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CORINE Land Cover 2012– 4th CLC inventory completed in Poland

Agata Hościło
Institute of Geodesy and Cartography, 27 Modzelewskiego St., 02-679, Warsaw, Poland
Tel.: +48 22 3291976, Fax: +48 22 3291950, E-mail: agata.hoscilo@igik.edu.pl

Monika Tomaszewska
Institute of Geodesy and Cartography, 27 Modzelewskiego St., 02-679, Warsaw, Poland
Tel.: +48 22 3291978, Fax: +48 22 3291950, E-mail: monika.tomaszewska @igik.edu.pl

Abstract: The first European and Polish CORINE Land Cover map was created for the reference year 1990, then subsequently for 2000 and 2006. The long heritage of CLC inventories allows researchers to perform a long-term analysis of land cover dynamics at national and European scale. This article focuses on the results of the CLC2012 inventory and analysis of land cover changes which occurred between 2006 and 2012. The 4th CORINE Land Cover inventory was carried out by the Institute of Geodesy and Cartography (IGiK). After an effort of one and a half year of mapping using visual satellite image interpretation, the CORINE Land Cover 2012 and land cover changes 2006-2012 for the entire country have been completed. The total area of land cover changes between 2006 and 2012 reached about 1% of the territory of Poland (309 741 ha). More than 75% of land cover changes occurred in forest and semi-natural class, almost 19% in the artificial class, 5% in agriculture land and the remaining 1% in wetlands and water bodies.

Keywords: CORINE, land cover, land cover change, Poland, managing natural resources

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1. Introduction

Information on the dynamics of land cover is essential to better understand and manage natural resources and monitor environmental changes at local, regional and global scale. There are several international programmes emphasizing the increased need for better land cover and land cover change information at different scale, for example the International Geosphere Biosphere Programme (IGBP), the NASA Land Cover and Land Use Change (LCLUC) program, Global Observations of Forest and Land Cover Dynamics (GOFC-GOLD), the Group on Earth Observation (GEO), and the European Copernicus GIO-Land Monitoring programme (Giri, 2012). The main objective of the European Copernicus programme (formerly the Global Monitoring for Environment and Security (GMES)) land monitoring service (GIO-Land) is to provide up-to-date land cover information to users in the field of environmental and other terrestrial applications at national and European level. There are four GIO-Land components: 1) pan-European land cover, land cover change, and land cover characteristics, 2) production of biophysical variables at the global scale, 3) a 'local' component providing high resolution information on specific areas of interest, and 4) access to a reference database built on the architecture of INSPIRE, which is useful for several Copernicus services (EEA Briefing, 2012).

The European Environment Agency (EEA) is responsible for the pan-European land cover component, which comprises 1) continuity of the CORINE land cover (CLC) inventory, 2) production of high resolution layers (HRL) with specific land cover characteristics, and 3) support for the harmonization efforts aiming to improve synergy between pan-European and national land cover activities. The European Union CORINE (Coordination of Information on the Environment) land cover inventory programme represents a comprehensive approach to provide an ongoing inventory for the

European Union. In total 39 countries (27 EU countries, 5 additional EEA member states and 7 collaborating countries) have signed up to the GIO-Land component. Poland had signed up to the verification and enhancement of the 5 HR Layers, mapping of CLC-Change$_{2006\text{-}2012}$, production of CLC2012 database, as well as dissemination activities. All these activities were carried out by the Institute of Geodesy and Cartography (IGiK) in Warsaw, which acts as one of the National Reference Centres (NRC) in Poland, nominated by the Chief Inspectorate of Environmental Protection (GIOŚ), which acts as the National Focal Point (NFP) for collaboration with the EEA in the framework of the European Environment Information and Observation (EIONET).

IGiK has participated in the production of all previous CORINE Land Cover inventories: CLC1990, CLC2000, CLC2006, as well as CLC-Change$_{1990\text{-}2000}$, and CLC-Change$_{2000\text{-}2006}$ (Ciołkosz and Bielecka, 2005; Bielecka and Ciołkosz, 2009). In 2008, IGiK also carried out the verification of the soil sealing layer for the territory of Poland. The 4th CLC2012 inventory comprises a correction of the CLC2006 database, mapping land cover changes that occurred between 2006 and 2012 and production of CLC2012. Correction of CLC2006 was requested and applied to avoid errors of propagation from CLC2006 to CLC2012. Occurrence of interpretation mistakes is an inherent characteristic of visual interpretation of remotely sensed data, coming not necessarily from negligence, but insufficient information available at the time of the inventories. During updating, by examining newly available satellite images or ancillary data usually a number of thematic mistakes are discovered in the database and need to be updated (Büttner et al., 2014).

2. Data and Methods

The CORINE Land Cover (CLC) inventory is a vector dataset with a scale of 1:100 000, a minimum cartographic unit of 25 ha and a geometric accuracy better than 100 m. The CLC nomenclature is a 3rd level hierarchical classification system and has 5 classes at the 1st level, 15 classes at the 2nd level and 44 classes at the 3rd most detailed level. A minimum cartographic unit for the CORINE Land Cover Change map is set to 5 ha. Mapping of CLC-Change$_{2006\text{-}2012}$ is carried out by applying the 'change mapping first' approach. Firstly, the necessary thematic/geometric correction of CLC2006 data was performed followed by the visual interpretation of changes occurring between 2006 and 2012. These two steps were carried out consecutively and correction of CLC2006 data preceded delineation of change polygons. The changes were interpreted directly, by comparison of reference images. For the reference year 2006, a set of multi-temporal images delivered by SPOT4 and IRS satellites in 2006 +/–1 year were used. In total, 141 satellite images were acquired over the territory of Poland, of which 91 images were delivered by SPOT and 50 by IRS satellites. For the year 2012, images from RapidEye and IRS satellites acquired in 2011 and 2012 were applied. Images from 2012 comprise 1461 scenes over Poland, of which 1163 scenes were obtained by RapidEye and 298 scenes by IRS satellites. Multi-temporal images (each location was captured by at least two satellite images) were useful in separating some land cover classes, e.g. arable land and pastures. The interpretation was supported by ancillary data such as national orthophotomaps, BDOT10K (available in the WMS format), Google Earth, and city maps.

Visual comparison of satellite images from 2006 with overlaid CLC2006 vector data (border-matched database delivered by EEA) and satellite images from 2012 was followed by the direct delineation of changes with a minimal area of 5 ha and minimum width of 100 m for the standard 44 CORINE Land Cover classes at level 3 (Büttner and Kosztra, 2011). The quality control was performed internally by experts in house and externally by the team from the EEA. The main goal of the external verification was to guarantee harmonized European CLC2012 and CLC-Change$_{2006\text{-}2012}$ databases. During two external verifications altogether about 21% of the territory of Poland has been checked. Verification was carried out by visual detailed checking of corrected CLC2006 and CLC-Changes$_{2006\text{-}2012}$ layers. Finally, the corrected CLC2006 and CLC-Change$_{2006\text{-}2012}$ were used to generate the CLC2012 database. The minimum mapping unit in CLC2012 is greater than 25 ha; polygons below this threshold were automatically generalized and assigned to neighbouring classes following the priority table for generalizing CLC classes (Pataki,

2008; Büttner et al., 2014). Simultaneously with the interpretation in working units, the metadata were generated according to the INSPIRE specifications.

Revision of CLC2006 and interpretation of CLC-Change$_{2006\text{-}2012}$ was done using the InterChange software, designed for the CORINE inventory. InterChange is a part of the CLC2012 Support Package that is a set of standalone applications developed with the Embarcadero Delphi XE2 and TatukGIS Developer Kernel. The CLC2012 Support Package has been developed by the Remote Sensing Centre of the Hungarian Institute of Geodesy, Cartography and Remote Sensing (FÖMI), in order to help the implementation of the European CLC2012 project. It is a significantly modified and improved version of the CLC2000 and CLC2006 Support Package.

3. Results and discussion

CLC-Change 2006-2012

The total area of land cover changes that occurred between 2006 and 2012 reached about 0.99% of Poland (309 741 ha). The average size of the changed parcel is equal 19.3 ha. The spatial distribution of CLC-Change$_{2006\text{-}2012}$ is shown in Figure 1.

Changes are not equally distributed across the country. The highest concentration of changes is located in the western part of Poland, which is predominantly associated with the forest management practices. Table 1 presents the total area of CLC-Change$_{2006\text{-}2012}$ in hectares at the 1st level of CLC classes. The forest and semi-natural class followed by artificial and agriculture classes were the most dynamic land cover types. All classes except agriculture were characterized by positive net change in land cover over the last six years (Table 1).

Table 1. Total area of CLC-Change$_{2006\text{-}2012}$ in ha aggregated to the 1st level of CLC classes

Class 1st level	Class name	Losses area [ha]	Gains area [ha]	Gains in [%]	Net change [ha]
1	Artificial	8 659	57 887	18.7	49 229
2	Agriculture	95 395	15 468	5.0	–79 927
3	Forest and semi natural	205 538	233 517	75.4	27 978
4	Wetlands	52	102	0.03	49
5	Water bodies	97	2 767	0.9	2 670
	TOTAL	309 741	309 741		

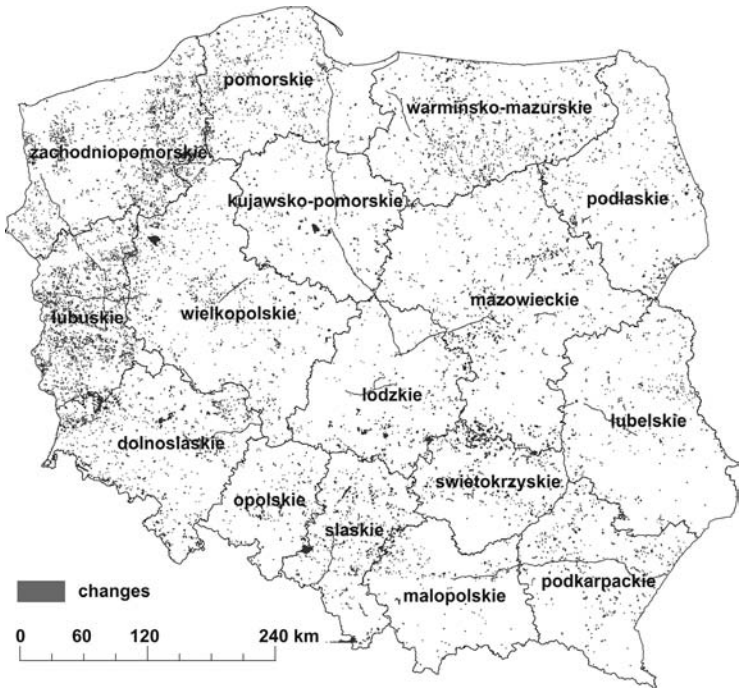

Fig. 1. Spatial distribution of CLC-Change$_{2006\text{-}2012}$; solid lines indicate administrative divisions

Table 2 shows that arable land (class 211) has been predominantly converted into construction sites (class 133), mineral extraction sites (class 131), built-up areas (class 112), newly built commercial units (class 121) and road infrastructure, e.g. highways (class 122), which are clearly visible in Figure 1 as long continous features. Analysis of net change in land cover confirmed that arable land experienced the heaviest losses over the period 2006-2012 (Fig. 2). A large part of arable land has also been converted into woodlands (class 324) and orchards (class 222). It is of interest that there was an increase observed in the area of fruit tree plantations, which presumably was related to the European Union subsidies to plantations and the growing popularity of energy plants as a new source of energy from biofuels. Reduction in grassland and pasture (class 231) was caused by natural expansion of woody vegetation and shrub encroachment (class 324), construction of new roads, and conversion towards arable land. Forests were the largest land cover class subject to changes over the period 2006-2012. Reduction in forested areas was partly associated with the construction of new roads and the enlargement of mineral extraction sites, as well as partly with the forest management practice (clear cuts/logging). By contrast, the large area of transitional woodland-shrub (class 324) has been converted into forest (98 456 ha). It has to be highlighted that class 324 contains land that has been converted from agricultural to forest plantations (afforestation and reforestation), land subject to natural woody succession as well as forest clear-cuts greater than 5 ha. Large areas of arable land (12 649 ha) and pastures (14 493 ha) have been afforested or are subject to natural woody succession. This could be an effect of the National Programme for Afforestation and Reforestation, which aims to increase the overall forest area in Poland to 30% by 2020 and to 33% in 2050 (Krajowy Program Zwiększania Lesistości, 2003). An analysis of the spatial distribution of newly planted forests indicated that most of the afforestation activities took place in the northern and south-western parts of the country. Overall, the transitional woodland-shrub area was subject to the largest increment and positive net change over the period 2006–2012 (Fig. 2).

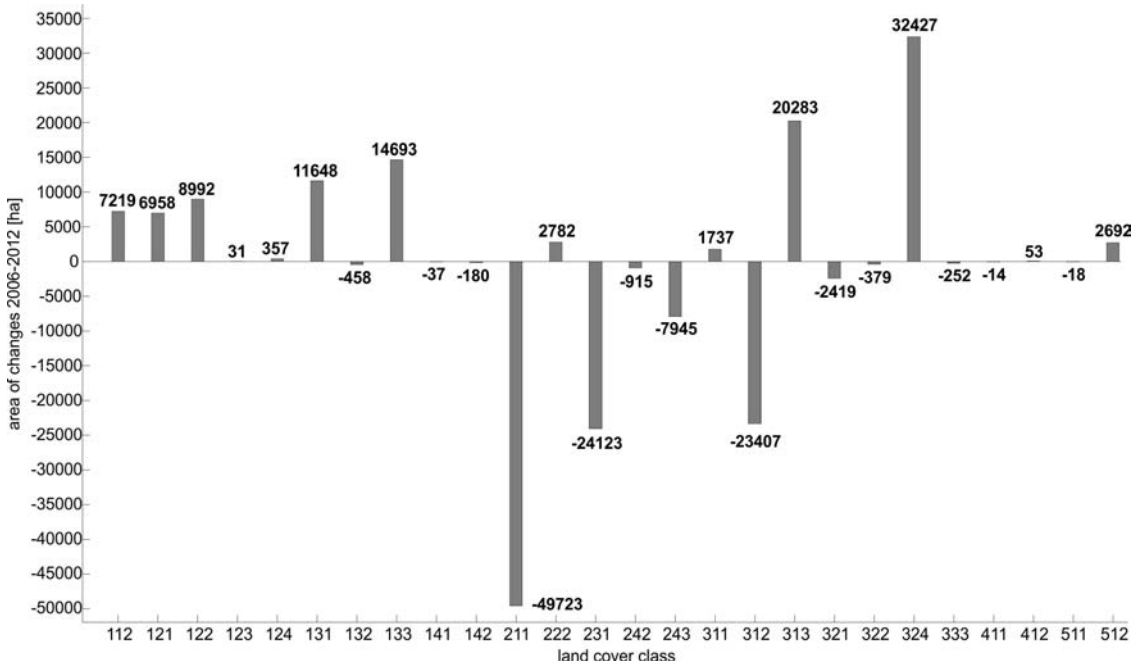

Fig. 2. Net change in land cover 2006-2012 in hectares for each of the land cover classes (CLC level 3)

Table 2. Total area of all particular changes in hectares [ha] presented as matrix table

		2006																							
		112	121	124	131	132	133	141	142	211	222	231	242	243	311	312	313	321	322	324	333	411	511	512	TOTAL
2012	112			6	9		1 672	13	41	3 795	25	902	862	240	6	28	57	16		76					7 749
	121	62		19	20		1 255	7	46	3 531	20	1 420	97	323	18	164	31			60					7 075
	122	115	38			28	2 428		89	3 644	48	647	115	249	147	514	459			458			12		8 992
	123						23													8					31
	124						66		19	100		32	15	7	9	64	70			33					415
	131	10	12				71			7 527		2 057	44	748	194	891	192			1 040		22		19	12 827
	132								10	67		10		41	13	13				23					176
	133	332	30					17	110	13 899	38	2 192	698	563	294	1 535	515			225		8			20 455
	142	12					40			48		41				5	6								151
	211				92		41		15		1 256	2 596	41	161	13	36	7			1 172					5 430
	222									4 105		121													4 226
	231		37		132	33	37			715	30				55	36		18		414					1 508
	242						69			711		154		47						18					998
	243									3 237		69													3 306
	311									13		5		54			7			6 488					6 567
	312									74		20		52			25			59 739					59 909
	313									22		33		71		8				32 229					32 363
	321															9	67				39				114
	322																				59				59
	324			33	556	573				12 649	21	14 493	28	8 524	4 001	79 998	10538	2440	438		174			18	134 486
	333																	19							19
	411																							38	38
	412														53										53
	512				371		61			1 015	6	841	12	170	26	16	105	39		77		22	6		2 767
	TOTAL	530	118	59	1 180	634	5 762	37	331	55 153	1 444	25 631	1 913	11 251	4 830	83 316	12 080	2 532	438	102 060	271	52	18	75	

The area occupied by roads, rail networks and associated land (class 122) increased by 9000 ha (Fig. 2); however, it should be noticed that transportation units seldom exceed the mapping threshold of width >100 m and are often included in other classes. Some of the roads were under construction in 2012 and thus were classified as construction sites (class 133). According to the Central Statistical Office, the total length of highways and express roads increased by 56% and 32% between 2006 and 2012, respectively. The length of highways in 2006 was equal to 663 km and in 2012 to 1183 km (GUS, 2011, 2013). It is of interest that the area of mineral sites (class 131) has increased by 11644 ha as a result of conversion from agricultural land, forests and woodlands. The land cover change inventory confirmed the continous urban growth concentrated on the outskirts of larger cities. The discontinous urban areas (class 112) increased by more than 7700 ha and decreased by 530 ha over the investigation period (Table 2).

Table 3 presents the CORINE Land Cover legend divided into three levels.

CORINE Land Cover 2012 inventory

The CLC2012 database for Poland is characterized by 31 out of 44 classes of CLC nomenclature (3rd level). Spatial distribution of CLC classes is shown in Figure 3.

Agricultural land is the dominant land cover type in Poland – it occupies almost 60% of the country (Table 4). Most of the agricultural lands are shared between arable land, pastures and heterogeneous agricultural areas (classes 242 and 243). Of the total agricultural area, arable land occupied 43.5%, pastures 8.8%, heterogeneous complex classes 6.7% and permanent crops 0.5% of the country (Table 5). Arable land is uniformly spread throughout the entire country and forms large polygons (average polygon size 656 ha). By contrast polygons of pastures are much smaller in size (average polygon size 157 ha). Compared to statistical data provided by the Central Statistical Office of Poland, there might be a slight underestimation of pastures due to the fact that a large number of Polish permanent meadows and pastures are smaller than 25 ha. The mosaic of small parcels (< 25 ha) of various crops, pastures, grasslands and scattered houses are mapped according to the CLC nomenclature as a complex cultivated pattern (class 242) and land occupied by agriculture with a significant area of natural vegetation (class 243). These two complex classes cover 2.7% and 4% of the country, respectively, and reflect a typical rural landscape in many locations, in particular in the mountain areas.

The second dominant land cover type in Poland is forest and semi-natural areas, around 33% of the country (forest itself occupies ~30.8%). Of the total area of forest, coniferous forest occupies the largest area (18%), mixed forest (7.9%) and broad-leaved forest (4.9% of the entire country). Forests are not equally distributed. The forested areas are mainly located in north-eastern, north-western and south-eastern regions of Poland (Fig. 3). Areas of natural development of forest formation, young forest plantations, as well as forest clear-cuts and various degenerative stages of forest were classified as transitional woodlands/shrubs (class 324) and occupied 1.7% of the entire country (53 0361 ha). Natural grasslands cover around 0.1% of Poland (32453 ha, 190 polygons). This class contains high mountain meadows in southern Poland. Heathland communities in Poland (class 322) include only *Pinus mugo* species located above the upper tree limit in the alpine zone or in the bottom of large depressions with temperature inversion. They can be found in the Tatra and Sudety Mountains with poor and rough soils. This type of vegetation occupies less than 0.01% of the total territory (4117 ha, 23 polygons).

The third dominant land cover class is artificial land, which occupies 5.7% of the country. This class is made of urban fabric (4.7%), industrial, commercial and transport units (0.5%), mineral, dump, and construction sites (0.3%) and artificial, non-agricultural vegetated areas (0.2%). Of the urban fabric, discontinuous urban fabric constitutes more than 4.6% of the country (1 448 713 ha) and continuous urban fabric occupies only 0.03% of the country (7890 ha). Continuous urban fabric was delineated in 67 polygons located in the centres of the cities above 100 000 inhabitants. More than 39% of the population lives in villages, which have been included in heterogeneous agricultural classes (242 and 243) due to the dispersed pattern of rural settlements. Industrial and commercial units cover almost 0.4% (12 1891 ha), roads and

Table 3. CORINE Land Cover legend, source: http://www.eea.europa.eu/data-and-maps/figures/corine-land-cover-2006-by-country/legend

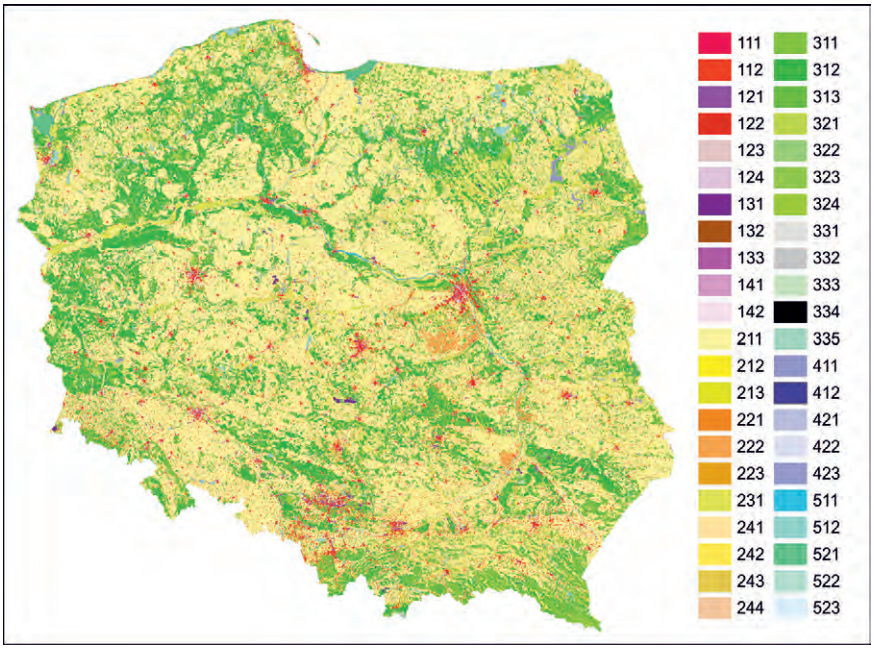

Fig. 3. CORINE Land Cover 2012 at the 3rd level for Poland (CLC legend see Table 3)

the rail network 0.08% (25 122 ha), and airports 0.07% (20 541 ha). The largest industrial areas (in total 1570 polygons, with a maximum polygon size of 1395 ha) and their higher concentration are characteristic for southern and western Poland (e.g. Upper and Lower Silesia, Great Poland). Transportation units seldom exceed the mapping threshold of width > 100 m and are often included in other classes. Only large railway stations located in cities or near industrial areas and highways are mapped. Mineral extraction sites occupy 0.16% of the country (49 365 ha). In total 623 mineral sites and 105 dump sites >25 ha were delineated. Sport and leisure facilities cover an area of 58 809 ha (in total 1036 polygons), whereas green urban areas 17 050 ha, in total 282 polygons.

The remaining 2.1% of the country is occupied by wetlands (0.4%) and water bodies (1.7%). Wetlands include non-forested areas covered by specific low ligneous or herbaceous vegetation in Poland and are divided into two classes: inland marshes and peatbogs. Inland marshes include treeless fens, transitional bogs without peat deposits or on shallow peat (less than 30 cm thick) (CORINE nomenclature). Peatbogs consist mainly of decomposed moss and vegetation matter, and may or may not be exploited. In Poland inland marshes cover around 101 871 ha (0.33% of territory, 874 polygons), whereas peatbogs 9112 ha (95 polygons greater than 25 ha). The largest wetlands are located in the northeast part of the country – the Biebrza Valley National Park.

Water bodies consist of inland and marine water. The inland water class consists of rivers, canals greater than 100 m in width (smaller rivers and canals are included in neighbouring classes) and natural and artificial water reservoirs, e.g. lakes and fish ponds. The water reservoirs (natural and artificial) cover an area of 3293 ha (1.3% of the country).

Table 4. Area of CLC2012 classes aggregated at the 1st level

Class 1st level	Class name	Area [ha]	Percentage of area [%]
1	artificial	1 781 826	5.7
2	agriculture	18 608 530	59.6
3	forest and semi-natural	10 202 896	32.6
4	wetlands	110 989	0.4
5	waters	542 910	1.7

Table 5. Area of CLC2012 classes aggregated at the 2nd level

Class 1st level	Class 2nd level	Class name	Area [ha]	Percentage of area [%]
Artificial	11	urban fabric	14 566 048	4.7
	12	industrial, commercial and transport units	170 151	0.5
	13	mineral, dump, and construction sites	79 212	0.3
	14	artificial, non-agricultural vegetated areas	75 859	0.2
Agriculture	21	arable land	13 596 353	43.5
	22	permanent crops	162 441	0.5
	23	pastures	2 743 997	8.8
	24	heterogeneous agricultural areas	2 105 738	6.7
Forest	31	forests	9 620 566	30.8
	32	scrub and/or herbaceous vegetation	566 932	1.8
	33	open spaces with little or no vegetation	15 398	0.05
Wetlands	41	inland wetlands	110 989	0.4
Waters	51	inland waters	467 872	1.5
	52	marine waters	75 038	0.2

4. Conclusions

The CLC programme has provided consistent, systematic and up-to-date information on land cover and land cover changes at national and European level since 1990. In Poland, the CLC databases have been widely used by decision-makers implementing environmental policies, scientists, and students. The results of the 4th CLC inventory revealed that the total area of land cover changes between 2006 and 2012 reached almost 1% of the country. This was about two times more than the area of changes reported in Poland in 2000–2006. The changes occurred mainly in forest, artificial and agricultural areas. The reduction in agricultural land and forest was associated with the construction of roads and highways. The area of agricultural land decreased also owing to afforestation activities and natural woody succession, which caused a significant increase in the area of transitional woodland-shrub.

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Wyniki czwartej edycji programu CORINE Land Cover 2012 dla Polski

Agata Hościło
Instytut Geodezji i Kartografii, ul. Modzelewskiego 27, PL 02-679 Warszawa
Tel.: +48 22 3291976, Fax: +48 22 3291950, E-mail: agata.hoscilo@igik.edu.pl

Monika Tomaszewska
Instytut Geodezji i Kartografii, ul. Modzelewskiego 27, PL 02-679 Warszawa
Tel.: +48 22 3291978, Fax: +48 22 3291950, E-mail: monika.tomaszewska @igik.edu.pl
Agata Hościło and Monika Tomaszewska

Streszczenie: Pierwsza mapa i baza danych CORINE Land Cover zawierająca informacje o pokryciu terenu została opracowana dla krajów Europy Zachodniej i Środkowej, w tym Polski, dla roku 1990, następnie dla lat 2000, 2006 i 2012. Porównanie baz danych pozwala na analizę dynamiki pokrycia terenu w okresie ostatnich 22 lat. W niniejszym artykule przedstawiono wyniki czwartej inwentaryzacji pokrycia terenu – CORINE 2012 dla Polski. Projekt CORINE Land Cover 2012 był realizowany przez Instytut Geodezji i Kartografii (IGiK) w Warszawie. W wyniku trwającej prawie półtora roku wizualnej interpretacji zobrazowań satelitarnych została opracowana baza danych, która obejmowała zmiany pokrycia terenu w latach 2006–2012 oraz baza danych pokrycia terenu CLC2012. Całkowita powierzchnia zmian pokrycia terenu w latach 2006–2012 stanowiła niemal 1% powierzchni kraju (309 741 ha). Ponad 75% wszystkich zmian pokrycia terenu miało miejsce na obszarach leśnych i w ekosystemach seminaturalnych, 19% na terenach antropogenicznych, 5% na obszarach rolnych i pozostałe 1% objęło obszary podmokłe i wodne.

Słowa kluczowe: CORINE, pokrycie terenu, zmiany pokrycia terenu, Polska, zarządzanie zasobami naturalnymi

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