ASSESSMENT OF THE OCNELE MARII SALT MINE EXPLOITATION IMPACTS ON THE VEGETATION COVERAGE USING MULTISPECTRAL REMOTE SENSING DATA

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Abstract

In Romania there are several inactive or abandoned mine sites which can create a significant impact on the environment, affecting the use of local surface and groundwater. The environmental impacts that can occur at an abandoned mine site can be divided into several categories, amongst which: metal contamination of ground surface water and sediments, air emission and deposition, erosion, physical impacts (slope failure, structural stability of tailings impoundments, ground subsidence, unsafe structure, mine openings and vegetation contamination). The Ocnele Mari salt mine is one of disused mines affected by subsidence phenomena as a result of pillars dissolution by uncontrolled leaching processes that led to the formation of a huge cavern of up 10,5 ha on horizontal direction and its volume of 2.5 million m³ of brine. The land deformation (subsidence and landslide) phenomenon influences vegetation coverage changes. The object of the present study is to investigate the temporal changes of vegetation caused by salt exploitation using multispectral remote sensing data (Landsat 5, Landsat 7, ASTER and MODIS). We elaborated maps for the vegetation indices: normalized difference vegetation index - NDVI, leaf area specific index – SLAVI, normalized difference water index - NDWI - and thermal index. The change detection technique in vectorial format is applied on NDVI data in order to determine the areas affected by land degradation, with direct effects on vegetation coverage. Thus, an analysis of vegetation index NDVI proves the vegetation degradation in Field II of probes of the mining area, especially in the area of the 360-366 probes, with an area of 146700 m². For the Field I of probes, sample 472, a decrease of 19800 m² of vegetation was noticed, while the third field, samples 431-433, decrease was determined to 30600 m². The results confirmed feasibility of using remote sensing technique to assess the vegetation growth status in the salt mining area.

Key words: change detection technique, remote sensing, NDVI, Ocnele Mari salt area, vegetation coverage

INTRODUCTION

There is an important concern from the scientific community and the private actors on the international level on monitoring the disused mines included in the touristic circuits, as well as the operational mines that due to the functional processes of extraction and storage of sterile material pollution of the environment. Disused mine monitoring is achieved both by using satellite data and in-situ measurement focused on suffusion parameter estimation (degree of land degradation, consequence of mining exploration) and the vegetation effects study with the direct impact of the environment. From this point of view, the vegetation and land degradation estimations are the primary need for the makers interested to monitor the mining areas affected by pollution in order to reduce the adverse effects on the environment.

Romania is also confronted with problems related to vegetation degradation, a phenomenon caused by several factors such as: original natural vegetation has been substantially modified, which led to the occurrence of landslides on the slopes used as pastures and hayfields, as well as arable land subsidence, expansion of the hedges on heavily eroded lands having a fixing role, transformation of the forest into agricultural lands, and construction engineering activities.
leading to the pollution of areas covered with vegetation and not least the extension of urban and rural areas [6, 9, 11].

In this context, the present paper assesses the effects of the Ocnele Mari mining activities on vegetation coverage by integrated the remote sensing data into a GIS environment and analyzed together with geological, geomorphology, soil and land use / land cover data. The vegetation indices (normalized difference vegetation index - NDVI, the specific area vegetation index – SLAVI), the soil indices (normalized difference water index – NDWI, drought ratio index – RDI) and thermal index retrieved from Landsat TM data are investigated to monitor the variations in vegetation coverage as a measure of the land degradation.

MATERIAL AND METHOD

Description of the test area
The salt deposit from Ocnele Mari area is located in the central-southern part of Romania, in the Valcea Sub-Carpathians area which is affected by uplift geotectonic movements at a rate of 2-4 mm/year, surrounded by hills with an altitude between 400m and 600m. The climate is temperate continental with an average precipitation of 700 mm/year, up to 1.225 mm and 1.295 mm registered in rainy years which favours soil erosion and gulling (Fig. 1) [2].

In the Ocnele Mari site many collapses took place over the time science 1968 when the first sign of surface damage occurred. In 2001, the field around of the S377 well collapsed and the brine was discharged at a rate of 17m³/s in the rural areas, devastating human settlements and polluting the Sarat River. In 2005, the field around of the S365 well also was collapsed as a result of the crash of the banks cavern so that the brine was discharged at a rate of 24m³/s over dam safety because the retention basin could not take the entire quantity of brine.

The Ocnele Mari salt mine area is composed of reddish-brown soils, chernozem, cambric chernozem, pseudoglay and alluvial soils. The chernozem soils, combined with the ravenna and deforestation phenomena, were conducted to the land degradation (Fig. 2).

According to the CORINE biotopes classification, land cover/land use of the studied area can be classified in seven categories: (1) deciduous; (2) transition areas with shrubs; (3) natural grasslands; (4) orchards; (5) rudder communities or extensive crop fields; (6) secondary grasslands and (7) towns, mines and saline.

![Image](https://example.com/image1.png)

**Fig. 1.** Ocnele Mari salt mine area: button up – Corine land cover classification (scale 1:200 000); button down – salt mine area (ANCPI source).
Dataset
In this study, Landsat TM and Landsat ETM+ datasets covering 1985 – 2011 time span period were processed, analyzed and interpreted in a GIS environment to evaluate the land degradation effects on vegetation coverage. The datasets were chosen so that the test site was not covered by cloudy formations; to correspond with collapses from 2001, 2005, 2007 and 2009; and the vegetation stages (from May to September).

An ASTER image acquired in July 2002 enhance the capability of vegetation and lithological discrimination between the rocks due to high resolution radiometer which collected data in 14 bands: three in the visible and near-infrared (VNIR) portion of the electromagnetic spectrum with 15 m spatial resolution, six in short-wave infrared (SWIR) with 30m spatial resolution and five in the thermal infrared (TIR) with 90m spatial resolution.

Methodology
Normalized difference vegetation index defined as the difference between the spectral reflectance in near-infrared (NIR) and red (R) bands over their sum \([8, 10]\) (eq. 1) reduced multispectral measurements to a single value.

\[
\text{NDVI} = \frac{\rho_{\text{NIR}} - \rho_{\text{R}}}{\rho_{\text{NIR}} + \rho_{\text{R}}} \quad \text{NDVI} \in [-1,1]
\]  

Areas of barren rocks, sand and salt show very low NDVI values (0.1 or less). Sparse vegetation such as grassland or senescing crops may result in moderate NDVI values (approximately 0.2 to 0.5). Dense vegetation such as forest or crops at their peak stage was associated with high NDVI values (approximately 0.6 to 0.9). NDVI values can be averaged over time to show the growing conditions in a region for a given time and the health of vegetation in that place. A NDVI temporal series analysis can reveal the thriving or stressed vegetation, as well as the changes in vegetation due to human activities, natural disturbances or changes in phonological stage of the plant.

Change detection methods are commonly used in monitoring land degradation. Change can be identified either as a change in the percentages of the components and as change in the number of environmental components. Visual interpretation and direct measurement using map algebra are used in this technique. Land cover degradation can be estimated using change vector analysis by assessment of the direction and magnitude of the change between two time periods \([1, 4]\).

Another critical parameter in the process-based models of vegetation canopy response to global change environment is leaf area index (LAI) defined as the total one-side area of photosynthetic tissue per unit ground surface area \([13]\). The LAI of vegetation depends on species composition, development stage and seasonality. There are two methods to estimate LAI: direct measurements (in-situ data) and indirect measurements (retrieved from multispectral satellite imagery).

Recently LAI research focus has shifted from an empirical and statistical stage to process based modelling stage due to involvement of remotely sensed datasets and numerical model implementation \([3, 12]\). The specific leaf area vegetation index (SLAVI) developed for Landsat imagery is computed by applying the formula:

\[
\text{SLAVI} = \frac{\text{NIR}^*}{\text{RED}^* + \text{MIR}^*}
\]

Where \(\text{NIR}^*\) = Reflectance in the Near-Infrared Band \\(\text{RED}^*\) = Reflectance in Red Band \\(\text{MIR}^*\) = Reflectance in Middle-Infrared Band.
Ratio drought index (RDI) is designed to detect vegetation drought conditions and with little moisture content relating precipitation with the evapotranspiration (eq. 3).

\[ RDI = \frac{MIR}{NIR} \]  

Normalized difference water index (NDWI) is used both to extract water body and to characterize the areas that were susceptible to saturation [5]. As the NDVI, the NDWI employ the near infrared band and a band from short-wave infrared (SWIR):

\[ NDWI = \frac{NIR - G}{NIR + G}, NDWI \in [-1,1] \]  

The radiant surface temperature provides information on energy balance between land surface and environment. Thus, the thermal index is based on two phenomena: one is the shielding effect of the canopy which blocks and absorbs energy and the other is evaporation from the leaf surface which mitigates warming. The source of thermal information is thermal infrared of Landsat 5 TM (band 6) which is calibrated in radiance for retrieving the ground temperature. The temperature calibration has been done using equations 5 and 6.

\[ L = L_{\text{min}} + ((L_{\text{max}} - L_{\text{min}})/255)*Q \]  

\[ T = k_2/(\ln(k_1/L + 1) \]  

Where:  
- \( L \): value of radiance in thermal infrared  
- \( T \): ground temperature  
- \( Q \): digital record.

**RESULTS AND DISCUSSIONS**

The Landsat MSS data were calibrated in radiance and reflectance for analysis and interpretation. The 4-5-3 composite (Fig. 3) allows distinguishing between vegetation types and highlights the land/water interface and variations in moisture content. Thus, vegetation appears in shades of red, plants having relative lower moisture content give orange color while the green tones tell us the vegetation reflects lower in VNIR and higher in SWIR. Urban areas and no vegetated soils give the blue towards grey tones.

The principal component analysis was applied to Landsat images using ENVI software to evaluate the variation in land use and land cover. The results in Fig. 4 show a decrease in the vegetation coverage and an increase in salty the soils and artefact. Land degradation is more pronounced in the data acquired after the Ocnele Mari salt mine collapse from 2009. As a consequence of this disaster, Romanian authorities decided to take measurements for ecologized and evergreening the mining area by elaborating a program for safe exploitation of the salt deposit which is reflected in the 2011 Landsat dataset.

The vegetation indices (NDVI) are retrieved from Landsat and ASTER imagery and integrated in ArcMap to mapping. The obtained maps are presented in Fig. 5, Fig. 6 and Fig. 7. It is noticed that NDVI are unable to highlight subtle differences in canopy density. Moreover, an anomaly is observed in the NDVI dataset acquired in July 2007 which is investigated taking into account specific leaf area vegetation index, potential evapotranspiration and thermal index [7]. The vegetation anomaly presence results from either drought phenomena or higher plant moisture content. The RDI and NDWI maps analysis (Fig. 8 and Fig. 9) explain the vegetation anomaly namely higher plant water content.

The NDVI change detection was performed based on the assumption that the values of the pixels associated with the vegetation changes present values significantly different from those of the pixels associated with unchanged areas, so called "difference image". Changes are then identified by analyzing (thresholding) the difference image. This unsupervised technique can influence the reliability and accuracy of the final change detection map. Landsat imagery acquired in June 1985, June 2007 and August 2010 was used to detect changes in the NDVI data.
Fig. 3. Landsat image color composite (bands 4-5-3) acquired on 27.06.1985

Fig. 4. Principal component analysis of Landsat imagery acquired in 1985, 2009 and 2010
Fig. 5. NDVI retrieved from Landsat 5 TM imagery: (1) top left: 27 June 1985; (2) top right: 3 August 2010; (3) Bottom left: 18 July 2007; (4) Bottom right: 22 August 2011.

Fig. 6. NDVI retrieved from ASTER imagery acquired on 2 July 2002 – zoom on the salt mine area
Fig. 7. Graphic representation of the NDVI data

Fig. 8. Drought ratio retrieved from Landsat imagery, 18.07.2007
Fig. 9. NDWI density slicing retrieved from Landsat imagery acquired on 18.07.2007

Fig. 10 Change detection technique applied to NDVI for 1985 – 2010 period monitoring (zoom-in)
The result shown in Fig. 10 confirms vegetation degradation in the Ocnele Mari salt mine area. A decrease by 14.6 ha is observed in the Field II of probe while the Field III and Field I are less affected by the degradation (3.06 ha and 1.98 ha).

The red band change detection analysis which allows the boundaries delimitation among different soil types and geological structures validates the previous results (Fig.11). Land degradation in the Field II of probes is about 20 ha while in the Field I and III the degradation phenomena is less semnificative (about 5ha and 3ha).

CONCLUSIONS

The paper presents the theoretical and experimental aspects related to the methods and techniques for determining the degradation of vegetation and land in the area of the rock salt deposit from Ocnele Mari.

In the vegetation coverage study, one must take into account several factors: climate regime, soil type, geomorphology and land use, being a key indicator of environmental conditions: any vegetation coverage changes allows understanding the phenomena that has led to changes in other factors of the environment. Vegetation indices are used for the detection of plant biomass and the analysis of the environmental changes in areas affected by drought or floods, as well as for the quantitative risk assessment of land degradation.

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REFERENCES


