Detailed Digital Terrain Models in the Research of Deserted Settlement: Hydrological Modelling and Environment of Settlement Areas

Lukáš Holata and Radek Světlík

Abstract This paper presents the use of detailed terrain models in archaeological research. We apply a LiDAR data (DTM of the 5th generation provided by the Czech Office for Surveying, Mapping and Cadastre) in the areas of five villages abandoned during the 15th and the 17th century. Surveyed sites are preserved in the woodlands in the form of relief formations and there have been carried out many surface surveys and geodetic-topographic surveys. Except the detection of previously unknown remains of human activities in LiDAR data (especially field boundaries, tracks or mining areas) we use also an analytical potential of detailed DEM to affect parameters of physical landscape. In particular, we focused on the attachment of deserted villages to water sources and slope gradient of their ploughlands. This allows us to reopen the old-fashioned questions regarding the role of the natural environment in shaping cultural landscape and try to answer them in the new perspective. Although three of considered deserted villages are situated outside of water sources, hydrological modelling of DTM 5G generates higher values of topographic wetness index within close proximity to each of these villages. The ploughlands of deserted villages were situated also in the areas with high slope gradient. These outcomes extend or revised the 'traditional statements' in older Czech literature.

Keywords LiDAR data · Deserted villages · Reconstruction of settlement areas · Hydrological modelling · Late middle ages and early modern period

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1 Introduction to the Archaeological Research of Woodlands and Deserted Medieval and Post-medieval Settlement

Except excavations, archaeology is also based on non-intrusive methods of field survey and tries to collect data from the surface. Particular remains of past human activities are preserved on the surface in the form of relief formations up to the present time. In the central Europe, these anthropogenic micro-topographic features can be discovered especially in the current woodlands (e.g. Kuna and Tomášek 2004). One of the most numerous types of sites preserved in this environment are deserted medieval (or post-medieval) villages, in many cases including their hinterlands (field boundaries, tracks, mining areas etc.; for the Czech Republic e.g. Klápště 1978; Smetánka and Klápště 1981; Černý 1992; Vařeka 2006, 2009). These monuments testify for the extensive reduction of settlement patterns particularly during the 14th and 17th century which occurred across most of Europe. Therefore, deserted settlements provide an extraordinary opportunity to study medieval or post-medieval rural environment and the research with quantity of themes or subtopics has a very long tradition within several disciplines (cf. several titles from different European regions: Beresford 1954; Beresford and Hurst 1971; Chapelot and Fossier 1985; Gissel et al. 1981; Nekuda 1975; Pohlendt 1950; Smetánka 1988).

New element in the research concerning deserted settlement is represented by airborne laser scanning (ALS). In the Czech archaeology, LiDAR data has been applied from 2011; currently Digital Terrain Model of the Czech Republic—5th generation (DTM 5G) is used in the largest extent. This technique in the research of deserted settlement has been usually applied to detect still unknown relief formations and thus for localisation and identification of new or hitherto unrecorded traces of past human activities which should be subsequently verified by surface survey—ground-truthing (cf. Lasaponara et al. 2010; Čapek 2013; Čapek et al. 2013). There is necessary to note that LiDAR data is particularly suitable for recording of the line features (field boundaries, tracks) which are on the contrary very hardly documented by surface survey (e.g. Klápště 1978; Smetánka and Klápště 1981)—some parts of these features could be only up to 0.5 m above/under level of terrain and thus visible only within specific conditions (to the general difficulties with the archaeological researches in the woodlands cf. Crow et al. 2007; Doneus and Neubauer 2008; Lennon and Crow 2009). Therefore, LiDAR data has changed the current state of the art because the previous reconstruction of medieval field patterns has been only sporadic (considered as an effect of woodland management; remarkable exception is constituted by numerous traces of deserted medieval fields in Drahany uplands—Černý 1992).

Nevertheless, the application of DTM 5G is much wider. This data has an extraordinary potential in many surface analyses and to study (micro)topography of deserted settlement compared to DEMs generated from different sources (e.g. The geographic base data of the Czech Republic—ZABAGED). This allows us to reopen the old-fashioned questions (often still unanswered) regarding the role of natural environment in the life of past communities. Czech archaeology and historical geography was concerned with the environment of medieval villages, role of natural parameters in selection of settlement areas or their abandonment especially in 1970s and 1980s. Although these interpretations were considered later as 'environmentally deterministic', recent works in historic landscape research have started to re-explore the role of the natural environment in shaping cultural landscapes (especially Williamson 2004; recently Rippon et al. 2014).

On the basis of LiDAR data, we have focused on the two parameters of physical landscape—hydrological character (drainage or water flows reconstruction) and topography (slope gradients of ploughlands). Both parameters have been considered (together with other factors—geological, pedological, geomorphological, climatic etc.) as significant in the location of settlement as well as in the existence of village communities, especially with regard to rural economy (cf. Klápště 1973, 1978; Pokorný 1973; Smetánka 1973, 1978; Snášil 1976; Kalina 1978; Žemlička 1978; Boháč 1983). Despite the fact that direct attachment of settlements to the water sources (streams, spring areas) is usually mentioned, three of considered deserted villages (Bukov, Kamenice and Sloupek) are situated outside of these positions (on the basis of surface surveys and ZABAGED). Therefore, through the hydrological modelling we try to determine hypothetical flows and other water sources in past landscape and explore the limits of water supply. Lay-out of ploughlands has been only estimated to favourable areas with only vague statements about agricultural exploitation of slight slopes. Despite many attempts, there still lacks a particular idea in which environment of the ploughlands could be extended. The aim of the paper is to assess the validity of previous statements using new techniques (ALS) in research.

2 Source Data and Methodology

DTM 5G provided by the Czech Office for Surveying, Mapping and Cadastre were taken for the study areas in the Pilsner region (Fig. 1). These data is the part of west zone of the scanning in the Czech Republic (with using of Riegl LMS-Q680) which was realised from the 11th October 2010 to the 27th June 2011. The altitude was determined 1200 m over ground level for woodlands areas. Data were delivered in ASCII format. Final data are represented as the irregular network of elevation points with density of ca. 0.3/m^2. These data has been evaluated in ArcMap 10.2 and Surfer 12. At first, it has been interpolated to DEMs with using algorithm Natural Neighbor (cell size is 0.5 m). Micro-topographic features including anthropogenic relief formations have been revealed by the method of anisotropic Sky-view factor (Zakšek et al. 2012).

Final DTMs have been confronted with the previous results of the surface surveys and geodetic-topographic surveys in the areas of five deserted villages (cf. Veselá 2006, 2008; Holata 2009; Vařeka et al. 2011). Abandonment of

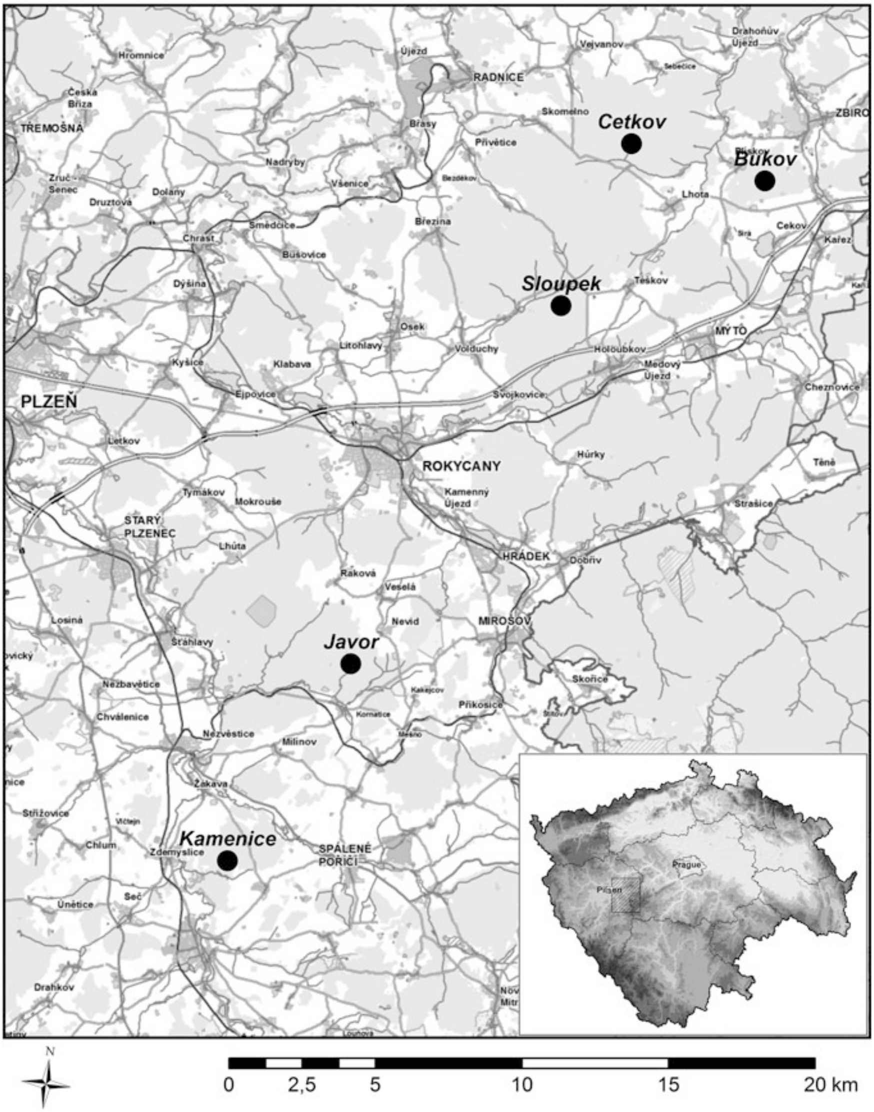

Fig. 1 Location of deserted villages mentioned in the text

Kamenice, Javor and Sloupek is dated (according to the written sources and pottery) to the first half of the 15th century; Bukov and Cetkov had more complicated settlement evolution and survived in shrunken form up to the first half of the 17th century (Rožmberský 2006, 2009). Questionable features in DTMs with more difficult interpretation have been verified by recent authors' surveys. The position and shape of the detected anthropogenic relief formations have been documented by GPS (Trimble Pathfinder ProXH in recent year) and total station (Leica TCR 407)

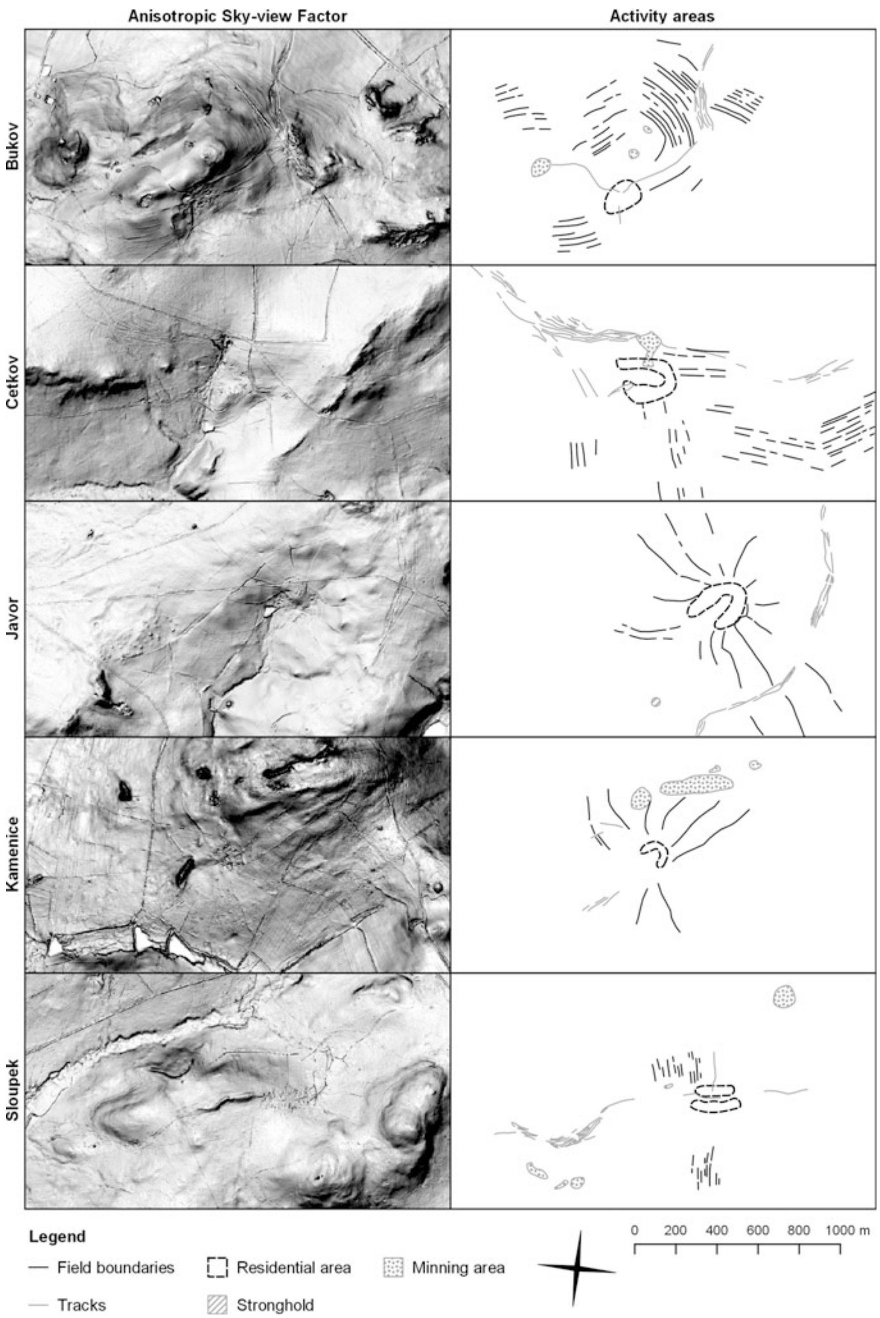

Fig. 2 DTMs of the broader areas involving deserted villages (visualised by anisotropic sky-view factor) and reconstruction of particular activity areas

and displayed on these DTMs as 'shapefile layers'. These both independent sources mutually validate each other and according to the identical morphological characteristics of other earthworks visualised by LiDAR data in the areas of deserted villages could be included to the resulting projections displaying particular activity areas (Fig. 2).

Both spatial analyses demand particular corrections of source LiDAR data. For the purpose of hydrological modelling of the past landscape, the recent features (especially roads and forest ways) had to be manually eliminated because of fundamental impact on flows and water accumulation. These "filtered" data has been applied to generation of new DEMs which constitute the bases for hydrological modelling in high resolution. It was realised in QGIS and SAGA GIS with using of SAGA Wetness Index algorithm (Böhner et al. 2002) for computing of modified Topographic Wetness Index (TWI) for three deserted villages currently without a direct attachment to the water sources. TWI is commonly used in prediction or distribution maps of archaeological sites in small scales (cf. Andresen 2008; Bevan et al. 2013). However, the calculation of TWI based on high resolution DEM can also reveals a local spatial patterns of hydrological character which can be very useful in archaeological interpretation of past land management and attachment to the water sources. Subsequently, also DEMs used for slope analysis had to be modified. The exact values of slope gradient in the areas of original fields are influenced by the later or recent features, especially by many windfalls or charcoal burning platforms (relatively dated to Early modern period) which overlay the medieval fields. Therefore, DEMs for slope analysis have been smoothed by the Low-pass filter. These corrections enable the approximation of DEMs to the original, medieval conditions without later disturbances and modifications (cultural and natural). Nevertheless, the critical evaluation of these bases is necessary. Potential transformations of the relief (e.g. extensive soil erosion) during the existence of village communities can be affected only by the systematic empirical research. This is the epiphenomenon of every research concerning the past landscape which should be overcome by testing the results in the broader geographical perspective.

3 Results

3.1 Hydrological Modelling

Hydrological modelling of the modified DTMs covers broader areas of Bukov, Kamenice and Sloupek. Due to the locations of these deserted villages on the hillsides or local saddles, the possibilities of using the surface water were limited. It is also indicated by ZABAGED (Fig. 3) where all these deserted villages are situated outside of streams. Therefore, the rainwater utilisation has been expected, as is evidenced by the presence of many small ponds or wells inside the residential areas or in their close proximity.

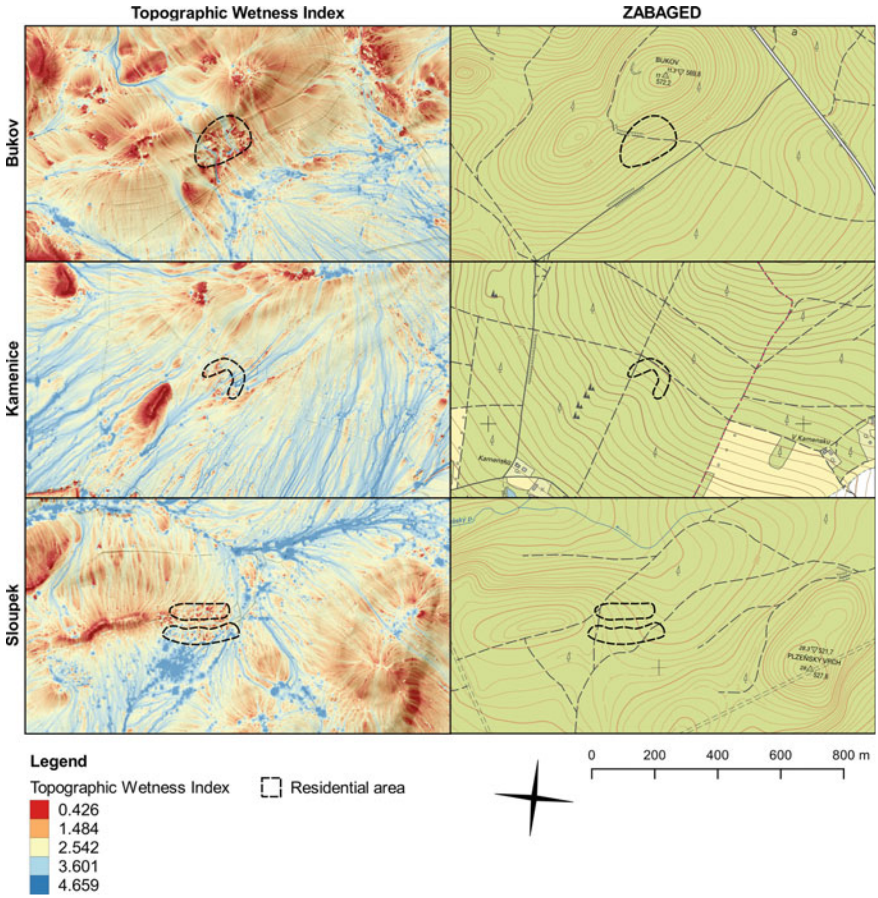

Fig. 3 Hydrological modelling on the basis of LiDAR data in the areas of three deserted villages compared with more general topography (ZABAGED)

High values of topographic wetness index indicate also the hypothetical flows or the areas with higher soil moisture just within close proximity to each of these villages (Fig. 3). In the case of Bukov and Kamenice there are apparent flows or concentrated drainage through their residential areas. Although the flow in Bukov is lesser evident, it is supplemented by the area with water accumulation in the southeast. Kamenice has several variously abundant flow accumulations in or around residential area. Deserted village Sloupek lies in the watershed with drainage to the north and south. Larger spring area is occurred in the east end of the residential area. Also the extensive area of soil moisture is situated behind the southern margin of this village. In addition, one more trend is apparent in the case of all these villages. There is certain extent of area around them with lower values

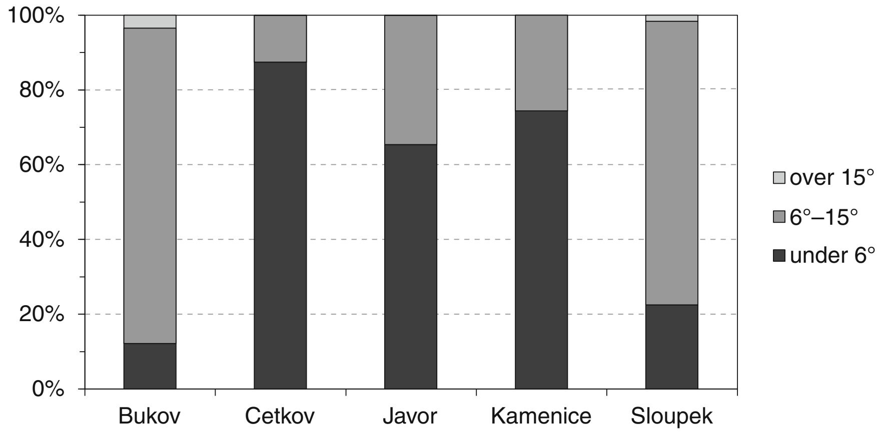

Fig. 4 Fields of deserted villages with the results of slope analysis

of topographic wetness index indicating the smaller flow accumulation or even dry areas. These areas correspond (at least partially) with the traces of ploughlands.

3.2 Slope Analysis of the Fields

Slope analysis has been done for the complete set of deserted villages. They can be divided into two groups according the slope gradient of detected segments of their fields (Fig. 4). The first group includes the villages of Cetkov, Javor and Kamenice. Their fields occupied relatively mild slopes (Mean 4.5°–5.3°). Although ploughland in Cetkov reaches the maximal value of this dataset (28°), it is represented by anomaly in DTM caused by the recent and unfiltered feature (0.09 % over 15°). The ploughlands in Javor and Kamenice also do not extend in this steep slope. The biggest part of the first group's fields is situated in areas under 6° (65–87 %). Nevertheless, particular segments fell also into steeper slopes up to 15° (12–34 %).

The second group is represented by Bukov and Sloupek. Their detected parts of fields are characterised by higher vertical articulation (Mean 8.6°–9°). Bigger portion of their ploughlands (74–87 %) was laid out in the areas which are affected by water erosion (over 6°) in greater extent (Šarapatka et al. 2002) whereas small extent is situated in mild slopes under 6° (12–22 %). The small parts of detected ploughlands in Bukov and Sloupek reached over 15° (1.6–3.4 %) which is considered as absolutely inappropriate for agriculture (Kolejka et al. 2009).

4 Conclusion

The paper presents the using of detailed terrain models generated by ALS in the archaeological research of deserted medieval or post-medieval rural settlement. These DTMs visualised by specific method (Anisotropic Sky-view factor has been used in this paper) are primarily applied to the identification and localisation of the remains of past human activities preserved as anthropogenic relief formations in woodlands. Together with the results of surface surveys they enable the reconstruction of the original settlements areas (villages with their hinterlands). However, these detailed DTMs have also broader analytical potential and it is possible to apply them in the study of deserted villages' environment.

We tested the premise involved in older literature that medieval settlement had a direct attachment to the water sources. This relationship has not been proved in the case of three surveyed deserted villages in Pilsner region by surface survey or with using of more general map basis (ZABAGED). Therefore, we applied hydrological modelling based on DTM 5G in these transects. The results demonstrate hypothetical flows or areas with higher soil moisture within residential areas or in their close proximity. All these villages were attached to water sources, their communities utilised rainfall water that was accumulated also in numerous water reservoirs or wells near the farmsteads. These outcomes extend previous statements on other suitable village locations in term of water supply. In this context, another factor can be relevant; all three pursued villages are also surrounded by the areas with smaller flow accumulation or even dry areas. Prevailing overlay with the traces of ploughlands is considered as unexpected and very interesting. The significance of this trend can be assessed only after inclusion of other deserted villages in the research. Currently we cannot exclude also the influence of post-depositional transformation in disappearance of field remains in the areas characterised by higher flow accumulation.

The lay-out of ploughlands in term of slope gradient has been only estimated to the favourable conditions in slight slopes. Specific visualisation of DTM 5G combined with surface surveys recorded field boundaries of deserted villages also in steeper slopes with extensive segments over 6°. These parts of relief can be affected by soil erosion and therefore they are considered as unsuitable for agriculture. Although we assume that only part of original ploughlands was recorded (especially in the case of Cetkov and Sloupek), gradient of slopes in fields cannot be regarded as a crucial factor in the choice of the positions for settlement areas. Using of ALS enabled us to revise the 'traditional' statements considering vertical articulation of settlement areas. We argue that the role of natural environment (concerning other parameters of physical landscape as well) in the shaping of historic landscape should be re-evaluated with the using of high-quality source data (e.g. numerous set of deserted villages, detailed map bases) and advanced spatial analyses in GIS. In this regard, their relations to cultural characteristics and human-environmental interactions in general have to be thoroughly explored.

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