POLISH ASSOCIATION FOR SPATIAL INFORMATION
ANNALS OF GEOMATICS 2009 ❍ VOLUME VII ❍ NUMBER 2(32)

LAND-USE CHANGE ANALYSIS IN THE BASIN OF THE UPPER NAREW RIVER USING LANDSAT DATA AND ARCHIVAL TOPOGRAPHIC MAPS

ANALIZA ZMIAN UŻYTKOWANIA ZIEMI W ZLEWNI GÓRNEJ NARWI NA PODSTAWIE DANYCH Z SATELITY LANDSAT I ARCHIWALNYCH MAP TOPOGRAFICZNYCH

Sylwia Nasiłowska

Department of Geoinformatics and Remote Sensing, Faculty of Geography and Regional Studies
University of Warsaw, Poland

Keywords: land use, change analysis, visual interpretation, Landsat data, archival maps
Słowa kluczowe: użytkowanie ziemi, analiza zmian, interpretacja wizualna, dane Landsat, mapy archiwalne

Introduction

Change analysis is one of the most productive methods by which to identify and detect processes shaping the natural environment. Land cover and land-use research provides information about not only urbanization but also the consequent changes to natural process (both of which require monitoring). Using Remote Sensing techniques for detecting changes in land-use has been the subject of numerous scientific papers. Furthermore, numerous well-developed techniques for modelling land-use dynamics exist; developed to further understanding and assess changes in land-use and land-cover (Parker et al., 2003; Veldkamp and Verburg, 2004).

Remote Sensing Data allows rapid and accurate land-use analysis. Many maps have been drawn from it. Examples include the CORINE Land Cover (CLC) program and the Land Use and Land Cover Change (LUCC) program (Lambin, 2006). However, difficulties develop when more extensive analysis is required. In such cases, topographic maps are required to provide the requisite degree of time resolution. Research reveals a variety of problems associated with undertaking this form of analysis. Bielecka and Ciolkosz (2000) show that the data are inconsistent and thus, detection of detailed change is impossible such that only 5 principle categories have been analysed due to the limitations inherent in the data gathering process. Dukaczewski (2005) adds that comparison maps and satellite imagery allow precise calculation of land-use in each period however determining dynamic change between periods is not possible, again due to limitations inherent in the data gathering process. This confirms the need to standardise all reference data in a single field of meaningful categories (a qualitative comparison) with a single geometrical standard so as to minimize inconsistencies (quantitative comparison). The flowchart (Figure 1) details our approach.

The aim of this thesis is to demonstrate quantitative multi-temporal analyses of land use. The base materials are satellite and cartographic data with their inconsistencies taken into

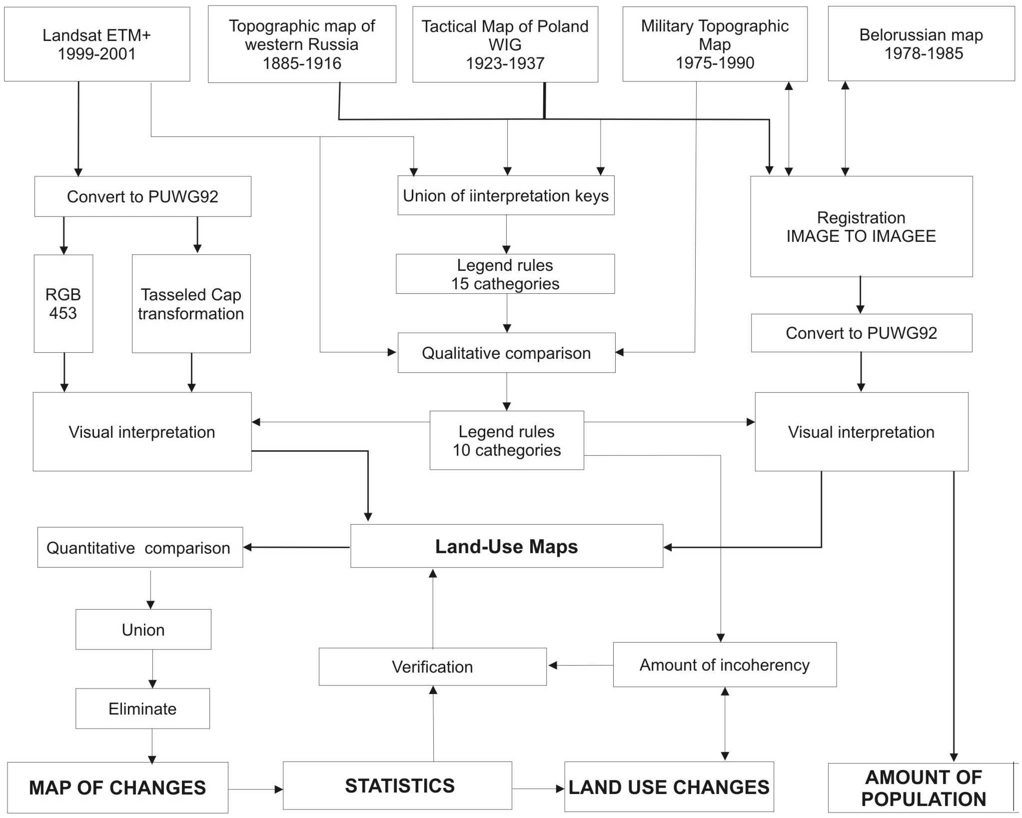

Figure 1. Algorithm of elaborated methodology

account. This thesis presents spatially explicit land-use change for the Upper Narew River basin over the past 116 years in an elaborated methodology.

Study area

The area investigated in this study is the basin of the Upper Narew River. This basin is unique in Europe because of its ecological value to the wetlands of the Narew River Valley.

The study area within the territory of Poland comprises 5576 $km^{2,}$ with an additional 603 km^2 within the territory of Belarus. The Upper Narew River is defined by its discharge measurements into the wetlands of Orlowo, located downstream to the inflow of the Suprasl River. The study area can be divided into three specific regions: a swampy river valley, surrounding arable land, and the third and largest is comprised of two large habitats, Bialowieza Forest and Knyszyn Forest. Because it is an anastomosing river system, the valley is unique in Europe. An additional factor is that metropolitan areas have spread through the study area during the period under analysis; the largest of which are Bialystok and Bielsk Podlaski. These sites are characterized by high-density urban areas (residential and commercial and industrial).

The strongly differentiated land cover and land-use are mostly determined by human impact. In the 20th Century (primarily during the 1960s) the Polish Government allowed a large proportion of the area to be drained for the purposes of development. Monitoring and mapping of the region is important in order to understand the processes underlying the visible changes. This thesis will explore the degree of impact of these changes to the environment of the Upper Narew River Basin.

Source Data

To calculate the amount of land use, it is necessary to generate a number of independent land-use maps. Such maps must be based on homogenised source data, however regrettably such data has not been available historically until the development of remote sensing technology. Consequently, several maps were selected which, while incomparable in theory (due to differences in projection, scale, date of print, accuracy, not to mention authors, symbols or even a common legend for such symbology) nevertheless could be compared in practice with large scale, complex, georectification and classification procedures.

The imagery used in this thesis consists of two LANDSAT-7 ETM+ images. The best images available for this path date from the 10th of July, 1999 for the eastern portion (the fragment within the territory of Belarus) and from the 1st of May 2001 for the western portion. To describe the period between WWI and WWII, the Military Topographic Map WIG, was employed: this is a tactical scale map of Poland (1:100,000). Available sheet maps of comparable scale cover the period 1923–1937. In the years between 1885 and 1916, the Topographic Map of Western Russia provided the necessary data. To georectify and calculate the population figures in 1942, Belarusian maps (1978–1991) and the Military Topographic Map were both used with projection scales of both maps of 1:100,000. This resulted in the most uniform maps possible with which to describe the entire region.

Methods

Satellite images and archival topographic maps are inconsistent with each other. To decrease the degree of inconsistency certain conditions must be met. Firstly, all source data must be reduced to a common projection so that accurate quantitative comparison is possible. Secondly, a uniform legend must be created. This must suit all source data, remain internally consistent and possess single, unambiguous meaning for each symbol. Thirdly, a method of comparing satellite data in a cartographic manner must be used, due to the unavoidable differences in data type and accuracy achievable with the given source data.

Geo-rectification

Projections of archival maps were incomplete, inconsistent (even within a single category of map) and at times unrecognizable. Consequently, image-to-image registration was the most advantageous method to co-relate geographic co-ordinates between maps to match to base image geometry. The reference maps were Belarusian maps and Military Topographic Maps. A three degree polynomial transformation (using nearest neighbourhood sampling) was employed in an effort to eliminate non-linear distortions (Richards, 1999). Afterwards, all data was resampled to a 10 m grid and reprojected to PUWG-92. Next, the area of interest was masked, following the borders of the basin.

Legend construction-qualitative descriptions

Polish samples of land-use maps made by Kostrowicki and Kulikowski (1971) were much more suitable to Polish conditions than data from the CORINE Land Cover and so formed the basis upon which to construct an elaborated legend. The selection of meaningful categories (due to the large sum of signs and meanings in all source data) proved to be a significant issue. Russian maps show land-use differently to military cartographic maps. Differences in meaning are not clearly defined. Based on the various legends available, 18 categories of land-use were selected with took into account a meaningful spectrum of categories without ratifying their meaning. To establish internally consistent meanings for each category a comparison study became necessary.

Comparison approach – quantitative comparison

The next problem was the comparison of cartographic materials with satellite data. Remote Sensing data provides the widest degree of possibilities in classifying land-use (especially when visual interpretation is acquired based on second-hand knowledge and secondary sources rather than on the topographic maps themselves). To become acquainted with these differences, a comparison study was conducted. To understand the degree of variation, comparisons between LANDSAT TM and military maps have been most fruitful. Differences were calculated to analyse the influence their inconsistencies added to the classification process. A sample area of the city of Bialystok and the swampy Narew Valley was examined. Different degrees of cluster tolerance and minimal area were tested. The results were evaluated statistically and visually. Correlations between images before and after aggregating the data were calculated so that the influence of ambiguous data could be eliminated during comparison and the results interpreted as genuine change and not merely artefacts of the process.

The results show that there is a big difference in accounting for pastures, meadows and arable lands. Furthermore, it is impossible to correctly isolate discrete, uncontiguous development or even types of forest from cartographic data. The study proves that additional methods of accounting and varieties of category must be used. To account for transport, industrial and commercial zones, town plans were utilized.

The biggest difficulty is observed in the wetlands. Symbols to represent wetlands are not only different but numerous; divided into subgroups without common references. The Tasselled Cap transformation was performed to improve visual classification. It used RGB composite images for three categories: wetness, greenness and brightness (Hejmanowska, Mularz, 2000). Rural development proved to be the most difficult to compare because some sets of data noted all structures while others only noted farms. This led to problems with calculating farm area as a total. Unfortunately, it was not possible to correct this discrepancy for the whole study area, thankfully, the elaborated methodology makes at least the degree of error known.

Calculating population proved easier, because each village had census figures with the number of inhabitants or the number of households.

The methodology of the study is based on a qualitative interpretation of source data; an estimation of the aggregate total of land use change was made using established methods and allocating the resulting aggregate quantities spatially using explicit rules. Regrettably, integration and summarization of content and symbols allows a maximum of 10 land use categories. Precise areas of land use interests were identical to the CORINE land cover figures. The minimal area as 25 ha with the shortest line being 100 m from which, tree maps at 1:100,000 were generated.

Map showing changes

Finally, the image classification results were compared, Individual multi-temporal maps were unified, showing the influence of land-use changes in the basin area. If spatial analysis were required then exact methods of unifying land-use maps could be accomplished using identical methods. Few attempts were made to eliminate inconsistencies due to the influence of source data. Results show that utilisation of various rates of cluster tolerance during unification of maps (with the intention of eliminating difference originating in source data inconsistencies) yielded varying results, making discovery of the extent of the error possible. Moreover, these maps allowed the creation of statistics which reveal all changes in the two periods being studied. The first table shows differences between the Belarusian and Tactical Maps of Poland and the second compares data prior to WWII and the year 2001.

Results

Maps of land-use made the calculation of the degree of change in each period possible (Table 1). Forests and arable lands were dominant categories of land use in all periods of research (each area approximately 40% catchment). The largest increase has been observed in artificial water bodies and urban areas. Natural water bodies have, for the most part, vanished. During the same period, large areas of swampy ground have also disappeared. Moreover, wetlands have been drained throughout the last 60 years in order to create arable lands, pastures and meadows. In addition, urban areas have grown at an accelerating pace, notably at the expense of arable lands, pastures and meadows necessitating further encroachment of swampy areas and wetlands.

Additional information uncovered during research concerns population trends. A summary of the results is presented in Table 2. It can be seen that prior to WWI, the majority of the population lived in the countryside. Furthermore, the wide, swampy Narew Valley played a crucial role as a natural barrier to development on the western side of the Narew Valley and a railway line begun towards the end of the 19th century was the single most important determinant of urban development on the eastern side. The rate of urbanisation increased from 23% to 71% during the period examined (116 years). Concurrently, the population density rose by a factor of 3. In outlying cities and towns, industrial, commercial and transport zones also continued to develop.

Table 1. Land use in upper Narew basin, 1885–2001, area (%)

Category	1885–1916	1923–1937	1999–2001
1. Residential urban development	0.26	0.42	1.07
2. Industrial and commercial zones	0.01	0.02	0.21
3. Transport zones	0.00	0.01	0.04
4. Arable lands	46.61	44.64	38.56
5. Pastures and meadows	3.46	5.04	12.36
6. Country development	0.51	0.76	1.16
7. Forests	34.83	34.05	41.87
8. Natural water bodies	0.07	0.03	0.00
9. Artificial water bodies	0.00	0.02	0.58
10. Wetlands	14.25	15.01	4.15
Total	100	100	100

Table 2. Population changes in 1885–1993

	1885–1916	1923–1937	1978–1993
Total Population	150 755	280 536	512 940
Rural Population	116 100	168 190	151 040
Urban development (%)	23.0	40.0	70.6
Density of population (person/km^2)	24	45	83

The map showing these changes reveals that significant transformations were observed for 32.8% of the study area. Until WWII (1885–1937) the figure was 13.6% and since 1945 the figure was 23.5% (1923–2001). Statistics show the exact amount of each particular change, however errors are perceptible. To become acquainted with genuine changes, results from the comparison study must once more be taken into account. Figure 2 shows only those modifications not influenced by ambiguous source data. During the study, those observed changes which were insignificant or artefacts (of either source inconsistencies or method) were recognized. The largest inconsistency was noted with respect to rural development, since rural development data was presented using widely varying methods and accounted for with divergent symbolism in each source map.

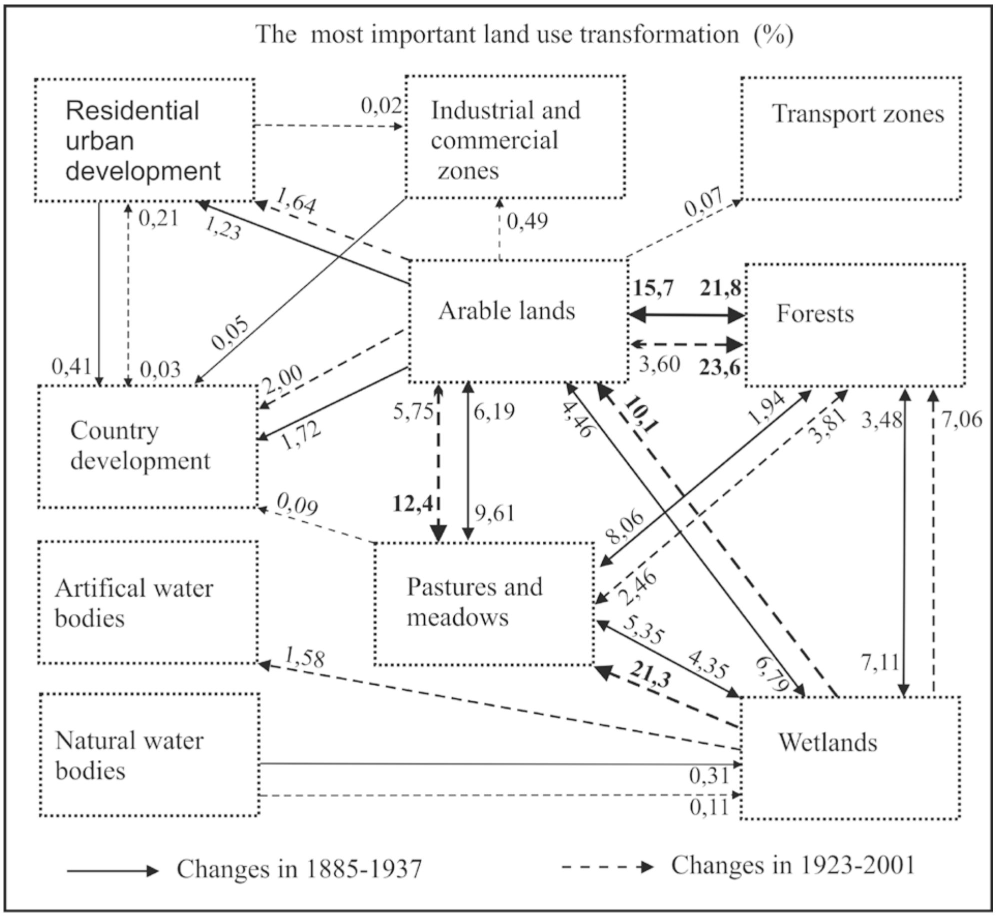

Figure 2. The most significant changes

Conclusion

The majority of changes in the area were natural or connected with traditional agricultural activities. For example, burning forests in order to convert them to arable lands and conversely arable lands left fallow becoming forests once more. The research clearly shows how draining land influences the environment (natural bodies of water and wetlands, along with the ecosystems they support, vanish).

The research shows it is possible to obtain coherent land-use maps which can be compared over time. The conditions for this process are ultimately a method of eliminating inconsistencies between source data and a common, properly elaborated legend.

References

Bielecka E., Ciołkosz A., 2000: Zmiany użytkowania ziemi w dorzeczu Odry w świetle zdjęć satelitarnych i archiwalnych materiałów kartograficznych. Fotointerpretacja w geografii, problemy telegeoinformacji, 31.

Dukaczewski D., 2005: Elektroniczna mapa animowana Gór Izerskich. *Polski Przegląd Kartograficzny*, 37(1): 23-36.

Hejmanowska B., Mularz S., 2000: Integration of multitemporal ERS SAR and Landsat TM data for soil moisture assessment, *IAPRS*, 33.

Kostrowicki J., Kulikowski R., 1971: Przeglądowe zdjęcie użytkowania ziemi (Projekt instrukcji). Dokumentacja geograficzna, Instytut Geografii Polskiej Akademii Nauk, 2.

Lambin E.F., Geist H. (ed.), 2006: Land-use and land-cover change: local processes and global impacts, Springer.

Parker D.C., Manson S.M., Janssen M.A., Hoffmann M.J., Deadman P., 2003: Multi-Agent Systems for the Simulation of Land-Use and Land-Cover Change: A Review. *Annals of the Association of American Geographers*, 93(2): 314-337.

Richards J.A., 1999: Remote Sensing Digital Image Analysis, Springer-Verlag, Berlin.

Veldkamp and Verburg, 2004: Modelling land use change and environmental impact. Journal of Environmental Management, 72(1-2): 1-3.

Streszczenie

W niniejszej pracy podjęto się wieloczasowej analizy zmian użytkowania ziemi. Obszar badawczy stanowiła zlewnia Górnej Narwi. Materiał źródłowy stanowiły obrazy satelitarne oraz archiwalne mapy topograficzne, co umożliwiło analizę w okresie 16 lat (1985-2001).

Specyfika danych satelitarnych nie pozwala na proste porównanie ich ze względu na użytkowanie ziemi z mapami topograficznymi. Dlatego też podjęto się próby zniwelowania różnic między omawianymi materiałami geoinformatycznymi.

Informacje pozyskane w procesie interpretacji wizualnej posłużyły do opracowania trzech map inwentaryzujących stan użytkowania ziemi. Agregacja treści oraz znaczenia symboli w poszczególnych materiałach źródłowych pozwoliła na wyróżnienie 10 kategorii użytkowania ziemi. Dokładność wyznaczania poligonów użytkowania ziemi wynosiła 25 ha, natomiast zmiany wykryto z 5 hektarową precyzją.

Niezmiennie dominującymi formami użytkowania ziemi są grunty orne oraz lasy, zajmujące po około 40% powierzchni obszaru badawczego. Naturalne jeziora w zakresie założonej dokładności zniknęły z powierzchni zlewni. Wraz z zanikiem zbiorników naturalnych, zmniejsza się powierzchnia obszarów podmokłych, a wzrasta areał trwałych użytków zielonych i gruntów ornych. Zanotowano intensywny wzrost powierzchni zabudowanej. Największy wzrost liczby ludności zanotowano dla Białegostoku, który niezmienne pełni funkcję najważniejszego ośrodka miejskiego na Podlasiu.

Przeprowadzona analiza wskazuje, że w badanym okresie przekształcenia nastąpiły na 32,8% powierzchni obszaru badawczego.

mgr Sylwia Nasiłowska
sylwia.agata.nasilowska@student.uw.edu.pl
+4822 5520654