RESEARCH OF HISTORICAL LANDSCAPE BY USING OLD MAPS WITH FOCUS TO ITS POSITIONAL ACCURACY

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Abstract
Old maps are an important historical source for exploring historical landscapes. They are often used as cartographic bases for studying structural changes and reconstruction of land use. This study is concerned with comparison of positional accuracy of a set of 'old maps' as compared to present-day maps. Determination of positional deviations defines the degree of precision of the old map and its potential for its use in GIS applications. The total of ten unique historical maps in different scales from the Čáslav region of Central Bohemia were examined regarding its positional accuracy.

Key words: Čáslav region, georeferencing, historical landscape, old maps, root mean-squared error

PREUČEVANJE ZGODOVINSKIH POKRAJIN S POMOČJO STARIH KART, S POUDARKOM NA LOKACIJSKI NATANČNOSTI

Izvleček
Stare karte so pomemben zgodovinski vir za preučevanje nekdanjih pokrajin. Pogosto se uporabljajo kot kartografske podlage za preučevanje strukturnih sprememb in nekdanje rabe tal. V prispevku je predstavljena primerjava lokacijske natančnosti izbranih 'starih kart' s sedanjimi. Lokacijska natančnost pomeni stopnjo natančnosti starih kart in možnosti njihove uporabe v GIS. V ta namen je bilo z vidika natančnosti preučenih deset zgodovinskih kart v različnih merilih iz okolice mesta Čáslav na srednjem Češkem.

Ključne besede: Čáslav, georeferenciranje, zgodovinska pokrajina, stare karte, srednja kvadratna napaka, RMS

1. INTRODUCTION

Maps, together with other cartographic artifacts, including globes, panoramic drawings and relief models, are pieces of cultural heritage (Jenny, Hurni, 2005). Except for depiction of the landscape and its individual elements forming the area in particular time, the maps also represent a historical source reflecting the geographical knowledge, cartographic skills and political context of the times they were elaborated (Kavalír, 1985). Historical maps are frequently treasured as works of art, too.

Information and data from the maps can be examined and studied by researchers from many sciences. In recent years, interest in antique and historical maps has been growing also among geographers with various specializations. The focus of the studies is mainly on the coverage of these maps as they often depict landscape which no longer exists, was entirely altered or only inconsiderable relicts of which remained. Thus, they are specific bearers of the landscape memory (Dohnal, 2006; Novák, 2001, Sklenička, Lhota, 2002).

In cases, where a set of old maps from various periods is available, changes in the landscape can be compared (Semotanová, 2002) and, consequently, forces that contributed to these significant changes can be identified (Bürgi, Hesperger, Schneeberger, 2004). While human geographers predominantly use historical statistics (related to specific region or district) for the assessment of the landscape macrostructure development (Bičík, 1998), physical geographers, landscape environmentalists and environmental historians focus in their map-related studies mostly on assessment of the landscape structure and development (Boltižiar et al., 2008). The old maps offer an ideal opportunity to acquire data on structure of the historical landscape, its land use and cover. From the environmental point of view, the old maps represent unique documentation of the landscape management in given time and place (Trpáková, Trpák, 2008).

Owing to digitizing of crucial map pieces (Roper, 2003) and the possibility of their processing in geographical information systems (Gregory, Healey, 2007; Knowles, Hillier, 2008; Lipský, 2002; Pearson, Collier, 1998), unprecedented potential has opened for deeper analysis of the historical landscape, its components, structure and comparison with the present-day land. Baily et al. (2011) investigated the possibilities of using digitized data from the First Land Utilisation Survey of Great Britain from the first half of the 20th century; Skaloš et al. (2011) similarly researched long term changes in the land cover of the Czech Republic from Old Military Survey maps. Leriche et al. (2004) were using old maps in the research of seagrass beds dynamics. Sprague, Iwasaki and Takahashi (2007) employed old Japanese maps Jinsoku Sukozu in the examination of rice paddy persistence. Petek and Urbanc (2004) accomplished the reconstruction of historical rural landscape in Slovenia taking advantage of maps from stable cadastre. Old cadastre maps were also used in studies of Cousins (2001) and Domaas (2007). The unique potential of the old maps was also used by the archeologists Williams (2007) and Barclay (2005).

There are many other good examples of studies, where old maps were used as sources of information. The question many of the authors had to deal with was the positional accuracy of these maps to transform the acquired data in down-to-date coordinates so that the data could be vectorized in the environment of GIS and make comparable

with present-day map reference parts and aerial photographs (Pavelková Chmelová, Netopil, 2007). The positional accuracy of a set of old maps, the possibilities of their georeferencing and transformation into down-to-date cartographic coordinates is the main theme of this study.

2. AIMS AND PURPOSES

The aim of this study is to determine the positional accuracy of a set of digitized historical maps on selected territory in the Czech Republic by applicable transformation. Within the map file, maps of large, medium and small ratio scales were examined. Emphasis was also laid on the utilization of generally accessible maps covering the whole Czech Republic as well as old maps from regional archives. According to preliminary hypothesis, the new maps should be more accurate compared to the old maps due to gradual perfection of geodetic techniques. Moreover, the maps in larger scales should be less distorted than small-scale maps.

3. MAP SOURCES

The leading Czech historical geographer E. Semotanová (2001) points out that it is necessary to draw the line between the terms 'old map' and 'historical map'. In the past, as 'old' were labeled maps created up to the first half of the 19th century. Such labeling was mainly due to artistic reasons. In the middle of 19th century the maps have lost their ornamental character and set a new path towards modern maps as known today. Insofar, as content of the map is considered rather than its design, then 'old map' is a map depicting a no-longer-existing state of the landscape. Time limitation, i.e. when the map becomes 'old', therefore does not exist, though in practice it is usually 100 years.

The term 'historical map' is, however, not a synonym to 'old map'. Historical map is a thematic map, it projects the outputs of historical research by modern cartographic instruments. A historical map, nonetheless, can simultaneously be an old map and vice versa. This happens when we consider map with historical content created in the past (Semotanová, 2001). Nine old maps were examined in this study together with two historical maps, which were – at the same time – old maps.

Map-piece information is extremely important in the study of old maps (date, author, projection, coordinate system, interpretation key). Regrettably, such data is not always available. The old maps created at the state level usually carry this valuable information or are described in other historical sources, which help the researchers to find necessary historical metadata. Many publications inform about their origin, purpose and use, such as for example Boguszak and Císař (1961), Kuchař (1958), and Semotanová (2008). Problems arise with the use of regional maps. Information about their authors and purpose are very fragmentary, often are the researchers reliant only on labels in inventory archives or acquisition of data from the map's framing (which is the case of some maps in this study). Basic information on the set of old and historical maps in question are provided in the following overview (institutions disposing of particular map pieces are listed in brackets).

3.1. General maps

1. Müller's Map of Bohemia *(The Institute of History, Academy of Sciences of the Czech Republic)*

Müller's survey of Bohemia in the scale 1 : 132,000 was performed in 1712–1718 (Čáslav region was mapped in 1717) (Čada, 2006b). The map of Bohemia alone was issued in 1722 and was divided into 25 sections. The author, Austrian military cartographer Jan Kryštof Müller, furnished the map with a frame with geographic coordinates. The map hypsography is depicted by 'hillock' method; settlements are shown with simple marks. Topography is supported by dense network of water courses, schematically symbolized green vegetation and communications. In terms of historical landscape study, important places such as farms, mines, abandoned residences, mills, iron-mills, vineyards, smelting-works, glass-works, post offices, etc., are shown (Semotanová, 2002).

2. 1st Military survey *(Geoinformatics Laboratory, University of J. E. Purkyne)*

The maps of the first Military survey (also called Josephinian) were created as a response to the necessity for systematic mapping of the Habsburg monarchy, particularly after the lost seven-year war with Prussia. The mapping was performed in the entire monarchy in the years 1763–1785. In Bohemia, it resulted in 272 map sheets in the scale 1 : 28,800 and 19 volumes of textual description (Cajthaml, Krejčí, 2008). Due to lack of time and limited budget, the maps were created without geodetic bases (triangulation nets). As a result, the guidepost for imperial officers performing the mapping was magnified survey of Müller, which infirmed the principle of mapping, namely that large-scale maps are derived from small-scale maps. Despite the obvious positional inaccuracy, the first Military survey presents invaluable record of the landscape before the superseding industrial revolution. The hypsography is marked by tacking and pseudo-slope hatches (Cajthaml, Krejčí, 2008). The planimetry uses coloring to show the main use of land (fields, meadows and pastures, built--up areas, water areas), further marking shows residences (including elemental marking of individual houses), water courses, churches, manor houses, town walls, post and trade roads, woodland and other cart roads, stone bridges, wells, canals, streams, etc.

3. 2nd Military survey *(Geoinformatics Laboratory, University of J. E. Purkyne)*

The second Military survey (called Franziscean) was also created as a response to military request for updated and accurate maps of the Habsburg monarchy (Veverka et al., 2007). In comparison with the first survey, it had the advantage of more accurate cartographic bases, in particular trig stations with rectangular plane coordinates of the cadastral system (Mikšovský, Zimová, 2006), which were used for the creation of stable cadastre and its metrical apparatus. Even though the works in some parts of the monarchy had started already in 1807, the mapping within the Bohemian region was performed between the years 1836–1852, again in scale 1 : 28,800. Cassini-Soldner's transverse rolling display with undistorted cartographic meridians was used, with the outset of the coordinates for Bohemia in Gusteberg (Cajthaml, Krejčí, 2008). In addition, the survey disposed of regular map sheets, which provided for the creation of maps with smaller

scales by derivation. The hypsography was made with Lehmann's hatches, which illustrated the direction and area of the gradient. The planimetry was specifically modified on the base of given map key (Mikšovský, Zimová, 2006). Regarding its accuracy, many scholars consider this survey as initial in the study of landscape development in the former Habsburg monarchy.

4. 3rd Military survey (*Geoinformatics Laboratory, University of J. E. Purkyne)*

The third Military survey was performed in Bohemia from 1880 to 1885 again as a response to military requests after the war in 1866 (Čada, 2006a). At that time, military maps were frequently used in the civil sector (administrative and economic bodies, etc.). By the decision of the Austrian Secretary of War, the mapping works began in decimal scale 1 : 25,000, for large cities and military areas in 1 : 12,500. Bases for the mapping were again innovated maps from the stable cadastre. The hypsography went through a revolution, when the base was acquired by rapid revision measurements of elevation, set trigonometrically from elevation angle and punched actual range, or with the use of hypsometer respectively in forested areas. The data were then recorded in the maps by a 'combined method' – with spot heights, contour lines, hatching and tacking (Mikšovský, Zimová, 2006). The mapping was processed through Sanson-Flamsteed's projection (Cajthaml, Krejčí, 2008), as reference area was selected Bessel's ellipsoid transferred into the level with spheroid trapezoids. The outset of the cartographic system was the Ferro meridian (though only roughly determined) (Čada, 2006a).

3.2. Regional maps

1. Map of the Battle of Čáslav *(The Institute of History, Academy of Sciences of the Czech Republic)*

The map was created shortly after the battle of Čáslav in May 1742. It is a thematic historical map, an old map showing the deployment of Austrian and Prussian troops. The map's topography is recorded in black color. Along with residences and the most important communications, the stream network, water areas and woods are also shown on the map. The hypsography is indicated by hatches. The map is available in the digitized map collection of the Institute of History, Academy of Sciences of the Czech Republic.

2. Special map *(Čáslav City Museum)*

The variation of a special map from the year 1945 made in the scale 1 : 50,000. The bases for the creation of this map were special maps in scale 1 : 75,000, derived from the third Military survey. The maps served the German occupation forces during the protectorate of Bohemia and Moravia. Digitized map sheets No. 4054 (Ost Kuttenberg) and 4055 (West Tschaslau) were used for research in this study.

3. Handy map of Political district of Čáslav *(Čáslav City Museum)*

The map in the scale 1 : 75,000 was issued by the district school committee in 1933. The author is the First Lieutenant K. Štumpera. The map was apparently based on the

special map from the third Military survey, its topography was updated with many toponyms, though. The map was used as contemporary school aid. It includes colored distinction of terrain, contour line on 50 and 100 m, wood areas including forest aisles, pinpoint signs for sacral and other monuments, alleys, protected trees, abandoned and existing industrial and agricultural facilities, electricity transformers and signboards. Particularly detailed is the record of hydrography and road network.

4. Map of the Čáslav District *(State District Archive in Kutná Hora)*

Map in unknown scale was issued in 1882. Its author is J. Spudil, other cartographic information is unknown. The map disposes color-determined elevation of the territory in several degrees. The content of the map is focused on distinction of road types and completed or planned railroads. Included are also churches, ponds and water courses, water and wind mills, quarries, lodges and sugar refineries.

5. Historical map of Bohemian Kingdom *(State District Archive in Kutná Hora)*

The map in the scale 1 : 537,000 was drawn up by the leading figure of the Czech National Revival of 19th century, a historian and politician František Palacký. It shows the reconstruction of the Czech kingdom in the 14th century using the historical sources. The most significant contribution of the map is that it portrays communications and abandoned settlements of the period. The cartographic base of this map is unknown.

6. Map of the Czaslauer Kreis *(State District Archive in Kutná Hora)*

The map of Čáslavský region was made by F. J. H. Kreibich in 1833. It is a miniature of Müller's map in the scale 1 : 240,000 apparently untouched by trigonometric works in the stable cadastre. It shows individual residences, churches, manor houses, lodges and detailed communications network. Hydrographic network is highly simplified, the terrain is schematically recorded by hatches and woods are marked only by punctual symbols.

3. CASE STUDY AREA

The territory concerned – Čáslavsko (Figure 1) is located in Central Bohemia and administratively is included in NUTS 2 Central Bohemia and NUTS 3 Central Bohemia region. The examined territory covers the area of about 274 sq. km, includes 37 municipalities with total of 25,000 inhabitants and Čáslav with 10,000 citizens as the only town (Czech Statistical Office, 2011). The region has predominantly flat character, shaped by the rivers Doubrava, Brslenka and Klejnarka, which belong to the Labe catchment area. In the north, the territory is bordered by Železné hory (mountain range) and in the south by the elevation of Českomoravská vrchovina (highlands). The region was permanently settled since 12th century, fertile soil and fair climate provided optimal conditions for intensive agriculture. This area was the center of historical Čáslavský region.

Figure 1: Location of study area (red contour)
Slika 1: Lega preučevanega območja (rdeč pravokotnik)

4. METHODS

4.1. Digitizing and tessellation

Maps from the Institute of History and Geoinformatics Laboratory were provided in digital format with satisfactory resolution. Maps from the regional archives had to be scanned in JPEG format, where 600 dpi resolution proved to be adequate for given purpose. It is generally not recommended to make use of digital photos for digitizing of old maps due to problems with distortion and its following complicated removal, which is usually hardly attainable without precious information about the digital camera lens (Dolanský, 2006). Because of large formats of several scanned maps, it was essential to operationally divide the maps into multiple sections and perform the scanning separately. Crucial was keeping certain scanning overlap so the sections could be joined again through tessellation. The mosaic was created with the use of graphic program Corel X5. Due to low number of pictures (maximum 3), it was not necessary to use specialized software like, for example, ERDAS. The tessellation runs through identification of common pivotal points on the borderline map sheets (roads, rivers, protected trees, etc.), thus creating jointless map which can be subsequently rectified.

4.2. Rectification

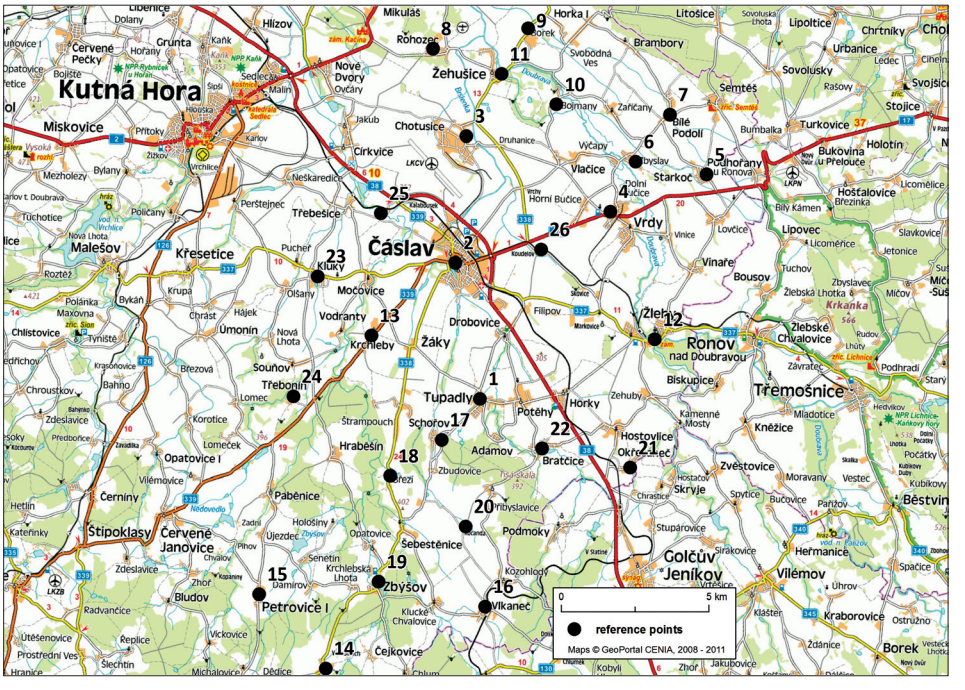
In light of major variability of cartographic coordinate systems, in which the maps in question were issued, it is crucial for the needs of further analyses to transform all the old maps into unified system. For the needs of this study, unified coordinate system S--JTSK was selected, defined by Bessel's ellipsoid with referential point Hermannskogel, employing Křovák's projection, which is double conformal transformation in general

position (Čada, 2011). It is a coordinate system commonly used for modern civil maps in the Czech Republic.

The transfer to unified system was realized through rectification, in which raster data of old maps are transferred via GIS environment into given coordinate system so that they are in their actual position and it could be combined with other, for example, vectorial data. Rectification is carried out through the method of identical points (Cajthaml, Krejčí, 2008; Skaloš et al., 2011; Sprague et al., 2007; Veverka et al., 2007). This method rest in the choice of at least three identical points in the old map and simultaneously in the referential base, which can be a vectorial map or aerial photo related to similar coordinates (Dolanský, 2006). Alternative method of rectification is projective transformation via coordinates of the maps' corners. This method is, however, applicable only for limited number of maps (Cajthaml, Krejčí, 2008; Čada, 2005).

For the needs of this study, the old and historical maps were rectified in the ArcMap program through the instrument Georeferencing (part of ArcGIS Desktop 9.3.1). For the rectification we used 26 explicitly determined and staggered points (Figure 2). For the processing of referential base, WMS Ortofoto ČR was employed, which is provided by the Czech geoportal CENIA.

Figure 2: Layout of the referential points in the area of interest
Slika 2: Lega referenčnih točk na preučevanem območju



4.3. Selection of identical points

Regarding the wide array of examined maps in different scales, projection and coordinates, we used the method of identical points as definitely identified objects in all the maps, which allowed for the finest comparison. The points were equally distributed over the target territory so that no area would be excessively weighted and distortion of results would be eliminated (Dolanský, 2006). It is advisable to select identical points such as crossroads (Sprague et al., 2007), already known geodetic or triangular points, buildings, sacred monuments, bridges, pond dykes and other transversal barriers on water courses (Zimová, 2005).

In terms of identical points selection for this study, particularly the sacred monuments (cathedrals, churches, chapels) and manor houses (residences of nobility) were selected, which have a long history in the selected territory and their position practically didn't change over the centuries (see Appendix 1). In addition, it is presumable that exactly these objects served as referential points for the authors of small-scale maps (Müller's survey, Historical map of Bohemian Kingdom, Map of the Czaslauer Kreis), marked by pinpoint signs. Many of the church towers and chapels were also included into historic triangulation networks due to its scenic dominance and thus served as bases for mapping (Čada, 2003). By contrast, the inclusion of crossroads proved to be inadvisable as the field research discovered frequent changes in their routing and crossing (see Appendix 2). They were thus used only in exceptional cases where no other identical point could be found in the vicinity. Impracticable was also the use of the pond dykes as most of the historical ponds in the region don't exist anymore (Frajer, Chmelová, 2006). The categories of individual identical points are shown in Table 1, while Table 2 provides for their detailed overview.

Table 1: Categories of identical points
Preglednica 1: Vrste identičnih točk

Categories of identical points	Number of points
Sacred monuments (church, cathedral, chapel)	16
Residences of nobility (castle, manor house)	6
Crossroad	3
Other objects (inns, yards etc.)	2

Table 2: Identical points overview
Preglednica 2: Pregled uporabljenih identičnih točk

No.	Cadastre	Category of point	Point name	First mentioned*
1	Tupadly	residence of nobility	castle	1635[1]
2	Čáslav	sacred monument	St. Peter and Paul's Cathedral	13th century[1]
3	Chotusice	sacred monument	St. Wenceslaus Church	1369[1]
4	Dolní Bučice	sacred monument	All Saints Church	1352[1]
5	Starkoč	sacred monument	Assumption of Virgin Mary Church	1352[1]
6	Zbyslav	sacred monument	Holy Trinity Church	1660[1]
7	Bílé Podolí	sacred monument	St. Wenceslaus Church	17th century[1]
8	Rohozec	sacred monument	St. Mary Magdalene Church	no evidence[1, 2]
9	Borek	crossroad	-	before 1700
10	Bojmany	crossroad	-	before 1700
11	Žehušice	residence of nobility	castle	1679[1]
12	Žleby	residence of nobility	castle	1289[1]
13	Krchleby	residence of nobility	former castle	1655[1]
14	Dobrovítov	sacred monument	St. Wenceslaus Church	1355[1]
15	Petrovice I	sacred monument	St. Wenceslaus Church	13th century[3]
16	Vlkaneč	sacred monument	St. Wenceslaus Church	1352[1]
17	Schořov	sacred monument	St. Mary's Chapel	1697[1]
18	Březí	crossroad	-	before 1700
19	Zbýšov	sacred monument	St. John the Baptist Church	1331[1]
20	Kocanda	other object	inn	17th century
21	Okřesaneč	sacred monument	St. Bartholomew's Church	1352[1]
22	Bratčice	sacred monument	St. Wenceslaus Church	1352[1]
23	Kluky	residence of nobility	castle	1660[1]
24	Třebonín	sacred monument	St. Matthew's Church	1352[1]
25	Lochy	sacred monument	St. Boniface's Church	1352[2]
26	Koudelov	other object	yard	16th century[1]

**Sources/Viri: (1) Birnbaumová (1929) (2) Kibic ml. (2010) (3) http://www.petrovice.estranky.cz*

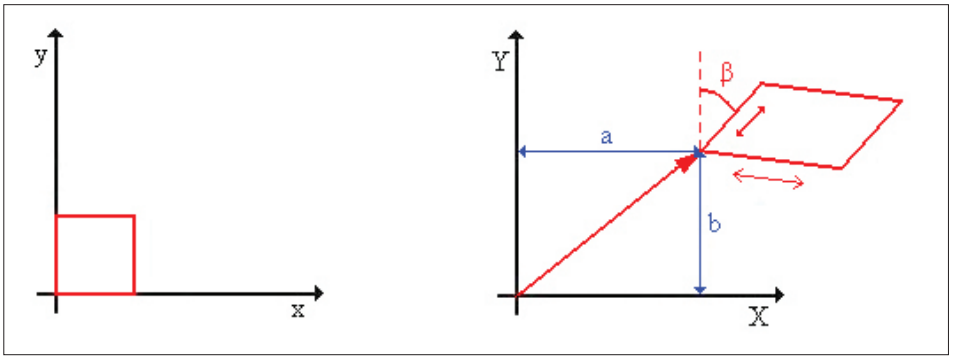
4.4. Transformation and setting of RMSE variation

Identical points are transferred into selected cartographic coordinates via transformation. Several types of transformation exist: parallel transformation, polynomial transformation, rubber sheetings, etc. (Dolanský, 2006). Affined transformation was selected for

the territory in question. It is a special case of polynomial transformation, particularly for the first grade polynomial. From the geometry's point of view, that is the translation, rotation and sloping of the grid.

The use of affined transformation is convenient from several aspects: The observed territory has considerably small area – about 20 by 15 km – thus it can be projected on a working plane. The use of higher grade transformation is more suitable for larger areas (i.e. regions). Affined transformation also provides for minimal distortion of historical map on its margins. Moreover, individual coordinates are transformed independently (in contrast to linear conformal transformation). Figure 3 clearly shows how the affined transformation can distort the input data (Fajt, 2003).

Figure 3: The principle of affined transformation (Fajt, 2003)
Slika 3: Princip afine transformacije (po Fajt, 2003)



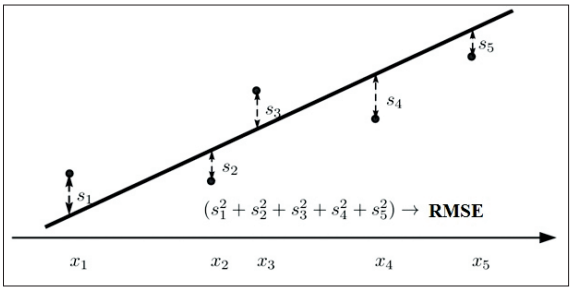
It is evident that the square has been, in comparison to the outset of the coordinate system, dislocated and indexed. In addition, it has also been enlarged and skewed. At least three pairs of identical points are required. Affined transformation is generally used for transformation of tablet coordinate system into the system of map coordinates during the digitizing process.

The transformation reference is then: $X = qRx + k = q\begin{pmatrix}\cos ß & -\sin ß \\ \sin ß & \cos ß\end{pmatrix}\begin{pmatrix}x \\ y\end{pmatrix}+\begin{pmatrix}a \\ b\end{pmatrix}$, where $q = (q_x, q_y)$.

The resultant transformation does not notably distort the drawing of the map and provides for improved information about the original map even at the expense of larger positional distortions. The use of polynomial transformations of higher grade or rubber sheeting without deviation would anchor identical points, but the grid of the map would be considerably deformed. These transformations are suitable for large areas, eventually for the comparison of landscape changes and development of water courses and water areas (Cajthaml, Krejčí, 2008).

Root Mean-Squared Error (RMSE) method was set for individual transformed points to review their positional accuracy. It is a sum of squares of difference between reference S_t and estimative S'_t, with the use of the smallest quad method (Figure 4). The higher is the RMSE value, the less the rectified map matches with its base (here: the ortophoto map of the Czech Republic).

Figure 4: Principle of RMSE calculation via the method of the smallest quads
Slika 4: Način izračunavanja srednje kvadratne napake po metodi najmanjših kvadratov



5. RESULTS

In georeferencing and transformation of the whole set of maps, RMSE was determined for each map and the results were compared to one another. The values of RMSE are listed in descending order in Table 3.

Table 3: Resultant values of RMSE
Preglednica 3: Dobljene vrednosti srednje kvadratne napake (RMS)

Map	RMSE
Map of the Czaslauer Kreis	847,82
Müller's map of Bohemia	673,26
1st Military survey	638,07
Battle of Čáslav	433,39
Historical map of Bohemian Kingdom	278,13
Political District of Čáslav	267,21
Special map	45,70
2nd Military survey	34,79
Handy map of Political district of Čáslav	33,80
3rd Military survey	29,17

The results show that highest deviations were recorded in the oldest maps, as expected – i.e. Müller's and the 1st Military survey. The deviations reach the values over 650 m. Considering the approximation of these deviations in both surveys, it is proven that the military geodesists used Müller's maps for the elaboration of the 1st Military survey and were able to improve their planimetry during the field surveys.

As surprising we consider the RMSE results for the oldest map – Map of the Battle of Čáslav, which shows relatively low positional inaccuracy, probably due to small scale and the fact it projects the battleground. Interesting are also the results of the Map of the Czaslauer Kreis, which is apparently based on Müller's survey, but is, by contrast, more inaccurate. The maps of the 2nd and 3rd Military survey show very slight RMSE deviation on the ground of the use of developed triangular nets for their elaboration. The Special map, based on the 3rd Military survey, discloses higher deviance as a result of smaller scale. Spudil's map Political District of Čáslav disclosed extreme deviance in two referential points, evidently caused by the author's inaccurate placement of sacred monuments in the horizontal projection of villages. These points were therefore not included into average positional deviation as it would significantly distort the overall result. Relatively satisfactory results were also recorded in Palacký's Historical map of Bohemian Kingdom, despite its rather schematic planimetry.

6. DISCUSSION

The results of positional accuracy analysis of old and historical maps largely validated the input hypothesis. The use of antiquated maps elaborated without triangular nets is rather problematic within GIS. Nonetheless, if we decide to 'respect' significant positional deviations, these maps can become valuable source of information for future analyses. Partial elimination of inaccuracy can be achieved by increasing the number of identical points used for georeferencing, which have to be evenly distributed over the given area, if possible. For more detailed studies, however, which require maximum accuracy, it is recommended to use old maps elaborated on the base of triangular networks. Other maps can then be used only for visual interpretation.

The accuracy of geodetical bases of old maps and their cartographic transformation is in the Czech Republic discussed by many authors (e.g. Brůna, Křováková, 2006; Čada, 2001, 2006a, 2006b; Krejčí, Cajthaml, 2007; Pešťák, Zimová, 2005; Šilhavá, 2006; Veverka, 2005, 2007) and for comparison we also include results of positional deviation within different territories in question (Table 4). Different results are related to the extent of studied area, selection and number of identical points and to the accuracy of mapping by individual groups of geodesists participating in the elaboration of the old maps.

The potential for further examination lies especially in Müller's and the 1st Military survey. Despite their considerable positional inaccuracy, these maps contain a treasure of information about landscape before the industrial revolution. Individual categories of their identical points could be the scope of further study of positional accuracy. That is to say, if we consider these maps were elaborated for military purposes, the recorded

strategic points (ridges, fords, crossroads, mills, etc.) should have higher positional accuracy than other points. At the same time, the maps should be more accurate in flat area than in dissected area (due to the use of surveyor cars and pacing). Rigorous analysis of Müller's mapping is required, especially his cartometric comparison with older map sheets, on which J. K. Müller could have possibly based his own work. The authors of this study plan to explore these subjects in their further works.

Table 4: Average RMSE in different areas of interest
Preglednica 4: Povprečna srednja kvadratna napaka na drugih preučevanih območjih

Authors	Examine map	Area of interest	Average RMSE
Krejčí, Cajthaml (2007)	Müller's Map of Bohemia	unknown	1938
Frajer, Geletič (2011)	Müller's Map of Bohemia	Čáslav	848
Mikšovský, Zimová (2006)	Müller's Map of Bohemia	Jindřichův Hradec	626
Veverka et. al. (2007)	1st Military survey	Nové Město	870
Mikšovský, Zimová (2006)	1st Military survey	Jindřichův Hradec	705
Frajer, Geletič (2011)	1st Military survey	Čáslav	638
Pešťák, Zimová (2006)	1st Military survey	Sušice	336
Veverka et al. (2007)	1st Military survey	Jindřichův Hradec	160
Veverka et al. (2007)	2nd Military survey	Jindřichův Hradec	< 50
Pešťák, Zimová (2006)	2nd Military survey	Sušice	49
Frajer, Geletič (2011)	2nd Military survey	Čáslav	35
Frajer, Geletič (2011)	3rd Military survey	Čáslav	29
Cajthaml, Krejčí (2008)	3rd Military survey	Neveklov	21

References

Map sources:
Čáslav City Museum:
Handy map of Political district of Čáslav; Special map
Geoinformatics Laboratory, University of J. E. Purkyne/ Austrian State Archive/Military Archive, Vienna: 1st Military survey, sections No. 146, 128 and 164; 2nd Military survey, sections No. O_9_VI, O_9_VII, O_10_VI and O_10_VII; 3rd Military survey, sections No. 4054_2, 4054_4, 4055_1 and 4055_3
State District Archive in Kutná Hora: Historical map of Bohemian Kingdom; Map of the Czaslauer Kreis; Political district of Čáslav
The Institute of History, Academy of Sciences of the Czech Republic: Müller's Map of Bohemia. Cimélie Mapové sbírky Historického ústavu AVČR na CD-ROM (2002).
Slacht bei Czaslau, 17. Mai 1742

Baily, B., Riley, M., Aucott, P., Southall, H., 2011. Extracting digital data from the first Land Utilisation Survey of Great Britain – methods, issues and potential. Applied geography, 31, p. 959–968. Sevenoaks.

Barclay, G., 2005. Farmers, temples and tombs (Making of Scotland). Edinburgh, Birlinn Press, 64 pp.

Bičík, I., 1998. Land use in the Czech Republic 1845–1948–1990. Methodology, interpretation, contexts. Acta Universitatis Carolinae, Geographica, 32, Supplement. Praha.

Birnbaumová, E., 1929. Soupis památek historických v okrese Čáslavském. Čáslav.

Boguszak, F., Císař, J., 1961. Vývoj mapového zobrazení území ČSSR III. Mapování a měření českých zemí od poloviny 18. století do počátku 20. století. Praha.

Boltižiar, M., Brůna, V., Chrastina, P., Křováková, K., 2008. Potential of antique maps and aerial photographs for landscape changes assessment – an example of the High Tatra Mts. Ekológia, 27, 1, p. 65–81. Bratislava.

Brůna, V. Křováková, K., 2006. Staré mapy v prostředí GIS a internetu. GEOS 2006. Zdiby.

Bürgi, M., Hersperger, A. M., Schneeberger, N., 2004. Driving forces of landscape change – current and new directions. Landscape ecology, 19, 8, p. 857–868. Amsterdam.

Cajthaml, J., Krejčí, J., 2008. Využití starých map pro výzkum krajiny. Sborník z konference GIS Ostrava, 27.–30. 1. 2008, p. 1–10. Ostrava.

Cousins, S. A. O., 2001. Analysis of land-cover transitions based on 17th and 18th century cadastral maps and aerial photographs. Landscape ecology, 16, 1, p. 41–54. Amsterdam.

Czech Statistical Office. URL: http://www.czso.cz/xs/redakce.nsf/i/2104_so_orp_caslav (Cited 12. 8. 2011).

Čada, V., 2001. Využití geodetických základů stabilního katastru, historie vzniku a užití mílových tabulek. Geodetický a kartografický obzor, 47, 10, p. 271–280. Praha.

Čada, V., 2003. Robustní metody tvorby a vedení digitálních katastrálních map v lokalitách sáhových map. Habilitation thesis. Plzeň.

Čada, V., 2005. Geodetické základy mapových děl 1. poloviny 19. století a lokalizace do S-JTSK. Zborník z vědeckej konferencie Historické mapy, p. 35–47. Bratislava.

Čada, V., 2006a. Analýza lokalizace rastrových ekvivalentů III. vojenského mapování do S-JTSK. Sborník konference Geoinformatika ve veřejné správě, p. 1–6. Brno.

Čada, V., 2006b. Kartometrická kvalita Müllerovy mapy Čech. URL: http://home.zcu.cz/~cada/www-kma/download/Kartometricka_kvalita_Mullerovy_mapy_Cech.pdf (Cited 15. 8. 2011).

Čada, V., 2011. Souřadnicové systémy. Přednáškové texty z Geodézie. URL: http://gis.zcu.cz/studium/gen1/html/index.html (Cited 15. 8. 2011).

Dohnal, M., 2006. Vesnická sídla a kulturní krajina na Táborsku v 15.–19. století. Národopisná knižnice, 41. Praha.

Dolanský, T., 2006. Metodika zpracování historických mapových podkladů. URL: http://mapserver.fzp.ujep.cz/hmu/dokumenty/metodika.pdf (Cited 15. 8. 2011).

Domaas, S. T., 2007. The reconstruction of past patterns of tilled fields from historical cadastral maps using GIS. Landscape research, 32, 1, p. 23–43. Manchester.

Frajer, J., Chmelová, R., 2006. Historie rybníkářství na Čáslavsku. Sborník příspěvků 21. konference ČGS Česká geografie v evropském prostoru, p. 1126–1136. České Budějovice.

Gregory, I., Healey, R., 2007. Historical GIS: structuring, mapping and analysing geographies of the past. Progress in human geography, 31, 5, p. 638–653. London.

Jenny, B., Hurni, L., 2011. Studying cartographic heritage: Analysis and visulization of geometric distortions. Cumputers & Graphics, 35, 2, p. 402–411. New York.

Kavalír, M., 1985. Několik poznámek o tzv. Klaudyánově mapě Čech z r. 1518 a významu starých map jako historického pramene. Historická geografie, 24, p. 7–30. Praha.

Kibic K. ml., 2010. Středověká venkovská a sakrální architektura na Čáslavsku. Vlastivědná knihovnička SPS, 17. Praha.

Knowles, A., Hillier, A,. 2008. Placing history: How maps, spatial data, and GIS are changing historical scholarship. New York, ESRI Press, 313 pp.

Kuchař, K., 1958. Naše mapy odedávna do dnes. Praha, 129 pp.

Leriche, A., Boudouresque, C.-F., Bernard, G., Bonhomme, P., Denis, J., 2004. A one--century suite of seagrass bed maps: can we trust ancient maps? Estuarine, coastal and shelf science, 59, 2, p. 353–362. London.

Lipský, Z., 2002. Identifikace historického vývoje krajinné struktury s využitím starých map. Krajina 2002. Od poznání k integraci. Ústí nad Labem.

Neoficiální stránka přátel obce Petrovice na Kutnohorsku. URL: http://www.petrovice.estranky.cz/ (Cited 12. 8. 2011).

Novák, P., 2001. Paměť krajiny. Novodvorsko – Žehušicko. Kutná Hora.

Pavelková Chmelová, R., Netopil, P., 2007. Historické letecké snímky v geografickém výzkumu – problémy při jejich zpracování a možná řešení. Miscellanea geographica, 13, p. 129–136. Plzeň.

Pearson, A., Collier, P., 1998. The integration and analysis of historical and environmental data using a geographical information system: Landownership and agricultural productivity in Pembrokeshire c. 1850. URL: http://www.bahs.org.uk/46n2a3.pdf (Cited 16. 8. 2011).

Pešťák, J., Zimová, R., 2005. Polohová přesnost objektů na mapách prvního a druhého vojenského mapování. Kartografické listy, 15, p. 1–9. Bratislava.

Petek, F., Urbanc, M., 2004. The Franziscean land cadastre as a key to understanding the 19TH-century cultural landscape in Slovenia. Acta geographica Slovenica, 44, 1, p. 89–113. Ljubljana.

Roper, C., 2003. Historical mapping is still under-valued and under-used. The cartographic journal, 40, 2, p. 131–134. London.

Semotanová, E., 2001. Mapy Čech, Moravy a Slezska v zrcadle staletí. Praha, Libri, 263 pp.

Semotanová, E., 2002. Müllerova mapa Čech z roku 1720 a Müllerova mapa Moravy z roku 1716 ve vydání z roku 1790. URL: http://oldmaps.geolab.cz/map_root.pl?z_height=500&lang=cs&z_width=800&z_newwin=0&map_root=mul (Cited 15. 8. 2011).

Semotanová, E., Kykal, T., Munzar, Z., Fiala, Z., Karas, Z., 2008. Czech lands on early maps. Praha, Ministry of defense of Czech Republic, 133 pp.

Sprague, D. S., Iwasaki, N., Takahashi, S., 2007. Measuring rice paddy persistence spanning a century with Japan's oldest topographic maps: georeferencing the Rapid Survey Maps for GIS analysis. International journal of geographical information science, 21, 1, p. 83–95. London.

Skaloš, J., Weber, M., Lipský, Z., Trpáková, I., Šantrůčková, M., Uhlířová, L., Kukla, P., 2011. Using old military survey maps and ortophotograph maps to analyse long--term land cover changes – Case study (Czech republic). Applied geography, 31, 2, p. 426–438. Sevenoaks.

Sklenička, P., Lhota, T., 2002. Landscape heterogenity – a quantitative criterion for landscape reconstruction. Landscape and urban planning, 58, 2–4, p. 147–156. Amsterdam.

Šilhavá, P., 2006. Topografické mapy II. vojenského mapování v oblasti Vitorazska. Diploma thesis. Plzeň.

Trpáková, I., Trpák, P., 2008. Historická krajina území kolem Špičáku v období stabilního katastru: modelový příklad katastrů obcí Hodňova a Olšiny. Sborník Prachatického muzea Zlatá Stezka, 15, p. 315–327. Prachatice..

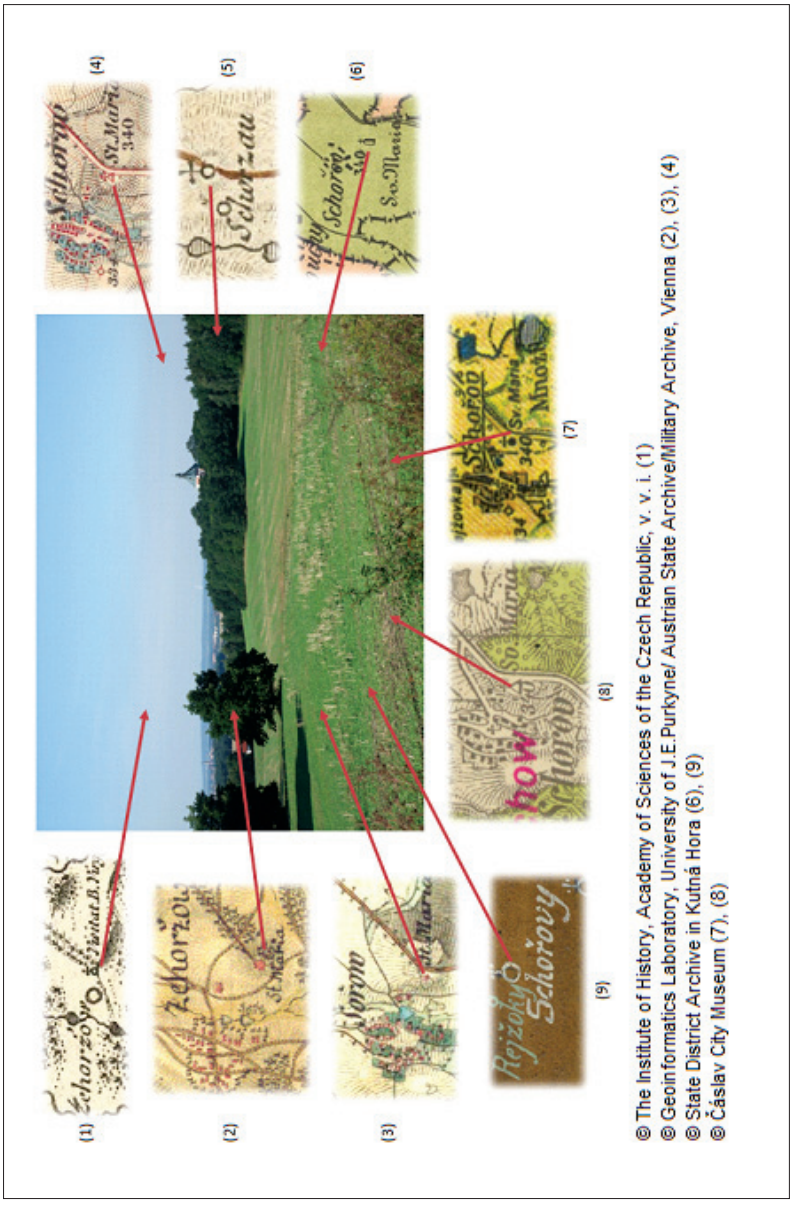
Zimová, R., 2005. Kartografická analýza map historických vojenských mapování. Geografické aspekty středoevropského prostoru. Sborník ze 13. mezinárodní konference 6.–7. 9. 2005. Brno. URL: http://projekty.geolab.cz/gacr/a/files/zimova.pdf (Cited 15. 8. 2011).

Veverka, B., 2005. Vývoj software pro lokalizaci map 2. a 3. vojenského mapování. Sborník vědecké konference Historické mapy, 17. 3. 2005, p. 239–245. Bratislava.

Veverka, B., Mikšovský, M., Zimová, R., Cajthaml, J., Krejčí, J., Pešťák, J., 2007. Georeferencing and cartographic analysis of historical military mappings of Bohemia, Moravia and Silesia. http://projekty.geolab.cz/gacr/b/files/cajthaml_al_4_07.pdf. (Cited 29. 8. 2011).

Williams, J. H., 2007. The archeology of Kent to AD 800. Woodbridge, Boydell Press, 304 pp.

Appendix 1: An example of identical point – St. Mary's Chapel near the Schořov village, on the dataset of old maps: (1) Müller's Map of Bohemia, (2) 1st Military survey, (3) 2nd Military survey, (4) 3rd Military survey, (5) Map of the Czaslauer Kreis, (6) Political District of Čáslav, Handy map of Political district of Čáslav (7), Special map (8), Historical map of Bohemian Kingdom (9); photo by J. Frajer, 2011



Appendix 2: The position change of road crossing– picture shows a change of position of crossroads near the village Zbýšov. The original road (yellow) in time of Ist Military survey led along the pond dam (1). After drying of the pond in the 19th century, course of road has been changed – the road has been straightened (red) and put on the former dam (3), and also the original intersection shifted for about 60 m (2).