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Effects of historical land use and land pattern changes on soil erosion – Case studies from Lower Austria and Central Bohemia

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ABSTRACT

This paper addresses changes in land use and in the spatial distribution of land units and their influence on the soil erosion risk in two areas with a different geomorphology and a different historical and political development: an intensively-used lowland agricultural watershed in central Bohemia, Czech Republic, and a partially hilly agricultural and wine-producing municipality in northern Austria. Our analyses sum up the development of these two study sites, on which the forces driving the land use and the land structure differ due to the different political background in the two countries since the World War II. A definition of the landscape structure was obtained for a sequence of historical time horizons, using the best available data sources. The first historical scenario is based on mid-19th century cadastral maps, while the later scenarios are based on aerial photographs. The soil erosion was then estimated by the Universal Soil Loss Equation in a distributed form application, using GIS preprocessing and the USLE2D utility to calculate the LS-factor. Parcel connectivity ranging from 0 to 100% in 25% steps was used for all of the simulated scenarios. The study shows that even if the spatial extent of the agricultural land does not change significantly, the inner organization of the farming blocks can have a strong effect on the risk of soil erosion. The absolute values of the soil loss are affected by the parcel connectivity used, but the trends defined by the landscape layout are obvious throughout the examined reference years nevertheless. The landscape structure and therefore the soil erosion risk is strongly affected by the economic and political situation and related decisions. Agricultural policies set the fundamental principles on which fragmentation is based.

1. Introduction

Soil erosion by water is one of the strongest factors influencing soil fertility and sustainable agriculture. In qualitative terms, erosion is a multifactorial process driven by a set of control factors such as soil and rainfall characteristics, slope properties, land use and land management. The degree of human influence on each of these factors varies considerably. It is strongest for land use and land management and decreases for soil, slope and is almost negligible with rainfall. Land use and land management involves not only the way in which individual parcels are managed but also the way in which individual parcels are connected and used within general landscape patterns of different land structure. They are influenced by a wide range of environmental, technological, socio-economic and cultural factors, including agricultural policy at all levels (Bürgi et al., 1999). Using historic data for soil erosion modeling provides an opportunity to study impact of land use changes on soil loss and thus soil degradation. (Jordan et al., 2005; Szilassi et al., 2006)

From 1830 to 1918, both Austria and the Czech Republic were part of the Austro-Hungarian Monarchy, under which there was a common agricultural policy. Based on the newly established triangulation network, the first cadastral maps (the “stable cadaster”) for the whole territory of the Austro-Hungarian Monarchy were created in the time period between 1826 and 1843 (Bičík et al., 2001), as a basis for land tax calculations. In Bohemia, this was the pre-industrialization period or the early stages of industrialization, characterized by increasing use of coal and by population growth (Kuskova et al., 2008). The intensity of agricultural management for this period may be characterized as very extensive.

The end of World War II marked a distinct change in agricultural management in the two countries. Animal traction in agricultural management was being replaced by machinery, and the intensity and

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the effectiveness of plant production rose significantly (Grešlová Kušková, 2013). In the Czech Republic, the political forces after 1948 installed a centrally planned economy and proceeded to nationalize industrial production and agricultural production (Bičík et al., 2001). In agriculture, this led to a transition to large-scale management. The amount of arable land was increased by bringing less suitable areas into use for intensive arable farming (Lipsky, 1995). At the same time the agricultural development in Austria was mainly driven by economic forces. The proportion of the land dedicated to vineyards, arable land and pastures varied according to market conditions and according to the demand for products.

However, a similar process of transition to larger scale management took place in Austria as well affecting field sizes and field structure. This was partly in response to state policy (Jepsen et al., 2015), but there was a much stronger component of market processes and inheritance processes.

While the political, economic and societal conditions were similar in the Czech Republic and in Austria until the World War II, later development differ substantially in all mentioned aspects. The common historical background of the two countries provides an opportunity to compare the effects of societal and technological changes during the last 150 years on the risk of soil erosion. We have investigated the extent of these changes, and their effect on erosion control factors and on the total soil loss risk. We provide details of the way our approach deals with site description, model selection, data sources, model parameterization and model application.

2. Materials and methods

2.1. Study sites description

We selected test sites in the Czech Republic and Austria for applying the model. The Austrian study site is located around the village of Kleinweikersdorf (population about 300) in the Weinviertel region of the Austrian province of Lower Austria. It is located about 70 km northwest of Vienna. This is a typically rural area of the region, with population densities below the average for Lower Austria. The site is far enough from Vienna to show a negative demographic trend.

The study site in the Czech Republic forms a part of the watershed of the Botič stream, approximately 10 km east-south from the capital city, Prague. This area is a typical suburban lowland landscape which was formerly used mainly for agriculture. It recently became influenced by the urban growth of the nearby city. Since the year 2000 the region has become an attractive suburban area but the local inhabitants of working age are employed mainly in Prague. Fig. 1 provides an overview of the location of the study sites within Europe, Table 1 sums up the basic characteristics of the study sites.

The selection of test sites was mainly driven by the access to digital information that could be used for the study. Therefore, we had to accept the fact that different environmental conditions did prevail.

2.2. Model selection

The challenge in quantifying long-term changes in soil erosion control factors is to select an approach that will account for changes in land use and land structure over a period of more than 150 years. To assess the soil erosion risk, we chose the distributed extension of the well-known Universal Soil Loss Equation (Desmet and Govers, 1996; Wischmeier and Smith, 1978) which describes soil erosion as a combined effect of different erosion-influencing factors:

$$A = R * K * L * S * C * P$$

where:

A = long-term mean annual soil erosion [$\text{Mg}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$]
R = rain erosivity factor [$\text{MJ}\cdot\text{cm}\cdot\text{ha}^{-1}\cdot\text{h}^{-1}\cdot\text{year}^{-1}$]
K = soil erodibility factor [$\text{t}\cdot\text{ha}\cdot\text{h}\cdot\ \text{ha}^{-1}\cdot\text{MJ}^{-1}\cdot\text{mm}^{-1}$]
L = slope length factor (-)
S = slope steepness factor (-)
C = crop and management factor (-)
P = support practice factor (-)

Many modifications and national adaptations have been proposed over the years. The main reason why USLE is still the most widely used approach for estimating the risk of soil loss is that it offers a relatively simple way to obtain parameter values.

For this study the model was implemented using the USLE2D software tool (Van Oost et al., 2000) which provides a possibility to include flow connectivity between adjacent field blocks. This way the model can incorporate the landscape structure into the soil loss estimate. One value of parcel connectivity is set for each single scenario i.e. all the field borders in the modeled area. Different parcel connectivity scenarios in range from 0% to 100% were simulated for all reference years on both study sites resulting in set of LS-factor layers.

The support practice factor (P) was not considered in this study because there are no data available regarding these practices for the historical periods examined in the study.

2.3. Data sources and model parametrization

2.3.1. Land structure

The first available land structure data that contains information about agricultural parcels derive from the so-called Franciscan Cadastre (1817–1861). This real estate cadastre was funded by Emperor Franz I, and is available for all countries within the former Austro-Hungarian monarchy. The spatial resolution of the stable cadastre information was 1:2880. This cadastral mapping gradually covered the different parts of the monarchy, and the time period that is captured depends on the region. For the sites included in this study, the date is 1822 for Austria and 1841 for the Czech Republic. Aerial photographs were available for later reference years. The availability of suitable land-use data defined the reference years used in the study. An overview of the reference years studied here, and the data sources used, is given in Table 2.

Information from the Franciscan Cadaster was used to identify the main land-use categories (arable, grassland, forest, vineyard, orchard, settlement) and the parcels outlines. However, we had to assume that the land-parcel structure was identical to the landowner structure. For following reference years when aerial photographs were used, the type of land use, including the field boundaries within arable land, were derived by visual inspection. This means that the field blocks are defined not by the ownership registry but rather by their practical exploitation, which is more appropriate for the purposes of soil erosion modelling (Van Oost et al., 2000).

The spatial accuracy of the aerial photographs differed according to their source and the year in which they were taken, but it was never lower than the level required for the digital elevation model used for soil erosion modeling. The spatial accuracy of the vectorization was inferred from the resolution of the digital elevation model, which was 5 m. Structures with dimensions less than 5 m were neglected, and their areas were divided evenly between the field blocks (or other land-use patches) situated along these structures.

2.3.2. Rain erosivity factor (R factor)

2.3.2.1. Austria. In order to calculate R-factor values, it is necessary to have rainfall data with high temporal resolution and time series of sufficient length. The Hollabrunn weather station, which is located about 13 km southwest of Kleinweikersdorf, was used to represent the climatic conditions of the study area. This weather station has provided daily rainfall records since 1896 and rainfall data with temporal resolution of 5 min since 1984. We used the RIST software tool (USDA, 2015) to calculate the R-factor values for rainfall events with daily rainfall > 10 mm for the period from 1984 to 2013, and we developed a transfer function of the form R-factor = −27.2 + 0.3 *

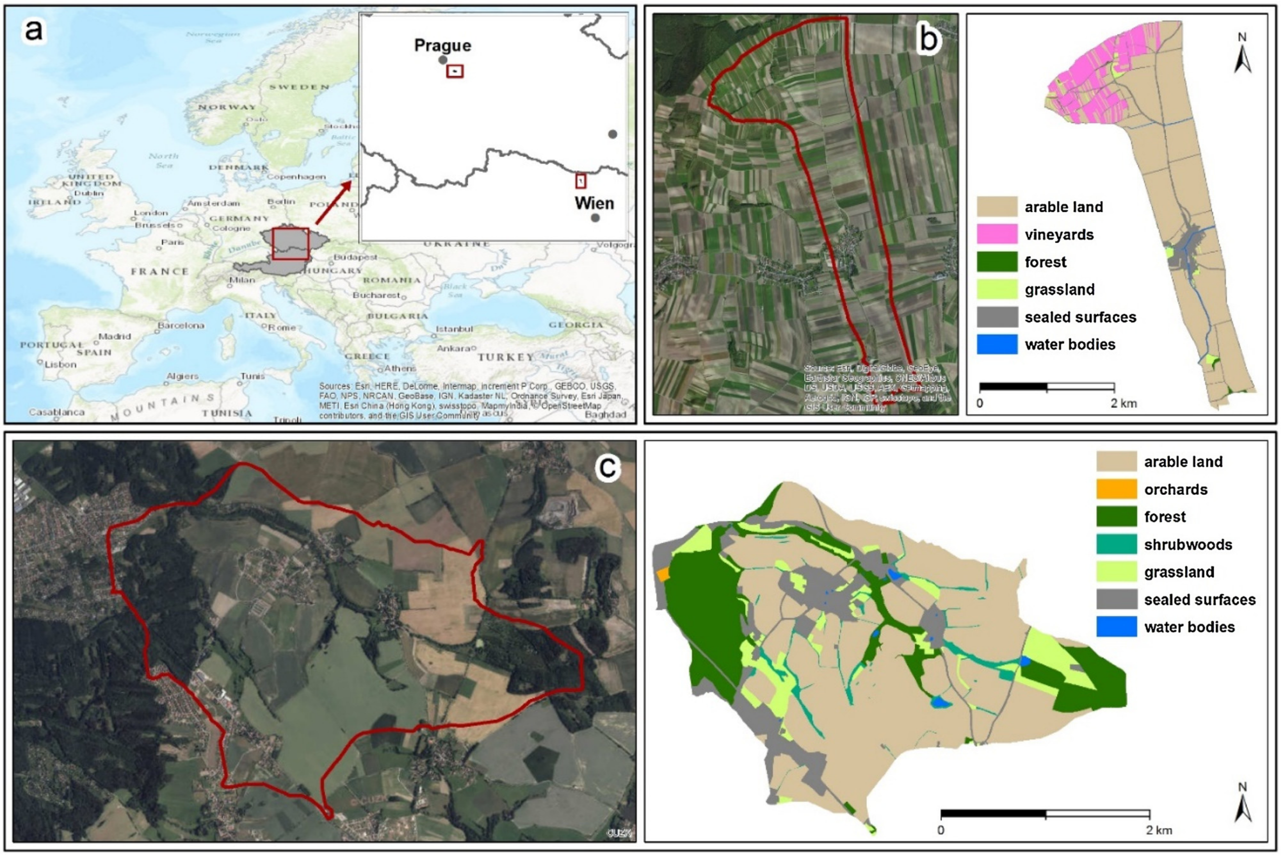

Fig. 1. a) Location of the study sites within Europe; b) aerial photograph and the land use units of the Austrian site; c) aerial photograph and the land use units of the Czech site.

Table 1
Basic characteristics of the study sites.

	Austria	Czech republic
Study site area	5.7 km^2	8.1 km^2
Arable land extent (2013)	4.4 km^2 (75%)	4.7 km^2 (58%)
Minimum elevation	208 m a.s.l.	365 m a.s.l.
Maximum elevation	328 m a.s.l.	486 m a.s.l.
Mean slope on arable land (2013)	5.5%	3.1%
Prevailing soil types	Chernozems, Anthrosols	Cambisols, Luvisols, Gleysols

Table 2
Reference years and sources of data used for assessing the parcel structure.

	stable cadaster	aerial photographs				
Austria	1822	1945	1966	1990	2008	
Czech Republic	1841	1953	1971	1989	2003	2013

annual rainfall (r^2 = 0.53, n = 28). We used this function for preliminary tests of the R-factors for other reference years with only daily rainfall data available. The mean R-factor for the period 1984–2013 was 47 MJ cm·ha^{-1} h^{-1} year^{-1}. A trend toward increasing R-factors in recent years is likely, but a comparison with past periods exhibited no significant difference for R-factors. However, it is essential to extrapolate R-factors with this kind of transfer function to other reference years, and the time series of high resolution data for the Hollabrunn station were not long enough to fully justify these changes according to the premises of USLE (means of 22 years of records). We therefore decided to use the mean R-factor value for all reference years.

2.3.2.2. Czech Republic. The rainfall erosivity values for the Czech Republic were calculated regionally in several projects and from a range of data sources (Krása et al., 2014). (Vopravil et al., 2014) recently performed a study to assess the annual R-factor for each year since 1961, and to predict future climate scenarios with spatial resolution of 500 m for the entire Czech territory. The study provided long-term averages for periods 1961–1990 and 2003–2012, and also estimates for 2051–2070 and for 2071-2100. Within these periods, the average R-factors for the entire Czech Republic increased from 65 to 70 in recent years. Historically, however there was no visible trend toward a vast change. In the area of interest, the long-term average is estimated to be 55 (MJ·cm·ha^{-1} h^{-1} year^{-1}). Since we had no reliable data for the 19th century, we assumed that the R-factor was unchanged for the entire study period, and we kept an average value of 55 MJ cm·ha^{-1} h^{-1} year^{-1}.

2.3.3. Soil erodibility (K-factor)

2.3.3.1. Austria. The spatial distribution of the soil characteristics for the Austrian site was obtained from the Austrian soil classification system, which provides soil maps on a scale of 1:50,000, and contains information on basic soil properties (Schneider et al., 2001). This information was converted into K-factor values, using the approach of (Strauss, 2007). The K-factor values that were obtained ranged between 0.07 and 0.68, with a mean value of 0.56 (± 0.15 standard deviation) on arable land and vineyards.

2.3.3.2. Czech Republic. The soil erodibility for the Czech study site was derived from available vector soil maps in 1:5000 scale, based on the 'main pedological unit' attribute, and using the conversion table provided by (Janeček et al., 2012). The K-factor values that were obtained ranged between 0.14 and 0.51, with a mean value of 0.42 (± 0.02 standard deviation) on arable land.

2.3.4. Slope length and steepness (LS-factor)

The source of elevation data for the Czech study site was a commercial product GEODIS with pixel size of 10 m based on digitized contour lines of older elevation measurements refined with photogrammetrically obtained data. The source of elevation data for the Austrian study site was the official LiDAR based DEM of the Federal Authorities of Lower Austria with a grid size of 1 m. The model was set-up using DEM with spatial resolution of 5 m for both sites which were resampled from the source raster DEMs by bilinear interpolation method.

For flow routing, we used the multiple flow algorithm proposed by (McCool et al., 1987), which is also incorporated into the revised USLE (Renard et al., 1997). It is suggested that this algorithm accurately represents vulnerable areas within parcels, deals with DEM-based hydrological discontinuities, and results in average values similar to those produced by other approaches (Liu et al., 2011)

Although buildings and vegetation are filtered in the surface elevation of DEM, it still contains all terrain structures present on the surface at the time when the elevation data was collected (around year 2000 for both test sites). These include man-made structures (road embankments and indents, ground works around large buildings, etc.) These elements cannot be removed safely from DEM. All the reference years therefore include them, even if the structures were not present at that time. However, there is only single instance of recognizable terrain change within both studied areas and it is of very limited spatial extent, see Fig. 2.

In general, the behavior of water and sediment on the boundary between adjacent patches is very complex, and has high spatial and temporal variability. The effect on water and sediment transport is assumed to be small when the same type of crop is growing on both sides of the boundary. However, the effect may be substantial when there are different types of crops, or if permanent vegetation is present (Van Oost et al., 2000). In USLE2D is the runoff/sediment connectivity between land-use patches described globally for the whole task by a single value for all the borders within modeled area. The connectivity issue is of critical importance regarding the resulting soil loss risk and obtaining reliable border characteristics for historical scenarios is impossible. Therefore, we repeated the simulations with connectivity ranging from 0% (total discontinuity of sediment transport on the border) to 100% (no influence of the border on the sediment transport).

Table 3
C-factor values used for the Austrian site for given reference years.

	1822	1945	1966	1990	2008
arable land	0.07	0.13	0.10	0.13	0.15
vineyard	0.46	0.46	0.46	0.46	0.03
grassland	0.01	0.01	0.01	0.01	0.01

Table 4
C-factor values used for the Czech site for given reference years.

	1841	1953	1971	1989	2003	2013
arable land	0.07	0.13	0.22	0.22	0.14	0.14
extensive orchard	0.02	0.02	0.02	0.02	0.02	0.02
grassland	0.01	0.01	0.01	0.01	0.01	0.01
shrubwood	0.005	0.005	0.005	0.005	0.005	0.005
forest	0.001	0.001	0.001	0.001	0.001	0.001

2.3.5. Crop and management (C-factor)

The C-factor value is influenced by number of aspects including the crop species, variety and condition, management technology and particular machinery used and others. (Renard et al., 1997) While C-factor values for crops and technologies used since 1970's can be found in various literature we have no reliable data sources for historical crop varieties and machinery. To estimate the mean C-factors, we identified typical cultivation methods and typical crop rotations for each reference year and derived the historical values by altering the current values based on known agro-technological development milestones.

2.3.5.1. Austria. The spatial data obtained from the stable cadaster maps was linked to the land-cover information obtained from agricultural surveys in 1874 ("Production des Jahres 1874 aus dem Pflanzenbau," 1875Production des Jahres, 1874("Production des Jahres 1874 aus dem Pflanzenbau," 1875) This annual publication gives the crop distribution for different regions of the former Austrian-Hungarian monarchy. Our Kleinweikersdorf test site is located in the province of Lower Austria, and forms a part of the Hügelland region. There is a comparatively large time gap between the data collection for the Franciscan Cadaster and the data collection for crop statistics; however this is the best available data. It can also be assumed that there were no significant changes in land structure during this time period, as the political and economic conditions were quite stable at that time. We also considered plant development and crop yields for the different reference years. In the second half of 19th century little fertilization was applied. We therefore considered that the development of canopy cover, plant height and biomass production would be lower than

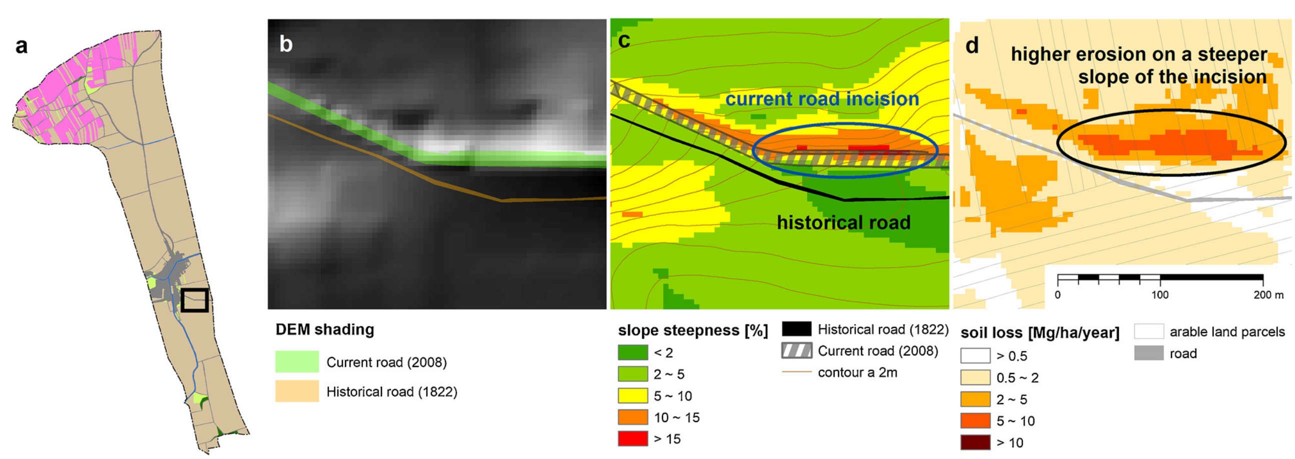

Fig. 2. An example of recent man-made structures influencing the shape of the terrain surface, Austrian study site: a) shaded terrain with the historical road route and the current road route, b) slope steepness, c) resulting soil loss for the 1822 reference year.

Table 5
Number of parcels and parcel size development on arable land – Austrian study site.

	arable land					vineyards				
reference year	1822	1945	1966	1990	2008	1822	1945	1966	1990	2008
number of field plots	1203	824	852	470	371	79	45	63	98	79
average parcel size [ha]	0.36	0.60	0.59	0.93	1.18	1.10	0.73	0.38	0.90	1.07
median parcel size [ha]	0.31	0.43	0.28	0.58	0.79	0.48	0.61	0.29	0.56	0.51
maximum parcel size [ha]	1.64	4.77	10.52	8.06	8.98	11.23	2.52	1.32	7.36	10.40
mean slope steepness [%]	5.5	5.5	5.7	5.7	5.1	8.9	8.6	8.1	8.1	8.8

Table 6
Number of parcels and parcel size development on arable land – Czech study site.

reference year	1841	1953	1971	1989	2003	2013
number of field plots	469	442	97	32	79	69
average parcel size [ha]	1.38	1.53	7.32	26.81	8.36	9.20
median parcel size [ha]	0.69	0.75	4.45	18.55	3.23	3.34
maximum parcel size [ha]	24.8	16.9	65.6	219.3	66.4	73.9
mean slope steepness [%]	3.1	3.2	3.1	3.1	3.0	3.0

nowadays. This assumption is supported by information taken from ("Production des Jahres 1874 aus dem Pflanzenbau," 1875Production des Jahres, 1874"Production des Jahres 1874 aus dem Pflanzenbau," 1875). For the reference year of 1874 no herbicides or pesticides were applied. We therefore estimated a 15% increase in canopy cover, plant heights and biomass production due to weeds. The mean crop rotation for the 1874 reference year was calculated using the typical three-field crop rotation with summer crop – winter crop – fallow. We used the BoBB software tool to calculate the C-factors for arable land. (Strauss et al., 2013) BoBB incorporates plant cover and R-factor development according to the RUSLE model (Renard et al., 1997). The C-factors for arable land for all other reference years (1945, 1960, 1990, 2008) were calculated on the basis of the crop statistics at community level and the yield statistics collected by the Federal Statistical Office in Austria (www.statistik.at). The C-factors for vineyards were taken from (Auerswald and Schwab, 1999), while the values for grassland were taken from (Bargiel et al., 2013). The final C-factor values used for Austrian study site are given in Table 3.

2.3.5.2. Czech Republic. For the 1841 reference year, C-factor values for Austria were adopted directly, because there is no reason to assume different conditions in agricultural technology and crop rotations and conditions. For the 1953, 1971, 1989, 2003 and 2013 reference years, the C-factors determined by (Dostál et al., 2003) were adopted, the values used are given in Table 4.

3. Results

3.1. Land use and land structure

The number of agriculturally-used land parcels and the size of the parcels reflect the huge political and societal changes in both countries during the observed reference years. Over a period of almost 100 years (from the 1820s until after World War II), there were only small changes in the number of parcels and in their size. Although the political systems had changed within this period due to the breakup of the Austro-Hungarian monarchy, there were only small effects on the agricultural structure. It was the second political distortion - World War II and the change to communism, together with the boost in agricultural technology - that led to changes both in Austria and in the Czech Republic. Time development of arable land parcels numbers and their basic properties is provided in Table 5 and Table 6, development of land-use throughout the reference year is shown in Fig. 3.

In Austria, a land consolidation plan was implemented in 1955. This might have been expected to lead to an increase in parcel size. However, the two distinctly different parts of the Austrian study site, with vineyards in the north and arable land in the south, also produced a different land consolidation effect. There were decreasing parcel sizes for the vineyard areas and increasing parcel sizes for the arable land. In total, this led to an overall increase in the number of parcels in the test site. During the years that followed, a steady decrease in the number of parcels and an increase in parcel sizes was observed, in accordance with the trends in agricultural economics and agricultural technology. This process has continued into recent years. For example, the number of arable parcels decreased from 470 in 1990 to 371 in 2008, and the average parcel size increased from 0.93 ha to 1.18 ha.

In comparison with Austria, the mean parcel size in the Czech Republic was already larger in 1841 (1.38 ha), while the size distribution of the plots was much more skewed. There was a median of 0.69 ha, and the biggest parcel was almost 25 ha in area. The greatest decrease in numbers of field plots was observed between 1953 and 1971, as an outcome of political decisions to convert privately-owned farms into state farms. The average plot size increased to 7.3 ha, and the

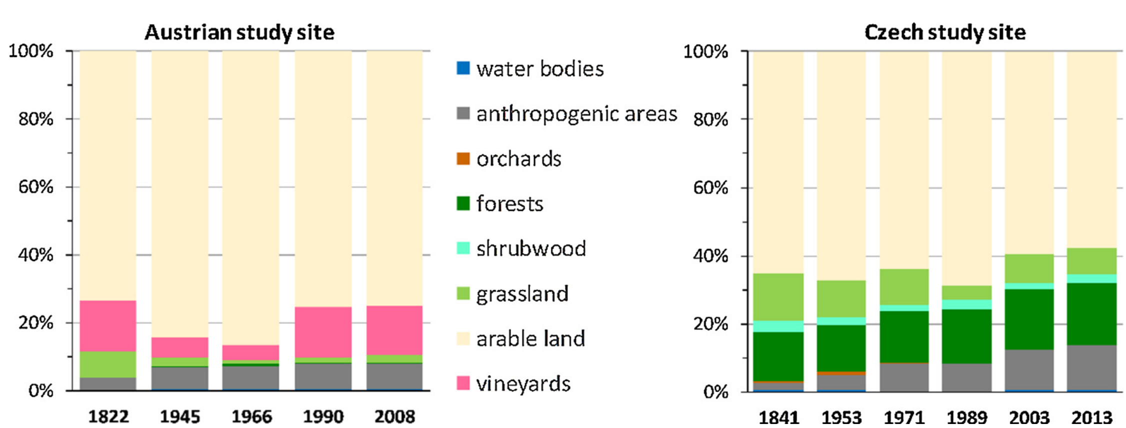

Fig. 3. Changes in land use classes throughout the examined reference years.

Fig. 4. An example of the temporal evolution of landuse throughout the reference years on the Austrian study site.

number of field plots dropped to 97. Further merging reduced the number of field plots to 32 in 1989, with an average plot size of 26.8 ha. By 2013, the changes introduced after the Velvet Revolution in 1989 and the resulting political changes had raised the total number of parcels to 79, with a mean parcel size of 8.36 ha. In 2013, the area of arable land had been reduced by 13.3 ha in comparison with 2003. However, the number of field blocks had decreased to 69, which shifted the mean field block area to 9.2 ha.

3.2. Soil erosion

To calculate accordant soil loss layers a calculated set of LS-factor layers with parcel connectivity range from 0% to 100% was used. The scenario with 100% connectivity represents hypothetical situations with no inner borders between parcels and other land-use patches as well. Only the anthropogenic (sealed) surfaces induce interruption of surface run-off in this scenario. The decrease of mean LS-factor in this case reflects the ongoing introduction of new roads and other infrastructure during the different periods. Results for soil loss in the next chapters are presented for a parcel connectivity of 50%.

3.2.1. Austria

The main changes in the distribution of land-use classes for the reference years concern the extent of vineyards and grassland. The

Fig. 5. An example of the temporal evolution of landuse throughout the reference years on the Czech study site.

development in area shares of landuse categories is shown in Fig. 3, an excerpt of the spatial development of landuse and agricultural parcels layout is shown in Fig. 4 .

The most significant decrease in vineyard area was observed for the 1945 and 1966 reference years, due to the high demand for basic food production after World War II. This increased the proportion of arable land, while the combined area of arable land and vineyards remained constant (90% ± 1%) throughout the reference years. The average soil loss on arable land in 1945 reached 224% of the value for 1822, while the C-factor increased by only 186%. As the average slope steepness remains constant this indicates a negative change in parcel layout with regard to terrain morphology.

Between 1945 and 1966, the average soil loss on arable land decreased by 23% (see Fig. 6). This is equal to the change in the C-factor, indicating that no significant change in parcel structure and reallocation had taken place. In contrast, the average soil loss in vineyards decreased to 84% of the 1945 value, while the C-factor value for vineyards was unchanged. This may be attributed to a change in parcel allocation, together with decrease in average slope steepness within vineyards (see Table 5) and reduction in patch sizes.

Due to changes in general wealth, and in order to achieve self-sufficiency in the main agricultural products, there was a switch from arable land to vineyards between 1966 and 1990. In 1990, vineyards covered 15.1% of the study area which is more than three times the

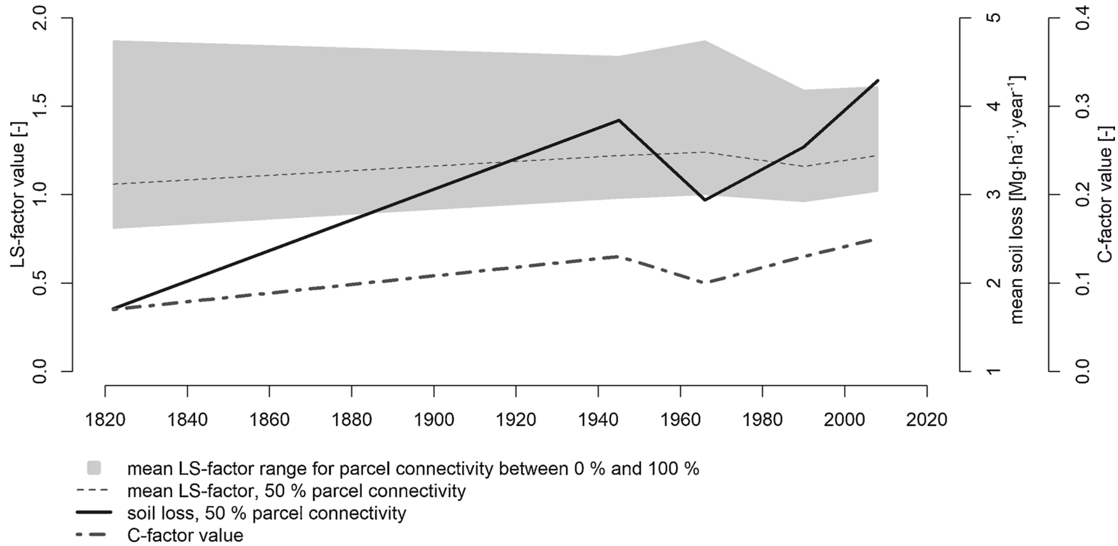

Fig. 6. LS-factor, soil loss and C-factor development on arable land on the Austrian study site.

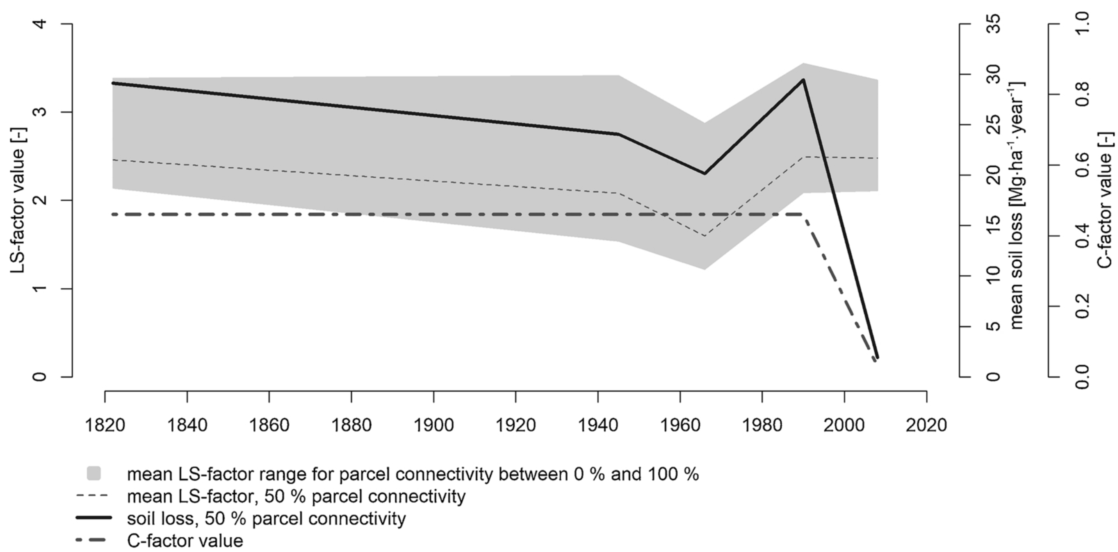

Fig. 7. LS-factor, soil loss and C-factor development in vineyards on the Austrian study site.

area in 1966. The newly-appearing vineyards consisted of merged blocks with an average parcel size of 0.9 ha. The removal of field borders and the reinstallation of vineyards on the steepest slopes led to an increase in average soil loss in the vineyards to 146% of the 1966 values. Interestingly, the area of vineyards in 1822 and in 1990 was almost equal (86.6 ha vs. 87.9 ha), and so was the average soil loss in the vineyards (29.1–29.4 Mg·ha^{-1} year^{-1}). However, only 51 ha of the vineyards are found in the same locations. On arable land, the average soil loss in 1990 was 120% of the 1966 value, while the C-factor increased to 130% of its previous value. The mitigation of the rise in C-factor is caused by the conversion of the steepest patches back to vineyards which is also indicated by changes in mean LS-factor on arable land and vineyards (compare Figs. 6 and 7).

For the latest scenario of 2008, there is a significant drop in the C-factor for vineyards that reflects the introduction of grass-covered interrows. This may be mainly due to the subsidies that were set up for this measure in the Austrian program for environmentally-sustainable agriculture (ÖPUL), after Austria joined the European Union in 1995. While the extent and the shape characteristics of the vineyard parcels are very similar to the 1822 scenario, the calculated soil loss is 93.5% lower. In 2008, by contrast, the average soil erosion on arable land increased by 21%, while the C-factor value increased only by 15%. The difference can be explained by the increase in LS-factor caused by changes in the parcel layout.

Temporal development of mean soil loss is documented in Fig. 6 (arable land) and Fig. 7 (vineyards), one example of temporal changes in spatial distribution of soil loss is shown in Fig. 8.

3.2.2. *Czech Republic*

The proportion of intensively-used agricultural land does not exceed 70% on the Czech study site. With the exception of some minor patches of orchards (1.2% of the study site), it consists only of arable land. The rest of the watershed is covered with grassland, forests or medium-height mixed vegetation (shrubwoods). For the historical development of areal extent of landuse categories see Fig. 3. However, it is the location of patches of grassland, forests and shrubwoods, not their absolute extent, that plays the important role in the soil erosion. An example of spatial changes in landuse categories and agricultural parcels layout is shown in Fig. 5.

A major difference in comparison with the Austrian study site is in the growth of anthropogenic areas. This was and still remains much stronger, due to the proximity of the study site to big city nearby.

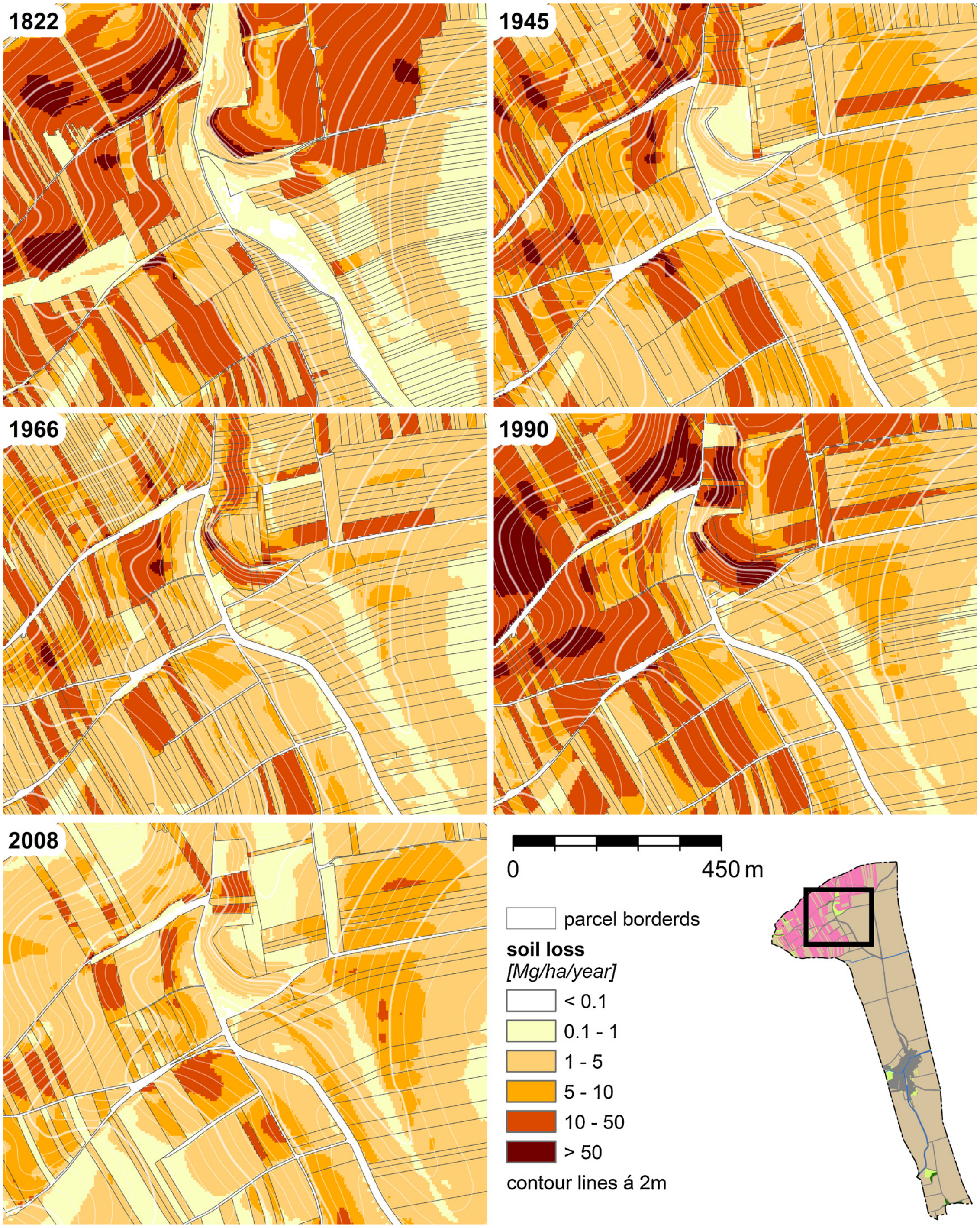

Fig. 8. An example of the temporal evolution of soil erosion throughout the reference years on the Austrian study site (see Fig. 4 for the legend of the landuse categories in the overview).

Between 1841 and 1953, the urbanized area doubled in size. Some minor service roads disappeared as a consequence of merging field blocks, i.e. some elements interrupting surface flow were removed from the landscape. In addition, there was an increase in the proportion of arable land (from 65% to 68%). In total, this led to an increase in average erosion (194% of the 1841 value) within the arable land, while the C-factor value is only 186% of the 1841 value.

For the 1971 reference year, the mean soil loss on arable land was 201% of the value for 1953, while the increase in the C-factor was only 171%. This clearly reflects a negative change in the structure of the agricultural landscape. In the 1989 scenario, the total number of field blocks dropped to 32, with a mean size of 26.8 ha (median size 18.6 ha), and the biggest field plot was 219 ha in area. For this reference year, we observed the strongest decrease in grassland patches within arable land. This was a result of the ongoing construction of subsurface drainage lines within the arable land. In addition, the overall length of service roads was at the lowest level of all historical periods, because the field blocks were big enough to be accessible from the major road network. The changes in land use and in the structure of the landscape led to an increase in mean soil loss to 107%, while the C factor value remained constant against the 1971 reference year. When combined with the growth in the amount of arable land, the total amount of soil loss

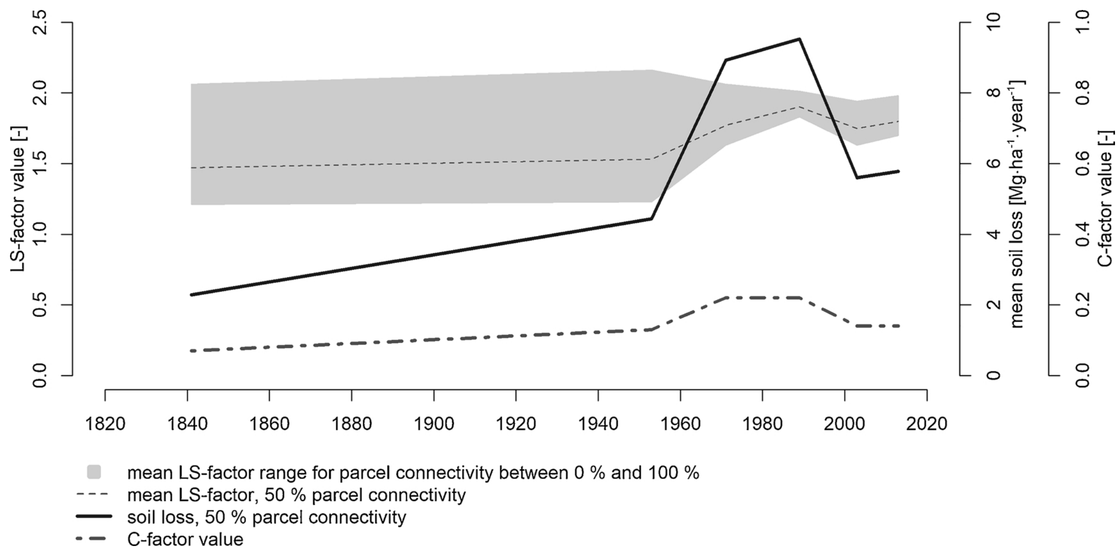

Fig. 9. LS-factor, soil loss and C-factor development on arable land on the Czech study site.

increased to 115%. Increase in flow routes lengths within parcels between 1953 and 1989 is reflected in increase of mean LS-factor for 50% parcel connectivity and the reduction of the parcel border lengths per unit area is reflected by the narrowing range between mean LS-factor for 0% and 100% parcel connectivity (see Fig. 9).

In 2003, the first reference year after the changes in the political system in the Czech Republic, revealed a substantial decrease in the area of arable land which decreased to 86% in comparison with the 1989 reference year (59.4% of the study site). By 2003 most of the land had already been returned to its former owners or to their heirs. Some of the new owners rented their land to the former state farms, but others kept the land for other purposes. This was the main driving force for the decrease in the area of arable land, and also for the appearance of a considerable area of new patches of grassland and shrubwoods. Urbanized areas grew from 8% to 12% of the total area.

The increase in patch border length is reflected in the decrease in average soil loss to 59%, while the C-factor value decreased to 64% in comparison with 1989.

In 2013, the area of arable land was 13.3 ha less than in 2003. However, the number of field blocks had decreased to 69, which shifted the mean field block area to 9.2 ha. While the C-factor value remained constant, less fragmentation of the arable land led to an increase in average soil erosion of 103% in comparison with 2003.

Temporal development of soil loss is documented in Fig. 9, example of soil loss spatial distribution temporal change is shown in Fig. 10.

4. Discussion

The USLE model was chosen especially for the ease of input data acquisition and generally well developed methods for input data derivation from national databases (soil types maps, crop properties, precipitation records etc.) across countries. The main opportunity was an easy implementation of the parcel borders influence on the distributed soil loss risk evaluation. Although the USLE has well-known weaknesses it still is the only model to allow mid-to-large-extent areas to be assessed easily with implementing the land-structure in course raster resolution.

Resulting values of soil erosion are strongly influenced by the choice of input factor values for the model. The derivation of climate and crop-management related factors was done by very simple methods but no other methods are available that could provide more certain values for historical situation. Neglecting the support practice factor (P) in the USLE calculations may lead to overestimation in the soil loss values on arable land. (Bakker et al., 2008) Including the P-factor in the calculation would introduce even more uncertainties and therefor was avoided.

We did not have sufficient information to deal with soil as a time dependent influence factor and thus kept soil erodibility constant throughout the different periods. The two sites had comparable soil erodibilities with slightly higher values for the Austrian site. We consider this difference a minor issue. The main influence on soil erosion is due to changes in agricultural structures and different crops. While the effect of different soils on erosion varies with the factor 10 it varies with the factor 100 for landuse in the model structure of USLE.

5. Conclusions

Uncertainties in the absolute values of the outputs are quite high; however, the comparison between study areas and reference years provides a valuable insight into the landscapes development. A comparison between test sites in the Czech Republic and in Austria revealed that, even for the first reference year within the 19th century, there were already different agricultural structures in terms of parcel sizes. This set the basis for different potential soil erosion. For later reference years, the main driving force for the change of soil loss risk could clearly be attributed to the technological development and to the political and economic framework of agricultural activities in the two countries. The biggest negative impact was clearly due to the changes in the political system after 1948. The central planning that was introduced in Czech Republic turned all arable land - after a transitional period - into state property. This provided a basis for almost unlimited merging of field blocks for the sake of management efficiency. After the Velvet Revolution and the return to free market principles, the land was returned to its owners and the farms were privatized. While the ownership of the land is much more scattered and is at present close to the 19th century situation, the usership structure remains very similar the 1989 reference year. Thus, the decrease in soil loss is caused mainly by the change in crop and management practices.

Strong land-use and land-structure consolidation process could also be observed on the Austrian site though driven by completely different forces. Although the land consolidation process was much slower, it has until now led to a continuous and tremendous increase in soil loss risk since the 19th century. It is evident that the increase in soil loss risk resulted from a combination of factors. The influence of these factors on the soil loss risk also differed on the different test sites and during the different reference years.

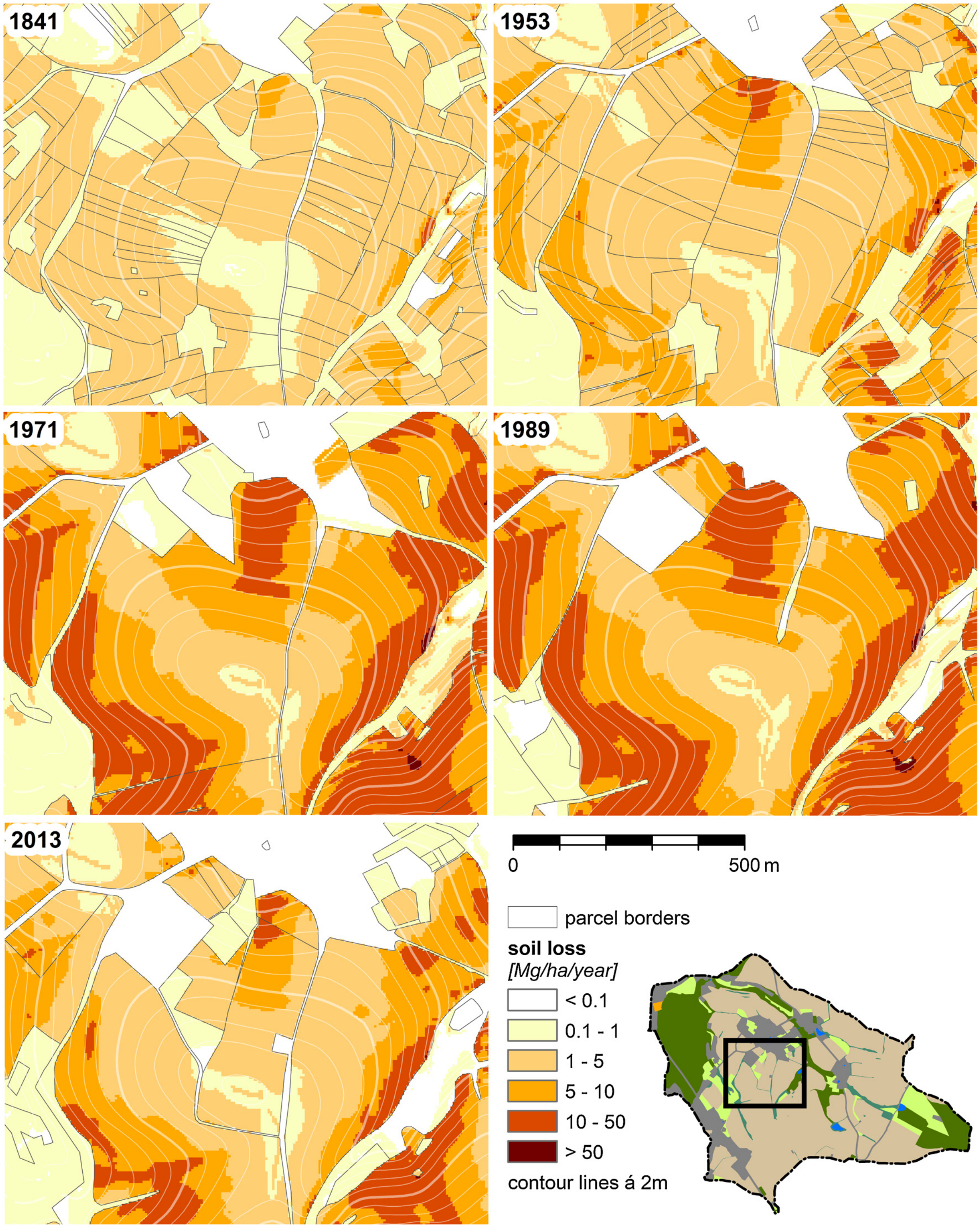

Fig. 10. An example of the temporal evolution of soil erosion throughout the reference years on the Czech study site (see Fig. 5 for the legend of the landuse categories in the overview).

The Czech study site illustrates the pressure on landscape utilization driven by population growth. This problem is less acute for the Austrian site, which is located much further away from the capital city.

The results illustrate that agricultural policies can have a powerful influence on soil erosion intensity, and may both mitigate and amplify soil loss. The impact of past policy decisions can lead to an ongoing struggle by the authorities to improve the situation through motivating farmers in a non-coercive way. Our results for soil erosion also suggest that cross compliance mechanisms can have a strong directive power to affect agricultural landscapes in a positive manner.

The application of the Franciscic cadastre work was carried out in all countries of the former Austro-Hungarian monarchy. Therefore, the methodology and results presented may serve as blueprints for other regions in Central Europe, though region-specific data acquisition would be a unique task for every country. Some of these data may be harder to obtain (19th century maps for countries outside Austro-Hungarian monarchy) and some easier (20th century aerial photographs for countries west of Czech Republic).

Presented study may serve as an example of historical agricultural landscape development. Obvious historical mistakes should serve for policy makers to improve future conceptual decisions. Though the Austrian landscape history lacks the rapid changes in policy of the

Czech Republic the trends of merging the agricultural land into bigger patches for management efficiency reasons should be watched closely. The cost of agricultural production should be always measured against value of a well-functioning and sustainable landscape

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