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Mapping of land use changes in Poland using Earth observation data

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Abstract. Mapping of land use for the needs of reconstruction of the country was one of the main tasks of the Head Office of the Land Surveying set up after the Second World War. Up to present day such map has not been made despite of many attempts and the high demand for this type of map primarily by the spatial economy. The main reason was the lack of raw materials and high cost of field works.
The situation changed with the launch of Landsat satellite. Images taken by this satellite were used for the preparation of land use map covering the entire country. They were also used to compilation the land cover databases developed within the three CORINE Land Cover (CLC) projects in 1990, 2000 and 2006. Comparison of these databases allowed an analysis of land use changes occurred within 16 years. These changes were relatively small, far below expectations.
CLC database was also compared with a map of land use developed on the basis of topographic maps from the 1930's. The comparison showed changes that have occurred on the surface representing almost 10% of the total area of the country. They reveal both some effects of hostilities, the current expansion of the country, as well as the effects of natural disasters which hit Poland in recent years.
Images taken by Landsat have also been applied to study the damage of forests in the Sudety Mountains. Several degrees of damage to spruce stands have been distinguished on the basis of satellite images. They were also used to study the development of brown coal mine and its impact on dropping the groundwater level in the vicinity of mine as well as to determine the development of Warsaw built-up areas in the last 80 years.

Keywords: land use mapping, land use changes, CLC-projects, forest damage assessment, depression cone

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1. Introduction

In four years it will be the hundredth anniversary of the beginning of work on the land use mapping. In 1916 the American geographers started a research on the classification of land use forms and their presentation on the maps. The works in this area had also been undertaken in other countries, including the Polish territories under Austrian rule, where almost simultaneously with the American geographers a map of "land use" has been developed by a well-known Polish geographer – Eugeniusz Romer. The map was included in the Geographical and Statistical Atlas of Poland published in 1916.

In the interwar period many land-use maps have been elaborated in Poland mostly from territory of the Eastern Carpathians, Podhale, Beskid and Polesie. The data for the development of these maps were acquired during field works. Due to high expenses of field works mapping of terrain was limited to relatively small areas, but it has never covered the whole country.

After World War II, when the country was faced with enormous tasks of reconstruction it was necessary to develop a large-scale economic map of Poland. The Head Office of Land Surveying undertook a development of such map as one of its main tasks. The map was to be made at the scale of 1:5 000. Compilation of large-scale economic map exceeded the technical capabilities and human resources of surveying services and within three years (1947–1949) a small number of maps covering only a few percent of the country have been developed.

Another project of the Head Office of Land Surveying turned out to be also unsuccessful. This time it was to be a map of land use at the scale of 1:10 000. About 10 000 sheets were to cover the whole country. A lack of uniform geodetic network and the source materials, first of all aerial photographs, were a main reason for stopping further works after compilation just of approximately 2 000 map sheets.

Problems of development of the land use map was again undertaken in 1979, when the Central Cartographic Information Service, analyzing the demand for thematic maps, fixed sets of maps necessary to carry out basic tasks of the national economy, as well as spatial planning and management at various levels of state administration (Madzińska, 1980). Among this set of maps to be developed for the whole country there were land use maps at scales of 1:25 000, 1:50 000 and 1:100 000. But in addition to developing the technical guidelines for land use maps at the scale of 1:25 000 no other works on a planned series of maps have been undertaken.

The issues of land use mapping have also been undertaken by geographers. They took the works on the land use map that would allow the estimation of losses, and yet it could be used in the reconstruction of war damage. Many of the initiatives ended up in developing the instruction specifying the method of field work and specifying the methods of presenting land use feature in maps. Several sheets of a detailed map at the scale of 1:25 000 have also been elaborated. The maps covering about 17 000 km^2 (less than 5.5% of the country), have been elaborated till 1970 (Jankowski, 1972).

In 1952, Uhorczak suggested another way to develop a map of land use in Poland. This time it was to be a general map at the scale 1:1 000 000. Topographic maps at the scale of 1:100 000 were the data source for that map (Uhorczak, 1969). Five main land use categories namely, water, meadows and pastures, forests, arable land and settlements have been outlined on the basis of these maps. The results of analysis of topographic maps have been drawn on tracing paper and then reduced 10-fold photographically. The smallest element distinct on the map depicted the area of 1 ha. Of the five forms of land cover all but the settlement were presented in homolographic projection. In the case of settlements separation line of equal distant of 50 m has been drawn to keep the detail of topographic maps. The image of the spatial distribution of the land use forms in the whole country has been published in a map at the scale of 1:1 000 000. This was the first map showing land use throughout the country. However, due to the fact that some of the topographic maps have been developed in the 1930's of last century, the land use map can be considered to some extent historical.

2. Satellite images and their application in land use mapping

A turning point for land use mapping came with the 1972 launch of the first satellite designed to study the Earth's natural resources. The images acquired by this satellite proved to be an excellent source of data about land cover and land use. Spatial resolution of Landsat images were sufficient for mapping of land use at general scales 1:200 000 – 1 000 000.

Poland was among the many countries which used images taken by the Landsat satellite for mapping land use. In 1979 the Institute of Geodesy and Cartography, Warsaw, acquired images taken in 1977–1978 to develop a land use map. Images in the form of colour photographic prints at the scale of 1:250 000 were analyzed visually. 10 forms of land use have been distinguished on the basis of these images. The map developed at the Institute was published by the State Cartographic Publishing House as a wall map at the scale of 1:500 000. It served for several years in education and public administration as the only source of information on the land use for the whole country (Ciołkosz and Poławski, 1980).

3. Application of satellite images to study changes in the environment

The Institute of Geodesy and Cartography has also used images taken by the Landsat satellite to study changes in the environment. The first works have been undertaken in the Western Sudety Mts. where the range of environmental changes were so large that the area was referred to as "Black Triangle". The biggest changes have taken place in the forests. Natural forests in the Sudety Mts. for a long time were heavily affected with anthropogenic factors. Air pollution caused by industrial gases emitted by large factories located in Poland and in surrounding countries led in seventies to large-area forest decline. In order to examine process of forest degradation in the Western Sudety Mts. images acquired by Landsat were applied. The images were collected in 1990.

False colour aerial photos covering a number of selected areas of the Western Sudety Mts. have been taken to facilitate the analysis of satellite images. Information derived from aerial photographs and field works were used for training areas in supervised classification of Landsat images. They have also been used to verify the obtained results and determine credibility of classification. As a result of classification five categories of forest areas were distinguished (Fig. 1).

The field observations were conducted in over 300 test sites, each covered an area of 100 m^2. In the course of these observations there were analyzed environmental conditions (slope, exposure, altitude) which affect both the stands and their image on aerial photographs and satellite imagery. The structure of forest stands namely: species composition, stand density, age, presence and severity of damage, as well as their physical condition, defoliation and discoloration of needles were also characterized during field observations.

Five classes of spruce stands, and three other forms of land use, including two forms of deforestation and mountain pine were distinguished on the basis of satellite images analysis. Accuracy of visual interpretation of satellite images was determined by TM pixel size (30 m × 30 m). During the visual interpretation of satellite images the different classes were separated with an accuracy of 1 pixel. Computer aided satellite image classification was performed with the precision of the 65 – 90%.

In order to determine the changes that have taken place in the environment of the Western Sudety Mts. satellite images taken 14 years earlier were used. Sudety Mts. were than imaged by Landsat MSS scanner. Despite the relatively low spatial resolution of these images and recording only four bands of the electromagnetic spectrum, their analysis revealed the extent of damage not only of the dominant spruce trees, but also helped to determine the degree of damage.

Comparison of results of analysis of satellite images taken between 1976 and 1990 showed that the health condition of spruce stands deteriorated substantially. At the end of the nineteen nineties the area of the stands in the best conditions diminished twofold in comparison with 1976. The area of moderately impaired spruce stands increased by 2.5% in 1990 while the area of heavily impaired and dead spruce stands decreased by 5.5% comparing to 1976 (Table 1). The most significant difference was observed in deforestation category. Deforestation occupied over 3 times larger areas in 1990 than in 1976. This fact results from the removal of dead and heavily damaged trees. Analysis of images taken in 2000 revealed that the Izery Range and western part of Karkonosze Range were almost totally woodless. It should be noted that the comparison of the results of satellite images ana-

Table 1. Area of the forest classes

Class	Area [ha]	
	MSS 1976	TM 1990
Slightly impaired spruce stands	18 529 (32.7%)	9 919 (17.5%)
Moderately impaired spruce stands	10 380 (18.7%)	11 792 (20.8%)
Heavily impaired spruce stands	9 938 (17.5%)	6 831 (12.0%)
Mixed stands	8 636 (15.2%)	10 104 (17.8%)
Deciduous stands	2 497 (4.4%)	435 (0.8%)
Openings	4 894 (8.6%)	16 714 (29.4%)
Mountain pine	1 845 (3.3%)	961 (1.7%)
Altogether	56 719 (100%)	56 756 (100%)

lyzes with the results of field studies showed more than 80% reliability of the classification images taken by the Landsat satellite (Bochenek et al.,1998).

The images taken by the French SPOT satellite in the years 1986–1987 were also used for analysis of forest in the Sudety Mts. Images acquired by HVR scanner on this satellite did not register mid-infrared part of spectrum therefore usefulness of these images to study vegetation was very limited. These images proved to be good enough only for the detection of highly damaged and dead spruce stands.

Revisits of the environmental satellite provided data to study environmental changes accompanying

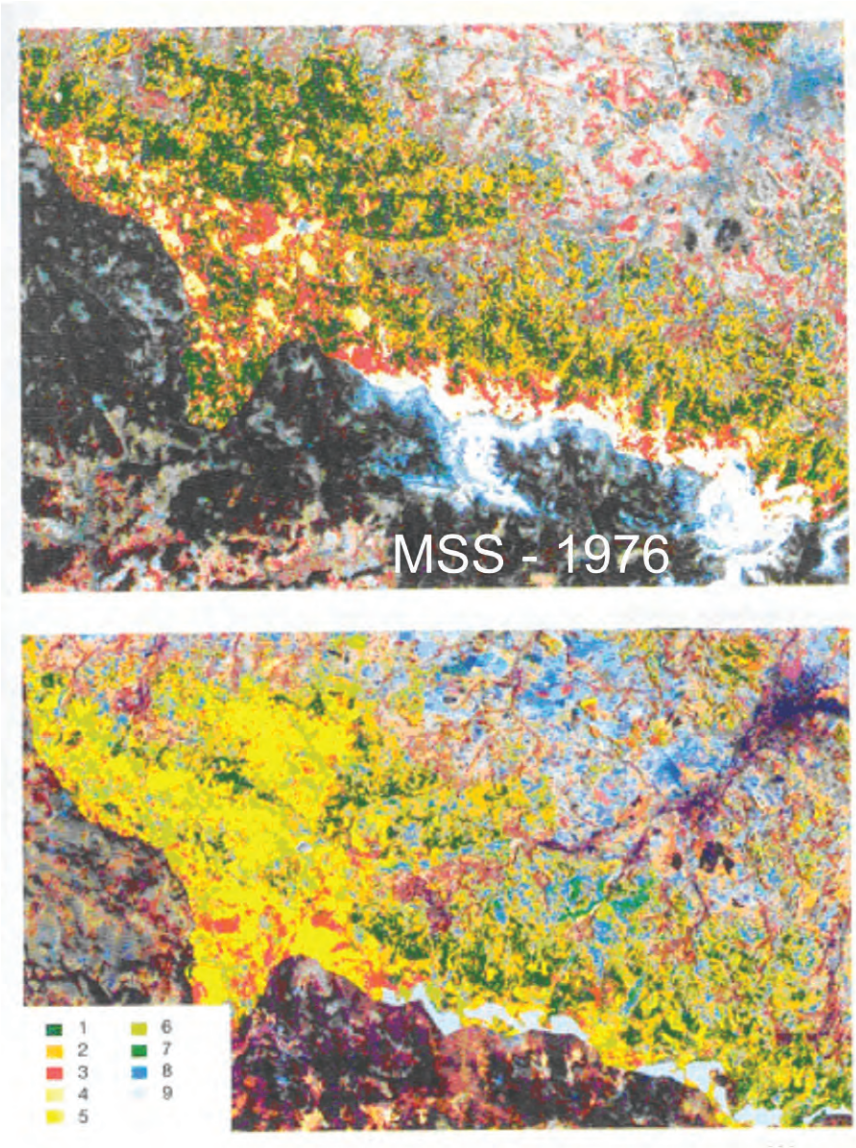

Fig. 1. Forest changes in the Western Sudety Mts.

1 – slightly impaired spruce stands, 2 – moderately impaired spruce stands, 3 – heavily impaired spruce stands, 4 – clear cuts, 5 – openings, 6 – vegetated openings, 7 – deciduous stands, 8 – mixed stands, 9 – mountain pine

the construction and operation of opencast brown coal mine in Bełchatów. The first mining works associated with removing the overlayer in Bełchatów began in 1977. The Institute of Geodesy and Cartography purchased the first images of the area in 1987 so the year prior to the planned size of the mine.

Since this year, approximately every two years successive images taken by Landsat TM have been analysed. Analysis of the images revealed the progress of the exploitation of the brown coal deposit, indicated in the image by a pit enlarging, primarily by occupying arable land and meadows and a small part of the forest. The satellite image taken in 2006 showed opencast brown coal mine which had over 12 km long and over 3 km wide, covered an area of just over 35 km^2 (Martyńska, 2005). In the next CLC project (CLC-2006) area of particular forms of land occupied by the expanded coal mine has been determined. As in previous years, this time the mine expansion took also place mainly by occupation of arable land (Fig. 2).

It is noteworthy that the surface of mine dump did not increased. Its current size (about 5.5 km length, more than 3 km width, and an area of less than 15 km^2) was reached in the mid-nineteen eighties. Inactive mine dump was a subject of rehabilitation. Satellite image of 1987 revealed that the northern slopes of the dump were already covered with vegetation, and the consecutive images showed that the vegetation entered the remaining slopes and only the peak of the dump was still not fully covered by it in 2006.

The Institute of Geodesy and Cartography in cooperation with the Institute of Land Reclamation and Grassland Farming have applied satellite images to determine the range of depression cone around a lignite opencast mine. It was assumed that meadow vegetation depicted on satellite images reflects the vigour and biomass of plants depending on their access to groundwater. The images taken in period of the lowest rainfall in the season of plant growth were used for this purpose. In this period one can observe a weakness of vigour of the plants and decrease of their biomass.

An analysis of rainfall in the last two decades of the last century revealed that the very dry periods in the season of maximum growth of vegetation coincided with the years 1987, 1989, 1992, 1993, 1995 and 1999. Landsat TM images acquired in these periods were purchased for analysis of the state of meadow vegetation. Normalised vegetation index (NDVI) defined as the ratio of the difference in value of reflected radiation recorded in channels 4 and 3 Landsat TM sensor to the sum of these values was calculated on the basis of these images. This index is a measure of vigour and condition of vegetation cover. Dense plant communities in good condition with green leaves have a normalized vegetation index close to 1.0, while low values of that index are typical of the plants dry, yellowed with soil showed through the meadow vegetation. By analyzing the differences of the state of vegetation depicted on successive images an area where one could observe low values of normalized vegetation index was defined. It was assumed that this is the area which experienced a reduction of groundwater level caused by mine drainage works (Fig. 3). It should be noted that the analysis of satellite images was confirmed by field measurements of soil moisture and assessment of vegetation condition (Miatkowski et al., 2006).

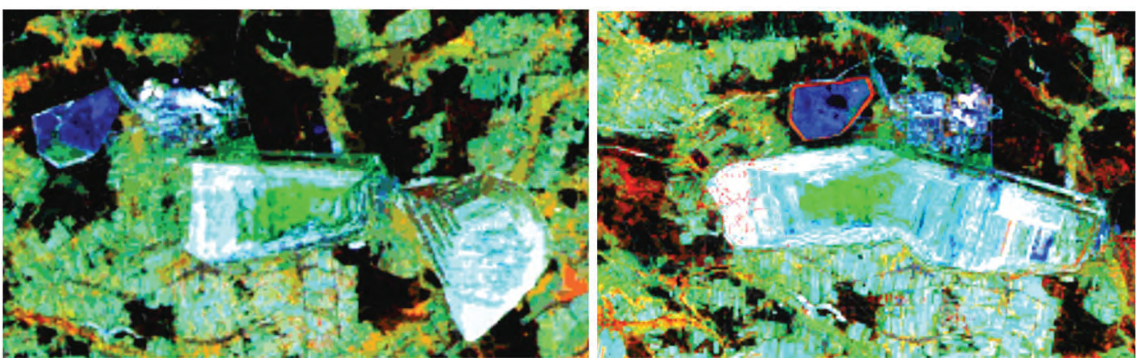

Fig. 2. Opencast brown coal mine “Bełchatów” in 1989 and 2000

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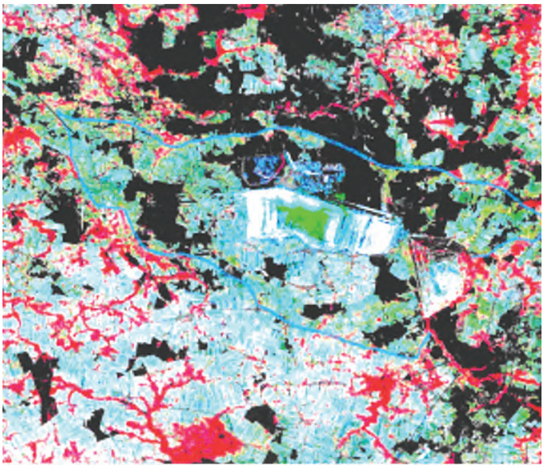

Fig. 3. Cone of depression (blue line) around open cast brown coal mine „Bełchatów"

4. Databases developed within the framework of the CLC projects

In 1993 Poland as the first country in Central Europe joined the CORINE Land Cover Project. The Institute of Geodesy and Cartography was selected as the contractor of land cover database (Ciołkosz and Bielecka, 2005). The Institute received colour images at the scale of 1:100 000 made by Landsat-5 in national projection. Interpretation of images was carried out visually, and its results were drawn on tracing paper and then converted into digital form and vectorised. In many cases the results of image interpretation were checked directly in the field.

A major problem during the visual analysis of satellite images was to determine the area of polygons similar in size to the area of 25 ha accepted as a minimum mapping unit in CLC program. It is not easy, even when using a standard template, visual estimation of the surface with an accuracy of 2–4 ha. It resulted in marking of a number of polygons of a size slightly smaller than 25 ha. The trouble with these small polygons appeared only in the development of the next database – CLC-2000. In this case the interpretation of the satellite images was carried out on the monitor in real time which allowed the precise identification of the area of individual polygons. It turned out that the database CLC-90 contains a number of polygons of an area slightly smaller than 25 ha. The database therefore required a large correction and generalization.

As it already was mentioned technology of developing of CLC-2000 land cover database based on an analysis of images directly on the monitor. This fact has allowed not only precise assessment of polygon's area, but by increasing the image scale, the possibility of selection of channels and selection of objects colour, it contributed to facilitation of the interpretation and increasing its accuracy and reliability. CLC-2000 database was established as the sum of the CLC-90 database and the changes identified in the analysis of new satellite images.

Two land cover databases, converted into a common reference system, out of which one presented the situation in 1990, the second one in 2000 led to the development of differences in land cover occurred in a period of 5 years. Changes in land cover were relatively small. They encompassed approximately 0.82% of the country. Figure 4 shows their spatial distribution (Bielecka and Ciołkosz, 2008).

Fig. 4. Land use changes in Poland in a period 1990–2000

Observing land use changes taking place at the turn of the centuries in Poland one can come to conclusion that they comprise larger areas than are presented in a database changes (CLC-90 – CLC-2000) This could arise either from too big mapping unit in CLC, or with too short period between years of elaboration of successive CLC databases. Increasing the detail of the development of the CLC database by reducing the size of mapping unit was associated with too high costs, which the Institute of Geodesy and Cartography could not incur. In this situation it was decided to apply earlier maps presenting land use. However, as already mentioned, there is a lack of such maps in our country which could cover the whole Poland. The only exception is the map prepared by Uhorczak at the scale of 1:1 000 000. This map contains five land use categories. It was therefore decided to compare the contents of this map with the contents of the CLC-2000 database generalized to the level I. This required from one hand the conversion of the analogue map to digital one, from the other hand to generalize the content of CLC database to the first level of its nomenclature (Ciołkosz and Poławski, 2006).

Comparison of the two maps revealed that changes in land use during the nearly 70 years have occurred in the area constituting nearly 9.5% of the country (Fig. 5). Nearly 90% of the observed changes occurred in the area of arable land and grassland. Major changes took also place in the forests. The area of forest has increased by over 15 000 km^2. New forested areas concentrated mainly in the northern and south-eastern Poland. Part of agricultural land, meadows and forests has also been transferred into industrial, and residential areas and was also occupied by new roads and water reservoirs.

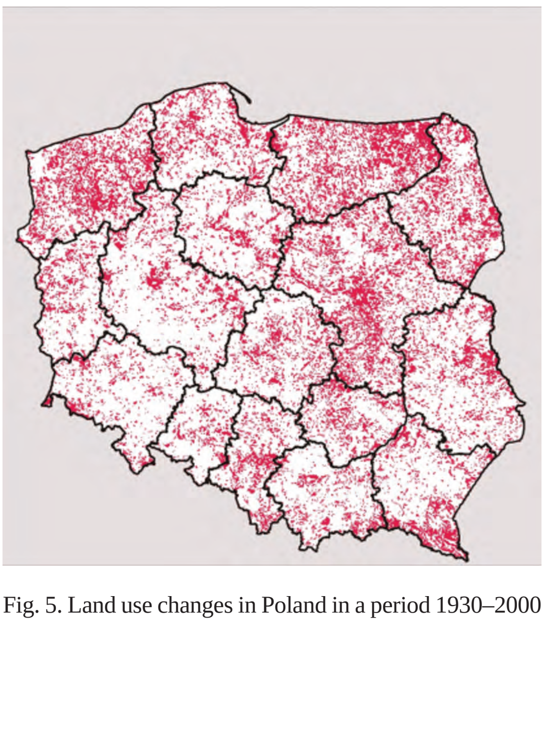

Fig. 5. Land use changes in Poland in a period 1930–2000

Great changes have taken place in big towns. Figure 6 presents spreading of Warsaw's built up areas in 80 years. The densely and scattered built-up residential, industrial and commercial areas (red colour) have been obtained after generalisation of the CLC-2006 database. In Warsaw District in 2006 they occupied 76 321 ha while in 1930 the area occupied by the same land use classes was much smaller – it covered 37 109 ha only.

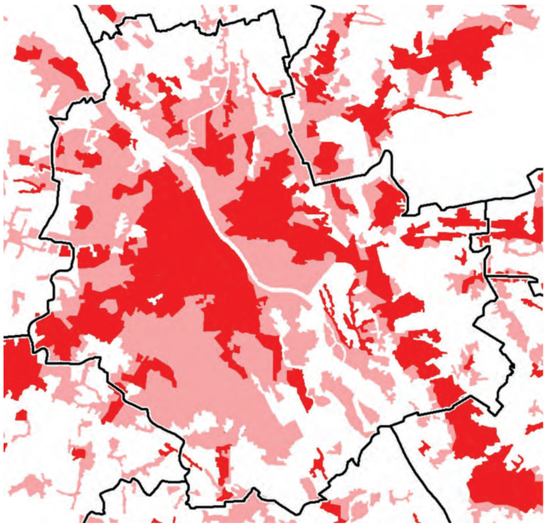

Fig. 6. Expansion of the built-up areas in Warsaw during the 80 years

In 2006 the team of the Institute of Geodesy and Cartography undertook compilation of a new land cover database in the framework of next CLC project. Also in this case a newly developed base was compared with the previous one. It allowed to determine land use changes that have taken place in Poland in 2000–2006. Despite the reduction a surface area of land use changes from 25 ha to 5 ha, the differences in land cover in six years were relatively small. Their total area exceeds only 0.5% of the country (Fig. 7). They occurred mostly in forested areas, which resulted mainly with the great forests devastation caused by natural factors. Smaller surface changes were noted in case of acquisition of area occupied by forest for construction of roads and highways. Forests and agricultural lands constituted a total of just over 94% of Polish territory.

Changes in these two forms of land cover include more than 92% of all the changes that occurred during this period in Poland. The changes observed in the other forms are very small. In total, they do not exceed 8% of all changes (Bielecka and Ciołkosz, 2009).

It was not expected in the CLC project to comprise the first database (CLC-90) with last one (CLC-2006). Comparison of these databases showed differences in land use that occurred in 16 years periods between implementation of the first and third CORINE Land Cover databases. The land use changes comprised slightly more than 5 000 km^2, representing 1.64% of the country.

Fig. 7. Land use changes in a period 2000–2006

Table 2 presents changes in land use in Poland in the period 1990–2006 generalized to the first level of the hierarchical nomenclature used in the CORINE Land Cover projects. Analysis of changes on the level III of the CLC nomenclature showed that the greatest changes occurred in the areas of discontinuous urban fabric. In the 16 years these areas have increased by 2 106 km^2, which means that the surface area occupied by a discontinuous urban fabric increased by 27.3%. The area occupied by sport and leisure facilities has increased about nearly 200 km^2. Changes of artificial surfaces decreased agricultural areas over 4 700 km^2. It should be noted that part of the arable land was afforested, which resulted in an increase of forest area during the period of slightly more than 2 800 km^2. It is worth noting that in the forests there was a significant increase of areas classified as transitional woodland (code 3.2.4 in CLC nomenclature). This was due to massive destruction of forest areas caused by windfalls.

New project CORINE Land Cover 2012 planned by the European Environmental Agency will provide new data to demonstrate the present land use pattern as well as subsequent land use changes in Poland.

5. Summary

The repeated efforts to develop maps of land use in Poland did not yield satisfactory results for several years. This was primarily due to the lack of suitable raw materials and high costs of field surveys. The situation has changed since the placement in orbit the Landsat satellites. The Institute of Geodesy and Cartography has used satellite images to prepare land use maps covering the area of the country, as well as to develop land use/land cover databases within the framework of CORINE projects. Landsat images have also been used to examine

Table 2. Land use changes in Poland in 1990–2006

CLC land cover forms (level I)	Area [km^2]		Changes	
	1990	2006	[km^2]	[%]
Artificial surfaces	10 250	12 516	+2 266	22.10
Agricultural areas	200 999	196 264	-4 735	2.35
Forests and semi-natural areas	94 888	97 694	+2 806	2.95
Wetlands	1 177	1 075	–102	8.67
Water bodies	5 157	4 922	–235	4.55

changes occurring in the environment under the influence of natural and anthropogenic factors. The spatial and spectral resolution of the images provided by this satellite proved to be sufficient for many other applications. Properly processed images proved to be useful even to examine the degree of damage to spruce stands. They also enabled to determine the impact of brown coal strip mine on the environment through the designation the extent a cone of depression. The Institute Geodesy and Cartography conducts further research on the use of Landsat images to study other components of the geographical environment and their changes.

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Kartowanie zmian użytkowania ziemi w Polsce z wykorzystaniem satelitarnych obserwacji Ziemi

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Streszczenie. Kartowanie użytkowania ziemi na potrzeby odbudowy kraju było jednym z głównych zadań Głównego Urzędu Pomiarów Kraju utworzonego po drugiej wojnie światowej. Mimo dużego zapotrzebowania na taką mapę przez gospodarkę narodową i wielu prób jej opracowania dotychczas nie udało się jej wykonać. Głównym powodem był brak odpowiednich materiałów źródłowych oraz wysoki koszt prac terenowych. Sytuacja uległa zmianie z chwilą wystrzelenia satelity Landsat. Zdjęcia wykonywane przez tego satelitę zostały wykorzystane do opracowania mapy użytkowania ziemi obejmującej obszar całego kraju. Zostały one także wykorzystanie do opracowania baz danych zawierających informacje o pokryciu terenu w ramach trzech projektów CORINE Land Cover (CLC) 1990, 2000 i 2006. Porównanie tych baz pozwoliło na analizę zmian użytkowania ziemi jakie zaszły w okresie 16 lat. Zmiany te okazały się stosunkowo nieduże, dalekie poniżej oczekiwań.
Baza danych CLC-2000 została porównana z mapą użytkowania ziemi opracowaną na podstawie map topograficznych z lat 30 ubiegłego wieku. Porównanie to wykazało zmiany jakie zaszły w ciągu niemal 80 lat w Polsce. Objęły one obszar stanowiący niemal 10% powierzchni kraju. Zmiany te odzwierciedliły zniszczenia wojenne, powojenny rozwój kraju, jak również wykazały skutki klęsk ekologicznych, które wystąpiły w Polsce w ostatnich latach.
Zdjęcia wykonane przez satelitę Landsat zostały także wykorzystane do badania zniszczeń lasów w Sudetach. Kilka stopni uszkodzeń drzewostanów świerkowych rozpoznano na podstawie tych zdjęć. Były one także wykorzystane do badania wpływu kopalni odkrywkowej węgla brunatnego powstanie leja depresyjnego jak również do określenia rozwoju zabudowy w Warszawie w ciągu ostatnich 80 lat.

Słowa kluczowe: kartowanie użytkowania ziemi, zmiany użytkowania ziemi, projekty CLC, ocena zniszczeń lasów, lej depresyjny