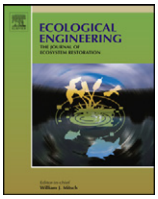
Ecological Engineering 43 (2012) 45–52

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng



Changes in vegetation cover, moisture properties and surface temperature of a brown coal dump from 1984 to 2009 using satellite data analysis

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ARTICLE INFO

Article history:
Received 1 February 2011
Received in revised form 10 March 2011
Accepted 15 March 2011
Available online 20 April 2011

Keywords:
Surface temperature
Surface moisture
Vegetation cover
Landsat
Time series analysis

ABSTRACT

This paper presents an evaluation of changes in the performance of the surface of the Velká Podkrušnohorská dump, a brown coal waste dump, over a period of 25 years from 1984 to 2009, on the basis of satellite data collected by the Landsat satellite. The changes in vegetation cover, surface moisture and surface temperature were evaluated on the basis of the NDVI index (Normalized Difference Vegetation Index), the NDMI index (Normalized Difference Moisture Index) and the Landsat satellite thermal band. Due to the intense piling up of extracted material and the removal of vegetation cover, there was a significant increase in surface temperature and a decline in NDVI and NDMI after the study of the dump territory began. The maximum surface temperatures and the minimum values of both indices were established in 2000. The trend of the changes in these values has reversed since 2000, due to intensive reclamation works as well as natural succession. The results indicate a significant role of vegetation cover in the formation of the surface temperature and moisture parameters, and the transformation of solar energy at the surface. We consider that the removal of vegetation cover over vast areas can have an impact on the regional climate and hydrological regime. Moreover, we recommend that emphasis be placed on this effect when planning structures for mining purposes.

1. Introduction

Vegetation cover in the landscape plays an important role in the transformation of solar energy at the surface of the Earth into individual energy fluxes, i.e. sensible heat, latent heat of evaporation and heat flux into the ground (Gates, 1980; Hayden, 1998; Monteith and Unsworth, 1990; Pokorný, 2001). The manner of solar energy transformation (dissipation) on the active surface has a significant impact on the formation of the local climate, and thus on the climate as such in a broader sense (see e.g. Hesslerová and Pokorný, 2007; Mahmood et al., 2010; McPherson, 2007; Pielke and Avissar, 1990; Pokorný et al., 2010). Land cover, or more precisely vegetation cover, has an important impact on the circulation of air in the boundary layer of the atmosphere (Mahfouf et al., 1987; McPherson, 2007), on climatic characteristics and also on the hydrological regime of a territory (Avissar et al., 2004; Jackson et al., 2008; Makarieva et al., 2006; Piao et al., 2007; Scheffer et al., 2005). Thanks to its ability to cool the surface actively during the evapotranspiration process (Fitter and Hay, 2002; Nobel, 1999) and the ability to retain and distribute water in the soil (Domec et al., 2010; Nadezhdina et al., 2009), vegetation can stabilise the temperature and moisture regime of a territory (Brom and Pokorný, 2009; Brom et al., 2010; Schwartz and Karl, 1990). In the course of surface mining, the vegetation cover and the draining regime are disturbed over enormous areas. In Europe alone, hundreds of square kilometers are currently affected by surface mining, with a significant proportion of the area free of vegetation cover, which changes the dissipation ability of the surfaces and also leads to changes in hydrology and climate. At the present time, because of the environmental impacts, attention is being paid to the issue of biodiversity, in particular, and also to the issues of material toxicity, water outflow and quality, and the remediation of areas disturbed by surface mining. The impact of areas disturbed by surface mining on climate parameters, or on eco-hydrological characteristics, has received only marginal attention (see He and Yin, 2010; Moreno-de las Heras et al., 2009; Pecharová et al., 2006; Pokorný, 2001; Pokorný and Šíma, 2006; Pokorný et al., 2007; Wechsung, 2000).

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doi:10.1016/j.ecoleng.2011.03.001

The aim of this work is (1) to describe the development of the surface temperature, the amount of vegetation and surface moisture as indicators of the function of the territory in terms of the transformation (dissipation) of solar energy during the previous 25 years (since 1984) and (2) to describe the relationship between the studied characteristics and the surrounding landscape and to evaluate the potential impact of the changes observed in the territory of interest on the surrounding landscape on the basis of the example of the Velká Podkrušnohorská brown coal dump.

2. Materials and methods

2.1. The study site

The study area of the Velká Podkrušnohorská dump (referred to as the VP dump) is situated in the western part of the Czech Republic, near the towns of Karlovy Vary and Sokolov in the Sokolov basin (see Fig. 1). The VP dump is one of the largest dumps in the Czech Republic. The VP dump study covers an area of 21.85 km^2. The broader study area, including the surface of the dump and its surroundings, covers 700 km^2 (see Fig. 1 and Table 2).

The first reference to coal mining in the Sokolov basin dates back to 1760. The development of modern industrial coal mining dates back to the era after the railroad construction was completed in 1871. After the Second World War there were 39 underground mines and 15 small mines operating in the Sokolov region. The underground mines were subsequently gradually closed down, and surface mining and large-scale mining started to develop in the region. Mining reached its peak in 1983, when more than 22.6 million tons of brown coal were mined in the region (Rothbauer, 2003). The VP dump had been created approximately 30 years before that by combining several smaller dumps to form the external dump of the Jiří brown coal mine. A total of approximately 886,000,000 m^3 of 23 overburden soils (mostly cypris clay, claystone, coal clays, coal remains and other materials) were piled up at the dump (Mikoláš, 2009). Since 2003 the storage activities have gradually been closed down (Rothbauer, 2003). Forestry reclamation combined with agricultural reclamation has been taking place in the VP dump area, accompanied by smaller bodies of water and wetlands, which are usually classified as forestry reclamation, due to their small area. A part of the area has been left to natural succession. The agricultural reclamation has been designated as permanent grasslands; forestry reclamation is planned in most of the area, with the forests covering the dumps classified as protective forests.

2.2. Description of the data

A set of available Landsat satellite scenes (Copyright ESA, distributor Eurimage) was used for assessing the functional characteristics of the VP dump in the period from 1984 to 2009. In order to eliminate the seasonal vegetation effect, only data from the end of June to the end of August were used for the analysed years. The acquisition dates of the data are listed in Table 1.

All of the data were acquired in 9:38 UTC + 1. The data were rectified into the S-JTSK cartography projection (EPSG: 2065) and corrected in atmospheric terms using the ATCOR2 PCI Geomatica modules for the optical bands and ATCOR2_T for the thermal band (Geomatica Algorithm Reference, 2003). Any areas impacted by cloud or by errors were excluded from further analyses. The extent of the areas used in the analyses is shown in Table 2.

The Normalized Difference Vegetation Index (NDVI), the surface temperature and the Normalized Difference Moisture Index (NDMI) were used for the time series assessment. NDVI was used as an indicator of the amount of vegetation at the surface, calculated from the red band (band 3) and the near-infrared band (band 4), as follows (Tucker, 1979):

$$\text{NDVI} = \frac{\text{band } 4 - \text{band } 3}{\text{band } 4 + \text{band } 3} \tag{1}$$

NDMI was used as an indicator of the moisture characteristics of the VP dump area. NDMI was calculated on the basis of the Landsat near-infrared band (band 4) and the shortwave infrared band (band 5) (Gao, 1996; Jin and Sader, 2005):

$$\text{NDMI} = \frac{\text{band } 4 - \text{band } 5}{\text{band } 4 + \text{band } 5} \tag{2}$$

The surface temperature was derived from the 6th Landsat band, using the PCI Geomatica 13 ATCOR2_T module (Geomatica Algorithm Reference, 2003). The original data gained from the satellite scenes was statistically analysed and summarised for the area of the VP dump. Due to issues connected with seasonal changes in vegetation cover and weather conditions, the features were standardised for the whole area, including the surroundings of the VP dump (see Fig. 1):

$$A_i = \frac{x_i - \bar{x}}{s} \tag{3}$$

where A_i is a standardised value, x_i is an original value, $\bar{x}$ is the mean value of the dataset and s is the standard deviation of the dataset. In this way, we obtained a mean landscape for each of the images, and individual characteristics of the VP dump were assessed consecutively in the context of these values. This means that the VP dump area is a subset of the whole area studied, including the surroundings of the VP dump. This can be expressed mathematically as follows:

$$A = \{A_i \in R\} \tag{4}$$

and

$$B \subseteq A \tag{5}$$

Table 1
Overview of acquisition time and satellites that were used.

Date	Satellite/scanner	Spatial resolution
3rd August 1984	Landsat 5/TM	30 m optical bands, 120 m thermal band
14th August 1988	Landsat 5/TM	30 m optical bands, 120 m thermal band
7th August 1991	Landsat 5/TM	30 m optical bands, 120 m thermal band
1st July 1995	Landsat 5/TM	30 m optical bands, 120 m thermal band
20th June 2000	Landsat 7/ETM+	30 m optical bands, 60 m thermal band
28th July 2005	Landsat 5/TM	30 m optical bands, 120 m thermal band
24th August 2009	Landsat 5/TM	30 m optical bands, 120 m thermal band

Table 2
Extent of the areas used for the analyses. The whole area, including the surroundings of the Velká Ppodkrušnohorská dump, is described for the standardised values.

Date	VP dump (number of pixels)	Whole area studied (number of pixels)
3rd August 1984	24,269	738,426
14th August 1988	24,281	778,180
7th August 1991	24,281	778,180
1st July 1995	24,281	777,915
20th June 2000	24,281	762,160
28th July 2005	24,281	778,180
24th August 2009	24,281	778,180