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LAND COVER STRUCTURE IN POLAND AND ITS CHANGES IN THE LAST DECADE OF 20TH CENTURY

STRUKTURA POKRYCIA TERENU W POLSCE I JEJ ZMIANY W OSTATNIEJ DEKADZIE XX WIEKU

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Introduction

The CORINE (**C**o-**OR**dination of **IN**formation on the **E**nvironment) Programme, set up in 1985, is a geographical information system to gather, co-ordinate and provide European policy makers with timely and relevant information on the state of the environment and natural resources in Europe. Since 1991, when European Environment Agency (EEA) and European Environment Information and Observation Network (EIONET) were set up by the decision of European Council, the responsibility of the CORINE databases and their up-dates has been relayed to the EEA.

The objectives of CORINE Programme were to compile environmental data with regards to certain priority topics, to create corresponding data sets and to ensure that information is consistent and data is comparable on pan-European level. Regarding land cover (LC), the major task was to produce land cover inventory and to compile digital data set of qualitative and quantitative land cover data. The satellite images taken by Landsat ETM were used as basic source of data on land cover.

CORINE methodology became a standard for land cover mapping and the CORINE data set is considered as a basic tool for spatial analysis and integrated environment assessment in all EU countries. The CORINE Land Cover (CLC) pan-European geographical coverage and its unique nomenclature allow to use it as a key reference data for spatial and territorial analysis at different territorial levels.

According to EEA obligation the CORINE databases should be regularly updated. To reach this goal EEA and DG Joint Research Centre (JRC) launched the IMAGE2000 and CLC2000

(I&CLC2000) project. The aim of this project was to produce the CLC database for the year 2000 and to detect LC changes in Europe, which occurred during the last decade (1990-2000). The inventory of LC changes is necessary for the analysis of reasons and consequences of natural and artificial processes, impact assessment, identification of trends, maintenance of ecological balance and its consideration in the decision-making processes. According to the INSPIRE assumptions CORINE Land Cover databases will become one of the crucial reference datasets for common environmental and economic policy of the European Union.

In Poland both CORINE Land Cover projects (CLC 90 and CLC 2000) were carried out at the Institute of Geodesy and Cartography. In 2000 all activities connected with the project were done under the umbrella of Chief Inspectorate for Environmental Protection, which was designated by the Ministry of Environment as the National Focal Point for the EEA and the National Authority in charge of the CLC2000 project in Poland.

Methodology applied

Initially in the CORINE Land Cover (CLC) Programme a visual interpretation of satellite image printouts was used as a method for land cover data collection. This proved to be the most feasible approach in the mid-eighties, the starting period of the Programme. Although this method assumed only limited use of image processing and GIS software but it has proven its advantage and its usefulness.

The CLC nomenclature, described in the CORINE Land Cover Technical Guide (CEC, 1994) and related Addendum (EEA, 2000), is a physical and physiognomic land cover nomenclature relevant for environment, nature and landscape protection. It distinguishes land cover classes grouped in a 3-level hierarchy. The classes of the first level are: artificial surface, agricultural areas, forests and semi-natural data, wetlands and water bodies. In a second level there are 15 land cover classes and in third one – 44. Each country can add supplementary 4th and 5th hierarchical levels, according to its special conditions and priorities, but the first three levels are identical for all countries. The nomenclature is strongly related to the process of image interpretation, the working and publishing scale and the smallest cartographic unit. It was assumed that the smallest cartographic unit is 25 ha with the minimum width of 100 m; mapping scale is 1:100 000; spatial accuracy better than 100 m and thematic accuracy at least 85%.

The mapping scale of 1:100 000 has been chosen bearing in mind pan-European geographical coverage of database and the fact that it is a basic topographical mapping scale in most of the European countries and it is used in different environmental projects (e.g. coastal erosion). This scale enables to do updating of the databases relatively easily on regular basis.

Heterogeneity of land cover classes, the limits of which are determined by physiognomic characteristics, does not allow to use automated computer classification methods neither for the first inventory nor for its updating. The methodology consists of the computer-assisted visual interpretation of satellite images, with the simultaneous application of ancillary data. It is based on the analysis of recognition feature of objects – colour, structure, texture, pattern, associations, by mean of which the objects of interest are represented on image.

The change detection process and the mapping of the land cover changes were carried out by means of image comparison, using computer assisted image interpretation tools. The methodology was developed by the JRC/SAI in collaboration with the ETC/LC and is published

by JRC-EEA (Perdigão *et al.*, 1997). The image processing software was mainly used to facilitate distinguishing particular land cover classes by simultaneous analysis of multitemporal images, spectral enhancement of different spectral bands as well as mutliband enhancement (principal component analysis) and image algebra (vegetation index). Checking the interpretation results and final verification of the database was done by overlaying the satellite data on the land cover vector data.

The process of land cover updating was done in three main stages. The first one was revision and correction of the results of 1990 CORINE Land Cover inventory (CLC90), the second one – land cover change detection (CLC-Change) and the third one – creation of land cover database for the year 2000 (CLC2000).

CLC90 revision. CLC90 data might have two basic types of errors: geometric and thematic. The revision of CLC90 database started from comparing geometry of satellite data used for collection of land cover data (IMAGE90) and 2000 (IMAGE2000). If a systematic deviation larger than 50 m was observed, the IMAGE90 data was corrected in order to have similar geometry like the IMAGE2000. The last mentioned images have positional accuracy better that 25 m. If the inaccuracy of the delineation of polygons was larger than 100 m the geometric errors were corrected. In this stage of work all polygons smaller than 25 ha were removed. Next thematic errors were detected and removed and the topology of the coverage was checked and topological errors were corrected.

Change detection. The single changes were introduced if they were in compliance with CLC standards. The size of changes has to be always bigger than 5 ha. In case of a completely new polygon (not present in CLC90) the CLC mapping criteria have to be met: minimum 25 ha area and minimum 100 m width. This means that not all detected (visible) changes were interpreted in order to produce homogeneous results for the country and Europe. The land cover change database is an "island" type as it stores only polygons were land cover class was changed.

CLC2000 database. The CLC2000 database is the output derived from the revised CLC90 database and the CLC change database. The CLC2000 database is created as the union of CLC90 and CLC change polygon layers by the GIS software analyzing tools. This approach was highly recommended to ensure consistency between the three databases.

$$CLC\ 2000 = CLC90_{rev} + CLC\_Changes$$

All steps of CLC updating were divided into basic interpretation units corresponding to the map sheets of the Topographic Map at the scale 1:100 000. After completing the interpretation of satellite images the working units were merged together to provide the topologically correct seamless databases for the entire country. A set of programs in ARC/INFO environment has been used to facilitate merging procedure and to control such technical requirements as: uniqueness of ID, label correctness, node errors, size of polygons and code of neighbouring polygons.

CORINE LAND COVER inventory in Poland

Source data. The complete coverage of Poland by satellite images required 28 Landat scenes. For CLC inventory (both in 90. and 2000) most of the scenes were acquired within the vegetation period from May to September. Due to unfavorable weather conditions only part of

Poland was covered by satellite images in 1990. To complete the coverage of the country 4 images taken in 1989, next 4 images taken in 1991, eight images taken in 1992 and one image taken in 1993 have to be chosen. The images used for updating of land cover data base were mostly taken in 2000, only 4 images were taken in 1999 and 5 in 2001.

As it is seen in the figure 1 there is significant overlap between the satellite images covering Poland. Due to this overlap the image-interpreters had at their disposal the images taken from adjustment orbits. This fact helps to improve the quality of the interpretation work and demands for the ancillary data and field checking decreased significantly.

Structure of CORINE Land Cover. Land cover in Poland (Fig. 2) is characterised by 31 out of 44 classes of the CORINE Land Cover nomenclature. In both CLC90 and CLC2000 databases similar land cover classes are represented. The analysis of land cover database revealed that arable land dominates in Poland. Some 45% of the total area of the country is occupied by this land cover class. Coniferous forest occupies 18%, meadows and pastures – 9% and complex cultivation patterns – 11% of the area of the country (Fig. 3). Almost 62% of Poland is classified as agricultural land. Land classified as artificial areas, according to the CORINE Land Cover nomenclature, occupied nearly 5%, and semi-natural and forest areas cover about 30% of national territory. The remaining 3% of Poland territory was classified as wetlands or water (Fig. 4). Area of CORINE land cover classes and its change between 1992 and 2000 is shown in table 1.

The small share of artificial surface (5%) shows that a big part of 40 million Polish population lives outside urban fabric areas. About 30% of population lives in villages, which have been included to complex agricultural classes (2.4.2 and 2.4.3) due to dispersed pattern of rural settlements. Continuous urban fabric occurred only in 77 areas in centre of the cities of above 100 000 inhabitants. Industrial areas occupies almost 10% of artificial surface which is merely 0,3% of total territory of Poland. The biggest industrial areas and their higher concentration are characteristic for Southern and Western Poland (e.g. Upper and Lowe Silesia, Great Poland). Transportation units seldom exceed the mapping threshold and are often included into other classes. Only big railway stations located in cities or near industrial areas are mapped.

According to the CLC nomenclature the agricultural area are divided into 11 classes. Only 5 of them occurred in Poland. Most of agricultural lands are shared between arable land, pastures and two complex classes (2.4.2 and 2.4.3). Arable land is uniformly spread throughout the whole country. The share of fruit berry plantation in agriculture area is small, however some big tree plantations in Central and Southern Poland are clearly visible on the map. Areas classified as pastures do not form large polygons and have the same distribution pattern as arable lands. Complex cultivated pattern (2.4.2) represents small parcels of diverse annual crops, pasture and permanent crops each of them smaller than 25 ha in size. This land cover class occupies approximately 10% of total area of Poland and 16,5% of agricultural areas. It is logical that this class is located in the vicinity of arable lands. The mostly evenly distributed is the class 2.4.3, which spreads everywhere in the provinces and in extensively cultivated areas. This class demonstrates the mosaic nature of Polish landscapes. These two complex classes reflect also the spread settlements pattern, which is very typical for Polish rural landscape.

The forests occupy 29% of the total area of Poland. Coniferous forests (17.6%) are widespread throughout the country. The predominance of coniferous forests is especially visible on the lowlands, although it is also the case in the highland and upper part of the mountains. The mixed forests (7,1%) occupy the territory of 22 358 km^2 spread over the whole country. Deciduous forests occupy more than 15% of forested areas. They exist in larger complex near

Table 1. CORINE Land Cover classes in Poland

CORINE Land Cover class	Area in 2000 [km²]	Area in 1990 [km²]	% of total territory	Area changed [km²]	% of category changed
Artificial surfaces, total					
1.1.1. Continuous urban fabric	82,73	82,73	0,026	0,00	0,00
1.1.2. Discontinuous urban fabric	7854,85	7771,39	2,512	83,47	1,06
1.2.1. Industrial or commercial units	1021,55	992,67	0,327	28,88	2,83
1.2.2. Roads and rail networks and associated land	119,26	113,82	0,038	5,44	4,56
1.2.3. Port areas	28,94	28,94	0,009	0,00	0,00
1.2.4. Airports	217,25	216,82	0,069	0,43	0,20
1.3.1. Mineral extraction sites	372,00	314,93	0,088	57,07	15,34
1.3.2. Dump sites	127,48	142,24	0,105	-14,76	11,58
1.3.3. Construction sites	54,20	65,31	0,088	-11,10	20,48
1.4.1. Green urban areas	273,96	275,57	0,088	-1,61	0,59
1.4.2. Sport and leisure facilities	329,03	328,47	0,105	0,56	0,17
Agricultural areas, total					
2.1.1. Non-irrigated arable land	138350,92	138509,87	44,246	-158,95	0,11
2.2.2. Fruit trees and berry plantations	899,01	904,40	0,288	-5,39	0,60
2.3.1. Pastures	27840,81	27995,82	8,904	-155,01	0,56
2.4.2. Complex cultivation pattern	17448,12	17454,84	5,580	-6,72	0,04
2.4.3. Land principally occupied by agriculture, with significant areas of natural vegetation	15431,83	15416,78	4,935	15,06	0,10
Forest and semi-natural areas, total					
3.1.1. Broad-leaved forest	15088,90	15075,46	4,826	13,44	0,09
3.1.2. Coniferous forest	55118,46	55508,99	17,627	-390,53	0,71
3.1.3. Mixed forest	22357,56	22312,10	7,150	45,46	0,20
3.2.1. Natural grassland	523,22	500,47	4,826	22,75	4,35
3.2.2. Moors and heathland	45,36	43,52	17,627	1,84	4,06
3.2.4. Transitional woodland/shrub	2426,07	1911,35	7,150	514,72	21,22
3.3.1. Beaches, dunes, and sand plains	65,58	69,81	0,021	-4,22	6,44
3.3.2. Bare rock	49,01	49,01	0,016	0,00	0,00
3.3.3. Sparsely vegetated areas	211,30	237,78	0,068	-26,48	12,53
3.3.4. Burnt areas	0,29	22,19	0,000	-21,90	7535,49
Wetlands, total					
4.1.1. Inland marshes	1014,81	1097,51	0,325	-82,71	8,15
4.1.2. Open peat bog	90,65	92,55	0,029	-1,90	2,09
Water, total					
5.1.1. Water courses	780,43	780,25	0,250	0,18	0,02
5.1.2. Water bodies	4461,55	4369,60	1,427	91,95	2,06
Total database	312756,23	312756,23	100	2600,07	0,83

Szczecin (Puszcza Bukowa), in Puszcza Knyszyńska and Białowieska (Eastern part of Poland) and in the Carpathian Mountains.

Natural grasslands (3.2.1) embrace less than 0,2% of Poland territory. This class forms the high mountain meadows. It is distributed mainly in the south of Poland. Heathland communities in Poland (3.2.2) 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 0.1% of total class territory. LC classes with little vegetation form all together less than 1% of territory.

The CLC nomenclature considers wetlands as a non-forested areas of low lying land flooded by fresh water, covered by specific low ligneous, or herbaceous vegetation. The biggest wetlands of Poland are located in the North-East part of country.

Rivers seldom exceed the mapping threshold and are often included into neighbouring classes. Only few big rivers are mapped and included in the CORINE database.

Changes in Land Cover between 1992–2000

Between 1992 and 2000 some 0.9% of Poland area had changed its land cover. The spatial distribution of area that had changed its land cover is shown in fig. 6. The most typical land cover change was a conversion from forest into category described in CORINE Land Cover nomenclature as a forest in transition. It evidently reflects the increase of forest cutting (1% of Polish forests) for internal needs and export. The invert process took also place, some 5% of clear cuts in 90. now became a forest.

Furthermore, a considerable part of land cover changes concern conversion from arable land into pastures or fallow land, and the conversion of arable land into artificial areas (urban, industrial, infrastructure). Afforestation of agricultural areas according to national plans of protection of the environment was one of the most important changes in Poland. The decrease of agricultural areas is quite small, only 1,3% of total agriculture was lost.

The prevalence of discontinuous urban fabric in Polish settlements shows the permanent growth by 1,06%. The industrial classes are also characterized by 7,5% growth. Significant increase of mineral extraction site (15.34%) is observed as well as decrease of dump sites and construction sites (app. 32%). A big construction site of A4 highway in the Southern part of Poland could be easily recognized on satellite images.

A loss of wetlands is considerable. About 7,65% of wetlands changed into meadows or were afforested. Increase of water bodies is due to new big water reservoirs on Dunajec and Warta Rivers.

Final remarks

The interpretation of CORINE land cover classes as well as land cover changes detection needs a big experience in satellite interpretation and knowledge of the region under consideration. Some difficulties were caused by heterogeneity of acquisition dates of satellite data (different vegetation season, different years), temporal dynamic of land cover classes and their reflection

in satellite images and fuzziness in land cover boundaries both on the ground and in the satellite image. All these reasons created a big challenge to unify the results of interpretation of land cover classes to obtain inherent land cover database for entire country.

CORINE Land Cover database is recognised by decision-makers as a key reference data set for spatial and territorial analysis at different territorial levels. There is a growing need to use spatial analysis for integrated environmental assessment within the European Commission Services such as DG-Regional Policy, DG-Environment and DG-Agriculture as well as in EEA and its European Topic Centres (ETCs). The inventory of LC changes is necessary for the analysis of reasons and consequences of natural and artificial processes, impact assessment, identification of trends, maintenance of ecological balance and its consideration in the decision-making processes.

According to European regulation it is mandatory to use CORINE Land Cover data when:

- establishing NATURA 2000 Geographic Information System (Habitat Directive),
- river catchments characterizing and assessing relations between agricultural water and nutrient flow (Water Directive),
- evaluating the European Strategy on integrated costal zone management (ICZM Strategy),
- estimating carbon sinks and sources (Climate Change Policy).

The Polish CORINE Land Cover databases will be published and delivered by CD ROM. The European products are planned to be published and delivered by Internet GIS application as well as by CD ROMs.

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STRESZCZENIE

*W roku 1985 Komisja Wspólnot Europejskich powołała program pod nazwą CORINE (**CoOR**dination of **IN**formation on the **E**nvironment), którego celem była koordynacja przedsięwzięć zmierzających do gromadzenia i udostępniania informacji o środowisku w Europie. W ramach programu utworzono system informacji geograficznej, którego baza danych składa się z kilkunastu warstw tematycznych, zawierających m. in. informacje o pokryciu terenu. Od 1991 roku obowiązek zarządzania programem CORINE, a w tym aktualizacji baz danych spoczywa na Europejskiej Agencji Środowiska (EEA).*

Rosnące zapotrzebowanie na aktualną informację o pokryciu terenu spowodowało, że w 2000 r. Europejska Agencja Środowiska razem z Wspólnotowym Centrum Badawczym (JRC) w Isprze zainicjowały projekt, którego celem jest aktualizacja bazy danych o pokryciu terenu w Europie (CORINE Land Cover) oraz utworzenie bazy pokazującej zmiany w pokryciu terenu w latach 1990–2000.

W Polsce utworzenie bazy danych CORINE Land Cover (CLC) w latach 90. i jej aktualizacja zostało powierzone Instytutowi Geodezji i Kartografii. Prace nad projektem koordynowane są przez Główny Inspektorat Ochrony Środowiska.

Informacje o pokryciu terenu uzyskano w wyniku wizualnej interpretacji zdjęć wykonanych przez satelitę Landsat TM, zgodnie z jednolitą dla całej Europy legendą CORINE Land Cover. Legenda ma charakter hierarchiczny i na poziomie krajowym, odpowiadającym mapie w skali 1:100 000, zawiera 44 formy użytkowania ziemi, z czego na terenie Polski występuje 31 (tabela 1). Minimalna powierzchnia jednostek pokrycia terenu rejestrowanych w bazie wynosi 25 ha, przy czym wyznaczana jednostka nie może być węższa niż 100 m. CORINE Land Cover jest wektorową, topologiczną warstwą geometryczną, przechowywaną w sposób „bezszwowy" w układzie współrzędnych „1992". Na poziomie europejskim treść bazy danych CORINE Land Cover obejmuje pięć klas pokrycia terenu: tereny antropogeniczne, tereny rolne, lasy i ekosystemy seminaturalne, bagna śródlądowe oraz wody.

Zmiany w pokryciu terenu rejestrowano poprzez wizualne porównanie zdjęć satelitarnych z lat 90. z nowymi obrazami wykonanymi w roku 2000. Warto zaznaczyć, że zgodnie ze specyfikacjami technicznymi w bazie znajdują się tylko te zmiany, których powierzchnia jest większa od 5 ha, a szerokość wydzielenie przekracza 100 m. Baza danych o pokryciu terenu w roku 2000 (CLC2000) powstała w wyniku połączenia dwóch baz: bazy z roku 1990 (CLC90) i bazy zmian (CLC_Changes). Polskę pokrywa 28 obrazów satelitarnych (rys. 1). Do inwentaryzacji pokrycia terenu wybrano zdjęcia bezchmurne i wykonane w pełni okresu wegetacyjnego (od maja do września). Ponieważ obrazy wykonane z sąsiednich orbit w dużej części pokrywają ten sam obszar interpretatorzy mieli do dyspozycji kilka zdjęć wykonanych w różnych latach i sezonach wegetacyjnych.

Dominującymi formami pokrycia terenu w Polsce (rys. 2) są grunty rolne i lasy. Tereny wykorzystywane rolniczo zajmują 62% powierzchni kraju, lasy 30%, tereny zabudowane 5%, wody śródlądowe i tereny bagienne 3% (rys. 3 i rys. 4). Powierzchnie poszczególnych klas CLC zostały zamieszczone w tabeli 1.

Analizując pokrycie terenu w latach 1992 i 2000 widzimy, że zaledwie 0,9% powierzchni Polski zmieniło sposób użytkowania. Największe zmiany wystąpiły w obrębie terenów leśnych i związane są z przebudową drzewostanów. Znaczące zmiany to ubytek terenów użytkowanych rolniczo, a szczególnie gruntów rolnych i łąk oraz wzrost powierzchni nieużytków rolniczych klasyfikowanych w CORINE jako grunty rolne z dużym udziałem roślinności naturalnej. Wzrósł również odsetek terenów zurbanizowanych, powstały nowe osiedla, zakłady przemysłowe i duże centra handlowe. Wzrosła powierzchnia terenów komunikacyjnych, zmalała natomiast – terenów eksploatacji odkrywkowej. Zaobserwowano zmniejszanie się powierzchni mokradeł co jest wynikiem długotrwałej suszy w latach 90. i przeprowadzonych zabiegów melioracyjnych. Budowa trzech dużych zbiorników wodnych spowodowała przyrost powierzchni wód o około 2%.

Bazy danych CORINE Land Cover dla Polski stanowią część zasobów europejskich i wykorzystywane są do wspomagania procesów podejmowania decyzji odnośnie kształtowania środowiska. Zgodnie z prawodawstwem europejskim stanowią źródłowy materiał do opracowywania rozmieszczenia obszarów chronionych w ramach programu NATURA 2000, planów ochrony wód i wybrzeża, planów rozwoju obszarów wiejskich i innych.

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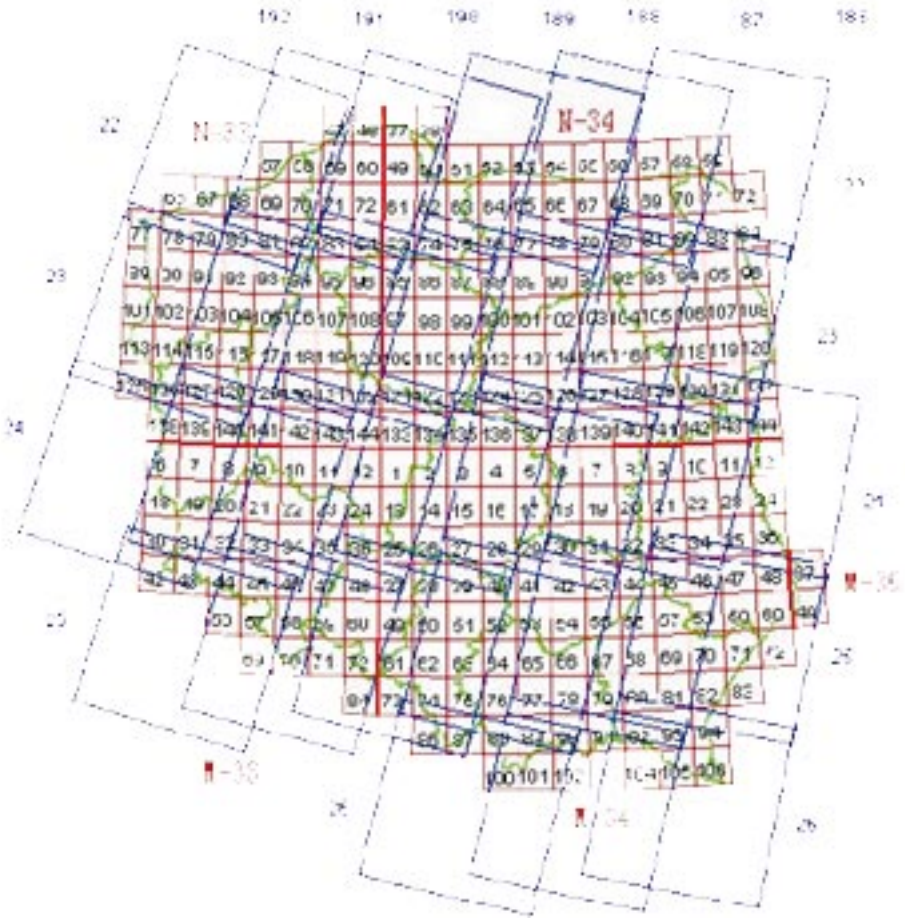

Fig. 1. Architecture of ICS-IEP system

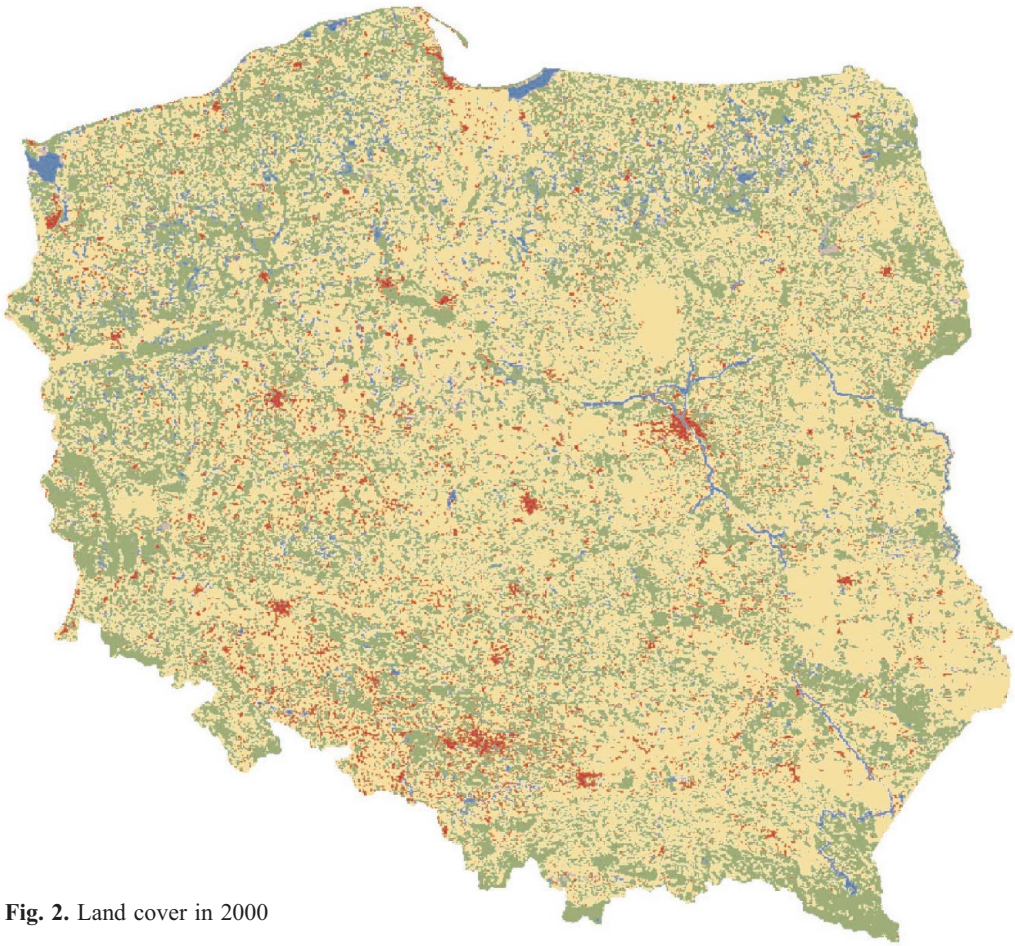

Fig. 2. Land cover in 2000

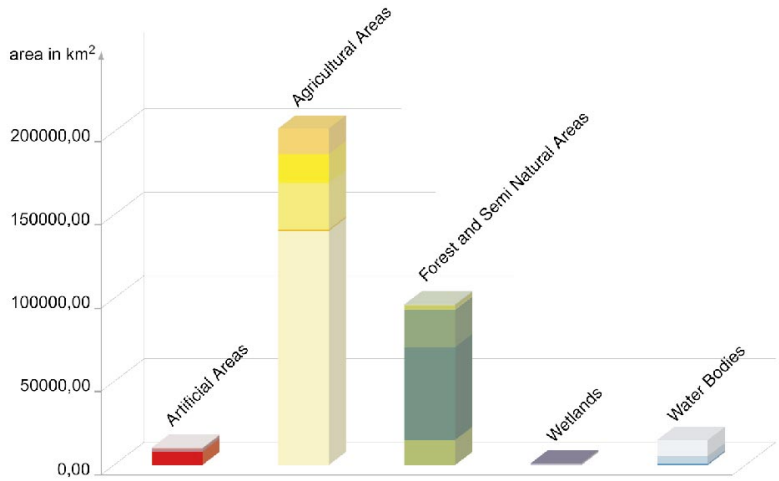

Fig. 3. Sharing of CORINE Land Cover classes inside 1st level class

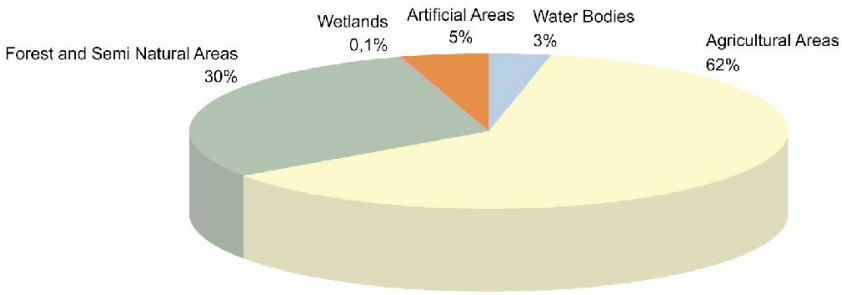

Fig. 4. Structure of land cover

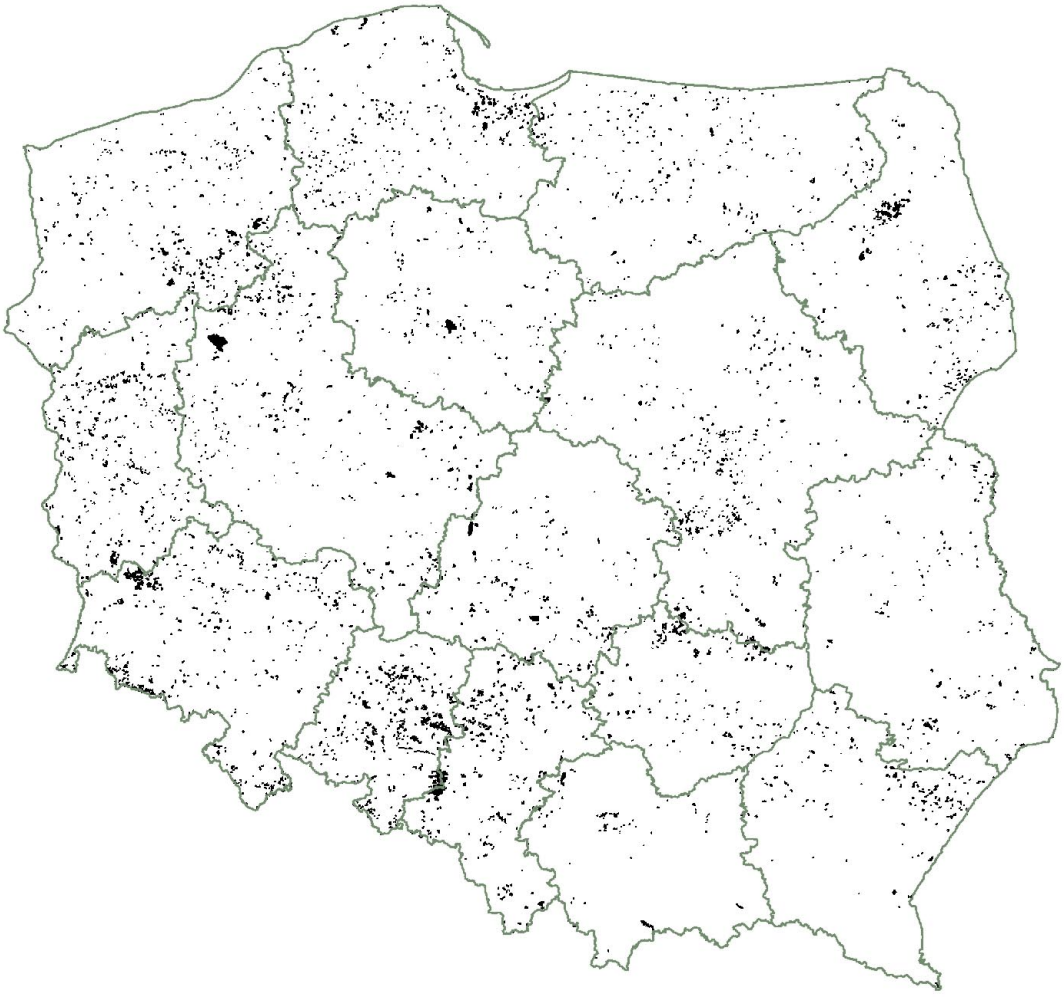

Fig. 5. Spatial distribution of land cover changes in the last decade of XX c

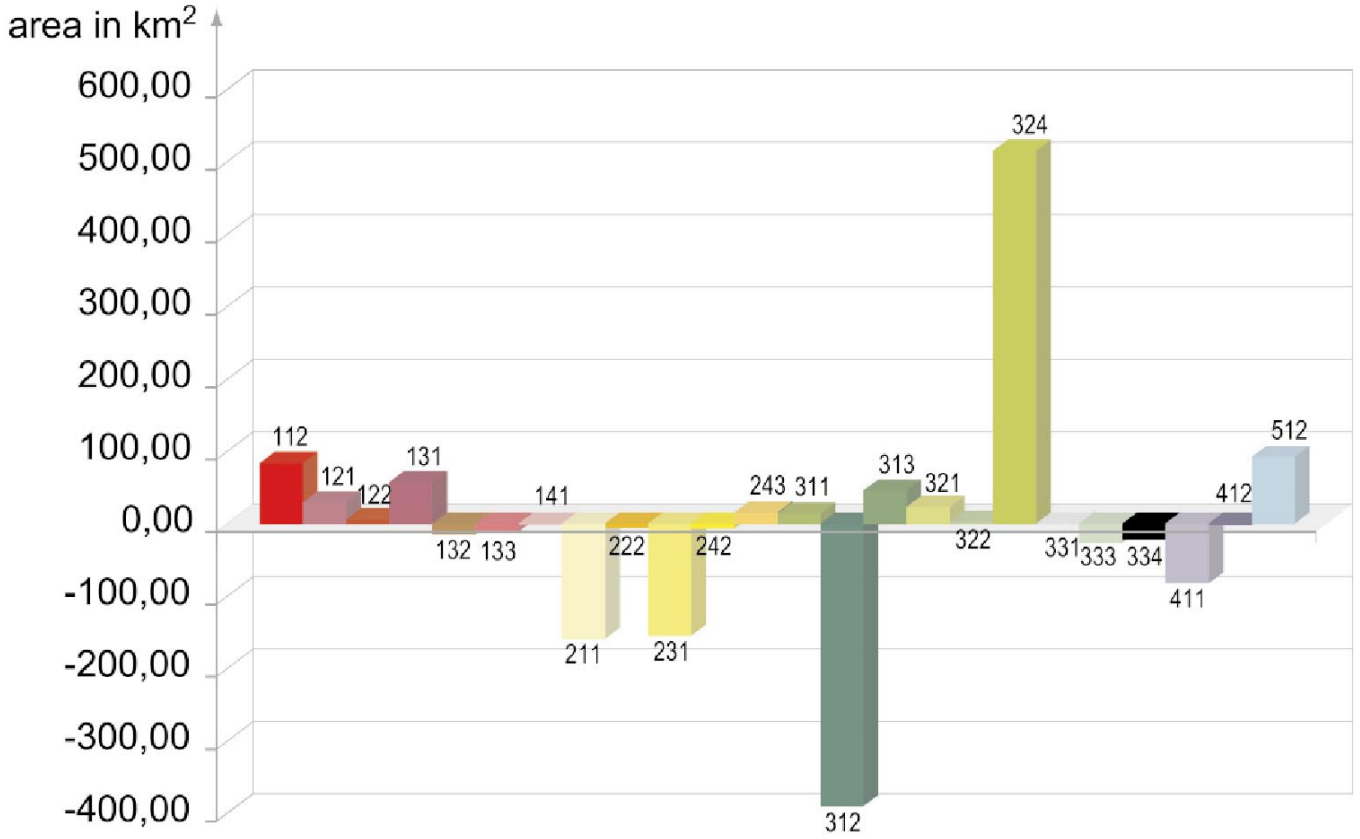

Fig. 6. Area of land cover changes in the last decade of XX c.