CHANGES IN LANDSCAPE ENERGY BALANCE AS A RESULT OF DIFFERENT LAND USE DURING THREE TIME PERIODS

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Abstract

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Functioning of the landscape was evaluated from the point of view of energy flow in the brown-coal mining area in the northern part of the Czech Republic. We assumed that the change of land use was also reflected in energy flows. Our attention was focused mainly on the proportion of incident solar energy that is changed to latent heat within the process of evapotranspiration. The area of interest included brown-coal opencast (14 km^2) and its close surroundings (53.1 km^2). The land use data were acquired by terrain mapping. An average value of evapotranspiration for growing season was assigned to each land use unit. These values were obtained from the literature. We also obtained surface temperature and surface wetness from Landsat TM satellite data for the whole area of interest. These data present a good evidence of incident radiation converted to sensible heat. Furthermore, we verified the relation between evapotranspiration and surface temperature, and between wetness index and evapotranspiration. These relationships appeared to be significant when tested by Kruskal-Wallis test. Thus it was possible to compare the estimated evapotranspiration for land use before the beginning of mining as well as for a proposal study in which inudation of the brown-coal opencast was taken into account after termination of mining activity. The presented results of the estimated evapotranspiration in the area of interest confirmed the hypothesis that changes of land use have a significant effect on the total average evapotranspiration as an important function of the landscape.

Key words: evapotranspiration, remote sensing, GIS

Introduction

The area of Northern Bohemia was significantly transformed by an anthropogenic activities, namely surface mining. Opencasts originating in brown-coal mining and numerous dumps of related waste rock are of great significance for affecting matter and energy flows in the landscape. In this work, we dealt with landscape functioning from the point of view of energy flows in the area of brown-coal opencast and its close surroundings. As the main energy flow is considered to be the change of proportion between the reflection of solar radiation, evapotranspiration and sensible heat. In the summer, in uncovered areas without vegetation, occurs a considerable overheating of surfaces. This is caused by change of Bowen proportion in favour of sensible heat (Pokorný, 2001). This phenomenon has a whole range of negative effects: increased losses of matter from the periodically dried soil profile as well as ambivalence of climate including its unfavourable effect on vegetative cover. On the contrary, areas covered with vegetation increase the conversion proportion of incident solar radiation to latent heat in the process of evapotranspiration (Ripl, 1995; Pražák et al., 1994). This results in more balanced area climate, without noticeable extremes, and closed small hydrological cycles, preventing matter losses from the basin (Ripl et al., 1994). Therefore, the evapotranspiration values are an important indicator of landscape functioning. The change of energy balance and subsequent change of microclimate with proceeding industrialization of the region below the Krušné hory mountains affected by brown-coal mining was studied by Pecharová et al. (2004). This resulted in a proposed model of energy flows within the landscape from the climax state, over the beginning of industrialization, and up to present and a suggestion of the desired state. The objective of this work is to estimate how effectively the area of interest can dissipate solar energy via evapotranspiration under the current conditions, in comparison to its state in 1841, and after the proposed recultivation.

Material and methods

The area of interest includes brown-coal opencast (near the town of Most) and its close surroundings. From the geological point of view there are two structural levels: the fundament and the platform cover. The fundament is the subsoil of the platform cover and includes both the oldest sedimentary and igneous rock of Proterozoic and Paleozoic age. The platform cover is a product of four big sedimentary cycles: Perm-Carbonic, upper Cretaceous, Tertiary and Quaternary. In the tertiary period a sedimentary area of a vast lake basin began to form, creating suitable conditions for deposition of coal-producing material. At the end of Pleistocene (approx. 15 000 years ago), a shallow flowing lake arose in the region under the Krušné hory mountains. This happened probably as a consequence of degradation of the permafrost in frost-claystones. This lake both filled and drained by the Bílina river went through all typical development stages from oligotrophic and eutrophic up to dystrophic. Historically, Komořanské Lake was its residue (Hurník, 2001). The lake area decreased under the influence of sedimentation and the lake split into several smaller lakes. The so-called Komořanské Lake had at the beginning of last century, an area of about 140 ha. In the 1830s, Duke Ferdinand of Lobkovic set the task of draining and drying the lake up. In the 1900s a brown coal opencast was open there. After finishing the coal-mining activities, the opencast pit should have been flooded according to restoration plans. Data for land use map were gathered in the field by detailed mapping terrain into the 1:10 000 maps. Subject content of the maps was converted into vector layer in GIS (see Fig. 1). For verification of the mapped units, a geocoded aerial photo was used. The result is a map of land use units where the main attention aimed at the vegetative cover. Further, a map of the estimated evapotranspiration was made. This map had two different data sources: 1) earlier mentioned land use units obtained by field mapping and 2) average values of evapotranspiration during the growing season for the given land use units obtained from the literature. Evapotranspiration values for individual land use units are stated in Table 1. Integration of these data was performed in GIS and resulted in a map showing distribution of estimated evapotranspiration or evaporation of the opencast and its surroundings. Satellite data showing temperature distribution and landscape cover wetness as well as health condition of the vegetation were processed. For the purpose of this project, we used data from Landsat TM 5 satellite, with localization 192/25 acquired 10-8-2004. The satellite scene was geocoded into coordinate system S-JTSK. From these data, we further acquired temperature values of the land cover (Geomatica Algorithm Reference, 2003), wetness index calculated by using TASSELED CUP transformation (Crist, Cicone, 1984) and the NDVI (Normalized Difference Vegetation Index). The resulting maps of the mentioned characteristics were expressed in pseudo-coloured maps and data from aerial photos were added for easier spatial orientation. Connection of estimated evapotranspiration and land cover parameters (surface temperature, wetness temperature, NDVI) proved by Kruskal-Wallis test. This is why it was possible to use the data of estimated evapotranspiration for land use before the beginning of mining in the area of interest as well as for the proposal study, which takes into account the inundation of the opencast after the end of mining activities. In order to obtain a map of estimated evapotranspiration before the beginning of mining, it was necessary to process historical land use data. These were obtained from the cadastral maps of 1843 in the scale of 1: 2280. Maps were geocoded and transformed into GIS. Values of estimated evapotranspiration were then assigned to individual land use units. The same method was used in the case of the proposal study for recultivation of the area after mining. However, here we used land use units considered in the recultivation proposal as a base for estimated evapotranspiration.

T a b l e 1. The estimated evapotranspiration values and sources

Type of cover	Average evapotranspiration in growing season (mm/day)	Source
	(VI – VII)	
Balk. mowed or mulched meadow	2.9	Šmahel et al., 2001
Balk. uncultivated meadow	1.9	Šmahel et al., 2001
Acidophil grass (*Violion caninae*)	2.0	Šmahel et al., 2001
Subxerophyte grass	1.0	Kurc (2002)
Subxerophyte shrubbery	1.2	Kurc (2002)
Calthion	5.0	Šmahel et al., 2001
Dewatered peat bog	2.2	unpublished data from Kapličky
Wetlands (Florida, USA)	2.1 (3.8)	Jawitz, Annable (2003)
Reeds marsh (USA)	3.3 – 5.6	Paul et al. (2002)
Spruce monoculture	1.5	Pivec (2002); Šach et al. (2000)
Natural spruce growth	2.5	Tužinský (2000)
Bottomland forest	3.8	Pivec (2002); Hinckley et al. (1994); Ambros (1978); Herbst et al. (1999)
Acid beech wood	2.5	Šach et al. (2000); Tužinský (2000)
Water surface	3.8	various data resources, but this value is most rainfall dependent

Results

The distribution of temperatures of the landscape cover in the area of interest is presented in Fig. 2. The highest values appear in the area of opencast or in built-up areas. The absolutely highest temperatures appear in the uncovered coal seam that lacks vegetation cover and is black, which extremely heats up the surfaces. The lowest temperatures appear on water surfaces, wetlands and forest growths. Wetness index values (see Fig. 3) and temperatures are in inverse proportion. The lowest values of this index appear in the area of opencast, where the absolute minimum is not at the coal seam, but on the slopes of the mining terraces that, as expected, contain the lowest amounts of water. Both parameters correlate well ($R = 0.80$, $R^2 = 0.65$, $P = 0.00$). Fig. 4 shows the NDVI. Absence of vegetation in the area of the opencast is evident here.

Maps of estimated evapotranspiration (see Fig. 5) where values of average evapotranspiration obtained from the literature were assigned to individual values of land use. To find out if the maps of estimated evapotranspiration correspond to the reality, we evaluated the relationship between these maps, temperatures and wetness index. Temperature and wetness values depended on land use and the character of the relief, so the normal (Gaussian) distribution could not be expected. Therefore, the non-parametric method (Kruskal-Wallis test) was used to evaluate this relation ($p < 0.0001$). There appeared a possibility to use maps of the stable local area of 1841, when there was no mining activity. The average estimated evapotranspiration of the area is estimated to be 1.6 mm/day (see Fig. 6 and Table 2). Estimates for the current state are 1.4 mm/day and estimates for future state after recultivation of the area vary depending on the extent of planned inundation of the opencast in the range of 1.8 and 2.2 mm/day.

Discussion

Although we did not assign measured values of evapotranspiration to the land use units but the values taken from the literature, the data show good connection with the values of surface temperature and wetness index. This is caused also by the fact that the land use of the respective area consists of units significantly different in their energy characteristics (bare subsoil of the opencast, meadow and forest growths in its surroundings). Quite complex landscape relief does not complicate the situation there.

The influence of the terrain depression has significantly lower effect on the microclimate than the fact that the surface of the opencast is not covered with vegetation. Thus, during summer months, occurs some overheating of these surfaces.

According to the fact that the surface of the opencast occupies 26% of the area of interest, the average estimated evapotranspiration of the area in 2004 was relatively low (1.4 mm/day). Despite our expectations, the values of evapotranspiration from 1841 are quite low as well (1.6 mm/day). This can be explained by a high proportion of arable soil that, if not watered, shows lower values of evapotranspiration than natural grass or forest ecosystems.

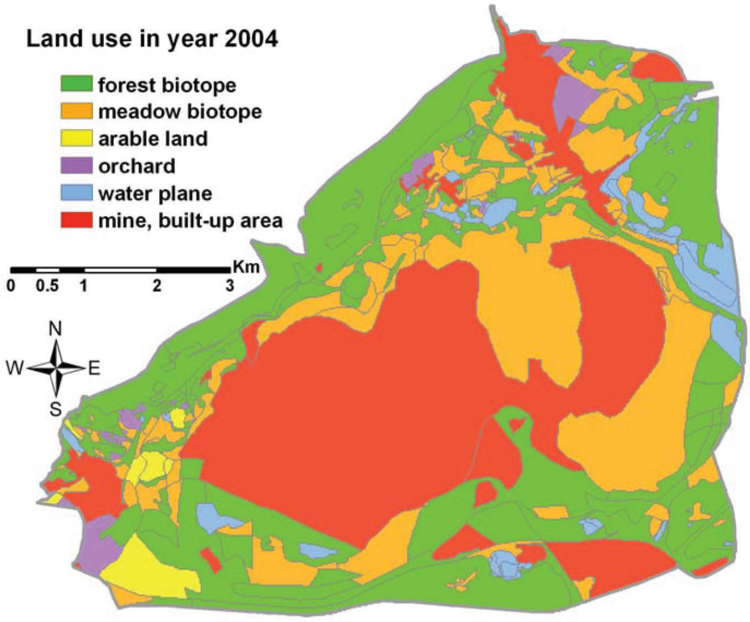

Fig. 1. Land use in the brown-coal mining area and its close surroundings.

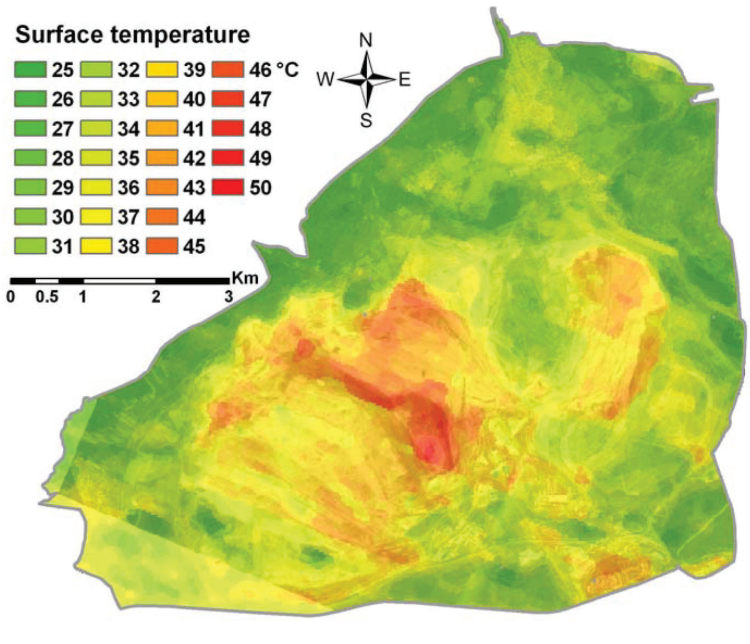

Fig. 2. Surface temperature from Landsat TM data.

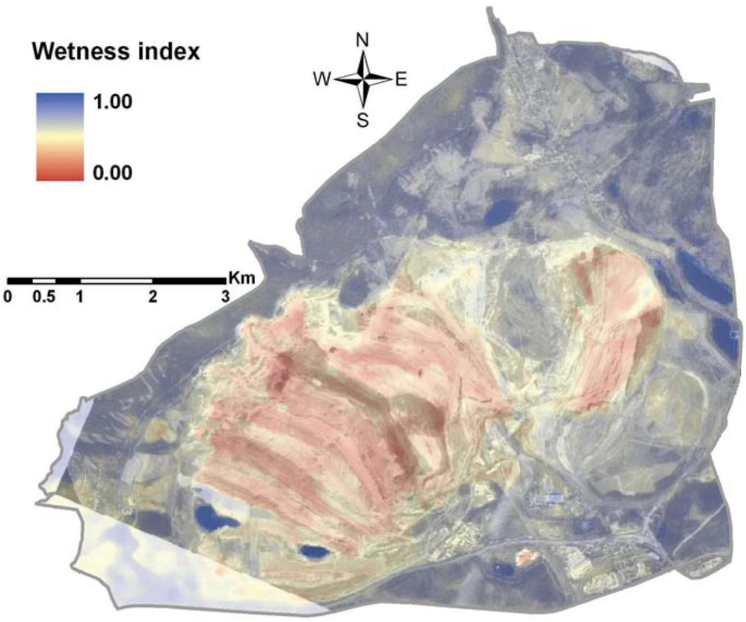

Fig. 3. Wetness index calculated using TASSELED CUP transformation (Landsat TM data).

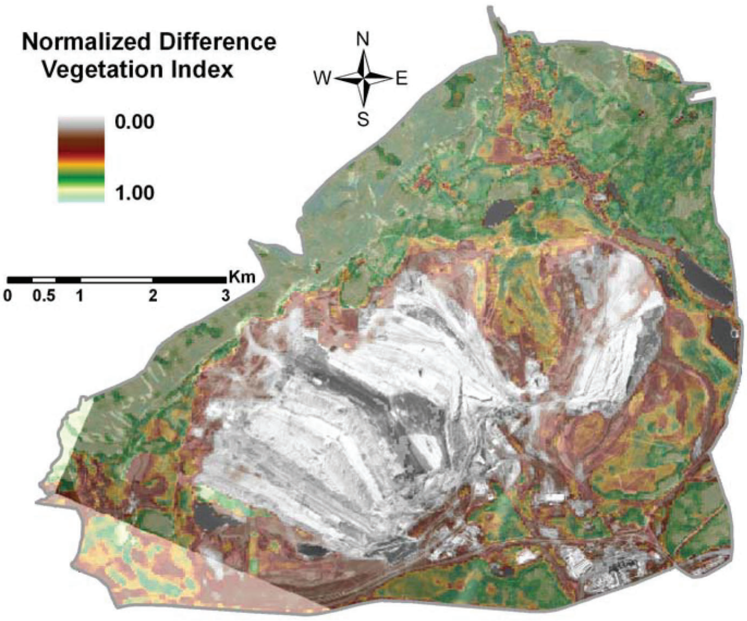

Fig. 4. Normalized Difference Vegetation Index (Landsat TM data).

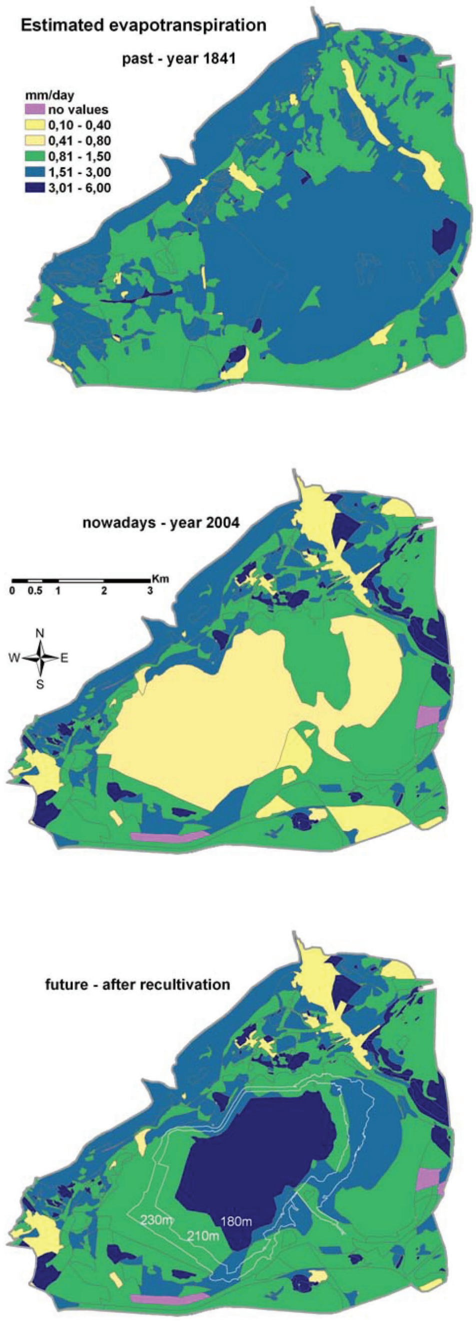

Fig. 5. Estimated evapotranspiration in the brown-coal mining area in three phases.

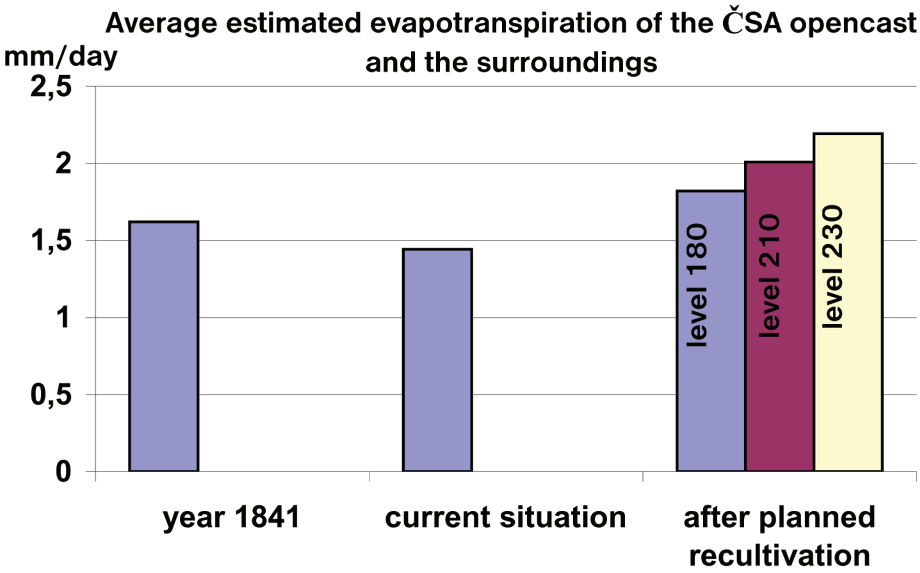

Fig. 6. Estimated evapotranspiration of the area of interest before the beginning and during the mining activity and after the planned recultivation in the three water levels: 180, 210 a 230 m.

T a b l e 2. Estimated evapotranspiration and the total daily evapotranspiration of the area of interest before the beginning and during the mining activity and after the planned recultivation

	Year 1841	Current situation	After planned recultivation	
Average estimated evapotranspiration (mm/day)	1.62	1.44	180m	1.82
			210m	2.01
			230m	2.19
Total daily evapotranspiration of whole area of interest (l)	85966522	75832750	180m	95680097
			210m	105548961
			230m	115252701

Higher values of estimated evapotranspiration of the whole area can be expected after the recultivation of the mining areas. This is caused by water surface, which contributes to the total average by higher values of evaporation (3.8 mm/day). After the proposed recultivation we can expect more favourable and balanced climate over the whole area of interest.

We assume that this proves the hypothesis that changes in land use may significantly affect the total average evapotranspiration of the given area.

It means that the land use affects the energy balance of the landscape in the given area. This piece of knowledge could be taken into consideration in Landscape planning.

Conclusion

The presented results of the estimated evapotranspiration in the area of interest confirmed the hypothesis that changes of land use have a significant effect on the total average evapotranspiration as an important function of the landscape. According to the fact that the surface of the opencast occupies 26% of the area of interest, the average estimated evapotranspiration of the area in 2004 was relatively low (1.4 mm/day). Despite our expectations, the values of evapotranspiration from 1841 are quite low as well (1.6 mm/day). A high proportion of arable soil can explain this. Higher values of estimated evapotranspiration of the whole area can be expected after the recultivation of the mining areas. This is caused by water surface, which contributes to the total average by higher values of evaporation (3.8 mm/day).

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Pecharová E., Hais M., Svoboda I.: **Změny v energetické bilanci krajiny v důsledku různého využití území ve třech časových etapách.**

Zabývali jsme se fungováním krajiny z hlediska toků energie v oblasti těžby hnědého uhlí na severu České republiky. Vycházeli jsme z předpokladu, že změna land use se odráží i v energetických tocích. Z energetických toků v krajině se naše pozornost soustředila zejména na podíl dopadající sluneční energie, která se v procesu evapotranspirace přemění na latentní teplo. Zájmové území zahrnuje hnědouhelný lom ČSA (14km^2) a blízké okolí (celkem 53,1 km^2). Data land use byla získána terénním mapováním. Každé jednotce land use byla přiřazena průměrná hodnota evapotranspirace pro vegetační sezónu. Tyto hodnoty byly získány z literatury. Dále byly získány teploty krajinného krytu a vypočítány hodnoty vlhkostního indexu z družicových dat Landsat TM pro celé zájmové území. Tato data do značné míry vypovídají o podílu přeměněného dopadajícího záření na zjevné teplo. Dále jsme ověřovali předpoklad nepřímé úměrnosti mezi evapotranspirací a surface temperature a přímé úměrnosti mezi vlhkostním indexem a evapotranspirací. Tato souvislost se ukázala jako signifikantní při testování Kruskal-Walisovým testem. Pak bylo možné data potenciální evapotranspirace použít pro land use před započetím těžby v zájmové oblasti a rovněž pro návrhovou studii, která počítá se zatopením hnědouhelného lomu po skončení těžby. Výsledkem jsou data potenciální evapotranspirace zájmového území před započetím těžby, v době těžby a po plánované rekultivaci. Rovněž se potvrdil předpoklad, že změny land use se mohou projevit významně na celkové průměrné evapotranspiraci daného území.