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THE IMPACT OF RECTIFICATION ERROR ON THE ANALYSIS OF LANDSCAPE TRANSFORMATION BASED ON ARCHIVAL MAPS

key words: landscape transformation, scale, cell, rectification, Poland, Odra Valley

PREFACE

Landscape transformation analysis can be performed based upon various data sources. The easiest approach, due to data availability, is a comparison of the share of individual land use/land cover categories (LULC), e.g. forest, grassland, wasteland, arable land etc., expressed as units of area or the percentage of area, for two or more periods. This sort of data are published e.g. in statistical yearbooks. Transformation assessment of small-size objects, such as small farmland ponds, is achieved by comparison of their number in different time points. These methods, using aggregated data for a particular territorial unit, allow only to asses the net land use/land cover change (net LULCC) for the unit as whole (Pontius, 2004). However, at the same time in the same area, two-way landscape changes may take place, e.g. grassland can be converted into arable land at one location within the area, while at the other location an opposite process occurs. Such transition is referred to us as a **swap** (Pontius, 2004). If the areas of such two transformations are equal or close, the net land use/land cover shows only intensity of these two processes, instead of quantity of landscape transformation. Yet from the ecological point of view, it is important to know not only how the relative share of each LULC class changes, but also how durable the individual patches are. A patch of forest, which has lasted at the same place for several hundred years, has a completely different ecological value than a patch of forest established 40 years ago on a former arable land – even if both patches have a similar species and age structure. Therefore, in landscape ecology a net LULLC analysis is not sufficient. By means of a detailed analysis of spatial data using geographic information systems (GIS), it is possible to obtain an information about the landscape transformation for individual LULC types, such as: gain and loss and total change, which is a sum of this two processes. Only such indices enable a search for landscape persistence over time, which is a clue of the landscape dynamics analysis (Pontius, 2004). These values can be calculated from a transition matrix between particular LULC types in „**cell-by-cell overlap**" analysis of paired maps.

In order to perform such an analysis, spatial data are required, i.e. maps, aerial or satellite imagery, representing different time points and rectified into a common coordinate system, so that the objects which did not change their location in the given period overlap. Unfortunately due to various errors originating from cartographic and geometric properties of the source spatial data, as well as the technical limitations of the rectification process, we usually face greater or smaller dislocations of objects which are supposed to be identical in our different time series. Such a dislocation does not influence the net LULCC, but it does impact the results of total LULCC, as it causes an artificial over-representation of changes through an increase in gain and loss of the exact LULC type. The analysis of rectification error and inclusion of the results in further analysis is thus inevitable.

In the literature about landscape transformation research methodology much attention is paid to classification error (Richards, 1996; Kuriakidis, Dungan, 2001; Patil, Taillie, 2003; Fang et al., 2006). The results of our query on landscape ecology literature show that the rectification error and its impact on LULLC research has brought much less interest so far.

The aim of this paper is to try to asses the rectification error impact on the estimation of land cover changes, in particular on the overestimation of total change of different size and shape patches in „**cell-by-cell overlap**" analyses. We analysed the impact of the of rectification error in range from 6 to 20 m. Indicators of LULCC results sensitivity to the rectification error were proposed, which enable the assessment of LULCC overestimation error for patches of different size and shape.

MATERIALS AND METHODS

Maps characteristics

The research area is covered by one Messtichblatt 1:25 000 topographic map sheet from 1993, sheet designation 4363, and by fragments of four sheets of Wojskowa Mapa Topograficzna 1:25 000 from 1993-1995, sheet designations M-33-21-A-a,b, M-33-21-B-a,b, M-33-9-C-c,d, M-33-9-D-c,d. The coordinate system of the Mestichblatt map is zone 5 of Gauss-Krüger System, datum DHDN (know also as datum Rauenberg or Potsdam). Contemporary maps are in the coordinate system of zone

33N UTM. Both systems are based on transverse Mercator projection. In case of Gauss-Krüger System the reference surface is the local ellipsoid Bessel 1841. For the UTM System it is the global WGS84 ellipsoid. The total area of 46 km2 was analysed.

Maps preparation for the analysis

Maps were scanned on a roll scanner with resolution of 300 DPI. The calibration into maps native coordinate systems was performed using SuperEdit Pro 2.6 software. In case of the contemporary maps, devoid of distortions typical for archival maps, a calibration on 9 regularly distributed points – 4 geodetic grid intersections at map sheets corners and and 5 intersections of sheets kilometre grid, using the bylinear transformation model was performed. The maximum RMS (root mean square) error of rectification was 4.8904, minimal was 2.3941.

In case of the archival map, due to non-systematic distortions of paper caused by many years of utilization and storage, the bicubic rectification method was applied, which requires a possibly big number of calibration tie points (16 at minimum) evenly distributed on the whole sheet. The maximum number of possible 217 tie points was used, including all geodetic grid intersections of the sheet, all intersections of sheets kilometre grid, as well as the intersections of the geodetic grid and kilometre grid on the sheets borders. The latter points coordinates were determined using GRASS GIS 6.3 software, by creating the geodetic grid graticule of the processed sheet, its re-projection into zone 5 of Gauss-Krüger System, creating the kilometre grid graticule of the sheet, patching the two graticules together, extracting their crossings along the map sheets borders and exporting them of vector points in dxf format. The operations were performed with v.in.ascii, v.proj, v.patch, v.clean and v.out.dxf of GRASS GIS 6.3. The resulting dxf file was then used as additional calibration reference points in SuperEdit Pro. The maximum RMS (root mean square) error of rectification was 3.6981.

The estimation of spatial discrepancy between the archival and contemporary map

The estimation was conducted using the method proposed by Jankowski (1961), based on the comparison of locations of the geodetic control points present on both maps. Together, 9 points were used – 7 present within the research area and 2 in its close neighbourhood.

The experimental estimation of errors impact on the results LULCC analysis

The experiment involved preparation of an artificial landscape consisting of square patches of focus land type of different size 0.1, 0.25, 0.5,1,5,10,50 and 100 ha. Every area size class was represented on the map by 10 patches of focus land type.

This vector map was used as a reference map for the study of the influence of the spatial error on the results of LULCC. Two vector maps affected by spatial errors were generated by shifting the reference map, in both N-S and S-W directions, by distance of 6 and 20 m.. The shift distance of 6 m corresponds to the RMSE calculated for the analysed topographic maps. A shift slightly greater than the calculated RMSE was assumed, as the accuracy of location of land cover features is worse than this of geodetic control points, used for RMSE calculation. The distance of 20 m, corresponds to the greatest acceptable error for 1:25 000 scale maps (Trausolt, 1958). Maps were then converted to raster format. Error maps were paired with the reference map and analysed "cell by cell" method of LULCC. The LULCC analyses were performed on these maps by cross-tabulation matrix (Pontius, 2004) calculation in GRASS GIS software. If not the shift in features location, the transition matrix should not detect any net changes nor total change, because the value of the gains and losses would be zero. The calculated gain and losses are simple effects of the shift between paired maps, which simulated the rectification error equal to the shift distance. To asses the raster resolution impact and the sensitivity of various size patches to the simulated rectification error, different cell sizes of 1m - 12 m were used.

RESULTS

The assessment of spatial error between archival and contemporary map

9 geodetic control points were used in the analysis, 7 of which lied within the research area and 2 in its close vicinity. The RMS error in horizontal and vertical axis was measured as, respectively, 4.6 and 3.6 m. A possible flaw of this method is that the location of geodetic control points is less biased than the location of land cover boundaries. It is thus necessary to keep in mind that such objects may actually be more shifted than the error calculated from geodetic control points suggests.

The impact of the rectification error on the landscape transformation analysis

To keep the analysis as simple as possible, we use the gain of the focus land class, expressed as a percentage of its original area, as the LULCC overestimation indicator.
The analysis of LULCC based on artificial landscape maps showed its relatively small sensitivity to rectification error. The 6 m shift yield a gain of a focus coverage type of 1.4%, whereas the 20 m shift yield a gain of 5.6%.

Small patches are much more sensitive to rectification error than large patches (fig. 1). The 6 m shift caused an overestimation of gain of 1.19 and 36.69%, respectively for patches of area 100 ha and 0.1 ha (fig. 1a). The 20 m shift evoked an overestimation of gain 3.9 and 86.1% for 100 ha and 0.1 ha patches, respectively (fig. 1b).

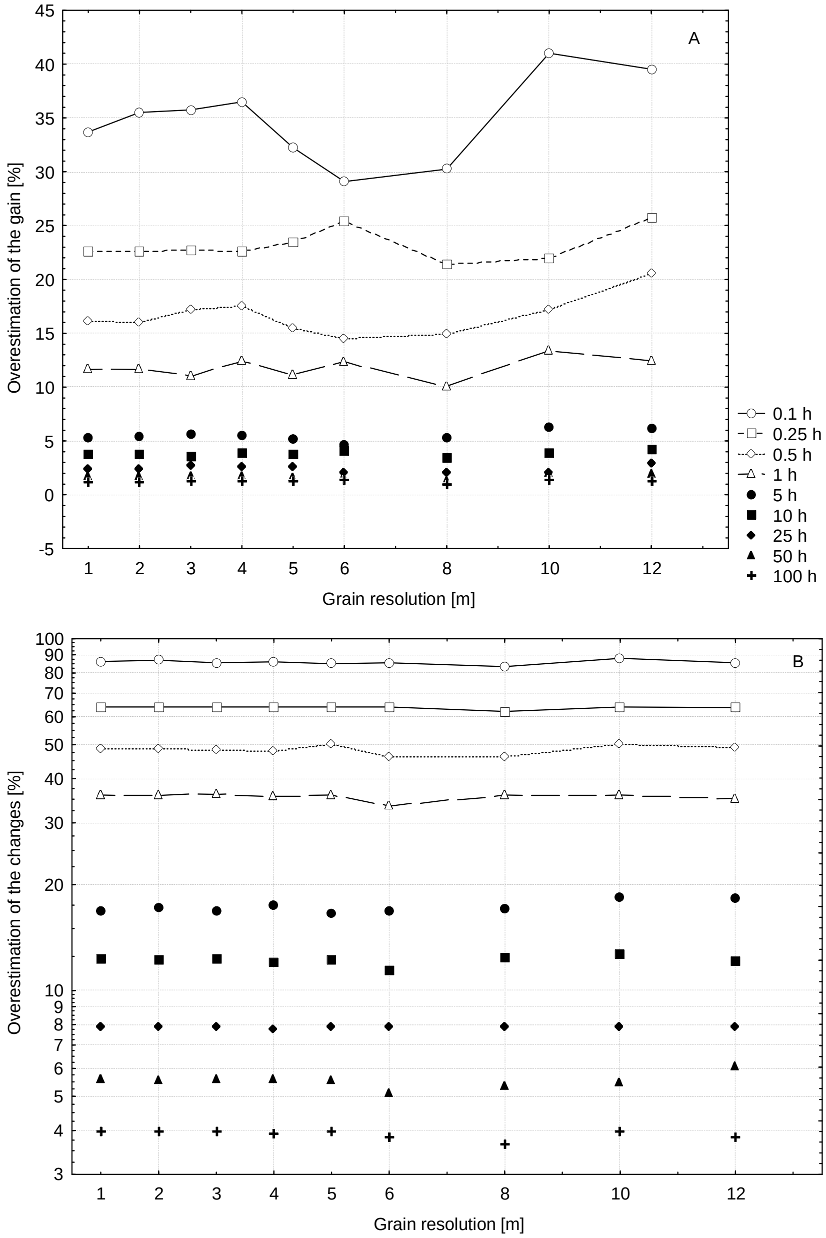

Fig. 1. Sensitivity of the different size patches to the rectification error of size 6m – A and size 20 m - B, analysed with different cell size (grain resolution). Note that Y axis on diagram B is in logarithmic scale.
Source: *compiled by the authors.*

The overestimation of land type transformation is influenced by the raster cell size. For the smallest patches, 0.1 ha, the error ranges from 29 to 42%, depending on the resolution of the analysed raster map, being lowest at 6 m resolution (fig. 1a). Next patch size class, 0.25 ha, showed a maximum error for the same cell size of 6 m. Thus it is not possible to find a raster resolution that would minimise the error of all size patches, as the resolution that yields the smallest error in one size class, can lead to a high error in another size class.

DISCCUSSION

The importance of direct map comparison by means of **cell-by-cell overlap** technique increases (Foody, 2002) – e.g. contingency table, Kappa statistics and also mixed methods connecting **cell-by-cell** analysis with landscape parameters such as neighbourhood (Hagen-Zanker, 2006). Their application for low-resolution satellite imagery (e.g. Landsat, Aster), the georectification error of which, in relation to their resolution, is low, does not bring problems. Yet their application for LULCC research based on topographic maps, aerial photographs or high-resolution satellite imagery, which have a much greater resolution, brings a question of the rectification error impact on the analysis results. The question is the more important, the finer is the resolution of analysed maps, expressed as the cell size dimensions. This issue has not been paid much attention in the literature as yet. The majority of publications regarding landscape transformation research based on high-resolution cartographic materials only contain a general information about rectification error (Bender et al., 2005).

The artificial landscape we used in the analysis presents low sensitivity to the rectification error. The overall calculated error is caused by the landscape properties, especially by patches size distribution. Our experimental landscape consists of an equal number of small and big patches, thus big patches have much more contribution to the total area of the focus land category than small ones. Such distribution differs from the usual right-skewed distribution of patch size, typical for rural landscape with a relatively high number of small patches. The second reason of low sensitivity of artificial landscape to the simulated rectification error is the patch shape. All patches were squares, which, in relation to real patches, has a smaller perimeter to area ratio. As we did not measure a different patch shape sensitivity to rectification error, detailed discussion of this issue is beyond this paper, so we confine only to a simple geometrical fact, that the shift of complicated shape patches will result in a higher gain overestimation, compared to compact shape patches. Thus, the sensitivity of the real landscape to rectification error, in "**cell by cell**" analysis, depends largely on the landscape structure, especially on the patch size and shape.

The rectification error has impact on the results of the landscape transformation analysis causing an overestimation of transitions of particular classes. The overestimation level depends on the rectification error, the size and the shape of patches on the analysed maps. The overestimation is greater for smaller patches of a complex shape than in case of bigger patches, of a compact area. Therefore, the rectification error will have a greater influence on the LULCC analysis of mosaic landscapes. In order to minimise the error it would be necessary to exclude small patches from an automatic analysis and analyse them with different methods. Thus, a question emerges: how small and how complicated should the excluded patches be? Or, other words, how small and how complicated patches should be still acceptable in the automatic approach? The answer can be given when the impact of the rectification error on LULC transition overestimation is known. It is then necessary to find an indicator, which would enable calculation of the overestimation for each patch of an exact size and shape. Such an indicator would allow to exclude patches, which would affect the analysis by a factor greater than the *a* **priori** thres-hold.

According to our analysis, it can be concluded that such an indicator can be a ratio of the shape indicator of a square of a side length equal to rectification error to the same shape indicator calculated for a patch.

$$S = K_1:K_2 ,\ \text{where:}$$

S – error sensitivity index

K_1 – shape indicator of a square of a side length equal to rectification error, expressed as the ratio of its perimeter to its area

K_2 – shape indicator of a patch, expressed as the ratio of its perimeter to its area

This indicator is is correlated with the LULCC overestimation value. Therefore it allows to calculate each patches contribution to the LULCC overestimation. As such, it can be used during patches selection for the analysis and to control the LULCC overestimation level.

The raster map resolution change does not bring the expected effect of a reduction of the error impact on the landscape transformation analysis result, due to its opposite effect on the patches of different size. Therefore the raster map resolution optimisation should be mainly driven by features independent of rectification error in the analysed raster maps. In order to avoid errors in the calculation of landscape structure measures it is recommended to use a raster cell size 2 – 5 smaller than the smallest patch and the research area should be 2 – 5 greater than the smallest patch (O'Neill, 1996).

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SUMMARY

Archival topographic maps are the main source of information about the land cover and land use (LULC) structure, particularly with reference to times before the application of aerial and satellite remote sensing. Maps created in different periods differ substantially in regard to cartographic technique, scale and generalisation level. This brings problems of using them as a data source in landscape transformation analysis. If these problems are not correctly solved in the initial stage of the research, the obtained land use/cover change (LULCC) results may be biased by errors leading to incorrect conclusions. For the interpretation of landscape transformation in the aspect of ecological processes, a simple comparison of proportions of particular LULC classes in certain periods is not sufficient, because a given transformation type in one place might be compensated by an opposite change in another place. Thus, in order to investigate the actual LULCC dynamics, and thereby to get to know its influence on vegetation, biodiversity and other landscape elements, it is necessary to use methods allowing for a detailed analysis of changes between LULC classes in the given period. One of the most straightforward approaches is a transformation matrix.

In order to apply a transformation matrix to cartographic materials from different times, they need to be rectified to a common coordinate system. Because of deformations of the topographic map contents due to the map scale, map projection, cartographic and print technique, the possible distortions during storage and utilization, as well as during the digital scanning of the map, different for each map series or even between single sheets of the same map series, a perfect georectification of a scanned topographic map is virtually impossible. Therefore, the transformation matrix contains the information about the factual transitions between LULC categories, as well as about the artificial ones, due to map rectification error. Spatial error assessment procedure is then necessary to extract the information about the real transformation that took place. In this paper a method for reducing the impact of rectification error on the LULCC analysis is presented, based on authors landscape transformation research, conducted in the agricultural landscape of the Odra valley, using digitized maps from 1930's-1940's and 1990's.