

## **SATELLITE IMAGERY FOR THE IMPROVEMENT OF SOZO DATABASE – THE CASE STUDY IN CENTRAL AND HIGH SUDETES**

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**Abstract.** SOZO database and its cartographic model – a sozological map is a thematic data source that represents the state of natural environment, as well as the causes and effects of both positive and negative transformations occurring in the environment. There is no doubt that the SOZO database should be a tool to investigate and evaluate the state of natural environment in a quantitative manner. However, the analysis of chosen features in the database reveals that they seem to be insufficient for conducting spatial analysis. The crucial problem is related to classes of forest damage represented by point features in a database without the extent of forest degradation. This type of presentation has limited use for geospatial analysis of environment therefore the Authors propose to use remotely sensed data to enhance SOZO database with updated data together with the spatial occurrence of the studied phenomenon. This research presents the potentials of determining class of forest damage based on the vegetation indices (NDVI and NDII) that successfully replaces the point-feature class of forest damage with polygon-based classes, thereby introducing the new quality of the data into the environmental database and make SOZO database a useful product in spatial analysis.

**Key words:** SOZO database, vegetation indices, polygon-based forest damage classes

### **INTRODUCTION**

The Infrastructure for Spatial Information in Europe (INSPIRE) Directive was put into force in May 2007 and within two years had to be adapted by national laws of all EU countries. In Poland the transposition of the INSPIRE Directive has been carried out through a separate Spatial Information Infrastructure Act [Ustawa o IIP 2010] together with the amendments [Ustawa Prawo geodezyjne i kartograficzne 1989]

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and regulations concerning the spatial data resources [e.g. Rozporządzenie RM 2011]. The new legislation states that General Surveyor of Poland elaborates, maintains and shares thematic and special cartographic products in a form of digital maps/databases [Ustawa Prawo geodezyjne i kartograficzne 1989, art. 7a, ust. 14e]. Among ten thematic maps there is a sozological map, which has been created and funded for many years by the General Surveyor of Poland, initially as an analog map in a scale of 1:50 000, and then as the thematic spatial database (SOZO).

The sozological map represents the state of the natural environment and the transformations occurring in the environment under the influence of heterogeneous processes, especially human activity. Currently, the sozological map (SOZO database) covers over 50% of the country. Over the years, the technical guidelines for elaboration of this map have been changing taking into consideration the technological progress in cartography. However, the current GIS-4 technical guidelines [Wytyczne Techniczne GIS – 4 Mapa Sozologiczna Polski w skali 1:50 000] are partially outdated and require amendments. On the other hand, there are some statements which are overemphasized, e.g. “a sozological map fulfills the principal GIS functions: data capture and collection, storing and maintaining data, update and retrieval data, performance of spatial analysis” [Wytyczne techniczne GIS-4 2004]. These assumptions not always are reflected by the actual state of the database. Therefore the questions on the data collection, updates, visualisation and possibility of performing spatial analysis need to be addressed. The motivation of this research is to prove that satellite imagery can be used to improve and update chosen features in SOZO database.

The SOZO database should be an important source data for all environmental studies. However, the analysis of chosen layers of this thematic source leads to conclusion that the content of the database is insufficient for conducting spatial analysis. The problems faced by Authors refer to the class of forest damage. The phenomena – according to technical guidelines GIS-4 – is indicated as a point feature in a database without the area of forest damage. This type of presentation (0-dimensional object) is inappropriate for spatial phenomena, and therefore the feature class in SOZO database has limited use for GIS analysis. Nowadays, remote sensing allows to capture the environmental phenomena at high spatial and temporal resolution, consequently it could be a credible source for collecting and updating the thematic database. The use of satellite imagery is proposed in this research to improve SOZO database with updated information about the magnitude and the extent of forest damage. The combined vegetation indices (VIs) extracted from satellite imagery and consecutively performed spatial analysis are used to delineate areas of distinct forest damage. Using the proposed methodology current point-feature class of forest damage can be replaced with spatially meaningful areal classes, thereby introducing the new quality of data into the environmental database.

## MATERIALS AND METHODS

### Case study area

The study area is located in southern part of Lower Silesia – a region in south-west Poland and includes two physiographic regions – the Central Sudetes and High Sudetes (Fig. 1). More than 40% of the area under study is covered by forests with different classes of degradation.

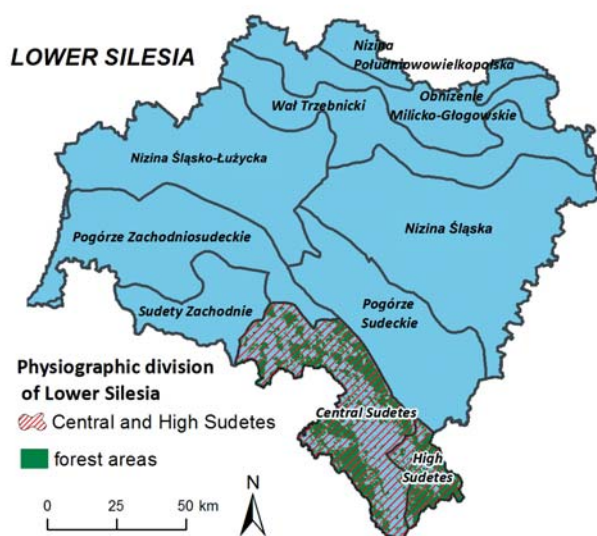


Fig.1. Study area – Central and High Sudetes

In the past, the Sudetes' stand has been severely damaged due to the air pollution coming from industrial areas, strong winds and increased pest invasion. Since the year 2000 the areas affected by the disaster have been almost completely renewed and the stands are constantly being regenerated [Raj, Zientarski 2004]. Therefore, these permanent changes in the state of forest health require appropriate updates in the thematic database.

### Sozological map (SOZO database)

The sozological map of Lower Silesian Voivodeship has been created in 1997–2000. Although, according to technical guidelines [Wytyczne techniczne GIS-4 2004, Chapter II, § 7] the map should be updated – every 3 years for urban and industrial areas, and every 5 years for the other areas – just chosen layers of the thematic map were updated in 2004.

The sozological map consists of 70 thematic layers which are categorised into six groups: forms of environmental protection, degradation of the environmental components, prevention against the environment degradation, reclamation of environment, barren lands and additional information. The reference background for the database are civil or military (Vmap L2) topographic maps in a scale of 1:50 000 and the reference frame is PL-1992. As the topographic maps are outdated, at present the works on the harmonisation of the national reference databases (BDOT10k) with thematic databases (SOZO) are being conducted [Gotlib et al. 2013].

In the case study the layer of forest degradation has been analysed. As stated in technical guidelines [Wytyczne techniczne GIS-4, 2004, Chapter 4.2] forest degradation is a result of a negative impact of any complex processes occurring in a particular forest area. Various physical, chemical and biological factors bring on a decrease or disappearance of vitality of trees, biomass and forest value. The class of forest degradation describes the degree and nature of stand's damage within a particular area in terms of morphological,

physiological and organic changes caused by the harmful effects of anthropogenic origin. The detailed classification of forest damage is based on the guidelines for forest management [Instrukcja zarządzania lasu 1994] and is assumed as followed:

- 1<sup>st</sup> class – Slightly damaged forest – the forest areas with 11–25% defoliation
- 2<sup>nd</sup> class – Medium damaged forest – the forest areas with 26–60% defoliation
- 3<sup>rd</sup> class – Highly damaged forest – the forest areas with over 60% defoliation

As mentioned before in the SOZO database (Fig. 2.a) the classes are point-like objects and to each point only the class of degradation is assigned without the range of the phenomenon.

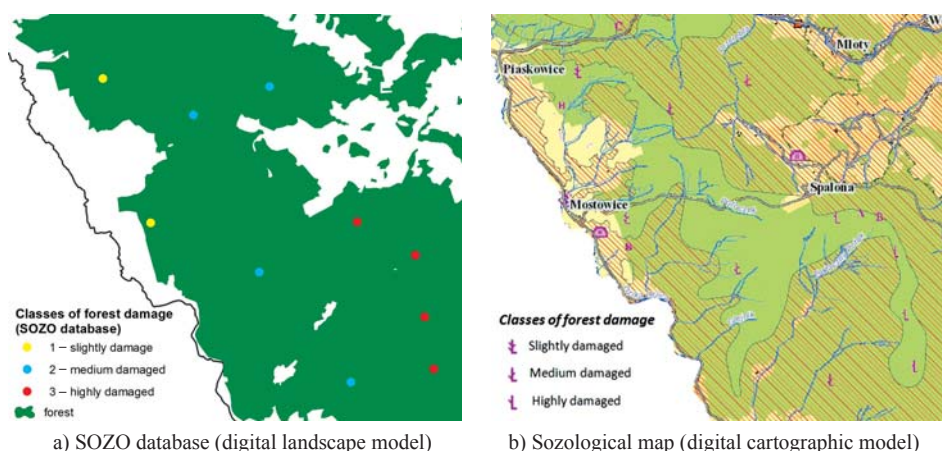


Fig. 2. Classes of forest damage stored in SOZO database and presented on a sozological map

With respect to the cartographic presentation rules areal phenomena can be represented using signature map [Slocum et al. 2009] and at some level of generalisation it may be even advisable. However, on the map in a scale of 1:50 000, the classes of forest damage should have reference to the areas instead of points. Visual analysis of a sozological map (digital cartographic model) (Fig. 2.b) brings the general information about the magnitude of forest degradation in a particular region. Interpretation of the symbols representing level of the stand damage together with other layers may deliver insight into the phenomenon in general. The power of digital cartography and GISystems is not only in the visualization, but most of all the possibility of performing spatial analysis and data geoprocessing in order to investigate and evaluate the state of natural environment in a quantitative manner. When a phenomenon referring to an area is represented by point-object, the possibility to perform spatial operations is limited, therefore multi-criteria analysis is difficult or even impossible to be performed and the reliability of the results is questionable.

## Satellite imagery and vegetation indices

Satellite remote sensing is very efficient technique – in terms of the spatial extent and cost of the data – for mapping the state of the natural environment and tracking its temporal changes. The paper presents the methodology of using satellite imagery to determine the extent of forest damage in order to update a sozological map (SOZO database). In this study multispectral Landsat 8 satellite imagery acquired on the 18.06.2014 is used to determine the classes of forest damage in Central and High Sudetes.

Vegetation condition is assessed through vegetation indices (VIs) which are dimensionless variables derived from the spectral reflectance of two or more remotely sensed wavebands to quantify vegetation biophysical characteristics and growth status. To assess vegetation condition, red, near- (NIR) and short-wave (SWIR) infrared bands are used as the infrared bands are strongly reflected by healthy plants.

The large number of vegetation indices can be found in the literature [Huete et al. 1997, Jones et al. 2010]. The broadband and narrowband greenness vegetation indices are the measure of general quantity and vigor of green vegetation, e.g. NDVI [Sellers 1985, Jones et al. 2010], EVI [Huete et al. 1997], SAVI [Huete 1988]. Another group of indices estimates the canopy water content and water stress which are an important vegetation property correlated with vegetation health, e.g. NDII [Hunt et al. 1987, Ji et al. 2009], MSI [Rock et al. 1986], CWSI [Jackson et al. 1981].

In this study, the combination of two VIs is used to indicate forest condition: the Normalized Differential Vegetation Index (NDVI) and Normalized Differential Infrared Index (NDII). NDVI is one of the most widely used VI because the combination of its normalized difference formulation and use of the highest absorption and reflectance regions of chlorophyll make it robust over a wide range of conditions [Sellers 1985, Adamczyk, Będkowski 2007]. The NDVI is calculated as follows [Rouse et al. 1974]:

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (2.1)$$

where: NIR – reflectance in near-infrared band, RED – reflectance in red band.

NDVI values range from – 1 to 1, where negative values and close to 0 mean snow cover, water or lack of vegetation. Moderate values correspond to sparse vegetation or grasslands, whereas healthy and dense vegetation is manifested by high values of NDVI (more than 0.5).

The second index which may represent health of the stand is the Normalized Differential Infrared Index (NDII) calculated as a ratio of NIR and SWIR bands. As Landsat provides two SWIR bands, the SWIR at 1.65  $\mu\text{m}$  was selected based on literature suggestion [Hardisky et al. 1983].

$$NDII = \frac{NIR - SWIR1}{NIR + SWIR1} \quad (2.2)$$

where: NIR – reflectance in near-infrared band, SWIR1 – short-wave infrared band at 1.65  $\mu\text{m}$ .

NDII values – same as NVDI – range from – 1 to 1. The values close to -1 refer to dried out plants or lack of vegetation. The higher the NDII values are, the better is condition of vegetation.

### Data processing and indicator modeling

Delineation of forest areas from the georeferenced Landsat 8 imagery was performed based on the reference vector data. Within these areas both indices were then calculated using given formulas (2.1, 2.2). In the study area the values of NDVI ranged from 0.01 to 0.64 and NDII values from -0.12 to 0.52.

In the extraction of forest damage classes based on the calculated NDVI and NDII values the indicator modeling – particularly the technique of factorial scoring – was used.

To enable simultaneous interpretation of NDVI and NDII the values of VIs were classified into groups and for each of the class factorial scores were assigned. The goal of this approach is to apply a common scale of values to the diverse and distinct input datasets in order to assess certain degree of the phenomenon (in this case the degree of forest damage) expressed in either binary, ordinal or quantitative scales. These factor scores can be summed to give the total score, which in the following step is to be classified according to the arbitrary chosen classification system [Morgan et al. 1984, Longley et al. 2006].

Following the above mentioned procedure NDVI and NDII values were reclassified into groups represented by factorial scores that range from 1–6 for NDVI and 1–5 for NDII. In the reclassification process the statistical distribution of the data was taken into account (Table 1). The classification is based on the Jenks Natural Breaks algorithm which minimize the differences among the data within one class and at the same time maximize the differences between classes [de Smith et al. 2006–2009]. Due to the small variation of values, NDII was classified into 5 classes. There were only a few pixels with negative values therefore they were included in the 1<sup>st</sup> class of NDII.

Table 1. Reclassification of NDVI and NDII

<b>Classes (scores)</b>	<b>NDVI</b>	<b>Pixels count</b>	<b>NDII</b>	<b>Pixels count</b>
<b>1</b>	<b>0.01–0.08</b>	531	<b>-0.12–0.15</b>	19 305
<b>2</b>	<b>0.08–0.25</b>	5 178	<b>0.15–0.23</b>	179 133
<b>3</b>	<b>0.25–0.35</b>	311 733	<b>0.23–0.26</b>	318 286
<b>4</b>	<b>0.35–0.42</b>	359 615	<b>0.26–0.32</b>	625 758
<b>5</b>	<b>0.42–0.50</b>	345 393	<b>0.32–0.52</b>	109 016
<b>6</b>	<b>0.50–0.64</b>	229 048		

The spatial distribution of reclassified VIs is presented in the figures (Fig. 3, 4). The northern part of the region is characterized by the higher values of both VIs, whereas in the south-western part these values are generally lower, what could correspond to damaged stands or areas where the forest condition is worse.



In the following step the reclassified VIs are summed to assess the forest condition, which is expressed by four classes (Table 2): non-damaged forest (class 0) for which NDVI and NDII have the highest values (the sum of scores 10–11) and classes from 1<sup>st</sup> to 3<sup>rd</sup> for which the sum of the scores for NDVI and NDII are 8–9; 6–7; 2–5 respectively. The factorial scoring is used carefully, counting for the limitations of this method, analysing the sum and combination of NDVI and NDII scores (Table 2). The categories of forest damage are also analyzed in terms of the percentage share of each score combination in the whole class. What can be seen in Table 2 (highlighted rows) some of the combinations can be considered as representatives of the class because of their high percentage share in the class (e.g. in the 1<sup>st</sup> class over 85% are combination of 5–4 and 4–4). The score combinations of extreme values (e.g. 6 – NDVI and 2 – NDII or 1 – NDVI and 4 – NDII) are not significant in terms of percentage share in a class and may be generalized as a result of further spatial analysis.

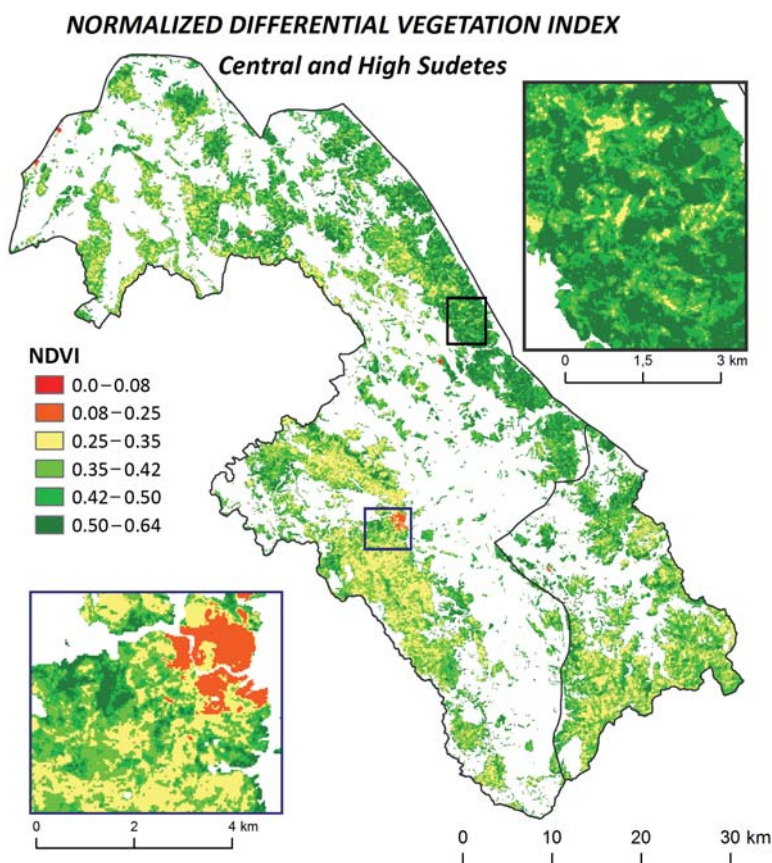


Fig. 3. Reclassified Normalized Differential Vegetation Index (NDVI)

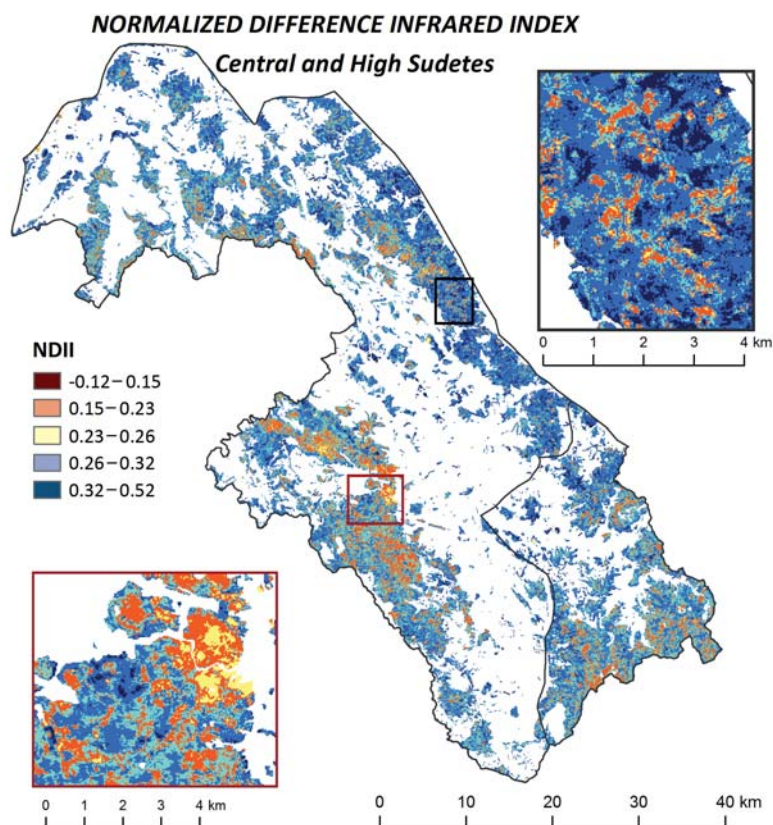


Fig. 4. Reclassified Normalized Difference Infrared Index (NDII)

Table 2. Classification of forest damage based on VIs combination

Class of forest damage	NDVI scores	NDII scores	Sum	Percentage in each class
0 – non-damage forest	2	3	4	5
	6	5	11	36.4
	6	4	10	56.8
	5	5	10	6.8
1 – slightly damage	6	3	9	0.7
	5	4	9	52.8
	4	5	9	1.0
	6	2	8	0.1
	5	3	8	9.8
	4	4	8	35.6
	3	5	8	2.0



Table 2 cont.

1	2	3	4	5
2 – medium damage	5	2	7	4.8
	4	3	7	30.5
	3	4	7	13.0
	2	5	7	1.3
	5	1	6	0.01
	4	2	6	14.0
	3	3	6	37.6
	2	4	6	6.7
	4	1	5	3.3
3 – highly damage	3	2	5	83.3
	2	3	5	4.8
	1	4	5	3.2
	3	1	4	8.8
	2	2	4	1.2
	1	3	4	1.6
	2	1	3	2.9
	1	2	3	0.2
	1	1	2	0.2

### Spatial analysis

The classes of forest degradation determined as a result of the factorial scoring aim to update and improve the SOZO database. Therefore, the output of the analysis should be adjusted – in terms of generalization criteria – to the scale of 1 : 50 000.

The major assumption is that the criterion of minimum area has to be fulfilled [Zasady redakcji mapy topograficznej w skali 1:50 000, 1998]. According to this criterion, the smallest unit represented on a map in a scale of 1:50 000 as forest area should not be smaller than 4 mm<sup>2</sup> which means 1 ha in ground units. In order to select over 1 ha forest areas of a particular degradation class a sequence of spatial analysis was performed. First, the homogenous regions of each class of forest damage were created (*Region Group* operation) along with the attribute information for their area. Then the NoData value was assigned to the regions smaller than 1 ha, to which – in the next step – the value of class degradation has been assigned based on Euclidean allocation rule (the value from the nearest pixel based on the Euclidean distance is assigned).

Through this generalisation process all groups of pixels smaller than 1 ha are joined to the surrounding classes, therefore the stands' areas are more compact (Fig. 5).

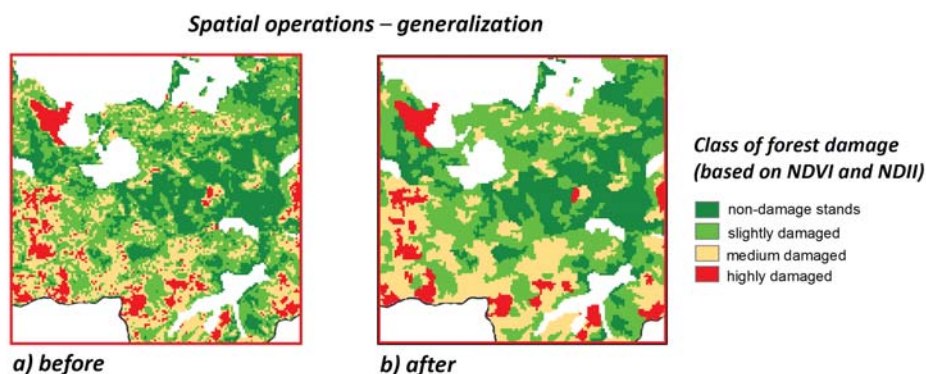


Fig. 5. Generalization of the areas of forest damage (minimum area criterion)

The last step is to convert the raster data to vector feature class. In order to present the classes of forest degradation on a sozological map (DCM) the boundary generalisation shall be applied. However, for the purpose of SOZO database (DLM) the raster may be transformed into vector without the boundary simplification. Thus, in this study the non-simplified polygons are used to update SOZO feature class.

## RESULTS

The results from the combined NDVI and NDII show that over 40% of stands in Central and High Sudetes are medium damaged, over 20% are non-damaged forests and only 0.9% are the highly degraded stands (Table 3).

Table 3. Area of forest degradation in particular classes

Class of forest damage	Area [ha]	Percentage of class area in total forest area
0 – non-damage	21700	21.2
1 – slightly damage	44592	43.6
2 – medium damage	35184	34.3
3 – highly damage	1110	0.9

Looking at the spatial distribution of the classes (Fig. 6) it is visible that the forests with the best condition of stands cover the northern part of the region, in the neighbourhood of Pogórze Sudeckie. Much worse stands' condition can be observed in the south-western part which could attribute to the terrain altitude, soil properties in high-mountain areas and the past degradation processes that had occurred in Sudetes in the 80s and the 90s.

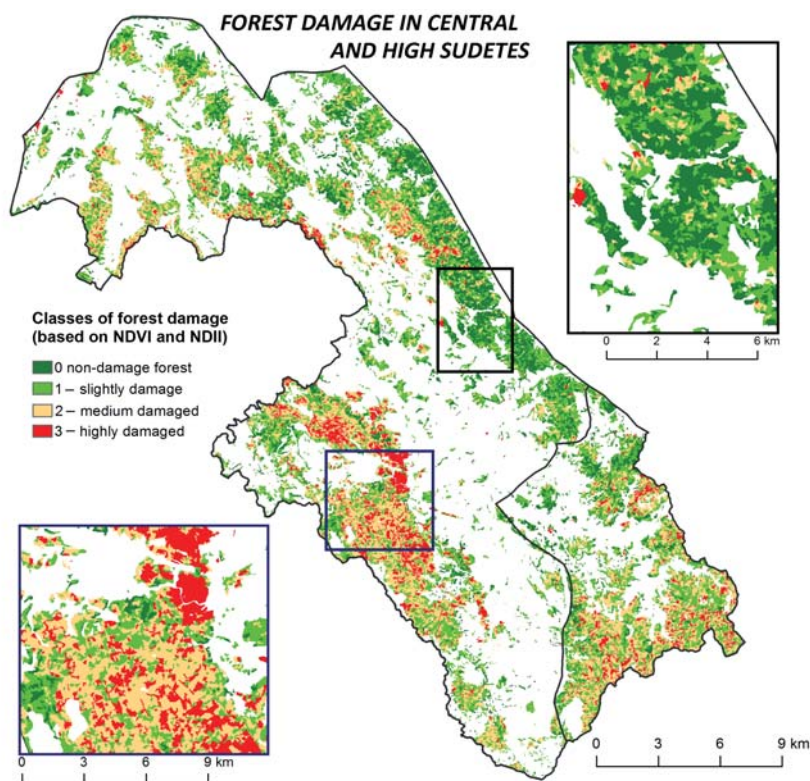


Fig. 6. Areas of forest damaged in classes determined based on NDVI and NDII

Obtained results were verified with SOZO database – points representing the class of forest damage from SOZO database were superimposed on the map obtained from this study (Fig. 7). It can be noticed that over 50% of the 1<sup>st</sup> class points (slightly damaged) from SOZO database should be transferred to the 2<sup>nd</sup> class (medium damage forest), and at the same time over 60% of points from 2<sup>nd</sup> class seem to represent stands of better conditions (slightly damage) (Table 4). Moreover, points from the 3<sup>rd</sup> class are equally distributed within the slightly and medium damage classes. This study shows also the actual occurrence of heavily damaged forests which cover only 0.9% of all stands in Central and High Sudetes. It means that the stands are renewed after the disaster in the 90s, however this areas should still remain under protection.

Table 4. Number of points representing the class of forest damage within the determined classes based on vegetation indices

SOZO database		Landsat 8 imagery (NDVI and NDII)			
Class of forest damage	Number of points	Number of points within class of forest damage			
		0 – non-damage	1 – slightly	2 – medium	3 – highly
1	142	4	61	77	0
2	141	0	87	54	0
3	69	0	34	35	0

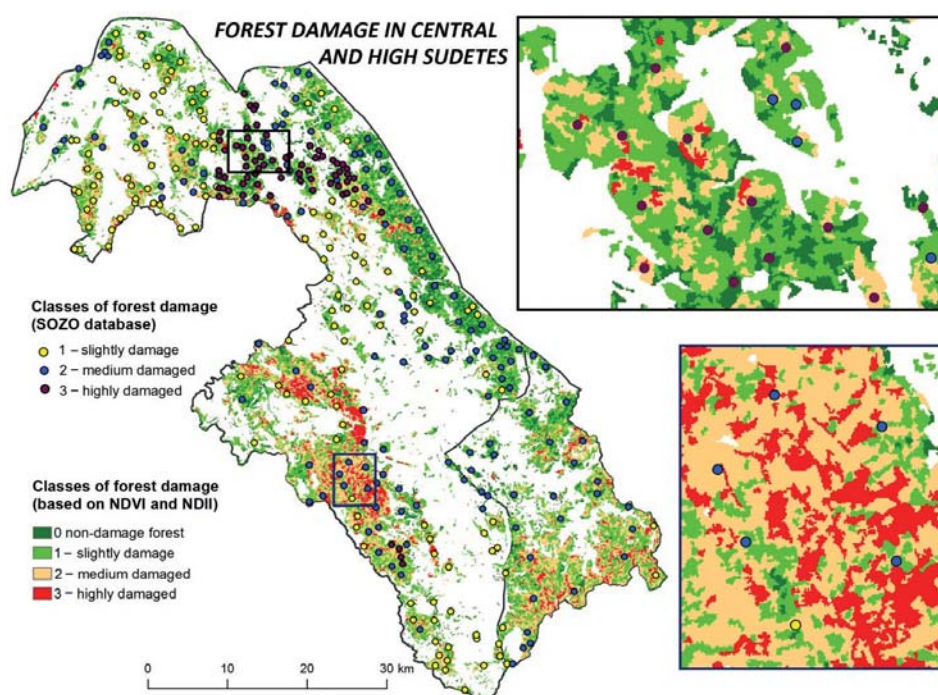


Fig. 7. Points representing the class of forest damage from SOZO database superimposed on the areas of forest damaged determined in the study

## CONCLUSION

The case study in Central and High Sudetes shows the possibilities of using satellite imagery to update and enhance a chosen layer of forest damage to functionally improved environmental database to perform spatial analysis. Although the SOZO database is designed to provide updated information on a state of the environmental hazards and pollution, and enable to evaluate the state of natural environment in a quantitative manner, the analysis of chosen layers of the map shows that some of the data are outdated and 0-dimensional features represent the phenomenon which refers to areal units. This study introduces a new methodology for the delineation of spatially meaningful areas with certain damage of stands based on vegetation indices calculated from satellite imagery.

The output of the study is appropriate in terms of the accuracy and type of the data for updating both digital landscape model (DLM) – SOZO database and digital cartographic model (DCM) – a sozological map.

The research proves that the usage of remotely-sensed data to improve the SOZO database (a sozological map) would make this environmental database an operational source of data, allowing to perform spatial analysis and create synthetic indices of the state of natural environment, as well forecast the magnitude of changes. It is believed that the potential of remotely-sensed data allow to update and enhance many layers of SOZO

database, especially those that represent the areal phenomenon as point-objects. The improved SOZO database could be successfully used by institutions and authorities for environmental protection and decision-makers at regional or national level.

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## **ZOBRAZOWANIA SATELITARNE JAKO ŹRÓDŁO ZASILENIA TEMATYCZNEJ BAZY DANYCH PRZESTRZENNYCH SOZO – NA PRZYKŁADZIE SUDETÓW ŚRODKOWYCH I WYSOKICH**

**Streszczenie.** Tematyczna baza danych przestrzennych SOZO wraz z jej kartograficznym modelem – mapą sozologiczną przedstawia stan środowiska przyrodniczego, przyczyny i skutki zmian zachodzących w tym środowisku oraz formy i sposoby ochrony jego naturalnych wartości. Nie ulega wątpliwości, że baza SOZO powinna służyć do analizy i oceny stanu środowiska naturalnego w postaci wskaźników i miar ilościowych. Jednakże, analiza wybranych warstw bazy wskazuje na pewne jej braki, które sprawiają, że wykonanie analiz przestrzennych jest niemożliwe. Dotyczy to m.in. warstwy klasy degradacji lasów reprezentowanej w postaci geometrii punktowej bez określenia zasięgu tych klas. W pracy zaproponowano zastosowanie zobrażeń satelitarnych jako źródło aktualnych danych dodatkowo zasilających bazę w zasięg występowania badanego zjawiska. Klasy degradacji lasu określono na podstawie wskaźników wegetacyjnych (NDVI i NDII), których kombinacja pozwala wyznaczyć stopień i zasięg degradacji lasów w postaci obiektów powierzchniowych. Jest to niewątpliwie bardziej użyteczna forma, która czyni bazę SOZO w pełni funkcjonalną w zakresie analiz przestrzennych.

**Słowa kluczowe:** baza danych SOZO, indeksy wegetacyjne, klasy degradacji lasów

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