USAGE OF SPECTRAL INDICES IN MONITORING OF GREEN IN THE SELECTED PARTS OF THE PARDUBICE REGION (THE CZECH REPUBLIC)

Pavel Sedlák, Jitka Komárková, Magdaléna Langerová, Ivana Čermáková

Affiliations: Include data for the authors as follows:
MSc. Pavel Sedlak, Ph.D., Assoc. Prof. Jitka Komarková, Ph.D., MSc./Ing. Magdaléna Langerová, MSc./Ing. Ivana Čermaková;
Faculty of Economics and Administration, University of Pardubice;
Studentská 95, 532 10 Pardubice, Czech Republic;
Ph.: +420 466036128, fax: +420 466036010, e-mail: pavel.sedlak@upce.cz;

Abstract
The aim of the project was to evaluate the possibility of using spectral indices in the monitoring of the green in part of the Pardubice region, namely municipality with extended powers Pardubice. Five Landsat datasets were selected in the time period from 1987 to 2013. The processed data comes from Landsat 5, Landsat 7 and Landsat 8 satellites. Next three scenes were taken from the Terra satellite MODIS scanner. Images were selected in such a way that the acquisition dates were approximately the same. Four vegetation indices were compared: ratio index NDVI, SAVI and MSAVI distance indexes, and orthogonal index GVI. A temporal analysis was carried out for these indices between 1987 and 2013. An unsupervised classification was performed to better interpret the images. Data were classified by ISODATA algorithm into fifteen classes, which were then aggregated into three classes. A majority filter was used for smoothening the classified results. NDVI and SAVI values show almost identical results in the area of interest and there were no significant differences after the classification. MSAVI versus NDVI and SAVI index is less sensitive to capture of concrete surfaces. The water areas were classified correctly. The GVI vegetation index differs considerably from NDVI, SAVI and MSAVI indices. After classification, GVI ranked green areas similarly to other indices. However, agricultural land was largely included in the class of water areas. Therefore, GVI is inappropriate to analyse the green of areas of interest. The best results are provided by the classified MSAVI. The minimum of concrete surfaces were assigned into the class of water bodies. At the end of the work, the detection of green changes was calculated. Changes between 1987 and 2013 were most evident in the southern part of the area. The highest changes in vegetation identified GVI index.
Keywords: *Spectral indices, NDVI, SAVI, MSAVI, GVI, Landsat, Terra, Changes of vegetation*

INTRODUCTION

Spectral indices include a set of relatively simple arithmetic operations that work with two or more bands of multispectral image. A large number of spectral indices are defined. Some are used to enhance the existing indices, others emphasize another image aspect. Algorithms examining the vegetation component of the landscape are called vegetation indices. Vegetation indices can also be used to determine quantitative indicators such as the amount of biomass or differentiation between kinds of vegetation cover, health status of vegetation, crop yields, etc. (Qi, J. et al., 1991). Spectral indices are used in a variety of applications.

Huete, A., et al., (1999) describe other uses of vegetation indices, for example, for yearly and annual vegetation monitoring, and they mention other areas too. Research by Pervez, S. et al. (2014) observed and mapped irrigated area in Afghanistan using the NDVI index derived from the MODIS sensor for fourteen years. Akmar, Che et al. (2009) describe the mapping and monitoring of mangroves forests and thickets in the peninsula of Malaysia, one of the most productive ecosystems in the world, realised by the University of Malaysia and the tropical forest center TropAIR. Several vegetation indices were used for mapping, for example: NDVI, DVI, RVI, PVI and SAVI. The resulting index values were compared and evaluated among themselves. The Santos-González, C. (2002) study in the Kakadu National Park deals with the detection of wetlands in northern Australia. Remote Sensing is an invaluable tool for the inventory of wetlands, which are distant, inaccessible and very extensive. Data from the AVHRR sensor NOAA was used and the NDVI vegetation index was used for wetland detection. Work Rock, B. N. (2003) describes in year 2003 completed research of the health status of monocultures spruce on habitats located along the Ore Mountains. The NDVI index was used in the research. Moisture Stress Index (MSI) was used to determine the amount of water in the needles. Wu, J. et al. (2007) present a study to reveal a corn and potato index using the vegetation index LAI. The LAI index was used to derive agronomic information for field management and yield prediction in the field of agriculture. High-resolution multispectral images taken from the QuickBird satellite captured in three growing seasons were used. Among the selected vegetation indices NDVI, SAVI, MSAVI, TSAVI and PVI, the modified MSAVI (Modified Soil Adjusted Vegetation Index) was the best choice for estimation of LAI.

Selected Vegetation Indices

Vegetation indices are obviously divided to three main groups. First group of indices is named ratio indices. The indices are calculated from simple or normalized ratio of surface reflectance in red visible and near infrared part of electromagnetic spectrum. The representatives of this group are NDVI (Normalized Difference Vegetation Index), RATIO (Simple Ratio) or TVI (Transformed Vegetation Index). Second group is called distance indices. Indices are focused on sparse vegetation. The representatives of this group are SAVI (Soil-Adjusted Vegetation Index), MSAVI (Modified SAVI) or PVI (Perpendicular Vegetation Index). The third group is called orthogonal transformations. The representative of this group is GVI (Green Vegetation Index). (Qi, J. et al., 1991; Rouse Jr, J., et al. (1974); Huete, A. R., 1998; Qi, J. et al., (1994); Huete, A. R., Jackson, R. D., 1987)

The chapter is in the next part focused on vegetation indices which are used for monitoring and studying changes of vegetation in the selected parts of the Pardubice region. Four indices were used: NDVI, SAVI, MSAVI and GVI.

NDVI (Normalized Difference Vegetation Index) is one of the most often used vegetation indices. One of the reason of frequent utilization is that the index is suitable in various conditions. The index combines images from near infrared and red (visible) part of electromagnetic spectrum, it is calculated according to the following equation (Rouse Jr, J., et al., 1974):

$$NDVI = (NIR – R)/(NIR + R)$$

where NIR = near infrared band and R = red band.

Values of the NDVI are between -1 and 1 (vegetation is between 0.2 and 0.8).

SAVI (Soil-Adjusted Vegetation Index) is used for minimization of soil influence on vegetation signal. SAVI used special constant L. L is explained like soil factor adjustment. Values of L constant are divide to 3 sections. The first section, L = 1.0, is a very low vegetation. The middle section (L=0.5) means middle vegetation. The last section, L=0.25, represents thick vegetation. SAVI is calculated according to the following equation (Huete, A. R., 1998):

$$SAVI = ((NIR – red)/(NIR + red + L)) * (1 + L)$$

MSAVI (Modified Soil-Adjusted Vegetation Index) is a modification of the SAVI, which can be used for example for green height (Huete, A. R., 1998). Difference again SAVI is that L-factor is dynamically adjusted using the image data (Huete, A. R., 1998; Qi, J. et al., 1994).

$$MSAVI = ((NIR – red)/(NIR + red + L)) * (1 + L)$$

L is calculated according to the following equation:

$$L = 1 – (2 * s\ (NIR – red) * (NIR – s * RED)/(NIR + red))$$

where *s* is the slope of the soil line from a plot of red versus near infrared brightness values.

GVI (Green Vegetation Index) uses all spectral bands and it uses the greenness component of it to show the vegetation. It is calculated according to the following equation (Eastman. J., 2001):

$$GVI = - 0.2848 * TM1 - 0.2435 * TM2 - 0.5436*TM3 + 0.7243 * TM4 + 0.0840 * TM5 - 1.1800 * TM7$$

DATA AND SOFTWARE

All satellite data was downloaded from the geoportal EarthExplorer. Single images were selected so that the data was approximately from the same time of year. If the stage of the vegetation period was significantly different, it would significantly influence the results. The choice of images was also influenced by a cloud cover over the area of interest. For example, a very high cloud cover of images in 2014 would make further analyses impossible, so a more appropriate images from 2013 were chosen.

Landsat and Terra datasets were used. Landsat data was the Level 1 Terrain (L1T) data set. Data set contains radiometric and geometrically correct data. Five Landsat data sets were used in the work, from 1987 to 2013. The USGS currently offers images of all Landsat 1-8 satellites, except Landsat 6 as a result of its accident. However, the used data comes only from Landsat 5 and Landsat 7 (acquired before the SLC corrector malfunction) and Landsat 8. MODIS Terra data was used as a second satellite data source. Although the area of interest of the municipality with extended powers Pardubice is very small and the scene from MODIS are very wide (2230 km wide, it is situated at the borders of the scanned scenes. Three scenes, h19v03, h19v04 and h18v03, were used to include the entire territory. The MODIS images come from 28 July, 2013. They can be compared with Landsat 8 images taken on July 27, 2013. The data are used with the WGS 1984 UTM Zone 33N coordinate system.

Software ArcGIS for Desktop 10.2 was used for data processing. It is software from the company Enviromental System Research Information (Esri). The Band Arithmetic function (in the Image Analysis window), which performs arithmetic operations with the individual bands of the satellite data set, was used to calculate the individual indices. This tool offers predefined algorithms but there is also the option to enter your own formula. The rasters are processed on-the-fly.

AREA OF INTEREST

The area of interest is administrative unit Pardubice (it is a municipality with extended powers (ORP in the further text)), which is located in the northwestern part of the Pardubice Region, the Czech Republic. The River Elbe flows through ORP Pardubice. Elbe forms the main hydrographic axis and dominates the entire territory.

STEPS OF PROCESSING AND RESULTS

Used indices

The NDVI ratio was used at first. This index was chosen because it is one of the most frequently used vegetation indices. The second used index is SAVI, which belongs to the distance indices as well as the third used one – MSAVI index. Their purpose is to separate vegetation information from soil information. They are based on the distance of the examined pixels from the soil line. The fourth used index is GVI, which belongs to the orthogonal indices category. It is calculated as a linear combination of the original bands of the multispectral image.

Calculation of Indices Based on Terra and Landsat data

The scene by the MODIS sensor did not cover the whole area of interest, so mosaic was created from three scenes. Images from MODIS Terra have lower informative value compared to Landsat 8 images, because data from MODIS has a 250 meters spatial resolution. The MODIS data provides only general view on the ORP Pardubice, so no further analysis has been performed on these images. A sample of the NDVI index obtained from both Landsat 8 and MODIS Terra are below (see Figure1); Landsat data taken on July 27, 2013 are on the left, data from MODIS Terra, July 28, 2013 are on the right. The reflectance of the vegetation was not affected by the change in the growing season, since the data are taken with a difference of only one day. When we compare the resulting NDVI values of the both satellites, it must be kept in the mind that the outputs do not have the same legend. The resulting NDVI for a given pixel should range from -1 to 1, but in the case of MODIS an interval from -0.2 to 1 is valid. Although the outputs do not have the same legend, they provide enough detailed result for the general overview.

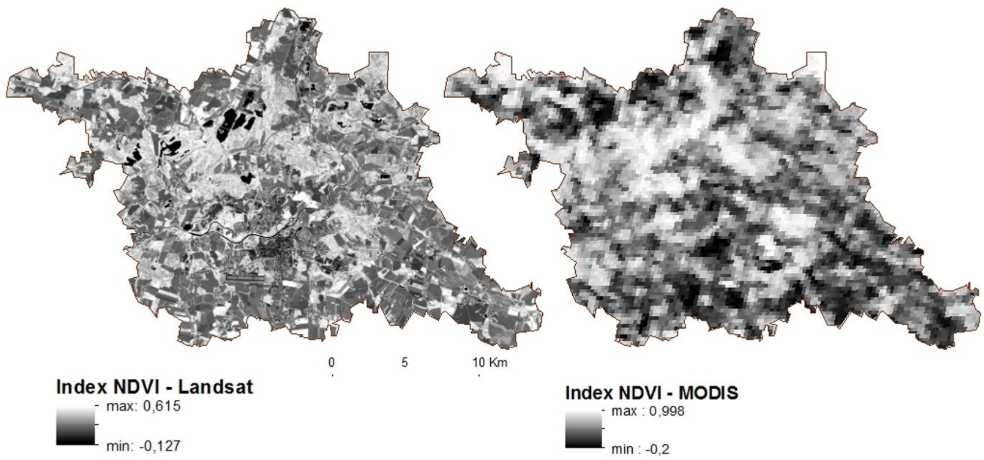

Figure 1: NDVI results from images of Landsat 8 and MODIS Terra

The resulting values of all vegetation indices are displayed in grey. A higher value in the wavelength range indicates a higher reflectivity that is reflected in a lighter degree. E.g. the value -1 for the NDVI index represents the water area, on the contrary, the value of 1 represents a dense vegetation. High value of green is showed in the northern part of the ORP Pardubice. Lower values reflect lower reflection. It is visible in the northern part of the ORP Pardubice.

Although the data was taken in the same August months (with exception for years up to 2003 – captured at the end of July), the index values differ for each image. This is due to spectral reflection of vegetation, which is different during the growing season. The differences are shown in Figure 2, where the MSAVI index values for all years of interest are displayed. Images from years 1987, 1994, and 2007 are taken by one satellite – Landsat 5. Other images, from years 2001, and 2013, are taken from different sensors. Landat 5, 7 and 8 have different displacements of the extreme values of each interval. If a same scale is used for all images, the results may be misinterpreted, and they do not have the correct significant value. This can be seen is the 2001 image from Landsat 7 in comparison with Landsat 5. Also Landsat 8 (2013) shows more values placed in the range of 0.2-0.4 than Landsat 5. Using a single scale, dividing values MSAVI into five classes, the data are visually incomparable. Index values were therefore further classified and post-classified (see Figure 2).

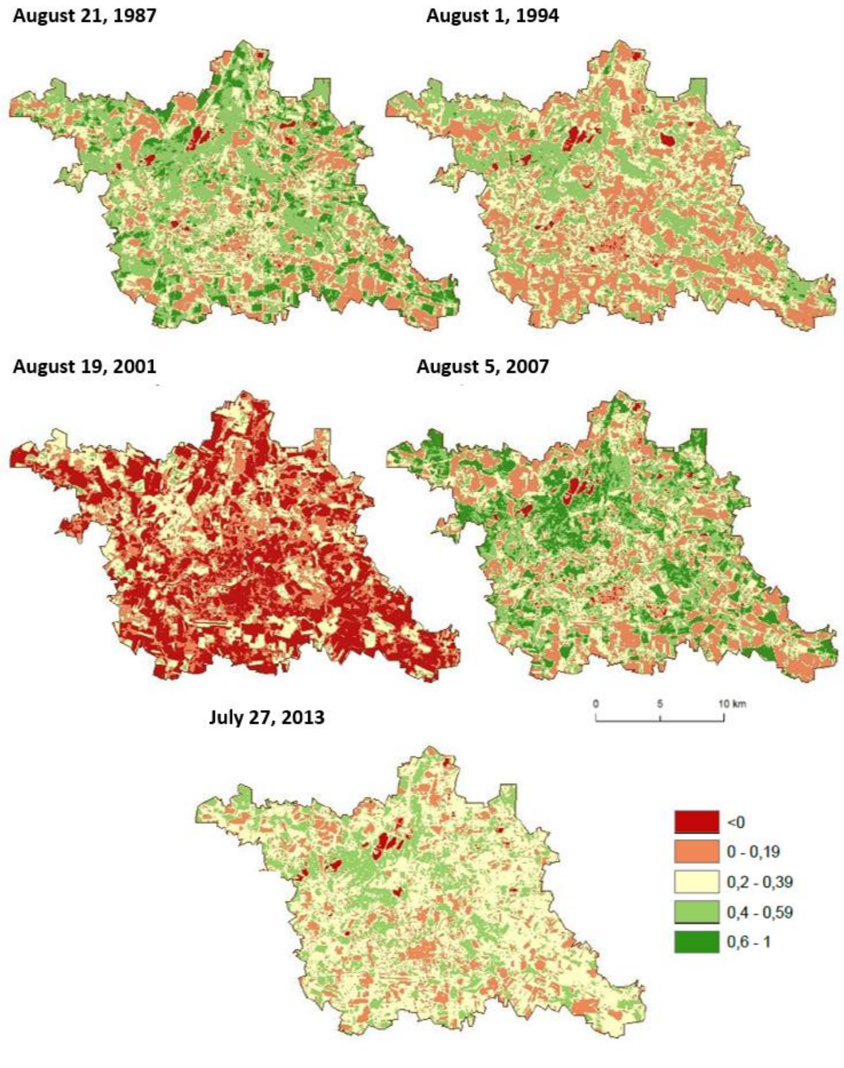

Figure 2: Comparison of MSAVI index results using uniform legend (for data see the previous text)

Image Classification

The image classification was performed after spectral enhancement. The method of unsupervised classification was used in the project. This method has a significant advantage in the speed. Four indices have been classified, each for all five years. The ISODATA algorithm, which is in the Spatial Analyst extension, is located in the Iso Cluster Unsupervised Classification tool. Using this method, predefined 15 clusters were created, ranked according to the spectral reflectivity of the objects. The classes were subsequently manually reduced. Thematic information was added to the three classes: a) forest and grass vegetation, b) water and concrete areas, c) agricultural land.

Although 15 classes were created using unsupervised classification, the ISODATA algorithm assigned water areas and extensive built-up concrete surfaces into one class (See Figure 3). Concrete runways of Pardubice Regional Airport (a), an industrial zone (b), the Elbe river, water areas (c, d) are classified too. So, the first class of the classified image is not limited to water surfaces but it also contains concrete surfaces that have similar spectral characteristics as water.

Classified data contains many isolated pixels. Therefore, post-classification adjustment was performed to remove the isolated pixels. A majority filter was used for these purposes. The resulting classified raster is smoothed after filtration and the image becomes clearer.

In addition, a temporary analysis for individual classified indices was done taking into account time period from 1987 to 2013. NDVI was used as the first index. As a result, it has become clear that over the years there has been a decrease of size of vegetation areas (See Figure 4). It can be observed on the southern part of the ORP Pardubice, where urbanization is taking place near the city of Pardubice. The decrease of vegetation predominantly affected dense vegetation and grasslands. The area of forests has not changed significantly over the years, as is evident, for example, in the northwest corner of ORP Pardubice. On the contrary, near the town of Pardubice, there was an increase in agricultural and urbanized areas. Significant conversion of grasslands into agricultural land can be observed from 2007 around the Bohdanečský pond. Water areas have remained mostly unchanged over the years. The exception is the area of sedimentary tanks in the northeastern part of the administrative unit, which has almost dried out over the years.

From the quantitative expression we can clearly see the loss of vegetation. Since 1987, vegetation has decreased by 8.6 % compared to 2013. Water and concrete areas recorded a large percentage increase in 2001. The reason, however, is not the actual increase of water or concrete surfaces, but again a different image capture. The image is captured by Landsat 7 satellite, which has shifted the extreme values of the spectral bands against the TM and OLI sensor. For this reason, classification included part of agricultural land into the class of water areas.

The SAVI vegetation index is less sensitive to changes in soil reflectance than the NDVI index, but in this study, the NDVI and SAVI values show almost identical results in the ORP Pardubice. After classification there were not shown any more significant differences. For the SAVI index, temporal development was also observed.

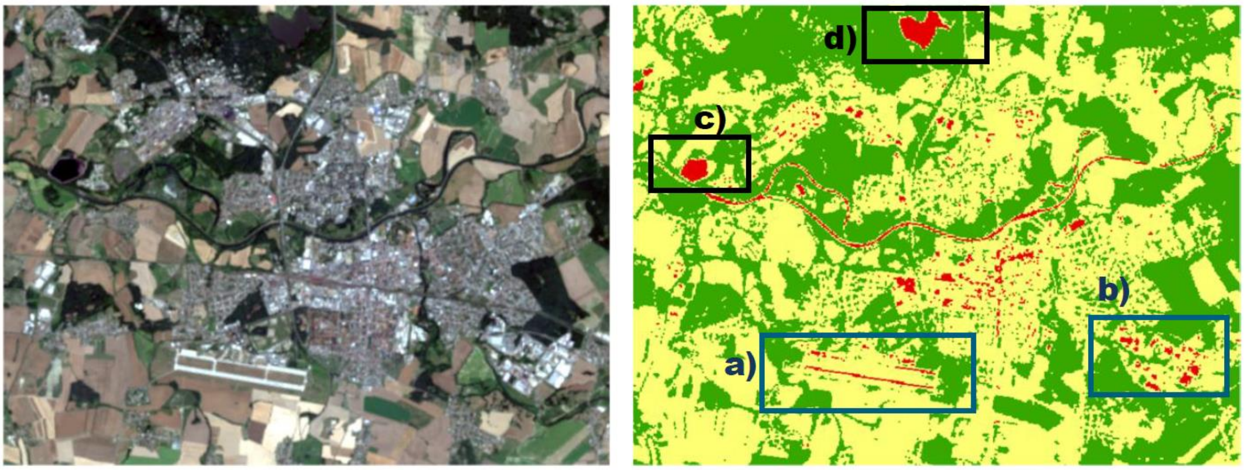

Figure 3: Image in natural colour (left), classified SAVI index (right) for year 2013

Comparison of the percentage of SAVI index classes with NDVI values reveals that the SAVI index varies by tenths of a percent, in the year 2013 SAVI is the same as NDVI.

Compared to the NDVI index, the MSAVI index for the monitored area shows a lower sensitivity for capturing concrete surfaces. It also displays smaller areas of vegetation and its chlorophyll sensitivity is lower than that of the NDVI and SAVI indices. However, the difference in the range of vegetation areas is tiny.

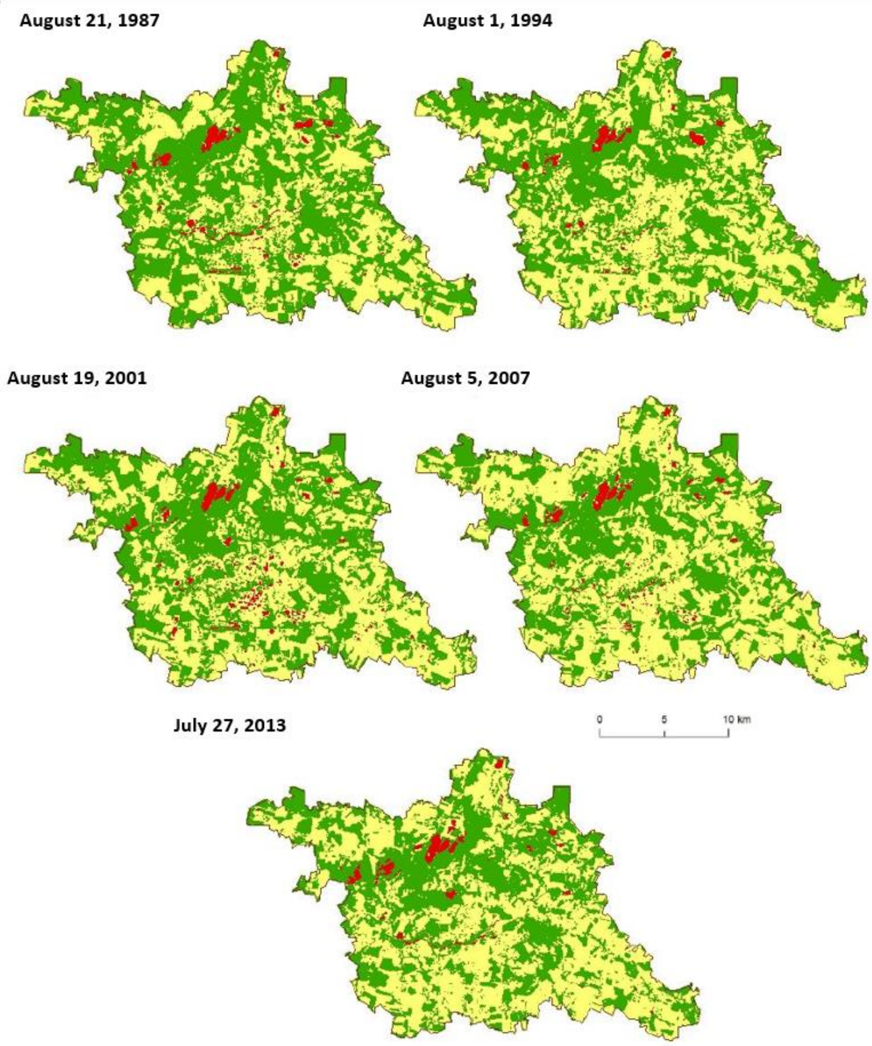

Figure 4: Temporal analysis of the classified MSAVI index

The time series of the ORP Pardubice region for the GVI index differ significantly from the NDVI, SAVI and MSAVI indices. This index classifies similarly vegetation areas as the other indices, but the agricultural land has often been assigned as very low reflection areas and thus it has been assigned as water areas. The index also shows a larger areas of vegetation for 1994 compared to other indices.

Figure 5 compares the classification of the four indices used for year 2007. The NDVI and SAVI indices show almost identical results for ORP Pardubice. The MSAVI vegetation index captures fewer concrete surfaces and keeps water areas. Therefore, MSAVI is the most appropriate index for vegetation mapping. As it has been mentioned before, the GVI index differs significantly from other indices. GVI shows fluctuations in individual years compared to other indices. For this study, the GVI index is the least appropriate one. When the percentage of the vegetation of the individual indices in the monitored years is compared, it is possible to observe the decreased of vegetation from 1987 to 2007.

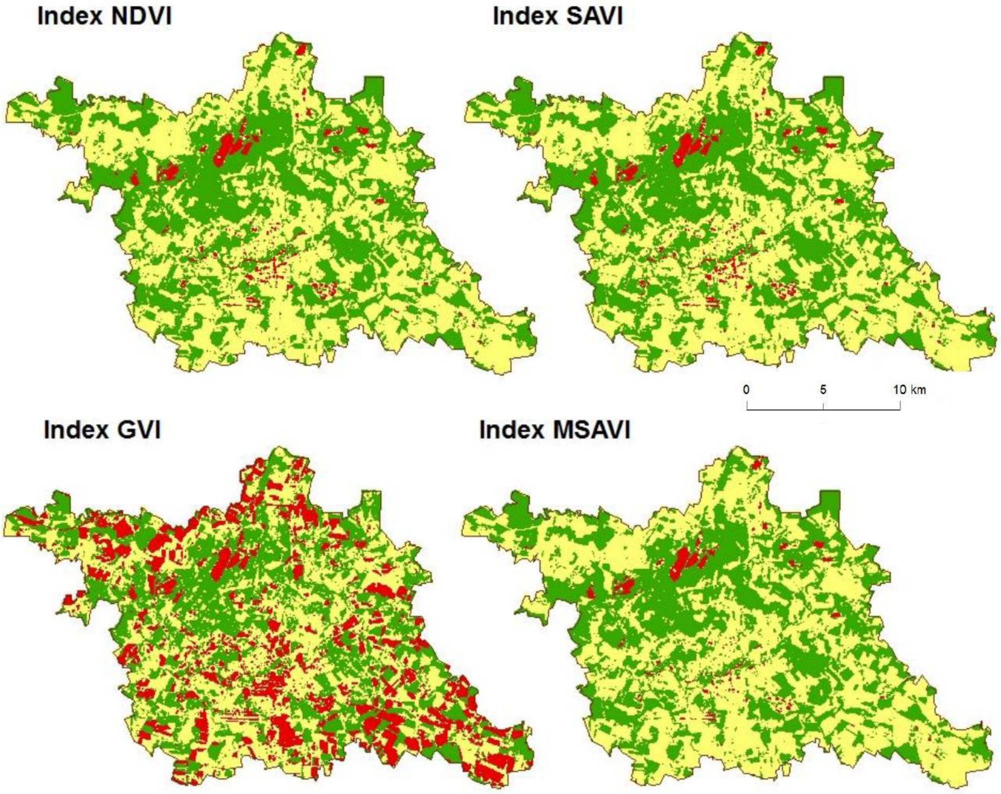

Figure 5: Comparison of classified NDVI, SAVI, GVI and MSAVI indices for year 2007

Analysis of changes using vegetation indices

The Arithmetic function tool was used for detection of changes. This function performs arithmetic operations between two partially or completely spatially overlapping rasters. The new output grid was calculated as the difference of one raster from the other one. Thanks to these arithmetic operations, time changes were observed in the landscape. Changes detection was performed on classified indexes. The resulting values are in the range of -14 to +14. Figure 6 shows the changes using the NDVI and MSAVI indices. Similarly to the SAVI index, there are no significant differences. Green values represent a positive increase (interval 4.8 to 14), red values indicate a decrease (interval -14 to -4.7). Yellow colour indicates minimal landscape change (range -4.6 to 4.7).

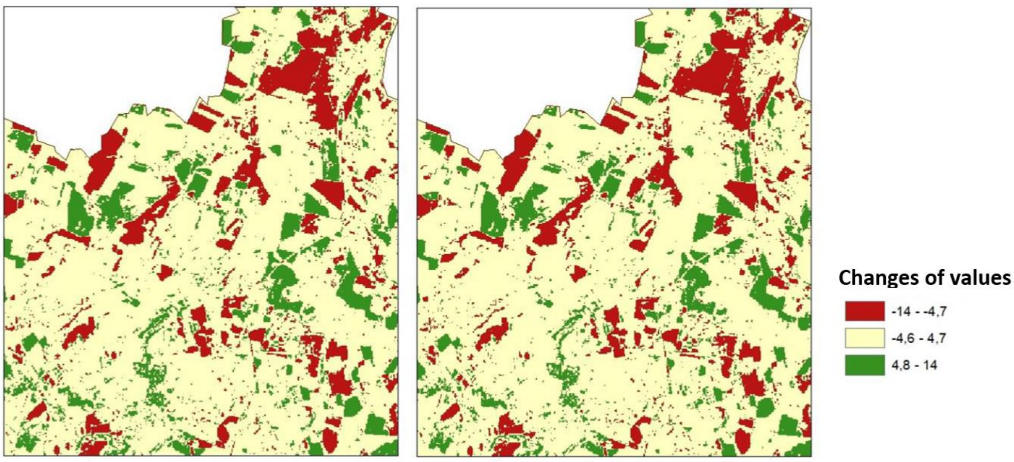

Figure 6: Comparison of changes in NDVI (left) index and SAVI index (right), year 2013

When changes of individual indices are compared, between years 1987 and 2013, the NDVI, SAVI and MSAVI indices are not very different. However, the GVI index provided a higher sensitivity with the Change Detection tool. The GVI index recorded a higher increase in vegetation than the other three indices.

Thanks to the vegetation indices, differences between years can be observed. When years 1987 to 2013 are compared (see Figure 7), it is clear that the northern part (a) and southern part (b) of the administrative district are unchanged. In the marked area (a), there are water areas and surrounding forests. Area (b) is the city of Pardubice, which has remained almost the same from the point of view of vegetation development since 1987. During closer observation, there is visible local decrease of the vegetation, but from the overall point of view there is no noticeable decrease or increase of vegetation areas. In area (e), there was a large decrease in vegetation area. The possible cause is the construction of the largest crossroads in the country near Opatovice nad Labem. Area (f) shows a forest that has remained unchanged over the years. In contrast, significant changes in land cover can be observed in the southeast (c) and southwest (d) ORPs.

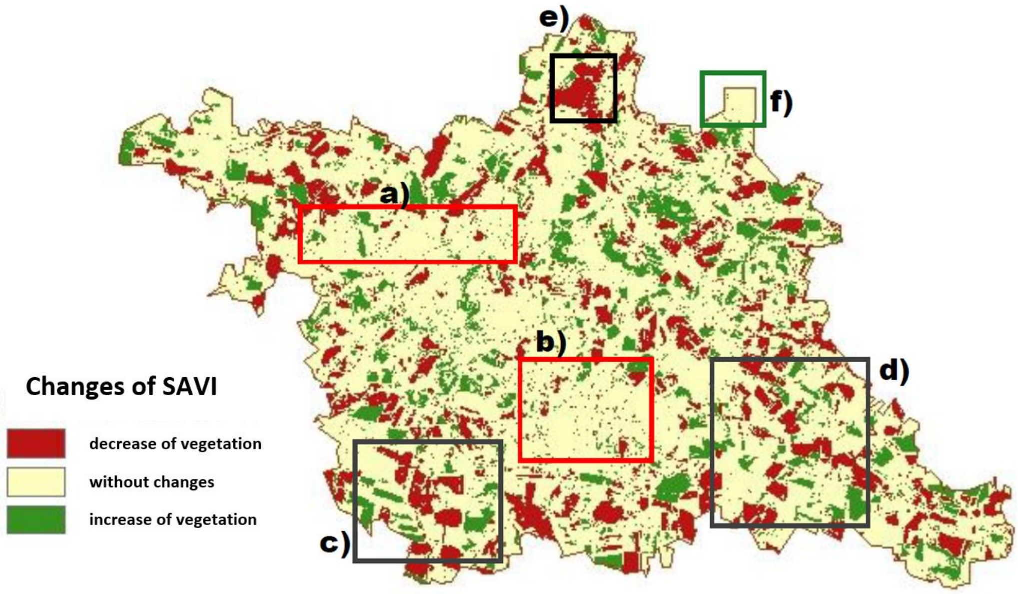

Figure 7: Changes of SAVI index between 1987 and 2013

A temporal analysis of landscape changes between years was made only for the SAVI index. Between 1989 and 1994, there is a greater decrease in vegetation than the increase. The opposite trend was observed between 1994 and 2001. The increase of vegetation is recorded in all administrative units. Over the years 2001 and 2007, vegetation growth was higher than its decrease, but with a smaller extent than in the previous years 1994 to 2001. The difference between 2001 and 2013 shows overall lower changes in both the decrease and the increase in vegetation. This can be due to a shorter time interval between these years. In all the years included into analysis, there is a yellow band, stretching from the south, where the city of Pardubice is situated, to the Bohdanečský pond in the west of the administrative area. The strip continues to the northeast where the forest stands. In this belt, vegetation is almost constant during all years.

CONCLUSION

The aim of the project was to map the possibility of utilization of spectral indices in the monitoring of the vegetation and its change in the Pardubice Region. For this work, five Landsat datasets were selected in the timeframe from 1987 to year 2013. Three scenes from the MODIS Terra scanner were also used. In total, four vegetation indices were compared: the NDVI ratio index, the SAVI and MSAVI distance indices, and the GVI index, which belongs to the orthogonal transformation. For these indices, a temporal analysis was performed from 1987 to 2013 and changes were detected. The resulting values of the vegetation indices are shown in grayscale. For better orientation and easier comparison of the images, an unsupervised classification was subsequently performed. The data were classified using the ISODATA method into fifteen classes, which were then reduced to three classes. A majority filter was used to smooth the classified results. The NDVI and SAVI values show almost identical results in the ORP Pardubice and there were no significant differences after the subsequent classification. The MSAVI is less sensitive to the capture of concrete surfaces in comparison with the NDVI and SAVI indices but the water areas have been classified correctly. The GVI vegetation index differs considerably from the NDVI, SAVI and MSAVI indices. After classifying GVI, it has assigned vegetation areas similarly to other indices, but the agricultural land has largely been designated as very lowreflecting areas, thus classifying them as a class of water. Therefore, it is inappropriate to analyse the vegetation areas of the administrative unit.

The best results are reported by MSAVI, which classified the minimum of concrete surfaces into the class of water bodies. Changes of landscape were detected. Changes between 1987 and 2013 were most evident in the southern part of the ORP, where land use changed. On the contrary, the northern part of the administrative district and the town of Pardubice remained almost unchanged during these years in terms of the increase and decrease of greenery. When changes between indices between 1987 and 2013 were compared, the NDVI, SAVI, and MSAVI indices are very similar. The GVI index captured higher changes in vegetation growth than the other three indices.

ACKNOWLEDGEMENT

This research is supported by University of Pardubice, SGS_2018_19 project.

REFERENCES

Akmar, Che et al., (2009). Comparison of Several Vegetation Indices for Mangrove Mapping using Remotely Sensed Data. Kuala Terengganu Malaysia: Environmental Science and Technology Conference, URL: http://www.academia.edu/230126/Comparison_of_Several_Vegetation_Indices_for_Mangrove_Mapping_using_Remotely_Sensed_Data

Eastman, J. Idrisi32 Release 2, (2001). Guide to GIS and Image Processing, Volume 2, ClarkLabs, USA, 151 s.

Huete, A. R., (1998). *A soil-adjusted vegetation index (SAVI).* Remote Sensing of Enviroment 25 (3), pp. 295-308.

Huete, A. R., Jackson, R. D., (1987). *Suitability of spectral indices for evaluating vegetation characteristics on arid rangelands.* Remote Sensing of Enviroment 23 (2), pp. 213-232

Huete, A., et al., (1999). *MODIS vegetation index (MOD 13) algorithm theoretical basis document.* [online, file pdf]., 129 ps. [cit. 2014-10-21]. URL: http://modis.gsfc.nasa.gov/data/atbd/atbd_mod13.pdf

Qi, J. et al., (1994). *A modified soil adjusted vegetation index.* Remote Sensing of Enviroment 48 (2). 1994. pp. 119-126

Qi, J. et al., (1991). *View-atmosphere-soil effects on vegetation indices derived from SPOT images*. In: J. J. Hunt (Ed.), Physical measurements and signatures in remote sensing. Proc. 5th international colloquium, Courchevel, Vol. 2 (pp. 785-790).

Rock, B. N., (2003). Lesy České Republiky, final report. [cit. 2014-11-07]
URL https://jacquelinepeterson.tamu.edu/access/access_papers/Rock_finalreport.pdf

Pervez, S. et al. (2014). Mapping irrigated areas in Afghanistan over the past decade using MODIS NDVI [online]. [cit. 2014-11-21]., USGS Staff -- Published Research. Paper 840. URL: http://digitalcommons.unl.edu/usgsstaffpub/840

Rouse Jr, J., Haas, R. H., Schell, J. A., Deering, D. W. (1974). *Monitoring vegetation systems in the Great Plains with ERTS*.

Santos-González, C. (2002). *Suitability of NDVI AVHRR data for wetland detection*. Australia: supervising scientis, URL: http://www.environment.gov.au/system/files/resources/76371c25-1515-4959-bbab-564f01c529e8/files/ir396.pdf

Wu, J. et al. (2007). *Assessing broadband vegetation indices and QuickBird data* [online]. [cit. 2014-12-12]. URL: http://rsl.gis.umn.edu/Documents/LAI_broadband%20VI_QuickBird.pdf

BIOGRAPHY

Pavel Sedlák works for the Institute of System Engineering and Informatics, Faculty of Economics and Administration, University of Pardubice as a cartographer and GIS specialist. He is major in two topics: a) changes of landscape by remote sensing data, b) usability in cartography.