case of the other combinations. It is precisely because of this weaker correlation between these components that the areas identified as being affected by desertification risk and re-growing are slightly different both in point of size and, in certain situations, of location. For all the combinations, the commission errors were more present in the case of classes with desertification risk and re-growing, which makes the labelling of those areas more difficult as compared to the persistence class.

The surface estimated as affected by the desertification risk following the application of CVA to the TCG-TCB combination was of 237,757 ha (27.85%). For the extreme desertification degree, the TCG-TCB combination estimated 1.19% of the studied surface, in the case of a high desertification risk 5.21%, in the case of a medium desertification risk 11.33% and in the case of a low desertification risk 10.12% (Fig. 3c). As compared to the other two combinations, where the distribution of surfaces by degrees of desertification risk was a decreasing one, in the case of the TCG-TCB combination, for the medium desertification risk degree, a larger surface was estimated. These lands are located especially between Jiu and Olt rivers, but they also spread in the southern part of the Bailestilor Plain, bordering the Danube floodplain. These areas are characterised by high temperatures and soils without vegetation, especially sandy soils, distributed mainly in the Romanati Plain (between the rivers Jiu and Olt), to the north of the villages Tunarii Noi and Piscul Nou, but they are also spread in the central-southern part.

TC transformation belongs to ortogonal indices, and in a way, it represents a poorer predictor of combined vegetation, made up of drying vegetation and sparse vegetation, as compared to an exclusively green vegetation cover. Thus, the spectral response of drying plants and of sparse vegetation is more likely to be found in the third component tasselled cap wetness (TCW) of the TC transformation, and not in the first two, TCG and TCB (Jafari 2007). This way, surfaces with drying vegetation or sparse vegetation were assigned high and extreme desertification risks, the TCG-TCB combination overestimating these surface areas.

An analysis of TCG values for the vegetation in areas with dunes and interdunes on sandy land showed that these are different. On dunes, TCG values are not significantly different; on the other hand, on interdunes, because of the steppe's different conditions, TCG values are significantly different. This was also noted in the case of NDVI values. Therefore, on interdunes, the development conditions of the vegetation cover are better as compared to dunes, which determines a different dynamics of vegetation and different displays of desertification risk, as also shown in other works (Kong 2012).

The TCB-TCG combination estimates re-growing in the extreme degree on 0.44% of the total studied surface and in the high re-growing degree, 1.65% (Fig. 3c). Most surfaces with re-growing are classified as low and medium which shows a weak evolution towards correcting the situation in the studied area. In the low re-growing degree, the estimated surface areas are larger than those with a desertification risk (Fig. 3c). Re-growth is the result of surface covered by trees, located especially not only in the northern part of the studied area (the south of the Getic Plateau), but also in the southern part, in the Danube floodplain and in isolated islands spread across the studied area. Also, re-growth includes surface covered by agricultural crops in various development stages which benefited from a more favourable microclimate and conditions. In the persistence class, the TCG-TCB combination estimated 49.52% of the studied surface (Fig. 4). These are characterised by an increase and decrease of vegetation.

CVA applied to the TCG-TCG combination was used in several studies regarding the risk desertification assessment, and the results obtained in this study are close to these. Flores and Yool (2007) have found that the method allows for the identification of changes in arid ecosystems vulnerable to human activities. Chen and Rao (2008) have used NDVI, TCG and TCB as the feature nodes of a DTC that contributed to the improvement of the results of the classification regarding monitoring land degradation in a transition zone between grassland and cropland of northeast China, where soil salinisation, grassland degradation and even desertification have been observed over the last years. Results have

shown that land degradation, especially the salt-affected soil, is accelerating.

*RGB combinations*

The obvious spatial variations highlighted by the CVA technique applied to the three combinations were recorded by RGB combinations for each degree of desertification risk (Fig. 5). The interpretation of the colours composition indicates that the surfaces highlighted by only one combination of indices or components after applying the CVA technique preserve the colour in which they were displayed. On the contrary, the surfaces highlighted

by two or all three combinations of indices or components are rendered in other colours than the fundamental ones. As such, very many locations were identified by all the combinations, but there are also locations identified separately by each combination; this is why the surface from each class is also different. Out of the three combinations, NDVI-albedo and NDVI-BI were estimated in approximately the same locations for the low desertification risk. In the case of the medium and high desertification risks, the same locations were identified by the NDVI-BI and TCG-TCB combinations (Fig. 5).

Taking into consideration the map of desertification risk and re-growth, the desertification risk prevailed
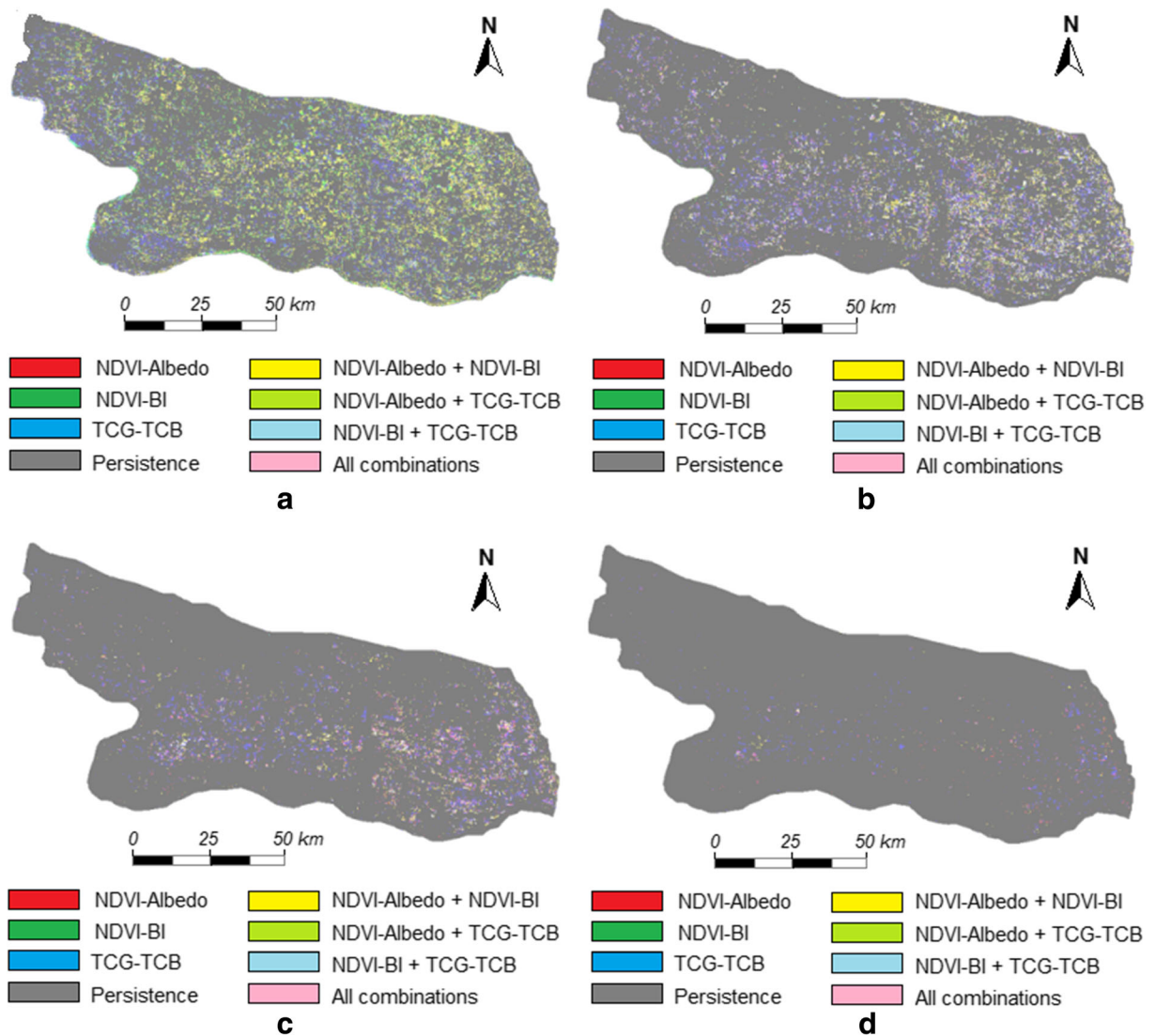


**Fig. 5** RGB combinations performed for the localisation of the desertification risk for the degrees of desertification. **a** Low. **b** Medium. **c** High. **d** Extreme

over re-growth in all the combinations, which shows the desertification tendency of the area (Fig. 6). The desertification risk affects not only, mainly, the Romanati Plain, but also the south of the Bailesti Plain, bordering the Danube floodplain. All the results show an increase of the desertification risk, and the high temperatures determined the expansion of these surface areas from the sands not only in Dabuleni, towards the west, to the Jiu basin, but also between the rivers Jiu and Olt, in the Romanati Plain. These results are in accordance with other studies conducted in the south-west of Romania based on terrestrial data, studies correlated with illegal loggings (Dumitrașcu et al. 2014) and studies based on remote sensing (Prăvălie et al. 2014) which used the NDVI index and the modified soil adjusted vegetation index 2 (MSAVI2). In addition, the Regional Environmental Protection Agency Craiova estimates that 4–5% of the soils in the county of Dolj are currently desertified. All the studies point out that the desertification risk intensifies and that desertification can become an irreversible process.

Analysis of the driving forces

The driving forces are represented by anthropogenic causes, which refer to the direct intervention of man in the landscape, especially after 1989, and by climatic causes. The concentrated action of the two categories of driving forces that led to the emergence and amplification of the desertification risk.

Before 1990, over 3 million ha of arable land was irrigated in Romania, the large irrigation systems being located in the Danube Plain, Baragan Plain and the regions of Oltenia and Dobrogea (Fig. 7). In the period 1969–1972, the irrigation system Sadova-Corabia was
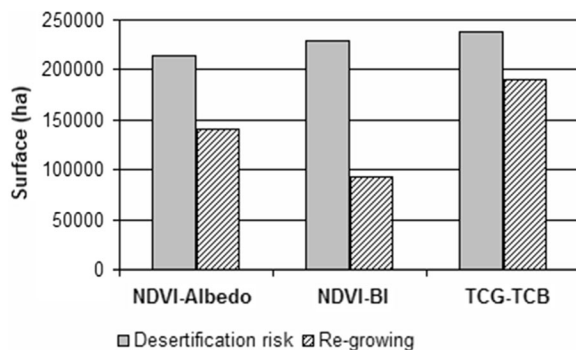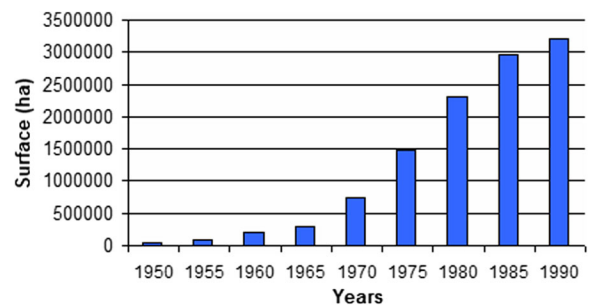


**Fig. 7** The situation of the irrigated surface areas prior to 1990 in Romania

built in the south-west of Romania with funds from the World Bank. The system was considered the biggest at that time in Europe, and it ensured the irrigation of 80,000 ha in drought. The entire agricultural structure, inspired by the Californian model of irrigated agriculture in the desert, allowed high production of vegetables, cereal and fruit, most of them being exported. By organising the territory according to the new irrigation system, by modelling and levelling, around 13,000 ha was deforested, especially acacia forests, and through a new organisation of the land forest, around 1700 km and 1600 ha shelterbelts were created. After 1989, the agricultural lands were fragmented by applying the land laws (Laws 18/1991, 1/2000, and 247/2005) and the irrigation systems stopped being used at their full capacity, being subsequently abandoned (Fig. 8). Thus, the irrigation system in the south-west of Romania was destroyed, and in the area known as 'the Oltenian Sahara', cultivating corn, sunflower or wheat was no longer possible. Today, the most important losses relate to the impossibility of growing cereal, which ensures to a great extent the food security of the population. It is estimated that corn production in Oltenia will decrease by 14% until 2020 and by 21% until 2050.

Before 1989, land was exploited in Romania mainly through the agricultural production cooperatives (3776 units in 1989), which owned over 68.8% of the agricultural surface, with an average surface of 2374 ha, and through the state farms (411 units in 1989), which held 29.7% of the country's agricultural land, their average surface being of 5000 ha. The fragmentation of large agricultural exploitations, as a result of applying the land laws adopted after 1989, led to the destruction of intensive agriculture and to a form of subsistence agriculture. The studied area is part of the micro-region 4 south-west Oltenia, which, in 2010, included 576,590 agricultural exploitations, with an average



**Fig. 6** The distribution of surface areas with desertification risk and re-growth determined by the CVA technique applied to the combinations NDVI-albedo, NDVI-BI and TCG-TCB
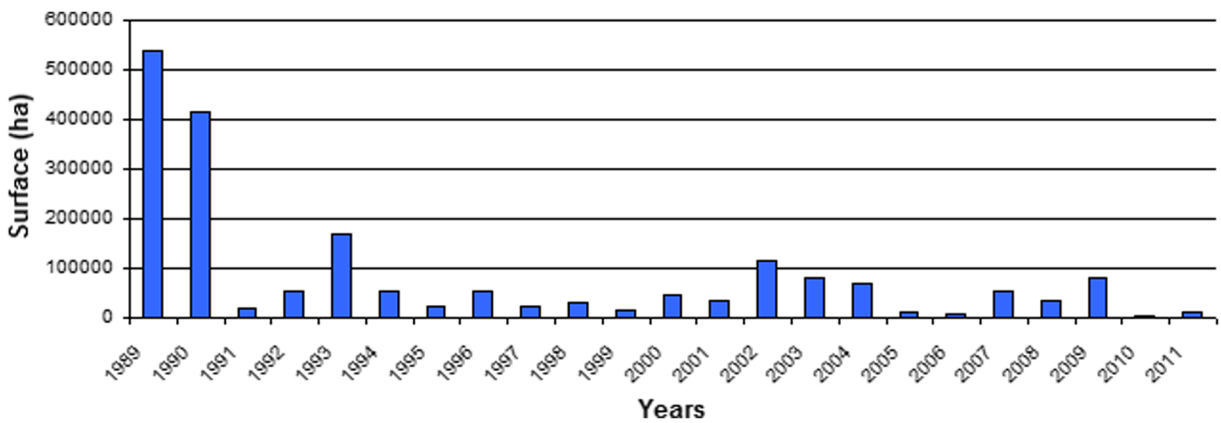
**Fig. 8** The distribution of the irrigated surface areas after 1989 in the county of Dolj

surface of 2.79 ha (General Agricultural Census 2010). Out of them, 573,768 were individual agricultural exploitations; 184 exploitations belonged to self-employed persons, legal persons and family businesses; 6 to autonomous administrations; 79 to agricultural companies; 1105 to private companies; 8 to state-owned companies and 6 to production cooperatives (General Agricultural Census 2010). This situation shows how fragmented the agricultural land is in the studied area.

In the context of global warming, a very important factor in changing the climate of the studied area and in amplifying the desertification risk was represented by massive deforestation. After 1989, in the region of Oltenia, illegal loggings affected several counties: Dolj (5230 ha), Mehedinti (1638 ha), Olt (303 ha) and Valcea (205 ha). A part of these deforested surface areas is located in the studied area. If in 1970 forests covered 12% of the surface of the county of Dolj, at present, they occupy only 7–8%, the average at the national level in Romania being at around 26.7%. Here, the acacia forests planted before 1990 to fix the sand dunes were cut after restitution to the current land owners. The specialists believe that in less than 50 years, the situation could become dramatic, with significant losses for agriculture, and the reforestations could last up to 20 years. Few land owners have begun to understand the importance of reforestation especially in areas with sandy soils.

In order to stop the expansion of sand in the studied area, in the 1970s, forest shelterbelts were planted to prevent sand from blowing. The desertification phenomenon accentuated after 1989 also because the forest shelterbelts were cut, especially the acacia ones, and the cultures used to fix the soil were eliminated. Before

1990, the soil was fixed using grape vines and peach plantations which, after the implementation of land laws, were cut by the current owners of the land.

The increase of the surface areas affected by extreme and high desertification risks is the result of the aridisation of the studied area. The analysis of the average annual temperatures and of the average annual amount of precipitation at the weather stations in the studied area (Drobeta Turnu Severin, Turnu Măgurele, and Craiova) in the last decades shows this ascending tendency of climate aridisation. Average annual temperatures generally increased, with some fluctuations determined by the relief, altitude, slope and existing vegetation cover (Fig. 9a). The amount of precipitation decreased, with some more important fluctuations in the rainy years (Fig. 9b).

The analysis of the values supplied by the De Martonne and UNEP aridity indices obtained from the same three weather stations during the past decades shows a decrease of their values indicating, at the same time, an increased climate aridisation. The most visible descending trend for the De Martonne index occurred after 1980 when its values started to fluctuate in intervals typical for the conditions of semi-arid climate and dry steppe (10–15 and 15–20) (Fig. 10a). The values of the UNEP aridity index also recorded a descending trend (Fig. 10b), especially after 1980, when they decreased frequently in the interval 0.2–0.5, typical for the presence of a semi-arid climate (UNEP 1992; Prăvălie et al. 2014).

A powerful drought, a very strong driving force, affected the studied area at several moments. During the drought in the period 1991–1993, which practically began in 1987, extremely dry months were recorded. In
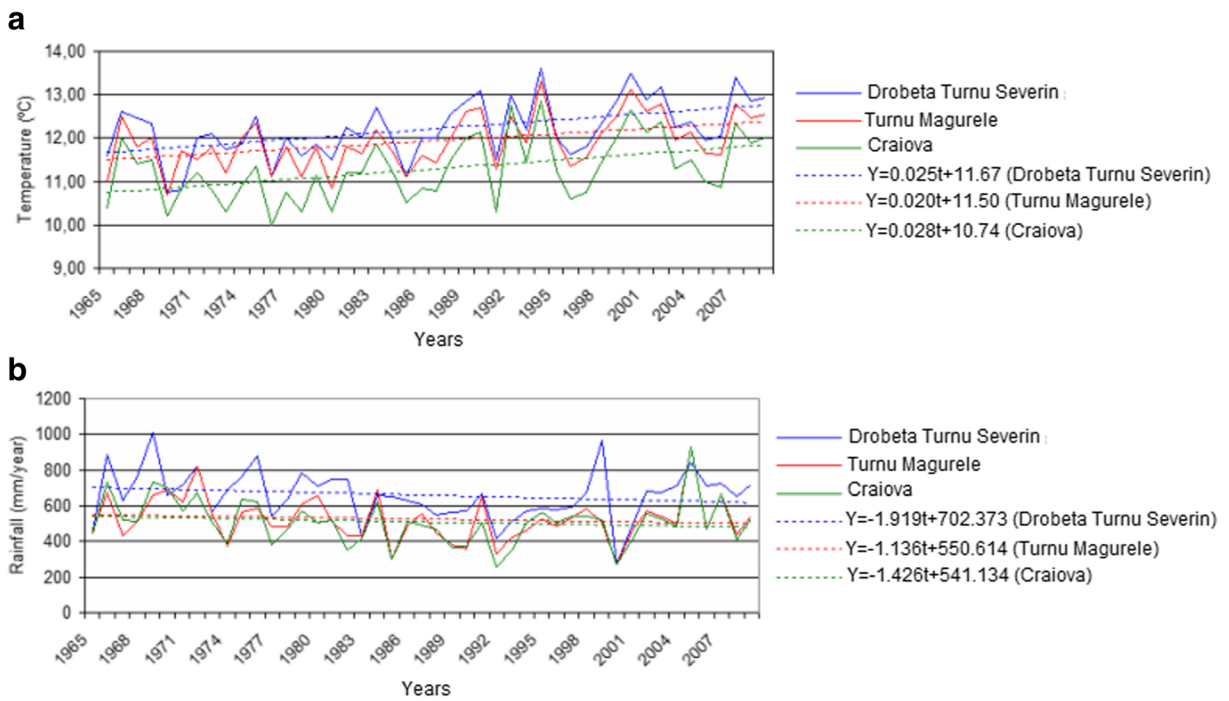
**a**



**b**



**Fig. 9** Fluctuation of average annual temperatures (**a**) and of the average annual amount of precipitation (**b**) for the period 1965–2009 and the evolution of their linear trend

the extreme south of the studied area, very dry months were recorded. Also, in 1983, 1985 and 1986, there were dry periods but the drought had a weak evolution in time, with short periods in which precipitation came
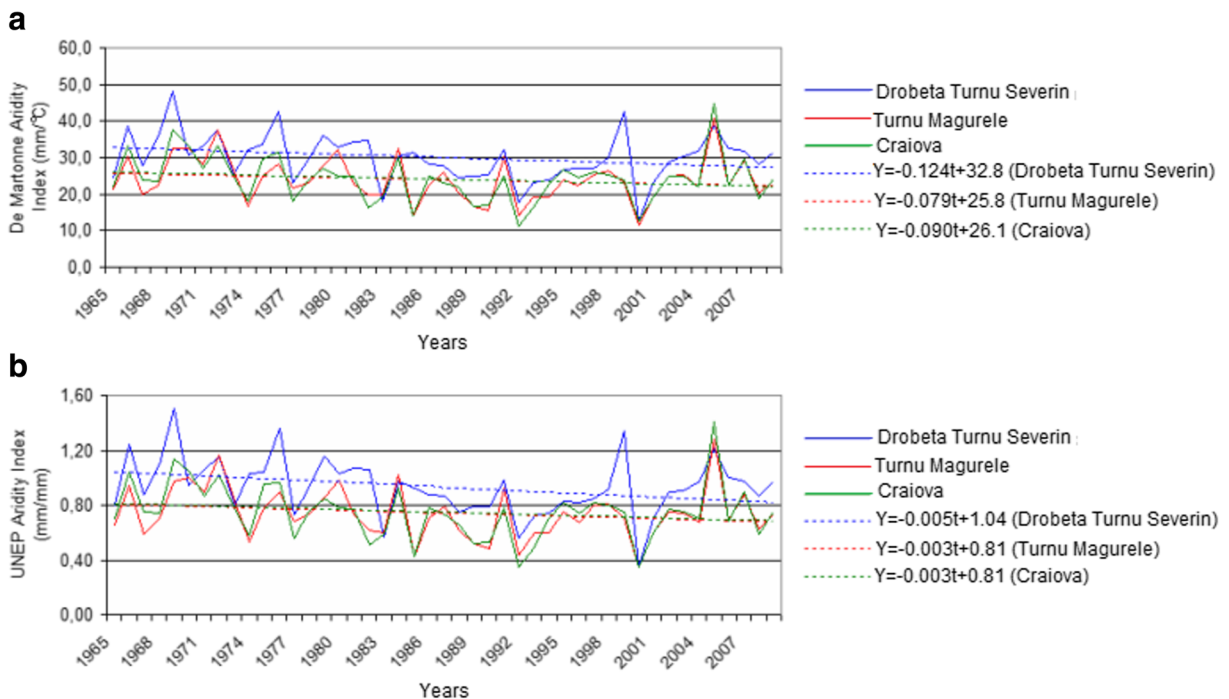
**a**



**b**



**Fig. 10** The annual dynamics of the values of the De Martonne aridity index and UNEP aridity index for the period 1965–2009 and their linear descending trend

back to normal. However, the deficit of precipitation in the soil increased over time and the layer of groundwater decreased, although the quantities of precipitation were close to normal. The maximum intensity of the drought occurred in the spring of 1993, when seven counties in the south of Romania, including the studied area, were severely affected. In the period 1987–1993, Oltenia was affected by drought between 50.49% in 1987 and 83.33% in 1992, with an average of 64.62% (Marinică and Marinică 2014).

The second period of severe drought was between 2000 and 2002. The drought began in January 2000, until July 2002; it was interrupted by three short rainy periods in 2001, and the rains were followed by sunny days, with wind gusts, which contributed essentially to the evaporation of water from the soil and thus recreated the water deficit in the stratum of arable soil. In Dolj county, in the period 2000–2002, the damaged agricultural surface represented between 79.6 and 87.8% of the total cultivated surface.

The third drought occurred in the summer of 2007 when the weather in the south-west part of Romania was extremely unstable. Among its most important aspects, there were six heat waves, two of them of high intensity. Twice in the summer of 2007, in June and July, the pasture vegetation dried up; several forest fires affected the south-west of Romania, and all the cultures were considerably deteriorated; the groundwater layer decreased and many villages were left without water supplies. Consequently, domestic animals died because of lack of food and water.

In the analysed area, the frequency of years with poor and very poor crops, as a result of drought, ranges from 36 to 39%. Because of the climatic changes, the areas in the south of Romania risk becoming difficult to inhabit and impossible for economic activities. Currently, in the southern part of Romania, approximately 350,000 ha is affected by desertification risk, and the existing models show that the surface will triple in the following 20 years in the absence of concrete measures.

Control measures

The measures to control the desertification risk are aimed at countering the driving forces. In this respect, measures to counteract the anthropogenic effect and measures targeted at the climatic factors are taken into consideration.

The forestation of land affected by illegal loggings after 1989 and of degraded land is one of the most important measures. The problem of soil desertification in the south-west of Romania received serious attention only in 1977 when, by Government Decision No. 876, 1291.78 ha of degraded land was reforested. The action started later in 1988 and was finished in 2002. Other normative acts addressed other areas affected by desertification risk, which were or are going to be reforested. Their surface is around 5000 ha while the surface with the most severe problems, covered by sand, exceeds 104,000 ha.

Planting forest shelterbelts has become a necessity. In 2000, Romania joined the UNCCD, and as a result the "National Strategy and Action Plan to Combat Desertification, Land Degradation and Drought" was elaborated based on the "Project concerning the strategy to combat desertification in Romania". This led to the elaboration of Law No. 289/2002 concerning forest shelterbelts which sets the areas with desertification risk and makes the forest shelterbelts compulsory. The practical effect of the law was to draw up the feasibility and execution studies for 19,800 ha of forest shelterbelts in the counties of Olt, Dolj, Mehedinti and Teleorman. Also, the new Forestry Code stipulates a series of facilities for the owners of agricultural land who agree to the plantation of forest shelterbelts on a part of the land they own. At this moment, very few results were obtained in this direction, and there is an acute lack of forest shelterbelts.

Restoring the old irrigation system, where possible, and implementing a new system (Greşiţă 2011, 2013) in the areas where it is missing are of paramount importance for the local agriculture. In this direction, several projects were proposed in time, financed by the government, the World Bank or from European funds. A part of the irrigation system was renovated using funds from the World Bank, but only 5% of the capacity has been used because of the small demand to buy the irrigation water.

Reducing the fragmentation of agricultural land can be achieved through a national agricultural policy including three directions, technical, legal and economic (Otiman 2012): (1) land reparcelling, through measures to stimulate economic growth and by appropriate regulations; (2) the increase of exploited surface areas and of their economic values and (3) the technical and economic consolidations of exploitations.

The projects to prevent the effects of climate change on agriculture and, implicitly, to prevent the increase of

the desertification risk must take into consideration the water, soil and climate resources. The water resources must be managed efficiently, without losses, and directed towards the areas exposed to a desertification risk. As for soil resources, the measures needed include implementing a minimal system for their preparation, modernising the anti-erosion works, controlled fertilisations, modernising and expanding the management and improvement works in the case of sand and sandy soils and restoring the reserve of organic material in the soil. Also, the soil management system can adapt to the humidity content in the planting season which supposes less deeper ploughing in order to preserve the water in the soil. Climate-wise, it is necessary to sow species which are resistant to drought (peanuts, sweet potatoes) and to perform works based on certain climatic scenarios. In addition, the beginning of each agricultural year could be chosen as the period in which to select a range of species and hybrids as well as the adequate technology according to the water reserve in the soil when sowing. Each agricultural year, it is recommended to implement an increasingly high number of species, with different vegetation periods, to better exploit climatic conditions. In the future, the goal could be to adopt a type of agriculture focused on species which increase the soil productivity and have lower energy consumption.

## Conclusions

The aim of this paper was to analyse the desertification risk in the south-west of Romania in the period 1984–2011 using Landsat TM satellite images and the CVA technique. Only Landsat TM images were used in the study because of the benefit of a direct comparison, thus eliminating the influences produced on recordings acquired by different sensors. Also, using a time series made up only of Landsat TM images led to having the same radiometric scaling for all the scenes processed on the ground for the studied period. This way, a standardised comparison could be performed, and in the case of calculating TCG and TCB, the same coefficients were used.

The analyses were based on combinations of two biophysical variables. The first one (NDVI and TCB) is positively correlated with the vegetation carpet; the second (Albedo, BI and TCB) is positively correlated with the cover of exposed sands. While the increase of

the values of the first component indicates processes of landscape restoration in terms of fractional vegetation cover and biomass, the decrease of the values of the second component shows sandification processes.

The results show an increase of the desertification risk as a direct consequence of the political, social and economic changes which occurred in Romania after 1989, as well as of climatic factors. The expansion of the surface areas affected by the desertification risk was facilitated by the destruction and abandonment of irrigation systems, land fragmentation, deforestations, inadequate agricultural practices, the destruction of the forest shelterbelts etc. which increased the vulnerability of agricultural lands to climatic factors. Negative effects were also generated by the abandonment of agricultural land in the strongly affected areas. All these led to the beginning of an aridisation process in the studied area.

The beginning of the aridisation process in the south-west of Romania is a phenomenon which has to be approached multi-dimensionally, because it has negative social and economic effects on the environment. Considering the importance of agricultural land, which predominates in this area, it has become increasingly necessary to implement certain land management strategies to reduce the desertification risk. In order to predict the practical measures to control aridisation and drought, the reactivation of sand dunes and the implementation of irrigations, it is necessary to perform complex and complete assessments with the view of correlating the most relevant climatic phenomena with agricultural crops (Bălteanu et al. 2013). Estimating climatic changes at a local and regional level would bring an important contribution to forecasting the major components, thus improving the decision-making process in agriculture and eventually leading to the implementation of specific measures to diminish negative consequences and impact (Bălteanu et al. 2013). The need to implement certain territory management strategies along with a good forecast of the climatic changes is more and more visible given the emergence of unbalances caused by deforestation, intensive agriculture on fragile soils and wrong management decisions.

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