Remote sensing of vegetation health for reclaimed areas of Seyitömer open cast coal mine

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A B S T R A C T
A remote sensing based vegetation cover monitoring and health assessment is presented and applied to a case study of the Seyitömer Lignite Enterprise (SLE) in Kütahya, Turkey. In this study, multi-temporal Landsat TM data sets were used to assist in identifying and monitoring the progress in the rehabilitation field. Evaluation was based on analyzing varying vegetation indices. In order to monitor and track the changes, which occurred from 1987 to 2006 in vegetation condition, Simple Ratio (SR) index, Reduced Simple Ratio (RSR), Normalized Difference Vegetation Index (NDVI) and Tasseled Cap Transformation analysis were employed in the study. The vegetation indices were mapped and evaluated. The result of these analyses showed that, the region has moderate to good reclamation success. As a result, it can be concluded that, the remotely sensed data are undoubtedly useful to provide up-to-date and quick data and are cost-effective in monitoring the progress of rehabilitation for large extended regions.

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1. Introduction

Open cast mining inevitably disturbs large amounts of land. This raises a number of environmental challenges, which may result in soil erosion, dust, noise, water pollution, and impacts on local biodiversity (WCI, 2010). Once mining operations have stopped, post-mining restoration has vital importance in order to minimize the impacts on the environment. In modern mining operations, mine reclamation activities are undertaken gradually. Reclamation programs aim to repair and restore the disturbed land and return the land to its natural state. They provide a number of advantages namely: accomplishing stabilization of the land, maintaining land for agriculture, forestry, recreation and wildlife habitat. It is clear that, without any reclamation activity, the land would be useless.

Besides the ongoing reclamation activities, it is important to re-evaluate the health of planted species and monitor the progress of rehabilitation until the vegetation is self-supporting. In addition to conventional field and laboratory measurements, which involve sampling sites for analysis of landscape integrity, soil surface condition (soil stability index, soil infiltration index and nutrient cycling index), revegetation dynamics (ACMER, 2010); remote sensing technology has focused attention on monitoring the planted species after rehabilitation of lands. Identifying and monitoring of vegetation condition on land surfaces in remote-sensing images depend on tonal signatures of vegetation on multispectral images. As a result, these spectral variations facilitate fairly precise spatio-temporal information in monitoring changes in vegetation condition and vegetation cover, often at quantitative levels (RST, 2010). Geographic Information Systems (GIS) can be used for spatial analysis of remotely sensed data in addition to the integration and examination of a variety of spatial data. Variables can be linked spatially in the GIS database to model and analyze a variety of geographic problems.

Most of the studies have confirmed the utility of remote sensing in mining. For example; it is useful in mapping surface mine extent through time (Prakash and Gupta, 1998; Townsend et al., 2009); detecting and monitoring coal fires (Mansor et al., 1994; Voigt et al., 2004), monitoring environmental impacts of surface coal mining (Rathore and Wright, 1993; Schmidt and Gaesser, 1998); discriminating mined areas (Anderson et al., 1977; Irons and Kennard, 1986; Wright and Stow, 1999; Richter et al., 2008) and mapping industrial open pit mines (Hagner and Rigina, 1998; Latifovic et al., 2005). However, mapping of mine reclamation studies is rare due to the difficulties in spectral discrimination of grasslands or pastures from reclaimed mines (Richards et al., 2004; Straker et al., 2004; Townsend et al., 2009). Most of the studies related to mapping of mine reclamation deal with the tracking of change through time by mapping the active and reclaimed mines. Among these, Townsend et al. (2009) employed a logical decision tree based on class transitions and ancillary data in order to distinguish active mines and reclaimed mine lands while using Landsat imagery for four image dates. Richter et al. (2008) quantified the rehabilitation process in mine tailing areas based on a novel procedure that combined a spectral mixing analysis (SMA) approach with a classification approach based on fraction maps using Hyper spectral data. Straker et al. (2004) identified discrete vegetation units on the reclaimed mine site by using supervised
computer classification. Latifovic et al. (2005) evaluated vegetation productivity and study land cover changes in the Athabaska Oil Sands region by using two Landsat scenes. Toren and Ünal (2001) identified and monitored the environmental impacts of the Soma coal basin by using digital image processing techniques on multi-temporal Landsat TM data sets. Schmidt and Glaesser (1998) monitored the environmental impact of open cast lignite mining in Eastern Germany based on the digital analysis of several Landsat-TM and ERS-1 data sets. Prakash and Gupta (1998) discussed the remote-sensing GIS techniques for identification of time-sequential changes in land-use patterns. They used the normalized difference vegetation index (NDVI) images for vegetation studies. Among these, few studies dealt with the integrated studies of GIS and remote-sensing in order to monitor the progress of rehabilitation and to evaluate the survival and growth of trees at surface mines. Therefore, the objective of our study is to evaluate the condition and health status of vegetation and to monitor the progress of rehabilitation using remotely sensed data and GIS technologies within the Seyitömer Lignite Enterprise (SLE), Turkey during a nineteen-year time period (1987–2006).

SLE is one of the biggest coal production areas in Kütahya and supplies coal to the power plant with capacity of 4×150 MW (Aykul and Yalçın, 2004). SLE has a permit to produce coal in an area of 6800 ha and, since 1960, 80% of the region was utilized for surface mining. As a result, coal mining has disturbed approximately 5440 ha since 1960 in Kütahya. Following the laws passed requiring mine operators to ensure some reclamation would take place, studies of surface mine revegetation with trees began in the 1990s. Since 1991, 371 ha of revegetation was completed in the fields called Aslanlı and Ağzören. Black pine was one of the plant species which provide viability on mined land of SLE. Deodar was another species that was successfully established with convenient maintenance of planting. Due to the lack of significant rainfall in Kütahya, generally dry soil moisture conditions were observed in SLE. Although, hoeing and weeding were done periodically to assist in maintenance of landscapes, irrigation was not executed by the enterprise. Therefore, walnut failed to grow on mined land of SLE, due to its demand for irrigation.

It is important to obtain information about the health of planted species after rehabilitation of surface mined lands. Manpower resources became insufficient and costly as the region expanded. Therefore, to increase the efficiency in monitoring and evaluating the vegetation condition, remote sensing was used in this study. Evaluation was based on analyzing various vegetation indices. In order to monitor the vegetation condition Simple Ratio (SR) index, Reduced Simple Ratio (RSR), Normalized Difference Vegetation Index (NDVI) and Tasseled Cap Transformation analysis were assessed. As a result of these analyses it is evident that, despite the challenges of monitoring reclaimed mines by remote sensing, it is undoubtedly useful to provide up-to-date and quick data. Additionally, it is cost-effective to monitor large extended regions.

2. Data and methodology

2.1. Research area

The Seyitömer Lignite basin lies in the province of Kütahya in the Middle Western part of Turkey (Fig. 1). It is located at the northwest of Kütahya City and it is approximately 21.5 km from the city centre. The mining operations in the basin are carried out by Seyitömer Lignite Enterprise (SLE) which is one of the establishments of the state-owned Turkish Coal Enterprises (TKİ). SLE is one of the biggest coal production areas in Turkey. According to the reports of 2006, the reserve boundaries occupy an area of approximately 29 km² (S.L. Raporu, 2006). The open cast mines and coal sectors to be mined are presented in Fig. 1. Calculated total apparent reserve of coal is 198,666,000 tons (Kütahya Haberleri, 2009) and annually about 7 million tons of lignite is mined from the open cast of SLE.

The average calorific value of coal deposits produced in Seyitömer lignite basin is 2018 kcal/kg. The moisture content varies between 33
and 39% with ash content varying between 35 and 46% (Sarıyıldız, 1992). The Seyitömer lignite basin dates from formation of a lake in Pliocene age. The basin is composed of serpentines and ultra-basic schists (Cabro, Diorite) (TEGIM, 2010). Solid material begins with conglomerate from the base and then blue-green base clays follow. The coal seam, referred to as seam B, is present in this layer. The thickness of seam B varies between 2 and 30 m and the average thickness is 20 m (Aykul and Yalçın, 2004). The upper seam comprised clay and marl and has an average thickness of 10 m. The layers are inclined to the southern direction with a slope of 5–100 m.

Serpentines constitute the main rocks in this region. Serpentines contain diorite, amphibolites and chromites glass. It lies in the eastern, north-eastern and north-western parts of the region. The age of the main rock serpentines has been determined to be cretaceous. The fault lines, which are oriented in the north–south direction, separate the region into two subregions, namely Aslanlı and Seyitömer. As presented in Fig. 1, Seyitömer 1 is composed of the Seyitömer-West and Dragline fields and Seyitömer 2 is composed of the Seyitömer-East coal fields (Fig. 1). The average elevation of the basin from sea level ranges between 1000 m and 1300 m. Continental climate prevails in the Seyitömer region and the mean annual precipitation is low, around 350 mm (TEGIM, 2010).

The reclamation fields are presented in Fig. 2. Tree plantation works were started by the General Directorate of Turkish Coal Enterprises in 1991, and approximately 437,000 trees were planted in reclamation fields 1 and 2 by 2006. 423,000 trees were planted in reclamation fields 3, 4, 5 and 6 after 2006. Fifteen species of trees were planted on each reclamation site. The percentage distributions of planted tree species are displayed in Fig. 3. Among these species, Black Pine was the most successful species and extensively planted tree type with 48% of the total. Acacia follows with 20%. As a result, 371 ha of the region in total was planted by 2009.

The facilities are prevalent in the reclamation field 2 and this constrains the evaluation of planted trees by low resolution Landsat images in the region. Additionally, due to unavailability of closer date remote sensing imagery, only the reclamation field planted before 2006 (reclamation field 1 as shown in Fig. 2) was evaluated in the study. The pictures in Fig. 4 illustrate the planted trees in the reclamation field 1 in 2005.

2.2. Data sets

In this study, Landsat TM and Landsat ETM+ data sets from the Seyitömer coal basin were used in order to assist in re-evaluating the health of planted species and monitoring the progress of rehabilitation in the reclaimed area. Images were acquired for the study area on
the progress of vegetated regions. They were calculated from the Tasseled Cap indices (Brightness and Greenness) in order to monitor Ratio (RSR), Normalized Difference Vegetation Index (NDVI) and each region including the Simple Ratio (SR) index, Reduced Simple planted species.

extract regions from Landsat images for re-evaluating the health of before 2006 were used. These boundaries were used in order to images before 2006, GIS coverages of reclaimed regions planted are the oldest, most well known, and most frequently used numerical indicators for quantitative assessments of vegetation cover by analysis of remote sensing spectral measurements (Tucker et al., 1991). In order to provide a relative comparison of the indices, the NDVI index was also employed in the analyses (Fig. 7). The combination of its normalized difference formulation and use of the highest absorption and reflectance values of Landsat TM and ETM+ spectral channels 3 (red; 630–690 nm), 4 (NIR; 750–900 nm), and 5 (MIR; 1550–1750 nm).

The Simple Ratio (SR) index is one of the commonly used vegetation indices (Tucker, 1979; Sellers, 1985). It provides unique information which is not available in any single band. It is used for discriminating between soil and vegetation in the study region. Live green plants reflect strongly in the near-infrared while absorbing in the red spectral region. By contrast, barren surfaces (rock and soil) and water tend to reflect similarly in the red and near-infrared. Therefore, the brighter the pixel is, the greater the amount of vegetation (Jensen, 1996). Chen (1996) demonstrated that the SR vegetation index was the most correlated with leaf area index (LAI). Therefore, the SR is used for this study. SR is defined via Eq. (1):

\[
SR = \frac{\rho_{\text{NIR}}}{\rho_{\text{RED}}}
\]

where \(\rho_{\text{NIR}}\) is the near-infrared channel and \(\rho_{\text{RED}}\) is the red channel of remote sensing images. The spatial variation of SR index for three different years can be visualized in Fig. 5.

Brown et al. (2000) and Stenberg et al. (2004) indicate in their studies that the reduced simple ratio (RSR) shows increased sensitivity to LAI. In addition, RSR demonstrates an improved correlation with LAI in individual pine and black spruce canopies. The reclamation field was mostly covered by black pine. Therefore, the RSR is also tested in the study region in order to identify the reflectance differences in the vegetation index maps (Fig. 6). The RSR is computed by Eq. (2):

\[
RSR = \frac{\rho_{\text{NIR}} - \rho_{\text{MIR}_{\text{max}}} - \rho_{\text{MIR}_{\text{min}}}}{\rho_{\text{MIR}_{\text{max}}} - \rho_{\text{MIR}_{\text{min}}}}
\]

where \(\rho_{\text{MIR}_{\text{max}}}\) and \(\rho_{\text{MIR}_{\text{min}}}\) are the maximum and minimum reflectance values in midinfrared (MIR) channel.

The Normalized Difference Vegetation Index (NDVI) is one of the oldest, most well known, and most frequently used numerical indicators for quantitative assessments of vegetation cover by analysis of remote sensing spectral measurements (Tucker et al., 1991). In order to provide a relative comparison of the indices, the NDVI index was also employed in the analyses (Fig. 7). The combination of its normalized difference formulation and use of the highest absorption and reflectance regions of chlorophyll make NDVI robust over a wide range of conditions. NDVI is defined by the Eq. (3):

\[
NDVI = \frac{\rho_{\text{NIR}} - \rho_{\text{RED}}}{\rho_{\text{NIR}} + \rho_{\text{RED}}}
\]

Table 1
Satellite image data used.

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Sensor</th>
<th>Date of acquisition</th>
<th>Path</th>
<th>Row</th>
<th>Bands</th>
</tr>
</thead>
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<td>01.08.1987</td>
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<td>33</td>
<td>1, 2, 3, 4, 5, and 7</td>
</tr>
<tr>
<td>Landsat 7</td>
<td>ETM+</td>
<td>12.06.2001</td>
<td>176</td>
<td>33</td>
<td>1, 2, 3, 4, 5, and 7</td>
</tr>
<tr>
<td>Landsat 7</td>
<td>ETM+</td>
<td>28.07.2006</td>
<td>176</td>
<td>33</td>
<td>1, 2, 3, 4, 5, and 7</td>
</tr>
</tbody>
</table>

Fig. 5. SR index variation computed using Landsat image for three different years.

Fig. 4. Photos taken from the southern part of reclamation field 1 in 2005. a. Black pine and acacia combination in the rearward and maple in the front planted after 1991. b. Acacia planted after 1996.
2.5. Tasseled cap

In order to derive information about the development and health of vegetation for the reclaimed regions, the tasseled cap transformation was used. This is a three dimensional construct where the crop development can easily be visualized. The tasseled cap transformation, developed by Kauth and Thomas (1976), originally constructed for understanding of crop development in spectral space. It performs an orthogonal transformation of the original data in order to reduce spectral data into a few bands associated with physical scene characteristics (Crist and Cicone, 1984). For Landsat TM data, the tasseled cap vegetation index consists of three factors: Brightness, Greenness, and Third. For Landsat 7 ETM data, the tasseled cap transformation produces six output bands: Brightness, Greenness, Wetness, Fourth (Haze), Fifth and Sixth. The Brightness and Greenness are equivalent to the soil brightness index (SBI), the green vegetation index (GVI), and the third component is related to moisture status of soil features. Generally, the brightness and greenness derived from the transformation contain most of the scene information (95% to 98%) (Jensen, 1996). As described by Kauth and Thomas (1976), in the brightness–greenness spectral space plot, the bare soil would lie parallel to the brightness axis. Because green vegetation is highly correlated with greenness, it progresses perpendicular to the plane of soils during a growing season. The further away from the plane of the soil, the greater the amount of green vegetation presents (Jensen, 1996). In order to measure the presence and condition of vegetation in recreational field 1, the Landsat TM image and Landsat ETM+ images are decomposed by using the tasseled cap transformation (Fig. 8).

3. Discussion

The remote sensing-based vegetation index analysis resulted in visualization of vegetation coverage on reclaimed coal regions. Fig. 5, Fig. 6 and Fig. 7 illustrate the SR, RSR and NDVI images respectively of the reclamation field over the three-year period. As presented in three of the vegetation index images (Fig. 5, Fig. 6 and Fig. 7), the southern part of the region was lacking in vegetation coverage and only moderate vegetation coverage visualized in the northern part of the region in 1987. Conversely, for most areas there was a slight overall increase in the reflectance of vegetation index images in 2001. Moreover, in 2006 the vegetation index increased significantly at the southern part of the site and slight decreases occurred above this region compared to 2001. It is clearly illustrated in Fig. 6 that the RSR has unified the subtle reflectance differences and provided smoothed images compared to SR and NDVI.

In order to evaluate the spatial distribution of vegetation condition and vegetation coverage for three different years, the components of tasseled cap were mapped in Fig. 8. Furthermore, the first three components of the tasseled cap transformation were quantitatively evaluated by analyzing the DN statistics (Table 2) and the display of the cluster plots (Fig. 9).

The values were normalized before quantitative evaluation of tasseled components in order to transform the values from subject space to a common space. Table 2 provides the overall evaluation of the region. It is clear that the green vegetation is higher in 2001 with 0.65 greenness mean values (Table 2). This is also demonstrated by evaluation of the greenness image of 2001 in Fig. 8. It is evident from

<table>
<thead>
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<th>Year</th>
<th>Brightness</th>
<th>Greenness</th>
<th>Wetness</th>
</tr>
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<tbody>
<tr>
<td>1987</td>
<td>0.57 ± 0.17</td>
<td>0.56 ± 0.19</td>
<td>0.55 ± 0.12</td>
</tr>
<tr>
<td>2001</td>
<td>0.54 ± 0.10</td>
<td>0.65 ± 0.14</td>
<td>0.46 ± 0.11</td>
</tr>
<tr>
<td>2006</td>
<td>0.63 ± 0.12</td>
<td>0.47 ± 0.16</td>
<td>0.37 ± 0.12</td>
</tr>
</tbody>
</table>

Fig. 6. RSR index variation computed using Landsat image for three different years.

Fig. 7. NDVI variation computed using Landsat image for three different years.

Fig. 8. Brightness (a), greenness (b) and wetness (c) images derived by applying tasseled cap transformation coefficients to the reclamation field 1.
the greenness image of 2001 (Fig. 8) that the vegetation is spatially distributed in the whole region which may increase the mean value of greenness index.

The brightness image is highly correlated with bare soil. The greater the amount of bare soil, the brighter the response. Owing to the fact that the reclamation studies began after 1991 in mining regions, especially the southern part (presented with A in Fig. 8a) the 1987 brightness image indicates the existence of bare soil. This might result in a lower greenness mean value in 1987 compared to 2001. Additionally, in 2006 a decrease in the mean value of greenness occurred in the overall region. This might be due to either the later flight time, a dry summer, or that the vegetation had run out of nutrients or a combination of these factors. The greenness image is highly correlated with LAI. Therefore, as illustrated in Fig. 8b, the local region illustrated with B in 1987 becomes much brighter in the images of 2001 and 2006, respectively. This illustration provides information concerning the change in the health of planted species in the region. Based on these indicators of greenness image it can be concluded that, compared to the overall evaluation of the whole region by statistics in Table 2, the progress of rehabilitation was improved in the local region (B) in 2006 compared to 2001. As a result, it is seen that the region has a moderate to good reclamation success.

The moisture component image (Fig. 8c) provides subtle information concerning the moisture status of the wetland environment. The north-western part of the region indicates brighter response which is due to presence of a mining lake. As expected, the moisture content might be present in the vegetated area compared to bare soil which is illustrated in local region C in 2006 (Fig. 8c) with brighter response of wetness image. However, when the mean of wetness values are evaluated (Table 2), it is clear that the wetness is lower in 2006 for the whole region.

Fig. 9 shows a cluster plot of greenness vs. brightness for three different years. For each year all plots illustrate a negative correlation of greenness and brightness. The variation is much higher in 1987 and 2006 compared to 2001. This is also be demonstrated by lower standard deviation values of greenness and brightness values of 2001 (Table 2). The radiance of green plant is located to the left, at the tip of the plots. Fig. 9 gives an idea of the distribution of soil reflectance. The reflectance of soil lies close to the brightness line. Therefore, as presented in Fig. 9, the distribution of soil reflectance is higher in 1987 compared to 2001 and 2006.

The quantification of green vegetation is a complex problem. Some indices may work better in certain conditions than others. The NDVI may be preferred to the simple ratio indices (SR and RSR) because it compensates for changing light conditions, slope, and aspect effects. In our case, the region does not show much variance on slope or aspect. For this reason, NDVI does not show much difference compared to the SR and RSR indices. Tasseled cap provides an opportunity to evaluate three different features of the surface simultaneously, namely: brightness, greenness and wetness. On the other hand, when the greenness index of tasseled cap is compared with the other indices (SR, RSR, and NDVI) it is seen that similar results are produced for the study region.

4. Conclusion

Coal mining, particularly open cast coal mining, causes disruption and degradation over wide regions. Post mining restoration has vital importance in order to minimize the impacts on the environment. Besides the ongoing reclamation activities, it is important to re-evaluate the health of planted species until the vegetation is self-supporting. In comparison with conventional data acquisition methods, remote sensing techniques are powerful in order to provide a cost-effective assessment of the relatively large reclaimed areas. This study provides an approach to evaluate the condition of vegetation coverage and monitor the progress of rehabilitation using vegetation indices. Landsat images were used to monitor and evaluate the vegetation condition of the reclamation field for three different years. It is not possible to assess the accuracy of the results if no in situ data exist about the past. Therefore, different vegetation index algorithms were evaluated for relative comparison of results. The vegetation
increase was associated with an increase in greenness index, SR, RSR, NDVI and decreases in brightness and soil. The analyses show a good agreement between the four different vegetation indices concerning the condition of vegetation for the same year. Depending on the results acquired for 2001 and 2006, it is seen that, the study region was successfully and sustainably reclaimed. However, it requires only a limited final assessment prior to application for reclamation release especially for the southern parts of the region.

The success of reclamation practices and its monitoring is very important for mining professionals, environmentalists, and for the society as well. Therefore, this type of research and resultant information is significant to present the efficiency of remote sensing-GIS usage in order to track the reclamation process through time.

References


