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Analysis of reclaimed areas in the Northern Bohemia brown coal open cast mining areas monitored by remote sensing data using cartography tools and GIS

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Abstract: - The Northern-Bohemia comprises large areas with underground mining – in prevailing part of brown coal - and brown coal open-casts. Abandoned open-casts have been being reclaimed. The history of the first reclamation is longer than thirty years. The reclamation was performed by several possible ways – new water basins were created in deep pitfalls, large areas were covered by forests, and large areas turned into agricultural fields. Their main purpose of water basins is to fill in land depressions after excavation. These basins allowed to transform surrounding parts of the landscape into recreational areas. Agricultural reclamation represents changing of previous open mines into agriculturally used areas. Forest reclamation is a creation of new mixed or deciduous forests whose good growth and sound stand is a measure of successfulness of the reclamation. Vegetation indices (VI) were used for evaluating of reclamation development from 3 multitemporal TM satellite data (1988, 1992, and 1998) and Ikonos data (2003). 12 vegetation indices were calculated from individual images (individual years). Their values were compared among individual years where average values of each reclaimed area were the comparable values. Relative values of VI were used for the final evaluation of reclaimed area developments. These values took into account climate differences among years. The final evaluation discovered reliability of ground truth data taken from reclamation projects and showed where the reclamation lasted longer and therefore ended later if compared to the projects, e.g. The evaluation presents more or less correlated VI values for certain age and forest types of reclaimed areas.

Key-Words: - vegetation index, remote sensing, reclamation, GIS, Landsat, Ikonos.

1 Introduction

Areas with open-casts cover hundreds of hectares in the study area near Teplice in the Northern Bohemia (Fig.1). Large areas have already been excavated and have been reclaimed and large areas are now technologically or biologically reclaimed. According to the Czech Mining Law, mining organizations are responsible for the post-mining reclamation. Reclamation investments reach high values. Their effectiveness has not yet been controlled in the Czech Republic. The goal of this project is to evaluate this effectiveness.

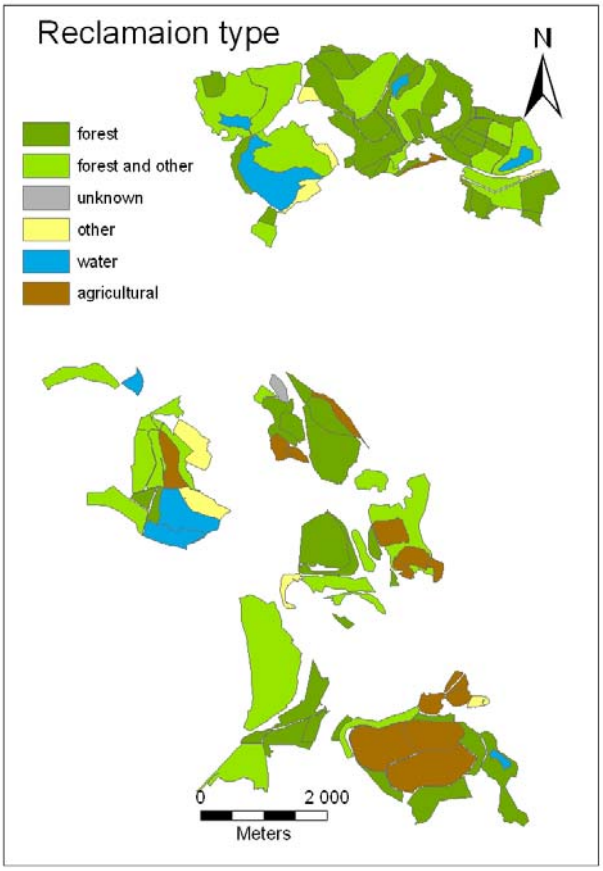
The reclamation process can be characterized by several phases. The first one is called technical phase and it lasts about two years. Terrain morphology is prepared including a final surface cover created by fertile soil layer. The morphology is determined by resulted landforms and their slope stabilities and by pit shapes themselves. Their final morphology and cover type are designed by experienced specialists in individual mining organizations. Selected areas with low slope were transformed to pastures or agriculture fields. Deep excavated areas are often transformed into water basins. The Barbora Lake as the largest one is an example of them serving now as an already famous recreational center. Certain areas were prepared for the permanent vegetation – forest or non-forest. The forests are mixed forest – with mixed deciduous trees, or deciduous and coniferous trees, and with shrubs sometimes (Fig.2), [18]. The technological phase has to create completely new landscape different from the one before mining activities. The final morphology is influenced by shapes of the final state of mining, however the final morphology is designed according to getechnics stability laws. At the moment, the ground surface is formed by deep soil layers whose character is not suitable for planting. New final soil layer with apropriate quality is distributed on these areas of previous mining. This step is the last one of the technological phase.

The second phase is a biological one when grass and two or three year-old trees are planted out. The biological reclamation comprises not only reforestation, but also new vegetation areas for pasturing and preparation of agricultural fields for crop growing. The main purpose of the biological phase is to create a new landscape surface resisting erosion. Combination of a long list of various trees and shrubs were used for individual areas to form

fully new natural conditions.
Mixed forests formed by deciduous trees, shrubs and conifers represent forestry reclamation. Forestry reclamations with deciduous trees comprise wild cherry-trees, red oak, poplar, ash-tree, alder, maple and birch and cover more than 200 hectares. Forestry reclamation with mixed forest combines aforementioned deciduous trees and elm, pine, larch, and spruce. The mixed forest covers more than 400 hectares. Reclamations with shrubs as alder, willow, juniper, hazel, smoke plant, privet etc. can be found on more than 800 hectares [1].
The third phase is a temporary period when regular controls once or twice a year verify stability of vegetation cover *in situ*. In case of the stable state, reclamation of an area is finished and the area can be sold to a new customer.
Reclaimed areas are formed by individual parts with different shapes and sizes varying from tenths of hectares to hundreds of hectares. Each part is characterized by its number, reclamation type, year when reclamation started and year of ending. The total area of reclamation has more then 3000 hectares in the study area. The first reclamation processes were finished already in 1959 – in the earliest case, and there are many reclamation areas whose reclamation process has not been finished yet [1].

Fig. 1. Arial photograph with boundaries of reclaimed areas.

Fig. 2. Types of reclamation in the reclaimed areas.



2 The Project Goal

The project should determine development of reclaimed areas and define methods that can be used for. Its purpose is therefore to analyze changes in reclaimed areas and their surroundings using remote sensing data and to compare them with reclamation projects and with the territorial system of ecological stableness (USES - current and designed bio-centers and bio-corridors). The goal is to determine which areas developed according to reclamation projects, and which developed diversely, what was the reason of it.
There are several methods used for the reclamation monitoring successfulness, the most efective will be recommended for similar analysis. Vegetation indices, their coincidence and diversity are compared for individual areas and years.
Vegetation indices are new channels calculated from measured bands [17]. There are more vegetation indices defined by various authors. They characterize behavior of vegetation in visible and infrared bands, which according to spectral reflectance curve differ from other materials. The vegetation behavior in the visible band covering 380 - 720 nm due to pigment absorption caused by chlorophyll, xanthophylls and other pigments

represents the darkest part of the vegetation spectrum usually. The highest values in reflectivity are in green visible band (around 550 nm) because the pigments have a lower absorption there. On the contrary the spectral range 720-1300 nm due to small absorption and strong scatter offers high values being therefore very bright. Leaf water and cellulose and lignin cause absorption in the spectral range 1300 – 2500 nm showing vegetation relatively dark.

Relations between the red visible band with lowest values of the visible band and the near infrared band (NIR) are used by newly calculated channels to differ vegetation from other materials.

Vegetation indices were calculated from reflectances that is why digital values were transformed into reflectance. The following equation shows the relation [4]

$$\rho_{meas}(\lambda)=\frac{\pi\cdot D^2\cdot L(\lambda)}{E_{sun}(\lambda)\cdot\cos\theta_Z}=\frac{\pi\cdot D^2}{E_{sun}(\lambda)\cdot\cos\theta_Z}\left[B(\lambda)+G\cdot DN\right], \quad (1)$$

Where: D is the Earth-Sun distance (in Astronomical Units, AU), Esun (λ) - band dependent mean solar exo-atmospheric irradiance (W/(m2 μm)), L(λ) - spectral radiance at sensor's aperture, θ_Z - solar zenith angle, B(λ) = Lmin(λ), G = Lmax(λ) - Lmin(λ), DN – digital number.

Dark object subtraction method [3] was used for the atmospheric correction individually for individual bands according to their histograms.

Nine vegetation indices were used for the evaluation: NDVI, DVI, RVI, PVI, SAVI [7, 8], MSAVI, TSAVI, EVI, and WDVI.

Following equations area examples of several indices:

NDVI is (the Normalized Difference Vegetation Index) is the best known and widely used vegetation index. Its values are in the <-1, 1> range. Its definition can be shown by the following equation

$$NDVI=\frac{NIR-red}{NIR+red} \quad (2)$$

- Shortcuts (NIR and red) mean reflectance in the near infrared and the red spectral bands. The NDVI was used by Kriegler et al. for the first time in 1969 [11].

The Ratio Vegetation Index - RVI [10] compares only single values of NIR and red bands. Its value can vary from 0 to infinity. Its definition is determined by the following equation:

$$RVI=\frac{NIR}{red} \quad (3)$$

The Difference Vegetation Index mentioned in Lillesand and Kiefer [12] as a used vegetation index expresses difference between NIR and red bands. It is calculated according to the 4th equation

$$DVI=NIR-red \quad (4)$$

The Perpendicular Vegetation Index was described by Richardson and Wiegand [14]. It belongs to a group of indices using the soil line. Soil line expresses the variation in the spectrum of bare soil in the image. The line can be determined by choice of two or more patches of bare soil in the image with different reflectivity and finding the best-fitted line in the spectral space. It can be a quite subjective decision. This index could be considered as a generalization of the DVI, which allows evaluation for soil lines of different slopes and passing through origin. Furthermore, the PVI is quite sensitive to its atmospheric situation, as Qi et al. [13] mentioned. It is important mainly in multitemporal image processing. The PVI expresses distance between pixel values in NIR and red band space to soil line. Pixels with the same PVI lie at the same distance from the soil line. PVI values are in the same range as NDVI values <-1, 1>. The equation defining the PVI is

$$PVI=\sin(\alpha).NIR-\cos(\alpha)red, \quad (5)$$

where α is the angle between the soil line and the NIR axis.

2.1 Data sources

The Landsat TM5 (7 bands) from August years 1988, 1992, 1998 with resolution 30m of the given territory were processed. Radiometric and geometric corrections were performed and the data are in the Czech Republic geographical coordinates.

The Ikonos data were the last satelite date set in the time serie. The image seriously influenced by haze and clouds was preprocessed (the method description is presented in a paper being prepared for press [5] .

All four bands are collected with 11bit radiometric resolution. The spectral characteristics of the IKONOS multispectral bands are approximately the same as the LANDSAT TM bands (1, -4).

Area measured by Ikonos is smaller than that of Landsat.

Table 1. Remote sensing data used for the processing

Sensor	Date
Landsat 5	14. 8. 1988
Landsat 5	9. 8. 1992
Landsat 5	10. 8. 1998
Ikonos	17. 9. 2003

Fig. 3. Comparison of Ikonos data and all reclamation areas

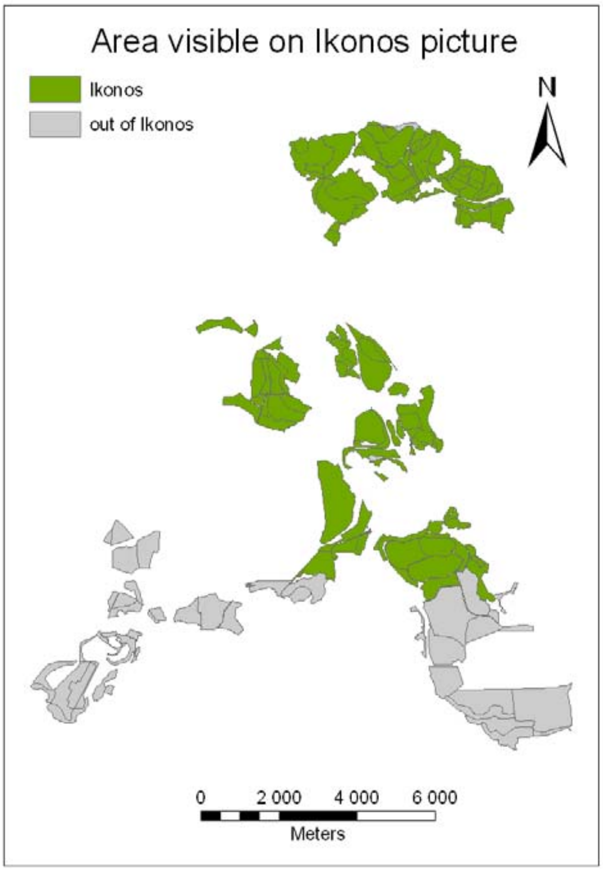
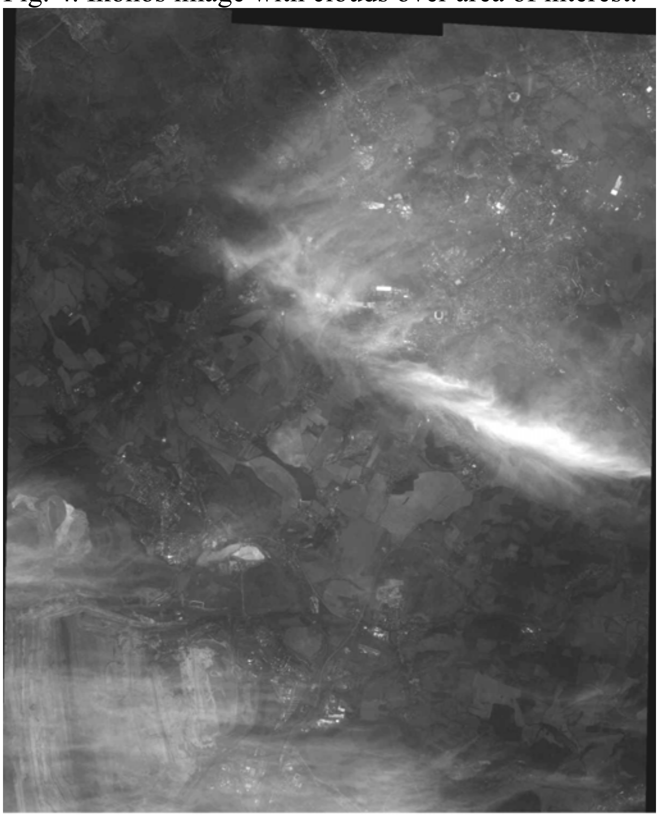


Fig. 4. Ikonos image with clouds over area of interest.



3 Problem Solution

VI calculated for all reclaimed areas were compared to NDVI values and for individual years. The comparison for one year depicts that the relation among VI (DVI, PVI, WDVI,…) and NDVI is not linear and that even for growing NDVI values, sinking VI can occur. These examples are highlighted by two red ellipses in Fig. 5.

Fig. 5. The graph shows relation among VI in the legend and NDVI for 10-year old forest reclamation. The ellipse shows nonlinearity of relations among VI and NDVI

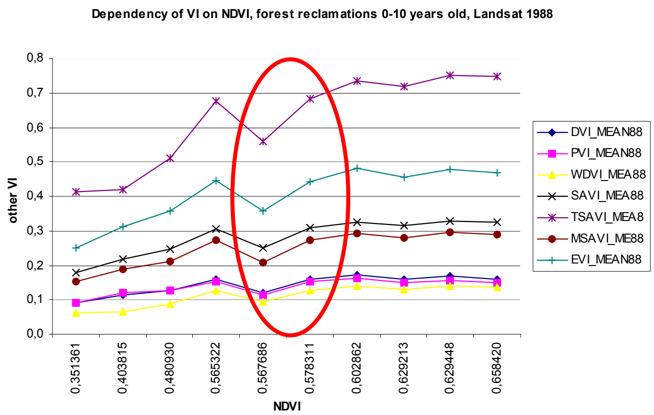
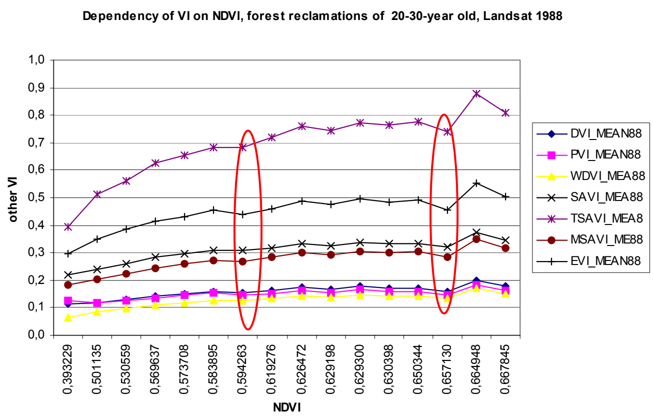


Fig. 6. The graph shows relation among VI in the legend and NDVI for 20-30-year old forest reclamation. The ellipses show nonlinearity of relations among VI and NDVI



Only TSAVI values have higher values than NDVI, the other VI have lower values if compared to NDVI. The lowest values were found for DVI, PVI, and WDVI with very small differences among themselves. The highest difference among them occurrs for the lowest NDVI value.
Comparing of NDVI in individual years shows Fig. 6.

The VI´s are seriously influenced by non-homogenous situations in individual areas. Fig 6 shows differences between pure forest reclamations in the left part of the graph and forest reclamations combined also with agricultural or hydric reclamations (the right part of the graph).

Fig. 7. Comparison of NDVI for forest reclamation among years (ranged by NDVI in 1988)

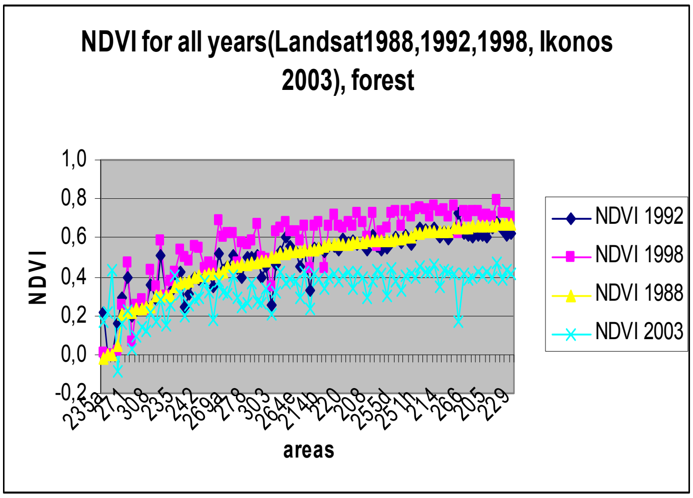
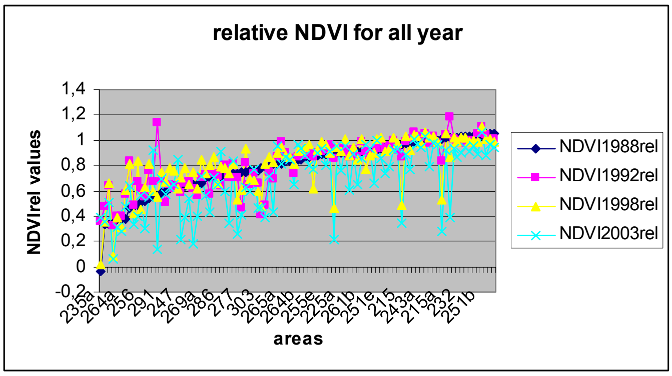


Fig 7 shows that most of VI in 1998 have higher values than NDVI in 1988. The lowest values were calculated for 2003

This graph can be used for distinguishing drier and wetter periods before measurements. This information can serve as a warning. The consequence of the fact caused that relative VI values were calculated. Relative values were calculated from original VI values divided by mean values of individual indices calculated for test areas. Test areas were formed by forest areas lying close to reclamed areas.

Fig 8. The graph presents VI values for the same years, but with different values. We can see that values of relative NDVI are having better results than absolute values, but still it doesn't show results we would expect which could be affected be manipulating with data when they were getting red of cloud over the area of interest.



NDVI in 2003 is NDVI in the second halft of September unlike other years which are from mid August.

4 Conclusion

Vegetation indices describe behavior of the land surface regarding the vegetation health state. To study the vegetation development from multitemporal data is a very sensitive problem. Three image data with nearly exactly several year differences (August 9, 10, 14). Differences between individual VI´s are not mutually linear for selected period. The younger the forest reclamation the higher differences between NDVI and other vegetation indexes (see fig. 5 and fig 6).

Similar trends can be found at MSAVI and SAVI, then at PVI, at DVI and at WDVI (see fig. 2 and 3). The decrease which is shown by all indices except for NDVI, is at six-year old area not only with forest, but also with a grass part (fig 5).

By comparing only time development of NDVI we found out, that it is not at all linear for individual areas (see Fig. 7). What can be clearly discovered are dryer (1992) and wetter years (1998,) if compared to 1988. Even that clouds on Ikonos image from 2003 have been removed, the results probably don't show real VI´s values (see Fig. 7). Reasons can be extremely dry summer at year 2003, Ikonos image was not taken in Äugust, but in September and the cleaning process may have affected the data.

Testing of 8 vegetation indexes showed that their assessment of improvement among years is not the same. DVI and PVI proved 60 per cent of improvement in areas (both reclaimed and tested) what was the optimistic result in the whole study period, while NDVI and RVI showed only 30 per cent (45 from 140) of improvement for reclaimed and 20 per cent for tested areas (4 from 20).

Acknowledgement

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