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Monitoring of forest damages in Poland and Slovakia based on Terra.MODIS satellite images

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Abstract. Ten years since the largest post war disaster in the Polish forestry have passed last year. Back then in July the hurricane in Masuria region caused a huge devastation in the area of Pisz forest. The pine monoculture deforestation caused by the destructive force of nature and the prevailing drought caused the fire risk conditions. For research of forest destruction the satellite images taken in 2000 and 2006 were used. The observations were conducted at the area of Pisz forest, the Slovak Tatra Mountains and the forests along A1 and A4 motorway construction sites. The method for determining the range of deforestation caused by natural and anthropogenic impacts was developed. To validate the results the changes in change database Corine Land Cover 2000–2006 were used. Terra.MODIS medium resolution images shown themselves good material for elaboration of effective method for monitoring of forest stands changes. The obtained accuracy of detecting changes in forest areas was very high reaching 96.1% for Pisz forest and 96% for Slovak Tatra Mountains. In case of deforestation at the motorways construction sites the accuracy was 57% and 54% for A1 and A4, respectively. The lower accuracy was due to narrow widths of the motorways construction sites while monitoring was based on the analysis of satellite images of spatial resolution of 250 m.

Keywords: CORINE Land Cover, forests damages, MODIS images

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1. Introduction

The natural risk contributing to the severe damages of trees appears almost every year in Poland. Elements such as fires, hurricanes, tornadoes cause havoc very hard to reclaim. The largest fires in the post-war history of Poland were observed in 1992 in the Notec forest and in the forest near Kuznia Raciborska. They resulted in destruction of over 15 thousand hectares of forests. The second mentioned fire is considered the largest not only in Poland but in the whole Central and Western Europe. Removing of the effects lasted until 1997. On the other hand during the last ten years the occurrence of hurricanes and tornadoes has intensified. The Pisz forest and the Slovak Tatra Mountains forest suffered from very strong hurricanes in 2002 and 2004. Up to the present day the restoring activities are carried out at the areas affected by the natural disaster.

From the very beginning of the satellite remote sensing technology the extensive research of forest damages were carried out. In these investigations images taken by environmental and meteorological satellites have been used. The meteorological satellites provide images of a low spatial resolution with a pixel of about 1 km but with much higher temporal resolution then environmental ones. Revisiting the area on almost daily basis makes possible the constant land cover monitoring including forests changes occurred in forests. This is a big advantage of missions of low spatial resolution meteorological satellites. The use of appropriate spectral characteristics and calculated greenery indices allows to detect and locate the changes. Along with the improvement the image sensors, the increase of the spatial resolution and the development of the advanced research methods it is possible to run the precise analysis of change ranges in the forest structure.

With the appearance of Landsat MSS first satellite images the research on forestry in Poland, in particular in the Institute of Geodesy and Cartography, Warsaw, had begun. Three types of forest stands: coniferous, deciduous and mixed have been recognized on the basis of those images (Ciołkosz and Poławski, 1980). In following years Landsat TM and SPOT improved images were used for study forests in the Sudety Mountains, the Tuchola forest and Knyszyn forest (Zawiła-Niedźwiecki, 1990). In 1993 the Institute of Geodesy and Cartography started to cooperate with the Forest Research Institute and the Ghent University to develop a system of identification of fire-site near Kuznia Raciborska (Karlikowski and Zawiła-Niedźwiecki, 1994). Even more advanced research was conducted in Sudety, using the images recorded by the Landsat satellite in 1976, 1984 and 1990. Based on field measurements and interpretation of false colour aerial photographs the model of training fields was developed to perform the supervised classification of satellite images. This was the basis to distinguish eight categories of forest stands, specifying the level of coniferous and deciduous forests injuries (Bochenek et al., 1997).

In this work the results of deforestation detection between 2000 and 2006 at the chosen areas, based on the medium resolution Terra MODIS satellite images have been presented.

2. Deforestation in Poland and Slovakia after 2000

In July 2002 the largest destruction of forests in the post-war Poland took place. According to the Regional Directorate of National Forests in Białystok, at the significant areas of Pisz, Kurpiowska, Borecka and Romnicka forests over 45 thousand hectares of pine monoculture have been devastated by tornadoes. The massive destruction extended over the area of the length of 130 km and width of 15 km. The largest loss, at the area of 12 thousand hectares, was reported in Pisz forest, that constituted 11% of its area (Fig. 1). The fallen trees caused a huge fire risk due to the summer drought. In addition the risk was increased by the destruction of pine monoculture containing flammable ethereal oils.

In November 2004 the Tatra National Park in Slovakia was heavily affected by an extreme windstorm (Fig. 2). The belt of wind-fallen trees 10 km wide stretching 60 km long was reported. The powerful windstorm severely impacted the main touristic centre of Slovakia. Up to the present day the restoring activities in semi-natural spruce fallen trees area are carried out and research on windstorm consequences is continued.

Fig. 1. The devastation of Pisz forest after a hurricane in 2002 (http://www.bialystok.lasy.gov.pl)

Recently the occurrence of tornadoes in Poland is more frequent. These tornadoes as well as hurricanes cause tremendous destruction of forest areas. Five cases of deforestation in Poland by tornadoes were reported in 2012 (http://obserwatorzy.org). In July 2012 one of them blew down 400 hectares of Tuchola forests in Kujawy and Pomorze geographical regions. Tornadoes and fires are the most dangerous natural threads for forests. In the first case, the meteorological documentation regarding the annual number of tornadoes appearance and deforestation caused by their activity does not exist. The occurrence of fires is not as intense, as recently observed increase of hurricanes and tornadoes appearance.

The removal of damage at the deforestation areas is very time and labour-consuming process. It requires a large expenditure of money, an engagement of forestry employees and the assistance of external bodies. For the Pisz forest this process lasted 10 years; for the Tuchola forest the works will still be continued in 2013.

Except for the natural deforestation causes, the anthropogenic element is also an important factor. In recent years, the number of sections of motorways opened for the vehicle traffic increased. To make their construction possible, the deforestation of the particular areas along the route of planned investments were necessary.

3. Satellite data and the research area

To study the deforestation the images taken by the environmental satellite Terra were used. The MODIS

Fig. 2. Wind-fallen trees in the Slovak Tatra Mountains after a hurricane in 2004 (http://www.tatry.sk)

sensor placed on board of Terra satellite scans the surface of the Earth in 36 narrow spectral bands from 0.4 µm to 14.4 µm. The first two channels of spectral band 0.62–0.67 µm and 0.841–0.876 µm, have ground resolution of 250 m. The images taken in the next 5 spectral bands are characterized by the 500 m ground resolution. For the remaining 29 channels the size of the registered pixel equals 1 km. The width of the MODIS-scanned area is 2330 km. This feature gives the possibility to cover the same area every one or two days depending on the latitude.

The free access to the Terra.MODIS products and daily satellite revisit over the same area were the main factors for the selection of those images to study forest damages. However, due to the specific climate conditions in Poland, characterized by large or total daily cloudiness, the composition consisting of images taken on the several days period was applied. The available eight days compositions from MOD09Q1 and MOD09A1 products were used for this purpose. In the study, in addition to eight-day compositions, the information contained in additional band called *Quality Control* has also been used. This band contains encoded pixels indicating clouds, snow or ice.

The reference material used in the study was CORINE Land Cover 2000–2006 database of changes. It is free available in a vector format from the Chief Inspectorate of Environmental Protection web site. The database was developed using the visual interpretation of Landsat satellite images dated 2000 and IRS and SPOT images dated 2006. According to the CLC 2000–2006 technical assumptions the minimal changes area recorded was 5 ha.

MODIS images due to their much lower ground resolution than Landsat, SPOT and IRS images cannot be directly compared with the above mentioned reference database. Too low spatial resolution of the images taken by MODIS affects their geometrization, which when comparing pictures from various periods often causes shifts pixels. This pixels shift gives the impression of objects changes and must be eliminated in the process of interpretation of satellite images. The first experience of forest changes detection in Europe using low resolution images conducted in the framework of GEOLAND2 SATChMo project (Lamarche et al., 2012) has shown that the smallest area possible to detect changes must have a size of at least 100 ha. That corresponds to at least 16 pixels at the MODIS 250 m image.

From 2000 to 2006 the changes of land use have been observed on 0.6% of the total area of Poland. They concern mainly forest areas of wood exploitation and the areas of natural disasters (wind-fallen trees). Table 1 illustrates the percentage of 2nd level land cover classes that had changed till 2006. Only areas of change over 100 ha have been included. A 36% of changes were observed in forests of 3.1 class and 23% of ligneous and shrubby vegetation included in 3.2 class. In general account, over 60% of observed changes occurred at the forest areas.

The changes consisting in the transition from the forest areas in 2000 (3.1 class – forests from the 2nd level of the CLC legend) into other land cover forms in 2006 were chosen from the CORINE Land Cover 2000–2006 reference layer. Then the neighbouring changes were grouped and groups smaller than 100 ha were removed.

The largest deforestation area in Poland is a part of Pisz forest. According to the CLC 2006, over 137 km^2 were devastated by the 2002 hurricane. Further significant changes occurred at the particular fragments of motorways construction sites: A1 near Grudziadz and A4 near Boleslawiec. Those are minor changes of 126 ha at A1 and 168 ha at A4 construction sites. Other areas of changes are so dispersed that their proper identification with the use of MODIS images is not possible. Therefore, another important deforestation area, situated outside the Polish borders, was taken into consideration in this study. This was the Slovak Tatra Mountains where in 2004 a powerful wind broke a large number of trees. According to CORINE Land Cover 2006 the destruction covered the area over 125 km^2.

4. Detection of forest damages

The eight-day compositions images with spatial resolution of 250 m and 500 m, from MOD09Q1 and from MO09A1, respectively, were taken from the WIST Echo server. For 2000 and for 2006 the compositions comprising the time between 169 and 177 day of the year, and between 177 and 185 day of the year, respectively, were chosen. The compositions for those periods are characterized by the high quality of data and the low presence of clouds. The clouds were hidden with the use of the *Quality Control* information channel from MOD09A1. Next the forest mask from CORINE Land Cover 2000 was applied. Only the areas coded as 3.1.1 – deciduous forests, 3.1.2 – coniferous forests and 3.1.3 – mixed forests were marked. The target spatial pixel size of the images is 250 m. Therefore the MOD09A1 images were sampled from 500 m to 250 m. For further works the MOD09A1 channel 5 was omitted, due to the presence of faulty scanning lines.

Due to the nature of investigated changes, the techniques considered reflect the state of moisture of forest environment and its vegetation. There are

Table 1. Share of land cover classes that have changed to 2006

CORINE Land Cover 2000 Classes at Level 2	Area [ha]	No. types of changes	Percentage of area [%]
1.3 Mine, dump and construction sites	6122.3823	8	15
2.1 Arable land	8726.8821	7	21
2.2 Permanent crops	151.0782	1	0
2.3 Pastures	1148.3914	4	3
2.4 Heterogeneous agricultural areas	502.6723	2	1
3.1 Forests	14852.8283	6	36
3.2 Scrub and/or herbaceous vegetation associations	9698.9453	3	23
3.3 Open spaces with little or no vegetation	363.5869	3	1
Overall sum	41566.7668	34	100

many effective methods to identify changes in an environment. However, each of them is based on a certain narrow spectral bands characteristics. This limits the possibilities of elimination the errors associated with the sensitivity of the spectral range to other environmental elements such as soil, phenological phase, the structure of tree canopies. Three methods diverse in terms of spectral range were used for the interpretation of satellite data and designation of deforestation areas. For each method, the chosen indices were calculated for year 200 and 2006 and combined into a single two-channel composition. Next, the standard classification unsupervised with ISODATA was made. Then, the three classification results were combined based on a particular criterion. This involved the acceptance of change recognition, if it was detected by two methods. However, if the change was recognized by only one method, it was rejected in order to minimize the risk of errors.

4.1. NDVI

The first of three detection methods used is a comparison of the NDVI index. This index describes the status and the level of plants development and their vigour, and allows to evaluate the biomass produced by the given ecosystem. Normalized greenery index NDVI is one of the simplest and simultaneously the most popular indices identifying the state of the environment. It is calculated based on the reflection in near infrared (NIR) band and RED band according to the formula:

$$NDVI = (NIR - RED)/(NIR + RED)$$

NDVI value ranges between –1 and 1, while for the healthy plants the assumed worth is above 0.3. In the past the method of compiling the long term NDVI values in a single three-channel colour composition RGB was often used for the research of forest area development (Wilson and Sader, 2002).

The NDVI index was calculated based on two-channel MOD09Q1 images. Next, the obtained NDVI distribution images were composed into a single two-channel composition, considering NDVI 2000 as the first channel, and NDVI 2006 as the second one. Further step was to run the ISODATA unsupervised classification. It resulted in the determination of groups of pixels that differ with the value of index in those two years. That is how the clearly evident deforestation areas appeared (Fig. 3.1 and Fig. 4.1). The blue colour marks the NDVI decrease in 2006 in comparison with 2000 while the yellow marks the increase of greenery index in the same period of time. The darker the shade is, the more intense indicator's value increased or decreased.

4.2. SWIR/NIR

The next task was weighting the spectral bands in SWIR/NIR infrared with the use of the short and near-infrared bands recording channels. The above mentioned bands are sensitive to water content in the forest stands and thus they make possible to evaluate the forest condition. The SWIR/NIR ratio is also known as *Moisture Stress Index*. This weighting method applied to further radiation

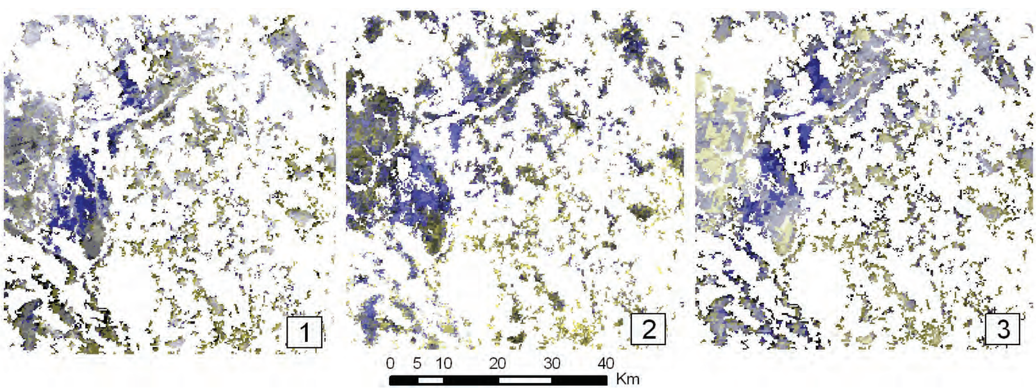

Fig. 3. Results of unsupervised classification for an area of Pisz forest based on:
1) NDVI 2) SWIR/NIR 3) *wetness channel*

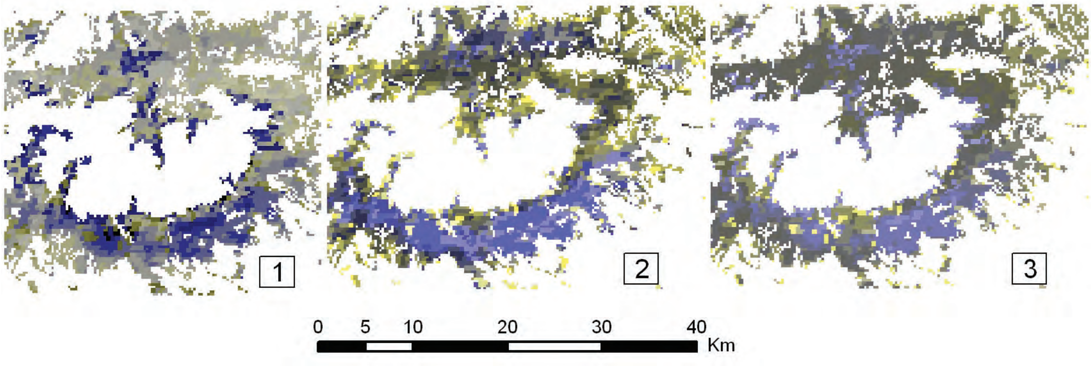

Fig. 4. The results of unsupervised classification for an area of the Slovak Tatra Mountains based on: 1) NDVI 2) SWIR/NIR 3) *wetness channel*

bands was used in the study of ecosystem changes, especially in forests (Wolter and White, 2002).

From the seven-channel MOD09A1 products, channel 6 was chosen as 1628–1652 nm SWIR. The MOD09Q1 channel 2 of 841–876 nm was chosen as NIR. The images were combined into one composed image, as in NDVI, and were also a subject to the unsupervised classification (Fig. 3.2 and Fig. 4.2). The blue colour indicates the increase of moisture stress, while yellow indicates the decrease of its. The darker the shade of blue or yellow, the more intense is the change.

4.3. Tasselled Cap

Tasselled Cap (TC) transformation is used for satellite images optimisation in vegetation analysis. This tool is based on information compression technique applied to the analysis of principal components. TC was developed mainly for the seven-channel images recorded by Landsat MSS, TM and ETM+. Optimum TC transformation factors are known for these sensors. To perform, however, the transformation for MODIS images, the factors retrieved from the literature were used (Zhang et al., 2002). As an input data the six channel MOD09A1 images were applied.

The results of TC transformation are the channels: *brightness*, *greenness*, *wetness* with information on the vegetation condition. In the *brightness* channel the most vivid pixels reflect the areas with low vegetation and with the best light reflection. The *greenness* channel is the one, where the brightest pixels give information on the high vegetation index. The last channel – *wetness* is sensitive to vegetation moisture and its structure. It is often used for ecosystems changes research due to its high dependence on moisture conditions in the environment (Zhang et al., 2002).

For further works the 2000 and 2006 *wetness* channels were used. Those channels were combined into the two-channel composition. Next the ISODATA unsupervised classification was carried out. The results were used to evaluate the change detection (Fig. 3.3 and Fig. 4.3). The blue colour indicates the humidity decrease, the yellow – its increase.

5. The results and validation

As a result of every investigated area three classifications were obtained basing on specific characteristics NDVI, SWIR/NIR and *wetness*, defining different plant-soil conditions. In each of them the change was marked with blue or yellow colour. The brighter the shade of blue and yellow, the closer to the absence of NDVI, SWIR/NIR and *wetness* changes in the 2000–2006 period. For further analysis the pixels expressing a decrease of NDVI indices, increase of water stress and humidity decrease were chosen. Those are typical and characteristic conditions for the deforestation process. Next, the results were combined taking into consideration the logical assumptions. At the end the images were filtered and all pixel groups of changes over 100 hectares, i.e. over 16 pixels were retained (Fig. 5 and Fig. 6).

The resulting raster layers were converted into vector format for the validation process and then they were compared with the reference layer. For the quantitative evaluation of the method three parameters were used (Zhan et al., 2002):

- *the detection accuracy* (%) – the ratio of area of changes from the reference layer indicated by the method to the total area of changes in the reference layer;
- *the overestimation error* (%) – the ratio of area of polygons indicated by the method but located outside the area of reference changes to the total area of polygons indicated by the method;
- *the underestimation error* (%) – the ratio of the area of those changes from the reference layer that were not indicated by the method to the total area of changes in the reference layer.

The accuracy of detection of forest damages expressed in terms of polygon number and the area of changes was investigated (Table 2 and Table 3). The results based on the area are more important since they describe the details of deforestation

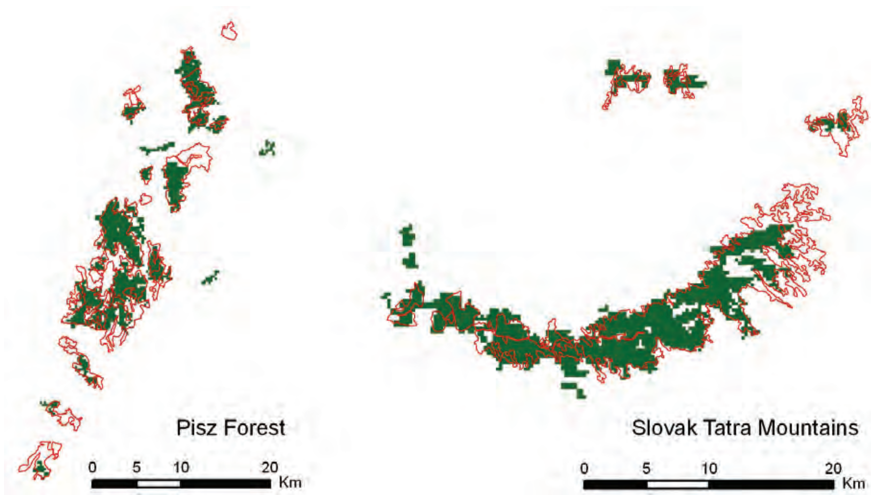

Fig. 5. Green colour – the final result of changes.
Red colour – reference layer changes from CLC 2000–2006

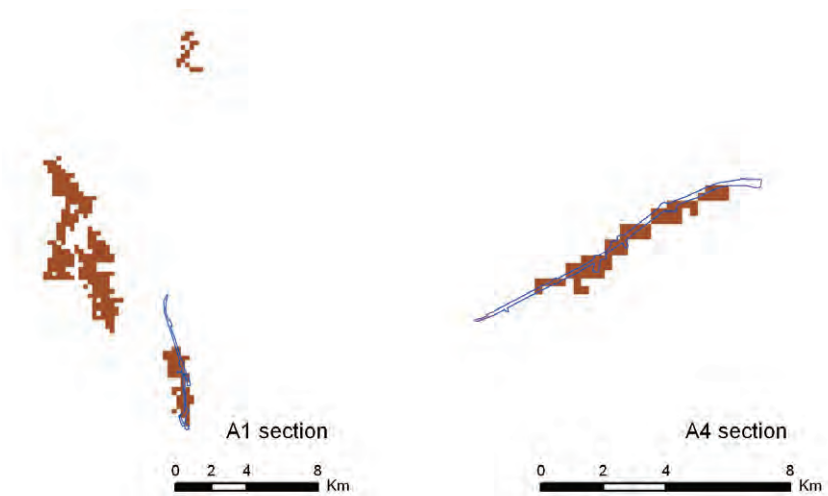

Fig. 6. Brown colour – the final result of changes**.**
Blue colour – reference layer changes from CLC 2000–2006

Table 2. Evaluation of accuracy based on the number of polygon changes

	A1 section	A4 section	Pisz forest	Slovak Tatra Mountains
Accuracy Assessment [%]	100.0	100.0	83.3	84.6
Commission Error [%]	66.6	0.0	2.0	37.0
Omission Error [%]	0.0	0.0	16.4	15.4

Table 3. Evaluation of accuracy based on surface changes

	A1 section	A4 section	Pisz forest	Slovak Tatra Mountains
Accuracy Assessment [%]	57.0	54.0	96.1	96.0
Commission Error [%]	81.0	75.0	4.0	3.0
Omission Error [%]	43.0	46.0	3.9	4.0

areas determination. While in case of large areas of the Pisz forest and the Slovak Tatra Mountains the obtained results were satisfactory, i.e. 96% in terms of area of change and 85% in terms of polygon number, for motorway construction site sections the unambiguous evaluation was very difficult. It is mainly related to the low spatial resolution of MODIS images. There is a large risk of incorrect over- or underestimation for long and narrow polygons. Therefore the detection degree based on the area is low and based on the number of polygons is high. In case of the A1 motorway construction site section, other changes absent in the reference layer were observed. This explains the big overestimation error obtained.

6. Summary

The areas for investigation of deforestation changes detection in Poland were chosen based on the CLC 2000–2006 changes reference data base. Since in the years 2000–2006 there was only one relevant forest change area – the Pisz forest, that is why the Slovak Tatra Mountains were included to the research.

The obtained accuracy of change detection confirms the legitimacy of the detection method applied. The technique is related to the specifics of the change, i.e. the decrease of NDVI in the time interval considered, changes of humidity or the vegetation state before and after the change process. The attempts of detecting of deforestation caused by other reasons were not undertaken, considering their insignificant share in the period investigated. Due to the small areas of deforestation it is difficult to evaluate them and carry out a reliable analysis.

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MODIS Product Table: https://lpdaac.usgs.gov/lpdaac/products/modis_products_table

CORINE Land Cover Project: http://clc.gios.gov.pl/

Monitoring zniszczeń lasów w Polsce na podstawie zdjęć satelitarnych Terra.MODIS

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Streszczenie. Minęło już ponad 10 lat od największej w powojennym okresie klęski w polskich lasach spowodowanej huraganowym wiatrem. Wówczas to zostały zniszczone ogromne połacie lasów sosnowych w Puszczy Piskiej. W badaniach obszaru tej klęski żywiołowej wykorzystano różne źródła pozyskiwania danych, w tym zdjęcia lotnicze i wysokorozdzielcze zdjęcia satelitarne. W opisywanych badaniach wykorzystano zdjęcia satelitarne o średniej zdolności rozdzielczej. Zdjęcia wykonane w latach 2000 i 2006 przez satelitę Terra za pomocą skanera MODIS objęły także lasy w Tatrach Słowackich oraz lasy położone w pasie budowy dwóch odcinków autostrad A1 i A4. W toku badań opracowano metodykę wyznaczania zasięgu wylesień powstałych z przyczyn naturalnych i antropogenicznych. Do walidacji wyników analizy zdjęć satelitarnych wykorzystano bazę danych zmian CORINE Land Cover 2000-2006. Średnio-rozdzielcze obrazy satelitarne Terra.MODIS pozwoliły na efektywne monitorowanie zmian stanu drzewostanów w przypadku gdy zaszły one na dużym obszarze.
W przypadku Puszczy Piskiej i Tatr Wysokich uzyskano dokładność wykrycia zmian stanu lasów w granicach 96 %. Natomiast w przypadku wylesień pod budowę autostrad otrzymano nieco niższe dokładności wykrywania zmian – 57% dla odcinka A1 i 54% dla odcinka A4. Nieco gorsze rezultaty prawidłowego rozpoznania zmian w lasach wynikają z zastosowania zdjęć satelitarnych o rozdzielczości terenowej 250 metrów do monitorowania wąskich pasów lasów zlokalizowanych wzdłuż pasów budowy autostrad.

Słowa kluczowe: baza danych CORINE Land Cover, zniszczenia lasów, zdjęcia Terra_MODIS