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CATCHMENT-SCALE RELIEF DEVELOPMENT AS THE RESULT OF LONG-TERM AGRICULTURAL ACTIVITY, CASE STUDY ON SZEKSZÁRD HILLS, HUNGARY

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Abstract

Human impact has played important role in the relief development of Szekszárd Hills, as the history of viniculture dates back to the Roman Times. Approximately 17 % of the area is used as vineyard. As viniculture is one of the most intensive land-use type and soil erosion is very severe on the loose loessy material of these hills, relief development is quite fast in the area. The aim of the study to estimate the catchment-scale erosional loss of the area caused by viniculture and to evaluate the role of artificial terraces on landscape development. Three smaller catchments were chosen as study areas in the north-east part of the hills. Based on the digital elevation model of the area the minimum net erosion was calculated. The calculations reflect that the amount of erosion was higher (1) on the slopes with southern exposure and (2) in tributary valleys close to the town. The accelerated erosion altered the longitudinal profile of the tributaries and the terraces changed the profile of the intercollin ridges.

Keywords: relief development, catchment-scale erosion, viniculture, artificial terraces

INTRODUCTION

Since the early periods of agriculture the surface has been changed by human impact. Ploughing is the oldest surface-modifying agricultural activity, but its effect was different in different periods and regions. The invention of agricultural tools (e.g. plough) allowed the cultivation of areas have not been used previously. The main effect of ploughing is evening the surface, but it also accelerates erosion resulting the reshaping of the landscape (Szabó 2006). Agriculture has direct and indirect impacts on landforms and in landscape development. The direct forms have been made on purpose, like ditches and channels to drain run-off or terraces to make steep slopes cultivable. Indirect forms developing by natural processes but driven by human impact, like ridges and furrows as the result of ploughing, gullies due to soil erosion, bank-in roads and artificial terraces in hilly areas.

Cultivation of terraces has a few thousand years-old history. It is most common in East-Asia where rice is cultivated on the terraces, but they can also be found in the wine and fruit producing regions of Europe. Various types of terraces exist depending on climate, landscape and tradition. The surface of the terraces can be horizontal or gently sloping, they can be supported by walls and may have rim at the edges (Szabó 2006). Regardless of their form, the creation of the terraces requires great amount of artificial material transport and deposition. The construction of terraces has numerous unfavourable environmental effects, especially in areas where their planning is not precise. In these areas runoff usually increases due to the disturbance of the surface and changed vegetation, and this results accelerated erosion (White et al. 1984). Therefore, drainage ditches are often built on the terraces to control run-off, however these ditches alter the timing of stormflow, increasing the discharge of the main stream and causing larger floods.

Besides the above described human induced changes the relief development still show the classical development phases typical for all landscapes. The studies on surface evolution of hilly or mountainous regions began in the 19th century. The concept of denudation cycle was developed by Davis and challenged by Penck and others (Summerfield 1991). In the Davisian theory surface dissection of a raised area is controlled by streams which besides incision eroding the intercollin ridges, decreasing the angle of the slopes (slope decline) and the elevation of the area. This theory is applicable to many hilly areas of the mid-latitudes, but it is quite general and considers fluvial erosion as the only one process in landscape development. Penck also worked out a model of slope development, but in his slope replacement model the process of flattening (erosion of the intercollin ridges) is from the base upwards when the slope profile is getting lower as the slope retreats. Based on the degree of erosion followed by the disturbance (uplift) stages of relief development were defined (i.e. youth, mature and old age). Though these models are quite simple and neglect several factors, some of their elements (i.e. slope development) still can be considered in modern relief modelling studies.

On agricultural areas and terraces accelerated soil erosion is the main process in altering the relief, but is role in long-term landscape development is rarely evaluated. Mostly, because soil erosion is usually studied on small parcels (e.g. Davis 1976, Stolte 2003, Kitka et al. 2009), but rarely on larger areas.

The aim of the research is to estimate the amount of (soil) erosion on catchment-scale relief development and to evaluate the geomorphic changes from the point of view of duration of human impact. The Szekszárd Hills were chosen as a study area, because they are one of the vine producing areas of Hungary with the oldest traditions. Here viniculture, which is one of the most inten-

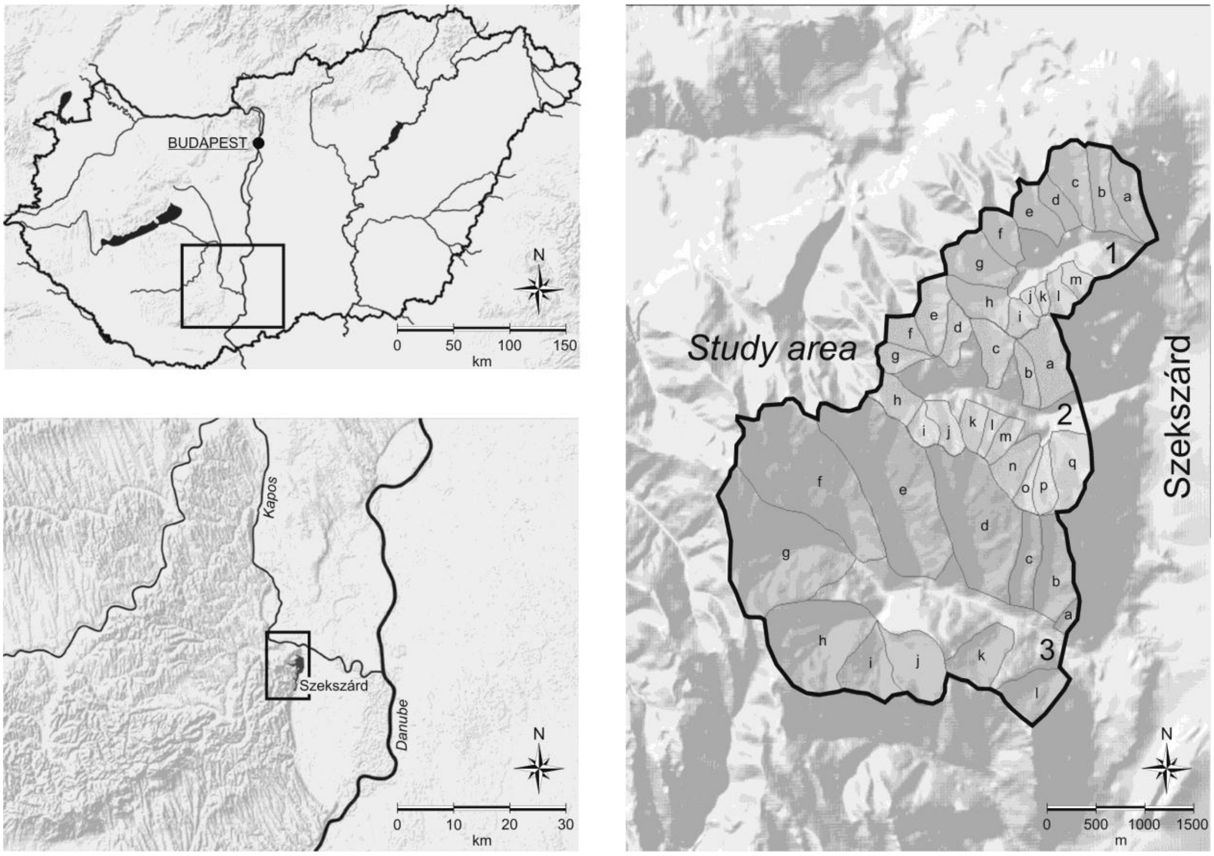

Fig. 1 Location of the study area

sive land-use, is combined by the formation of terraces. The problem is, that the region is characterised by thick loessy deposits, therefore the hilly surface is highly erodible. On about half of the region the rate of soil erosion is over 90 % (Ádám 1964), but considering the study area the spatial extension of such highly eroded soils is even more, as it is over 90 %.

STUDY AREA

The study area is located in the north-eastern part of Szekszárd Hills, which is the easternmost member of the Transdanubian Hills (*Fig. 1*). The study area represents three catchments of the region, west of the town of Szekszárd, which is the regional center. The size of the studied catchments is increasing towards south and their total area is 11.7 km^2. The highest point of the study area is located on the south-east divide of the area (285.9 m asl), the mean height is 145 m asl The relative relief of the area is 120-150 m/km^2. The studied catchments are opened towards east, the tributaries are perpendicular to the main streams (*Fig. 2*).

The main features of the landscape were formed during the Pleistocene, when thick 40-50 m loess and loessy materials were deposited (Marosi 1990). In the Middle Pleistocene the area was elevated between fault-lines. A steep scarp developed on the eastern edge of the studied catchments separating them from the sinking plain (Ádám 1969). Valley incision started due to the pronounced relief differences along the tectonic fault. In the catchments the slopes are asymmetric as slopes with Southern exposure are longer. This asymmetry partially can be explained by tectonism, but also by Pleistocene solifluction and Holocene fluvial erosion (Ádám 1964). The bottom of the valleys are wide (*Fig. 2*), due to the intensive accumulation of the eroded sediment and probable due to human impact (Pécsi 1981).

The average mean temperature of the study area is 10.2-10.5 °C. The annual mean precipitation is 650 mm, and because of the continental climatic trends most of it (380-400 mm) falls at summer. This is important in relief development, as heavy summer rainfalls have greater effect on surface erosion (Kerényi 1991, Pinczés 1980).

The original vegetation was oak, ash and elm forests (*Querco-Ulmetum*, *Convallario-Quercetum*), but it

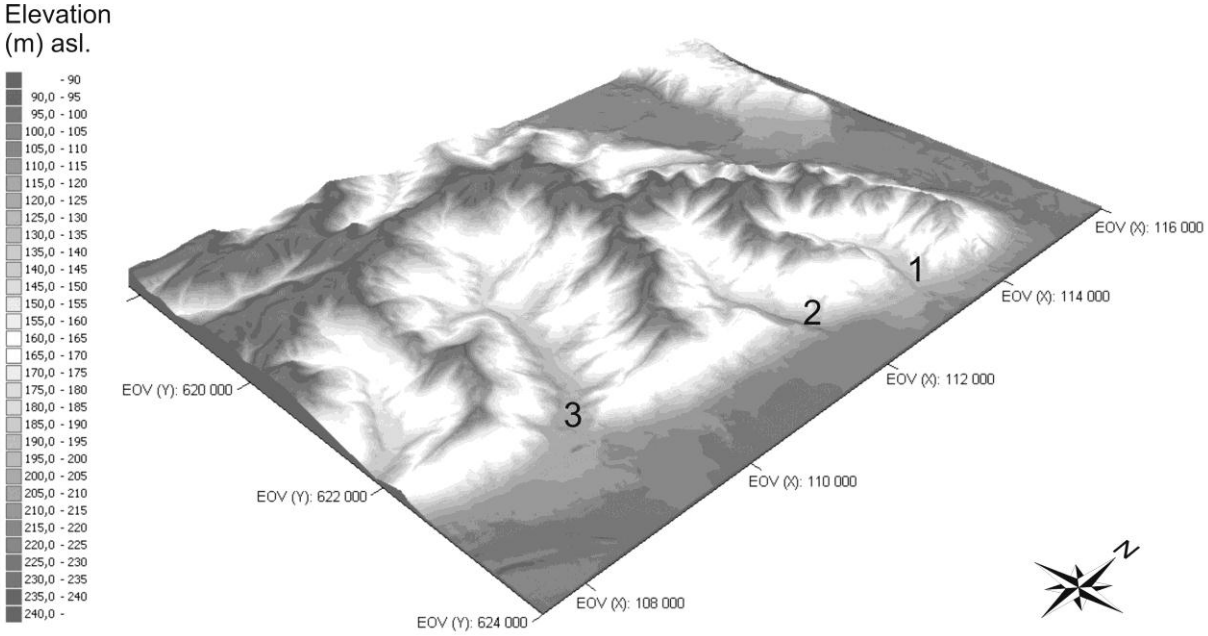

Fig. 2 3D-view of the sub-catchments

was cleared since the Middle Ages, therefore nowadays only 28 % of the area is forested. Fragments of natural vegetation can be found in the bottom of the narrow valleys and ravines. The forests were replaced by agricultural fields, especially vineyards. Most of the area is covered by *brown forest and forest-steppe soils*, though they are strongly eroded especially under vineyards (Pécsi 1981).

HISTORY OF VINICULTURE OF THE STUDY AREA

The production of vine in the western part of Hungary dates back to the Roman Ages (Balassa 1982).Viniculture was already introduced in the Szekszárd Hills during the reign of Emperor Probus (4th c. AD), when not only legionnaires (Syrians) and the settled veterans cultivated vineyards here, but also the local Paleochristians and Celts (Töttős 2008).

The exact history of the viniculture in the Middle Ages is not known. In the 12-13th centuries Vallons and Serbians fleeing from the Ottomans and Germans from the West Europe also played important role in enriching the traditions of the Hungarian vine production. By the 13th century about 3-5 % of the area of the country was covered by vineyards, and this ratio (or may be even greater) probably was also characteristic in Szekszárd (Kaczián 2004).

During the Ottoman-Hungarian wars (16-17th c.) the vineyard area of Szekszárd – unlike the others in Hungary – remained almost unharmed, its prized vines were drank by the Osmans too, despite of the prohibition of the Coran. The vine became a precious product of the town being its main income. In 1728 the total area of vineyards was 78 ha and by 1769 it increased to 350 ha. The vine became a premise of prosperity to the town, as before the river regulation works the floods of the Danube and Sárvíz Rivers often ruined the plough fields on the plain. In these years the trade of vine made possible to buy the needed cereals (Kaczián 2004).

In the end of the 19th c. the vineyards of Hungary were seriously damaged by the contagion of grape phylloxera. The damage was especially great on vineyards, where the soil was not loose, so on loess and rhyolite tuff, though the pest caused less damage on sandy soils. Therefore, after the phylloxera pest the vine producing regions were rearranged: originally only ca. 14 % of vineyards were located on sandy areas, but after 1890 it increased to 59 % and many of the traditional vine producing areas were abandoned (Balassa 1982). In the vineyards of Szekszárd the harm was made in vine quality but not in quantity. Here, by 1910 as a result of the replantation campaign the total area of the vineyards increased by 25 %. In the 1960's new grape species and machinery were introduced to serve the demands of mass vine production. The steeper areas were not cultivable by machines, therefore the vineyards were relocated at the foothills and larger terraces were formed. As the territory of foothills is limited, the new plantations occupied the less sunny northern and western slopes. Besides deep bank-in roads were covered by concrete making the transportation easier. This promotes suburbanization, which also has an unfavourable effect: houses and other infrastructural objects were built on vineyards, therefore the traditional landscape altered decreasing the esthetical and traditional value of the vineyard region (Máté 2001).

EFFECTS OF VINICULTURE ON RELIEF DEVELOPMENT

Vineyards were traditionally hoed twice a year, but from the 19th c. grape rows were hoed three times a year to improve the quality of the vine. At the same time ridges were formed between the rows and the trenches under them to collect the summer precipitation for the plants (Balassa 1982). As the grape rows run perpendicularly to the contour-lines, these small artificial trenches had increased the run-off considerably, accelerating linear soil erosion (Kerényi 1991). The trenches were buried after the harvest to protect the roots from frost, therefore their effect on enchanting erosion was pronounced right in the stormy summer season. In the vineyards soil erosion was so intensive, that for example in 1961 the streets of Szekszárd were buried under 25,000 m^3 mud eroded from the vineyard hills during a heavy summer storm (Pataki 1961).

In the course of intensive cultivation the dirt roads were used frequently. Under the vehicles the loess lost its original structure and the weathered material was eroded down slope. In this way bank-in roads were developed along the transportation routes. These bank-in roads are usually 5-6 m deep, but some incised up to 10-12 m depth depending on the frequency of use. In some cases they transformed into 20-25 m deep ravines, thus they do not function as roads any more (Ádám 1964). The bank-in roads are about 1-4 m wide depending on the size and type of the transport vehicles, and they are broadening due to lateral erosion.

On the steep slopes terraces were created to support viniculture (Marosi 1990). The territory, elevation and the morphology of the walls of the terraces is quite diverse: near to the town the terraces are smaller and higher as they occupy quite steep slopes, whilst the further vineries are on lower terraces with larger area and less steep slopes. The walls of these terraces ranges between 1 and 4 m, they are usually very steep. The larger terraces are cultivated using heavy machines, here the soil is compressed decreasing its infiltration capacity, therefore runoff and erosion is more intensive on the lower areas than on higher and smaller terraces (Pataki 1961).

METHODS

Since the aim of the study is to evaluate effect of agriculture on relief development on a larger area (11.7 km^2) GIS tools were applied. In order to determinate the amount of eroded material the volume of the present day and the potential relief was calculated. The volume of the present day surface was calculated for each sub-catchments, and it was defined as the volume between the present day surface and the base level surface was drawn at the height of the outlet of the sub-stream. The volume of the potential relief was defined as the volume between the imaginary flat surface between the points of the opposite divides and the base level. The amount of net erosion was calculated by substructing the volume of the present day relief from the volume of the potential relief. Some slopes of the main streams drain the run-off directly into the main stream, and these areas were not considered during the study (i.e. valley slope between b-c sub-catchments of No.2. catchment (*Fig. 1*).

To perform the measurements the digital elevation model (DEM) of the area was created. The basis of this DEM was 1:10000 scale topographic contour maps in EOV projection system (EOV – *National Standardized Projection System of Hungary*). The DEM was created as a raster feature under ArcGIS 9.3, applying the *topo to raster* option with a resolution of 2 m. The sub-catchments were generated as polygons, separated from each other along their divides. In order to measure erosion a new TIN elevation models were created for each sub-catchment, where the potential surface was created by segments connecting the top of the divides (*Fig. 3*). Then from these TINs a raster DEM representing the potential surface was created for each sub-catchments. Using the potential and the present day surfaces the software can calculate the volume differences (net erosion) using *cut/fill* option.

The longitudinal profiles of the valley floors and divides were performed by *interpolate line* function. The profiles were compared based on their concavity index defined by Langbein. Concavity was calculated as it follows (Knighton 1998):

$$C = \frac{2A}{H}$$

where C is concavity, A is the elevation difference between the mid-point of the profile and the middle of the line aligned to the end points of the profile, and H is the total height difference of the profile.

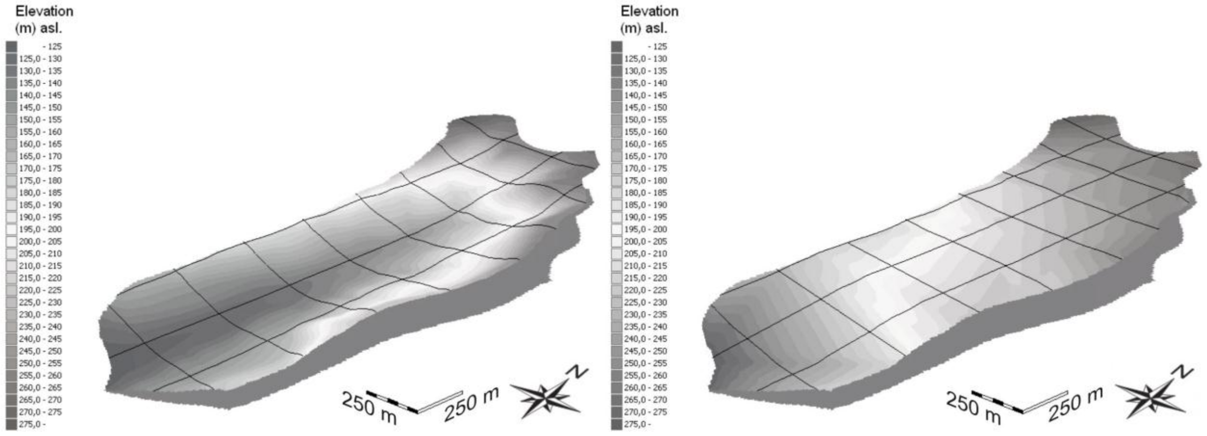

Fig. 3 Present-day and potential relief of a sub-catchment

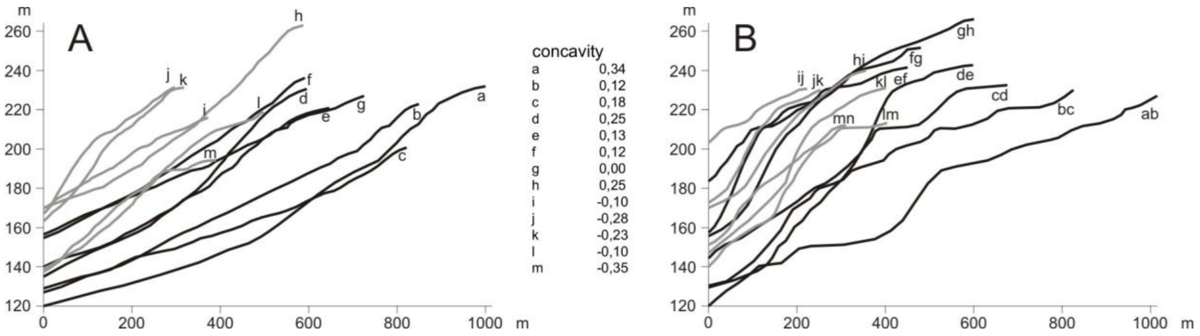

Fig. 4 Longitudinal profiles of the valley floors (A) and the intercollin ridges (B) in case of No.1. catchment (black lines: southern exposure; grey lines: northern exposure)

RESULTS AND DISCUSSION

1. Longitudinal profiles of the valleys and divides

The main valleys run from west to east, therefore the longitudinal profiles of their tributaries show typical trends based on the exposure. The tributaries with southern exposure have concave profiles. The concavity indices of these valleys fall between 0.0 and 0.34. The greatest values were measured in the easternmost tributaries near to the outlet of the main valley. The concavity index of the tributaries exposed to south decreased towards west, as the westernmost valley has a value of 0.0 suggesting that the valley floor is almost straight. In contrary, the tributaries exposed to north has smaller concavity index, as it varies between -0.35 and 0.25, negative values mean that the longitudinal profile of a valley is convex (*Fig. 4*). The differences between the valleys suggest that fluvial erosion dominates in the valleys exposed to south, while in valleys exposed to north the convex longitudinal profiles indicate the dominance of derasional processes (as freeze and thaw activity).

There is also difference in the longitudinal profiles of the divides. The divides with northern exposure have smooth curves, whilst the southern exposure divides are less steep, but they characterised by several breaks in their longitudinal profiles. These brakes and steps show the location and extension of the artificial terraces carved into the loess ridges. Some divides are gently terraced (see *bc* profile on Fig. 4B), while others has huge terraces, especially near the outlet of the main stream (see *ab* or *cd* profiles on Fig. 4B). These altered longitudinal profiles suggest huge artificial material transport on slopes with southern exposure.

2. Amount of net erosion

The construction of potential surface enabled to calculate the amount of net erosion (%) of each sub-catchment. The catchments exposed to south are much more eroded (min: 7.5 and max: 30.3 %), than the sub-catchments on the opposite side (min: 1.0 and max: 22.1 %). However, the mean values of southern exposure sub-catchments are larger (18.6-25.8 %) in all the three catchments. The most

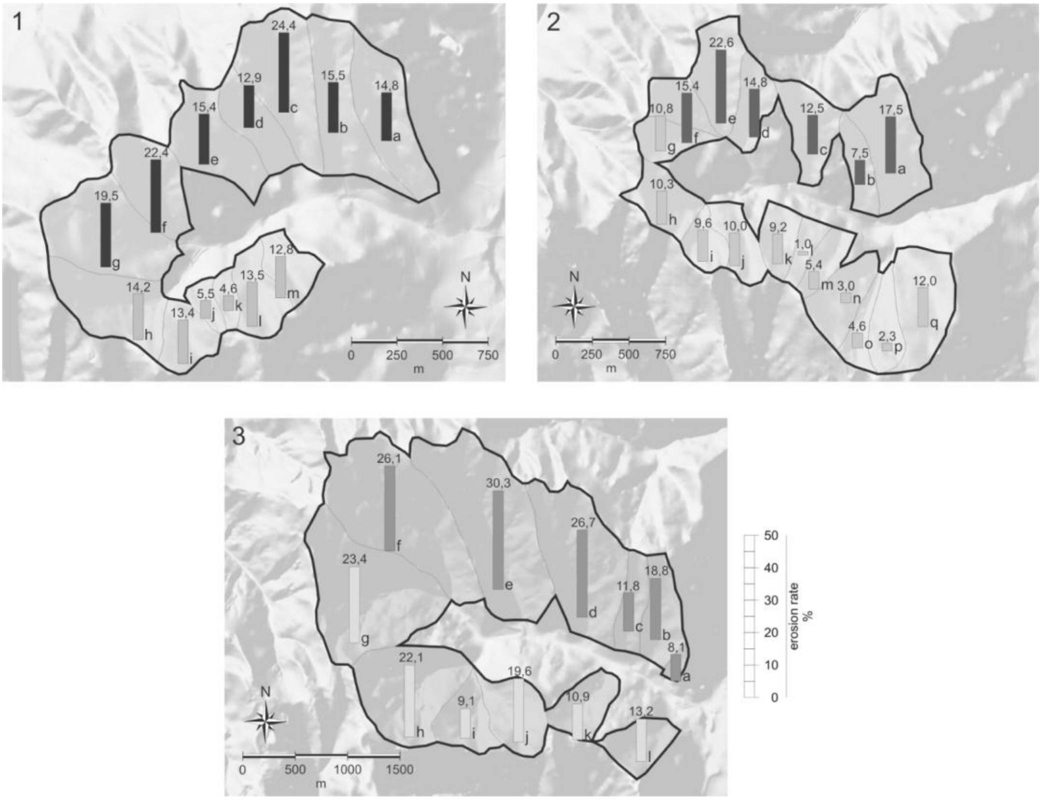

Fig. 5 Calculated net-erosion of the sub-catchments. (The main catchments are numbered 1-3, the sub-catchments are labelled a-q counter-clockwise)

incised valleys and the most eroded surfaces (net erosion: 23.4-30.3 %) are located in the north-west part of the southern catchment. These tributaries have the largest area, suggesting that there is a positive connection between the net erosion and the size of the sub-catchment. However, but there are several smaller sub-catchments with similar amount of erosion (e.g. *1/c*: 17.5 %; *2/a*: 24.4 %) indicating that there is no close connection between the size of the valley and the amount of erosion.

However, there is an increasing trend of the amount of erosion from east to west (from the valley-mouth to the upper part of the main catchment) on both sides of the main valleys, suggesting more intensive erosion of the interior sub-catchments. However, it opposes the general surface-development model, where headward erosion proceeds from the mouth of a catchment to its highest parts, therefore, the net erosion of the upper parts (interior) of the catchments is lower. However, this statement is valid just in the first stages of the surface dissection (juvenile state), when the ridges have not been eroded yet. By the progress of the surface development (mature state) the ridges and divides will also erode and they become lower by some kind of slope development (i.e. Davisian slope-decline or Penk's slope-replacement). Therefore the divides of sub-catchments closer to the mouth of the main watershed are eroded longer, therefore in greater degree than the ones in the upper part of the catchment. The studied catchments are in this phase of the development, as the divides on the eastern (outlet) part of the catchment are lower by 30-40 m than the inner ones (*Fig. 4B*). Therefore, it must be considered as natural feature that the valleys in the interior of the watersheds seems to be more eroded, because the ridges at the edge of the hills had already suffered erosion. Hence, the calculated net erosion is strongly underestimated, especially in tributary catchments near the mouth of the main stream.

As it was mentioned above, the amount of net erosion is increasing towards west. However, some sub-catchments do not fit into this trend (*Fig. 5*), as over-par erosion (14.8-24.4 %) was measured in some cases on slopes with southern exposure near the catchments mouth, near the town (e.g. *1/a-b-c* or *2/a*). Therefore, here the surplus-erosion can be explained by concentrated anthropogenic impact, as longer history of cultivation, thus longer accelerated soil erosion (*Table 1*).

The evidence on intensive erosion close to Szekszárd has been confirmed by field work. Some of the bank-in roads run on divides, cut 2-3 m deep into the surface serve as good examples on rapid erosion and fast divide erosion. In some cases the back-wall of terraces carved into the slope almost reaches the walls of the bank-in roads, and there is only about a 0.5-1 m thick loess edge left (*Fig 6*). In other cases these narrow loess

Table 1 Main and erosional parameters of the studied sub-catchments

	Exposure	Sub-catchment	Area (m^2)	Valley mouth (m asl.)	Volume of potential relief (m^3)	Erosional loss (m^3)	Net erosion (%)	Mean erosion (%)
Northern catchment (1)	south	1A	215228	117.1	13 970 734	2 060 809	14.8	18.6
		1B	223728	126.4	13 274 964	2 052 116	15.5	
		1C	253120	129.8	18 714 351	4 572 060	24.4	
		1D	115612	129.8	7 056 410	912 091	12.9	
		1E	182108	138.5	12 397 993	1 914 608	15.4	
		1H	164828	155.1	12 332 149	2 766 586	22.4	
		1I	277852	156.4	20 601 181	4 026 051	19.5	
	north	1J	208492	170	13 108 539	1 862 993	14.2	12.9
		1K	93056	170.3	4 589 618	613 494	13.4	
		1L	36076	166.8	1 414 534	77 750	5.5	
		1M	34216	165.8	1 345 001	61 617	4.6	
		1N	108380	139.3	6 804 375	918 877	13.5	
		1O	80504	136.6	4 178 669	535 915	12.8	
Central catchment (2)	south	2A	295580	126	18 697 600	3 264 944	17.5	15.7
		2B	106864	128.9	5 416 098	406 894	7.5	
		2C	188308	139.4	13 184 667	1 587 495	12	
		2D	128520	159	7 648 957	1 129 323	14.8	
		2E	210060	166	15 264 293	3 452 949	22.6	
		2F	113720	166	7 520 924	1 154 506	15.4	
		2G	108328	166	8 085 736	871 967	10.8	
	north	2H	153364	178.6	9 718 391	1 000 912	10.3	7.5
		2I	91592	178.6	5 519 206	530 701	9.6	
		2J	127168	165.4	7 731 536	772 465	10	
		2K	109380	153.5	5 080 230	467 311	9.2	
		2L	64524	154	2 355 509	24 510	1	
		2M	92456	135.5	4 709 677	253 505	5.4	
		2N	171736	134.9	10 653 162	320 281	3	
		2O	80416	137.1	5 776 133	268 102	4.6	
		2P	120408	136.3	7 901 118	178 596	2.3	
		2Q	280184	127.5	14 857 053	1 785 909	12	
Southern catchment (3)	south	3A	51020	110.2	1 583 665	128 675	8.1	25.8
		3B	326412	115	22 152 245	4 172 991	18.8	
		3C	219560	118.5	13 351 380	1 573 724	11.8	
		3D	938212	116.1	84 635 592	22 580 641	26.7	
		3E	1275716	120.3	119 495 600	36 185 369	30.3	
		3F	1253228	128.8	129 301 639	33 722 601	26.1	
		3G	1172324	128.8	109 324 174	25 615 504	23.4	
	north	3H	778828	127.5	71 325 942	15 766 935	22.1	17.6
		3I	289448	127.5	18 994 362	1 732 918	9.1	
		3J	365384	127.5	28 313 881	5 550 291	19.6	
		3K	285168	114.2	20 389 781	2 218 838	10.9	
		3L	256724	113	17 548 181	2 310 230	13.2	

Fig. 6 A bank-in road running on a divide. A: The bank-in road became elevated, as the terraces eroded intensively on both sides, thus now the road is bordered by terrace back-walls. B: The same road continues between 2-3 m high loess walls, however they are only 0.3-0.5 m wide walls, behind cultivated terraces are.

walls have already been cut off, and the originally deep bank-in roads are relatively raised over the terraces, bordered with 1-2 m high strip wall. These examples show that surface erosion due to recent anthropogenic terrace formation is so high that the ridges erode and lower quite rapidly. It also support the idea, that the net erosion measured by GIS method is lower than the real erosion, as the recent divides under human impact are at least few meters lower than the possible natural surface, so the real volume of erosion can be much higher than the measured.

CONCLUSION

In the study area viniculture has a long history. On slopes exposed to south and close to the town it probably had begun earlier, therefore runoff accelerated and linear erosion became dominant. Therefore, here the valleys have concave longitudinal profile, and the divides between the sub-catchments are also more eroded and large terraces dissect them. Valleys with northern exposure probably were cultivated less intensively and the vineyards are probably younger, therefore valley development was significantly slower and the slopes suffered less erosion. The GIS analyses showed that catchment with southern exposure are eroded most intensively (net erosion 15-25 %), as they lost 8 % more material than of the catchment with northern exposure (net erosion 7-17 %). Sub-catchments closer to the town of Szekszárd have greater amount of erosion, as it is shown by the high erosional values not fitting into the trend of natural surface dissection. Besides, near to Szekszárd the divides have already been eroded, therefore the results of the calculations are under estimated. Since there is no possibility to reconstruct the real original relief no more precise data can be obtained on the volume of net erosion. To solve the problem we plan to calculate the volume of deposited material in the form of alluvial fans and to date the deposit by absolute dating methods (OSL) to determine the age of the deposited material and the rate and periods of erosions.

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CHANGES OF LANDSCAPE STRUCTURE AND SOIL PRODUCTION FUNCTION SINCE THE 18TH CENTURY IN NORTH-WEST SAXONY

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Abstract

The objectives of this paper are (1) to reconstruct time series of the historical and current landscape structures based on historical documents and serial cadastral maps, (2) to analyse the changes of agricultural production function by the application of historical soil assessments and (3) to analyse the connections between landscape structure and production function in reference to the social and economic driving forces.

The case study area is today an intensively-used agricultural landscape located nearby Taucha-Eilenburg (NW-Saxony), Germany. Arable landscapes in Germany are changing with increasing dynamics: valuable structures and landscape functions of the traditional and multifunctional landscape were lost. New landscape structures replaced the traditional ones slowly or sometimes also in short time steps. Therefore, this paper focuses on the changes of landscape structures and that of the soil production function induced by land use since the 18th century. The changes are analysed on the basis of historical and serial cadastral maps and documents by covering four time steps from 1750 to 2005. The historical maps were scanned, geo-referenced and digitalised in GIS. Thus, quantitative analysis of landscape structure changes on parcel level is enabled. The production function is explicitly reconstructed on the basis of the Prussian Taxation of the real estate of 1864 (Preußische Grundsteuerbonitierung) and The German Soil Taxation (Reichsbodenschätzung) of 1937.

Changes observed on the serial cadastral maps were linked with the social and economical driving forces and the soil production function. Moreover, there is a high demand for the development of methodologies to analyse and to assess time series of landscape structures, land use and landscape functions in the historical context of landscape development.

Keywords: landscape dynamics, landscape structure, production functions, soil assessment, GIS

1. INTRODUCTION

From the end of the 18th century, social and economic changes had considerable influence on the landscape structure and the soil production function in Europe. Furthermore, land use changes result in less diverse landscapes and the degradation of landscape functions (Antrop 2000). The long term process of structural changes leads to changes in usability of the landscape.

Landscape dynamics is intensively induced by natural and anthropogenic processes. Landscape dynamics is defined as the changes of structure and function of a landscape that caused and steered by “driving forces”. “Driving forces” are the whole of factors that influenced the development of landscape (Bürgi et al. 2004). In case of the present study area anthropogenic processes are the main drivers of landscape dynamics.

Bastian and Bernhardt (1993), and Bernhardt and Jäger (1985) reflect the anthropogenic impacts on landscapes in the investigated area in four time periods. The increasing impact of man on the landscape is described as nearly logarithmic in the following main periods: the Neolithic revolution, the land use expansion in the Middle Ages, the Industrialisation (19th century) and the scientific and technical era (since 1960).

The landscape dynamics in historical time steps in the study area is discussed in this paper in the context of a today intensively-used agricultural region (Krönert 1996). The aim is to support decision making for landscape and land use planning for a sustainable development in the future (Antrop 2005, Bastian – Schreiber 1999, Bender 1994, Egli 1991, Fehn 1986, Marcucci 2000). Bastian (1987) and Bastian et al. (2002) stress the importance of the analysis of (historical) landscape dynamics to recognize negative landscape changes as soon as possible. Furthermore, the documentation of historical economic time steps and the knowledge about recent cultural landscapes are important for the protection and the sustainable use of cultural heritage. In Germany, similar to other European countries, the environmental law leads by several articles and political guidelines to the protection of cultural heritage (e.g. Nature Conservation Act, Environmental Impact Assessment Act). The European Landscape Convention stresses the importance of the cultural dimension of landscape. Moreover, long-term monitoring of landscape allows conclusions about the effectiveness of economic and political guidelines on a European level (e.g. on the Natura 2000 network, Common Agricultural Policy).

Landscape functions are defined as the goods and services from nature that provided by land use for human being (Bastian – Schreiber 1999: 38, De Groot 1992, De Groot et at. 2002). Landscape functions can be categorised into four main groups: production functions, regulation functions, carrier functions and information functions (De Groot 1992: 13). Production functions in the focus of this study are economic functions describing the availability of renewable resources. It includes the production of vegetable as well as animal biomass (agricultural land, grassland, timber etc.), and water (drinking water, groundwater) (Bastian – Schreiber 1999: 39f). These productions functions are strongly related to the site conditions of arable lands and grasslands (as a function of climate, geology, slope, soil, water, the cultural technological history and the land use system). Soils are also interpreted as the archive of historical impacts and results of the land use.

The use of time series based on historical maps and land registers combined with historical documents is a common scientific method for the analysis of landscape dynamics and has proven to be very useful (Bender et al. 2005, Haase et al. 2007, Ihse 1996). The study of land use changes and the quantitative analysis of time steps and time series are used to demonstrate how land use changes have influenced landscape structures and landscape functions in historical times. Therefore, we ask how landscape structure has changed in the study area and what have been the main historic "driving forces" of the landscape dynamics observed? The other main question is how landscape dynamics has influenced the temporal changes of production function? Subject, is the changing potential to biomass production by agricultural land use. Soil as the basis of agricultural land use is evaluated in regard to the natural production by using of different governmental soil taxation results. The feedback of the soil as an archive to land use changes refer to the use of the (several) landscape functions (Bork et al. 1998). These historic soil changes should be used in future landscape planning (Beierkuhnlein 2002).

The relation between landscape dynamics and production function will be discussed. As a conclusion, an overview is provided about the current and future values of historical landscape analysis.

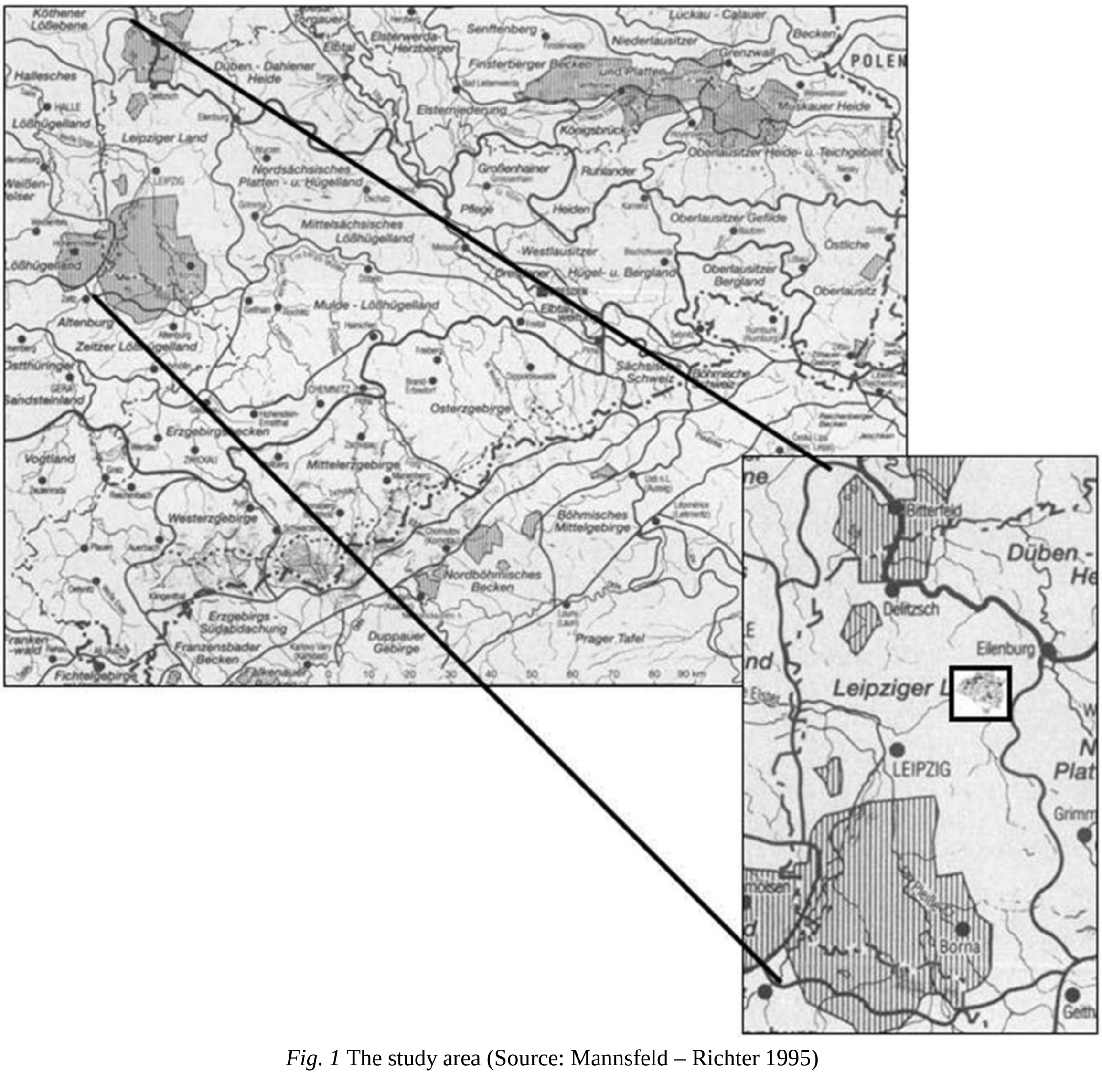


Fig. 1 The study area (Source: Mannsfeld – Richter 1995)

2. RESULTS

2.1. Investigated Area and Data

The study area (*Fig. 1*) is located in the northeast of Leipzig in NW-Saxony, Germany, as a part of the municipal region of Jesewitz. The borders of the area are determined by the borders of the municipalities Jesewitz, Pehritzsch, Weltewitz and Wöllmen named in cadastral maps as "Gemarkungen". The study area is part of the natural region of the Leipziger Land. The area is characterized by precipitations between 550-600 mm/a and the average year temperature of 8.5 °C (Mannsfeld – Richter 1995).

Historical topographic maps provide a suitable cartographic database for the reconstruction of landscape structures. The present investigation is based on historical documents (landscape descriptions, local chronicles) and serial cadastral maps and data sheets from the 18th century and to the beginning of the 19th century (*Table 1*). Geographical information system (GIS) was applied to analyse data and to visualise the results in maps. The quantitative analysis with GIS needs first an examination to determine congruence and comparability between historical and modern maps (Bender et al. 2005, Neubert – Walz 2002, Walz et al. 2004). In this investigation maps of different scales and diverse content in geometry and legends are used. The "Sächsische Meilenblätter" ('Saxonian mile maps') and the serial cadastral maps up to the time step of 1850 have been parallelised and adopted. Thus, for oldest time step (1750) analysed in this study the geometry from the cadastral maps from time step of 1850 was used.

The historical cadastral maps for time step 1850 were scanned, geo-referenced and digitalized on screen by using the GIS-programme ArcGIS9. The information of the cadastral registers was adopted into attribute tables to generate a spatial explicit data set at ownership allotment level. The information of "Saxonian mile maps" was overlaid by vector data of the time step of 1850. The data set and the attribute tables were adapted to the content of "Saxonian mile maps"; and other information of historical documents and regional maps information was added.

For the time steps 1950 and 2005 the vector data of the digital governmental cadastral map of ownership plots (Automatisierte Liegenschaftskarte, ALK) were used. The data set for time step of 2005 have been integrated and revised by the author by field survey mapping in the year of 2005. The data set of the time step 1950 was adopted to the content of cadastral registers, survey maps; information has been added by the interpretation of aerial photographs of the year 1959.

The development of field management practices since the 18th century in the study area is described for the assessment of production function. Two soil assessment maps (1937 and 1864), originally produced for

Table 1 Input data and data origin of the four time steps 1750, 1850, 1950 and 2005

Time	**Data source**	**Scale**	**Archive**
1750	Sächsische Meilenblätter (1780-1811), Dresdner Ausgabe, Bl. 21/30	1:12 000	Hauptstaatsarchiv Dresden
	Petrikarten (ca.1760), Bl. 1-2	1:33 000	Institut für Länderkunde, Leipzig
	Atlas Augusteus (1722-1742), Bl. 21	not known	Staatsarchiv Leipzig
	Schumannsches Lexikon 1813(+)		Institut für Länderkunde, Leipzig
	Geometries: Urkatasterkarten 1864		Staatliches Vermessungsamt Torgau
1850	*Geometries :Urkatasterkarten (1864)*	1:2500/1:3000	Staatliches Vermessungsamt Torgau
	Separationskarten (1810-1840)	1:2500/1:3000	Landesarchiv Wernigerode/ Staatliches Vermessungsamt Torgau
	Flurbücher des Urkatasters		Staatliches Vermessungsamt Torgau
1950	Liegenschaftskataster	1:2500	Staatliches Vermessungsamt Torgau
	Luftbilder (1959), 159/59/111-116	1:12 400	Militärarchiv Potsdam
	Messtischblatt 1905-1912 (2609)	1:25 000	Institut für Länderkunde, Leipzig
	Geometries: Automatisiert Liegenschaftskarte (ALK)		Staatliches Vermessungsamt Torgau
2005	*Geometries: ALK*	1:1000	Staatliches Vermessungsamt Torgau
	Own investigation		

Note: In Cursive: Data source of the geometry for the time series.

land taxation purposes, have been digitalized for the analysis of changes in natural soil productivity. The data sets were overlaid to the data layers described above in the GIS. Thus, a spatial explicit and quantitative analysis and comparison were enabled.

The German Soil Inventory (1937) is available and documented for all agricultural and horticultural land in Germany. Sample points of this inventory are fixed in the soil inventory maps and detail described in inventory books (Schätzungsbücher). Today these data are stored and managed by the German local financial authorities. The data used in this case study is available from financial authority of Eilenburg, NW-Saxony.

2.2. Time steps of land use development

The land use categories applied for the comparison of the four historical time steps are arable land, grassland, forest, water bodies, settlement areas, and other land uses. Furthermore, also the changes of the road network have been analysed (*Fig. 2*).

Before the Prussian agricultural reforms

The hilly landscape of the study area was formed by glacial and periglacial landscape development since the Saale glacial period. Predominantly aeolian sediments of the earlier Weichselian glacial period overlay sandy loess of periglacial origin by an average sediment layer of one meter. The sandy loess is the basis substrate for soil development. Main soil types in the heterogeneous study area are lessivé and brown soils of medium suitability for agricultural production (Meyer 1997).

After the Weichselian glacial period and several fluctuations including colder and warmer periods the study region was occupied by a more or less widespread forest of beech trees (Fagus sylvatica) and oak trees (Quercus). The first settlement activities in the study area are assumed for the Palaeolithic time (Dunkel 1969, 1977, Hanitzsch 1956, 1962, Moschkau 1957, Töpfer 1958). Lüning (1997) proved that settlements since the Neolithic time are stable according their site location.

At the end of the medieval period to the beginning of modern times (1500-1800 AD) the land use structure and the distribution of land use types were relatively stable (Blaschke 1995). In the study area of a size of roughly 2.639 ha agricultural land still dominated in the time step 1750 by 1.938 ha or 73.4% of the total area. Grassland covered 583 ha or 22.1% of the area. The other land use types are not of high significance by a percentage of 2.2% of forest, 1.1% of water bodies and 1.1% of settlement areas. The road network has been constructed since the medieval period of land colonisation with a length of approximately 34.1 m/ha (*Table 2*).

Separation – Changes in landscape structures

In the 19th century political, social and economic influences particularly changed the landscape structure (Rakow 2002). After the end of the Napoleon era and the Wiener Congress (1815) the study area became a part of the Prussian kingdom. Induced by the Napoleon wars, Prussia had an economic crisis at this time. During the reformation of Prussian agricultural management systems (1807-1850) a new land ownership allocation and land use distribution (so-called “Separation”) emerged.

The comparison of the time steps 1750 and 1850 results an increasing percentage of arable land from 73.4% to 86.0% in the area studied. Grassland decreased of roundly 43% of the origin level. No dramatic changes occurred in the other land use types. Forest and settlement area increased slightly, water bodies decreased slightly and land use type “others” remained at the same level. The road network increased from 34.1 m/ha to 35.8 m/ha (*Table 2*).

After the Second World War in the middle of the 20th century the social and political situation changed dramatically. The land management practices have been mutated to the socialist planning regime of the German Democratic Republic (GDR) by following the Russian Soviet example. This organisation led to landscape structural changes with high impacts, for example, on flora and fauna water, soil, recreation or on the production potential of the landscape. Traditional and diverse land use practices have been replaced by a new form of agriculture based on the intensive use of machinery and the increasing input of fertilisers (Baessler – Klotz 2006).

Table 2 Percentages of land use types of the time steps 1750, 1850, 1950 and 2005

Time step	**Land use type**												
	Arable land		**Grassland**		**Forest**		**Water bodies**		**Settlement area**		**Other**		**Road**
	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	m/ha
1750	1938.0	73.4	582.8	22.1	60.9	2.2	24.7	1.1	29.5	1.1	3.7	0.1	34.1
1850	2270.1	86.0	249.2	9.4	60.3	2.3	24.1	0.9	32.1	1.3	3.7	0.1	35.8
1950	2316.5	88.7	141.4	5.1	70.6	2.7	20.1	0.8	55.2	2.1	14.6	0.6	36.4
2005	2297.0	87.2	110.0	4.2	70.5	2.7	20.1	0.8	106.4	4.0	30.4	1.1	28.7

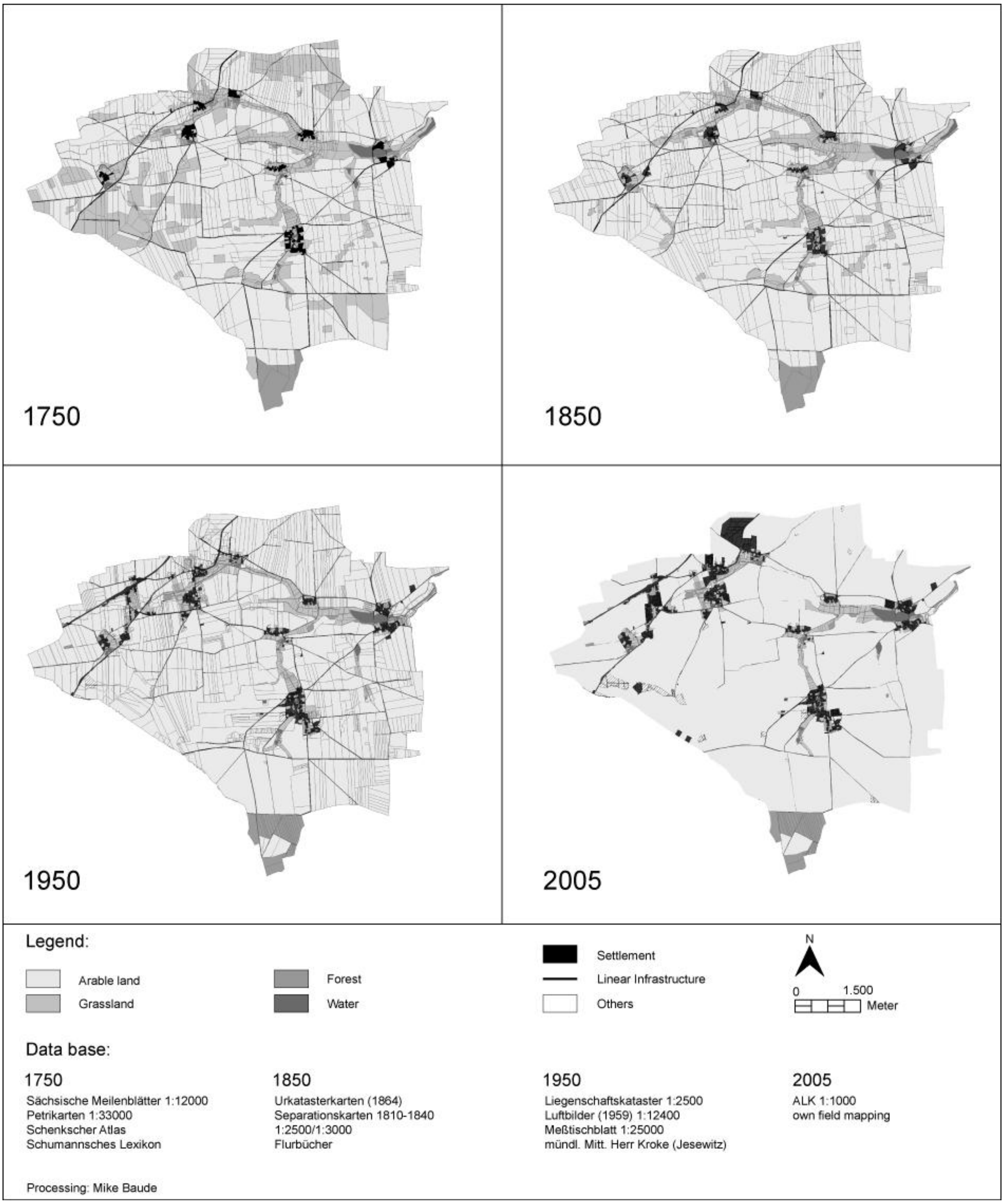
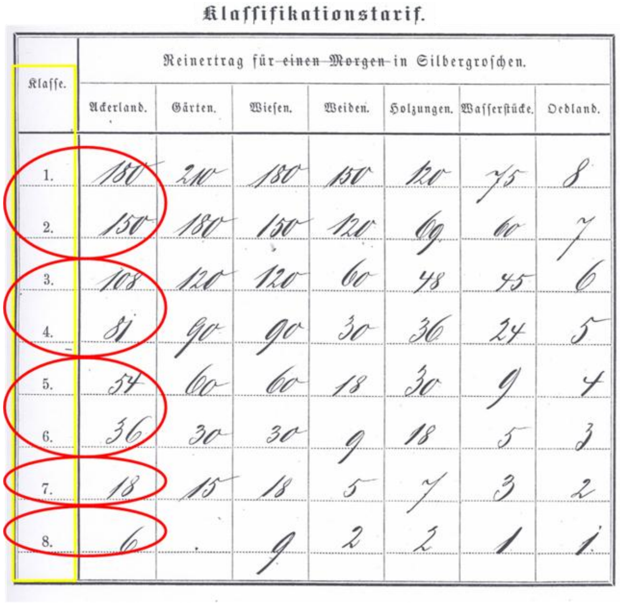


Fig. 2 Landscape dynamics in the four time steps 1750, 1850, 1950 and 2005
(digitalisation and processing have been carried out by the authors)

Landscape changes since the middle of the 20th century

Two main steps of land transformation can be observed. In the first period until the 1950th grassland decreased with roundly 43%, and the arable land increased around 2% (1850=100%). At the same time, there was no significant change in the percentage of forest and water bodies. The settlement area increased with 72%. Slight changes in the road network can be as well detected. However, the extensive management practices with multiple crop rotations and a lower level of techniques and fertilizer promoted a high biodiversity after the Second World War until 1960 (Baessler – Klotz 2006).

The second time step of 2005 shows that arable land has nearly the same amount as in the 1950th. Nevertheless, grassland still decreased with 22% in comparison with the earlier time period. The intensification of agriculture by changing the landscape structure into very large-sized fields, the melioration, the irrigation and the application of pesticides and fertilisers have steered increases in food production over the past 50 years (Matson et al. 1997). The road network was accommodated to the technical field management practices and decreased from 36.4 m/ha to 28.7 m/ha. Since 1990 the total amount of land that used for agriculture is declining because of the impacts of the common agricultural policy of the European Union by the promotion of set aside, and also due to market changes. Additionally, intensive settlement activities of the urban sprawl of the city of Leipzig have been observed since 1991. Thus, settlement area increased from 55.2 ha to 106.4 ha, complies roundly 93%. The percentage of forest and water bodies remained on the same level. The decrease of land use type "others" since time step 1850 has been effected by the exploitation of sand and gravel (*Table 2*).



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1.	180	210	180	150	120	75	8
2.	150	180	150	120	69	60	7
3.	108	120	120	60	48	45	6
4.	81	90	90	30	36	24	5
5.	54	60	60	18	30	9	4
6.	36	30	30	9	18	5	3
7.	18	15	18	5	7	3	2
8.	6		9	2	2	1	1

Fig. 3 Classification tariffs for the study area (Source: Staatliches Vermessungsamt Torgau)

2.3. Comparison of the soil assessments of 1864 and 1937

In the middle of the 19th century the first soil assessment was executed in Prussia by the order of the Prussian Law of real estate tax ("Preußisches Grundsteuergesetz") from the 21st of May in 1861. The Prussian Taxation of real estate was based on soil attributes and economic values. The Prussian taxation is distinguished in eight classes (*Fig. 3*). The first class indicates soils with very good production services; class eight indicates soils with least production services. The high of classification tariffs ("Klassifikationstarife") for the eight several classes and various land use types (e.g. agricultural land, grassland) were determined by the local market situations (*Fig. 3,* shown in elapse). Thus, soils assessed in the first class have the highest tariffs and so on. The classes described the quality of natural soil fertility depend only on the natural soil attributes (without economic values). The Prussian Taxation of real estate was introduced in the study area around 1864. Similarly, the sample points of this assessment have been extrapolated to the allotment level located in the cadastral maps of the year 1864. These maps also contain other soil parameters. The assessment level of natural productivity is classified in 8 levels of scoring. The soils evaluated into level 1 are of the highest natural productivity. For more details about the Prussian Law of real estate tax and their execution see Amend (1997).

In the study area the German Soil Inventory was introduced in the year 1937, according to the Law from 1934 (Bodenschätzungsgesetz). The German Soil Inventory database describes various soil parameters down to 1m depth. Furthermore, there is also data on the geological origin, humus content, soil texture and other parameters (Syrbe et al. 2007). The database divides the soil parameters and aggregates these different aspects into a scoring-index between 0 and 100. Soils with the index of 100 are of the highest natural productivity in Germany (e.g. Magdeburger Börde). For the comparison the soil numbers (soil numbers between 0-100; soil with soil number 100 have the most natural soil fertility) were used. The explicit description of the methodology of the soil assessment comparison is demonstrated by Baude and Meyer (2006).

In *Figure 4* the distribution of the Prussian soil assessment in the study area is presented. The borders between the classes from classification tariffs of the

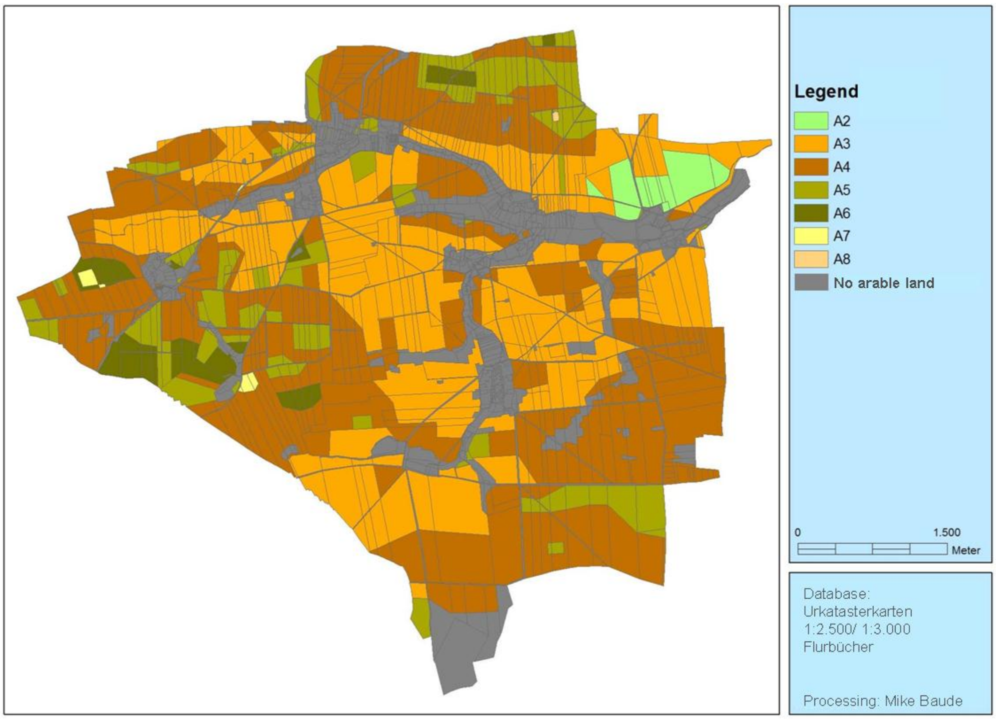

Fig. 4 Prussian soil assessment from 1864 (digitalisation and processing were carried out by the authors)

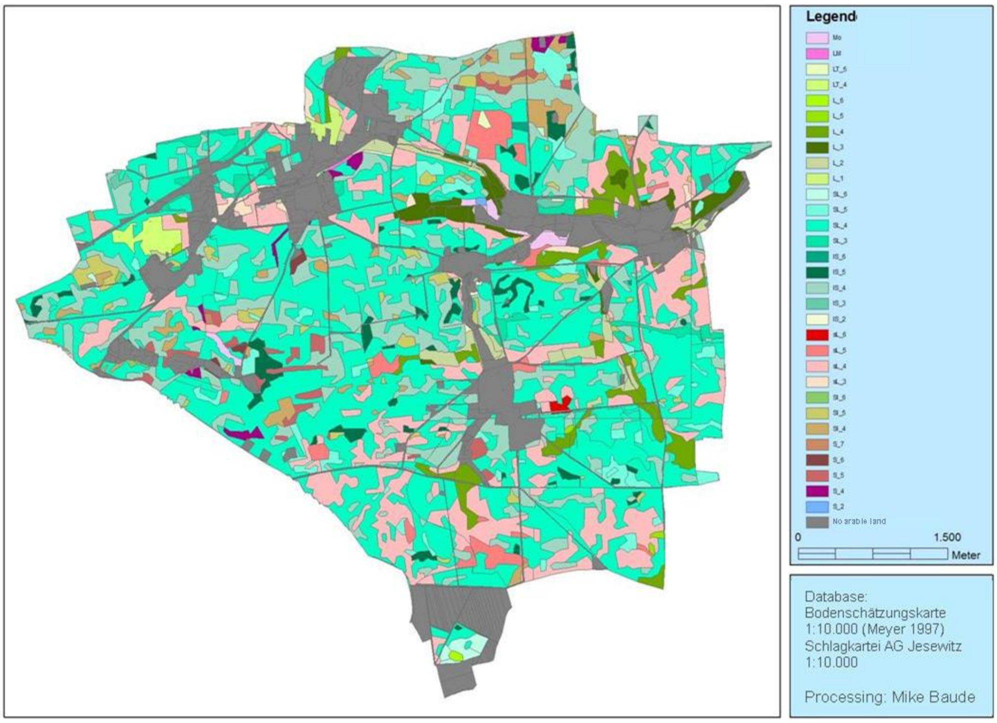

Fig. 5 German Soil Inventory from 1937 (digitalisation and processing were carried out by the authors)

Prussian Taxation were oriented according to the field borders on ownership allotment level. Within these fields plots of the same classification can be found. There is no specific exploitation raster. The Soil taxation correlated with the field on ownership allotment level. The Prussian Taxation shows the natural character of suitability for agricultural production, because melioration and fertilization started later, with the industrialisation, after the Prussian Taxation. The differentiation in the map of the German Soil Inventory (in *Fig. 5*) is effected by the exploitation in raster 50x50 m. Furthermore, the extended soil exploitation distinguished 31 soil types with several soil characteristics. Thus, the characterisation of the different soil characteristics is enabled.

Although the approach used for the analysis of the German Soil Inventory (1937) has been adapted on the soil assessment of the year 1864, the different data sets cannot be compared without 1:1 GIS-adaptation (Freund 1998). Thus, for the comparison of the two different soil assessments we applied a generalization of the data of German Soil Inventory. The differentiated data set of the German Soil Inventory (1937) were first summarized to five main groups according to the soil numbers and assigned to the “grouping of usability” (‘Nutzbarkeitsgruppen’) (Matz 1956). The grouping composited the soil number according to the soil type. In this case there are five groups of usability with the associated soil numbers. Furthermore, the classification tariffs were composite to five main groups according to the level of their taxation class and assigned to the “grouping of usability” as well (*Table 3*).

This generalization provides a methodology to compare the two soil assessments based on a more summarised character of the different data sets. The comparison based on GIS-analysis of land which was used as arable land between the time periods 1850 and 2005. A quantities analyses of the changes of the soil characters between 1864 (Prussian Taxation) and 1937 (German Soil Inventory) is applied. Validity of results of the German Soil Inventory is applicable to describe the current soil characters when the actual morphological dynamics are integrated (Finke 1994).

The comparison permitted that 97.7% of the comparable agricultural land can be ranged in five groups. *Table 3* shows that the second group of usability dominated in both soil assessments with 66.6% (GSI) respectively with 83.72% (PT). In group 3 there are 22.9% (GSI) respectively 14.07% (PT) of comparable agricultural land. Thus, a significant part of the agricultural land can be associated to the groups 2 and 3. The groups 1, 4 and 5 are without a higher importance for the soil assessments and described 10.5% (GSI) respectively 2.21% (PT) of the comparable agricultural land.

3. DISCUSSION

3.1. Interpretation of historic maps and soil taxation

The spatial explicit mapping of landscape structural changes is accompanied with uncertainties concerning scales and contents of the information included. The landscape dynamics analysed in the time steps and the interpretation of their impacts on structure and function of recent landscapes should be seen on the background of historical data sets and maps.

Historical landscape analyses on the basis of GIS data offer new views for the knowledge about dynamics, structure and functions of landscapes. Long time series permit landscape assessments of changes related to economic, ecological and social aspects. With regard to their validity historical data sources must be critically checked. While the scale of the data set makes the exact reconstruction difficult, the knowledge about the landscape functioning in the past is very useful to understand recent processes of landscape changes.

In our study, land use changes and the quantitative analysis of time steps are used to demonstrate how land use changes influenced landscape structures and landscape functions. Therefore, we ask how landscape structure has changed in the study area and what have been the main historic “driving forces” of the landscape dynamics observed? The other main question is how landscape dynamics has influenced the production function during time?

Table 3 Comparison of German Soil Inventory (GSI) and Prussian Taxation of real estate (PT)

	Soil number					**Classification tariffs**
Grouping of usability	**IS/SL**[1]	**GSI in ha**	**PT in ha**	**GSI in %**	**PT in %**	**Arable land**
1	64-81(+)	85.8	43	4.09	2.05	1/2
2	49-63	1395.7	1752.9	66.6	83.72	3/4
3	36-48	480	294.6	22.9	14.07	5/6
4	29-35	53.2	3.2	2.54	0.16	7
5	(-)18-28	81.1	0.05	3.87	0	8
	Sum	2095.8	2093.8	100	100	

[1] Main soil type of case study area

In the following chapter, we discuss shortly how the landscape has developed since the Neolithic. Starting with the beginning of the Prussian agricultural reforms we analysed four time steps in the context of the main drivers of landscape change. We proved two periods in change of the production functions in regard to the main driving forces.

3.2. Land use changes in the context of driving forces

The first permanent settlements of the study area in the Neolithic Revolution were accompanied by the first strong human influences of the landscape. During this period the cultural landscape usage began with common forest pasture and led to first deforestations. However, after this first deforestation began a reforestation period until the Slavic colonisation during the migration period in the 6th century (Gringmuth – Dallmer 1983, Bork et. al. 1998). Thus, the human impacts of Neolithic Revolution were without high importance.

The first major landscape changes caused by the Slavic colonisation associated with population growth and an increase on cultural land use. After the beginnings of the colonisation by German settlers, the so called 'East expansion' in the 10th century, the population grew up to decuple. The agricultural land increased in according to further land use practices to a first maximum in the 14th century. During the 'East expansion' the landscape structures changed dramatically. Until the end of the Middle Ages the indigenous forest area decreased by 90%. At that time arable land became the dominant land use type. Blaschke (1995) and Nitz (1995) proved that the distribution of land use types in the study area has not changed after the end of the Middle Ages. However, with the Prussian agricultural reforms the landscape structures changed again distinctly.

Our spatial explicit analysis, starting in the middle of the 18th century, results that arable land increased significantly at the begin of the 19th century. Up to the middle of this century until today the land use type distribution was relatively stable, when compared with large land cover changes e.g. in Estonia (Mander – Palang 1994). The area of grasslands decreases in our investigation area continuously; forests and water bodies are normally stable, located on the same plots, the area for settlements increased slightly. The linear infrastructure changed with the Separation by the new property situation and the needs for new agricultural methods. The development in the 19th century coursed mainly by the Prussian agricultural revolution, when the economic situation after the Napoleon wars were disastrous and new field management and practices were needed. In the course of the “collectivisation” in the years between 1950 and 1960 the linear infrastructure changed dramatically, when several paths and country roads have been deteriorated and most of the field margins and hedges were destroyed to arrange the countryside in the of form of large field plots for mechanised crop production. Furthermore, another main development period was initiated by the GDR government to copy the Russian Kolkhoz system to Germany. The extension of mechanical and chemical agricultural practices needed large field sizes and less linear infrastructure inside the fields. The heterogeneous agricultural landscape, structured until the 1960s, has been diverted into a homogeneous and intensively-used mono-functional agricultural landscape without clear cultural orientation and coupling the formally agricultural villages.

The development of land use types depends on several driving forces: In the past natural hazards such as extreme weather and intensive rains with high impact on the landscape have changed the land use (Bork et al. 1998). Furthermore, landscape structure changes were influenced by social and political events like medieval diseases, wars (Thirty Years' War, 1st and 2nd World War) and economic crisis (e.g. the agricultural crises at the beginning of 19th century, the collapse of agriculture after World War 2). There are several public reformations such as the Prussian agricultural revolution in the 19th century or the planning economy of former German Democratic Republic which have also influenced the development. Today EU-norms and regulations steer the development of landscape structures, i.e. by the Common Agricultural Policy, the Habitats Directive and NATURA 2000 network.

3.3. Soil productivity changes - Knowledge for sustainable land use

The production function in the study area is mainly characterised by the agrarian productivity. Thus, this agrarian productivity depends on natural soil productivity in addition to the soil characteristics.

In the period between the Slavic colonisation and the beginning of the Prussian agricultural revolution and the industrialisation in the second half of 19th century the agrarian productivity depended mainly on the expansion of agricultural land. The expansion of agricultural land came to an upper limit when the best lands were cultivated (Mottek 1987).

To the beginning of the Prussian agricultural revolution the growth of production function is also steered by the expansion of agricultural land use. The maximum of agricultural land is achieved. The beginning of the industrialisation defined that the growth of agrarian productivity based as of now on new technical achieve-

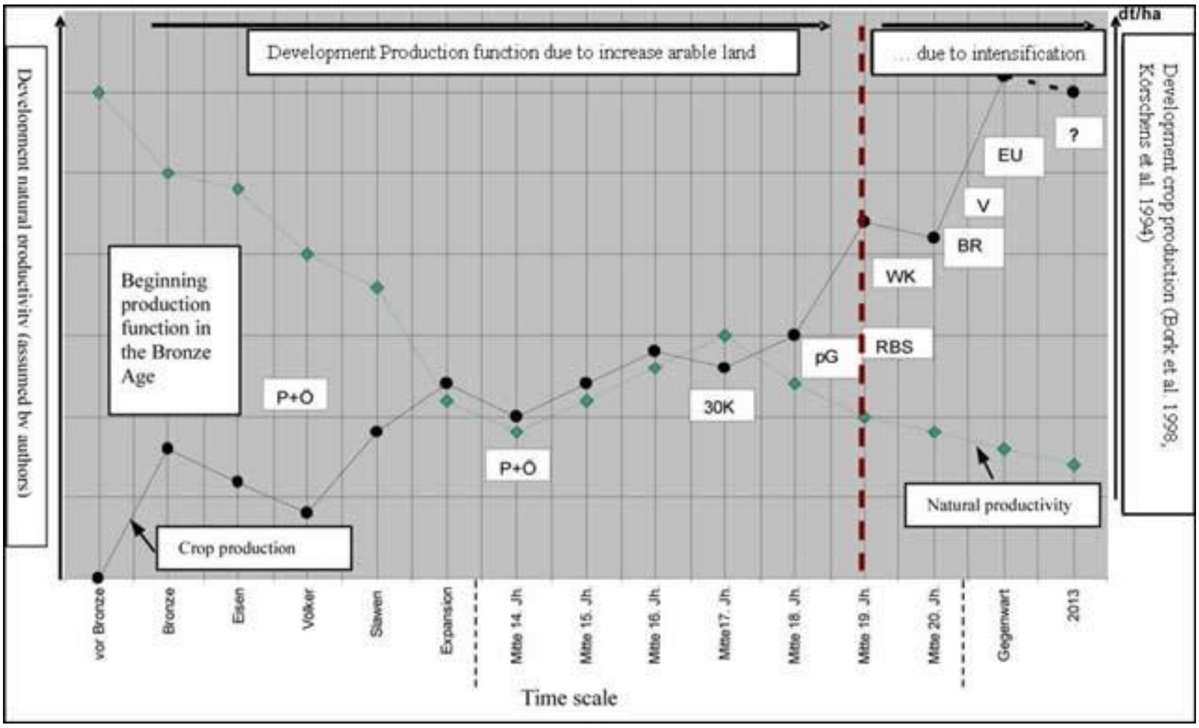

Fig. 6 Development of production function according to main driving forces, Legend: P+Ö=Pestilence and Ecological Changes, 30K=Thirty Years' War, pG=Prussian Taxation, RBS=German Soil Inventory, WK=World Wars I / II, BR=GDR Agricultural Reform, V=GDR "Collectivisation", EU=European Agricultural Policy

ments, modern management practices and the expansion of new mineral fertilizer (Müller 1998).

The intensity of agrarian productivity became a new dimension after the "collectivisation" around the 1960th. The new farm management system with large field sizes and technical field management practices, and also the intensive melioration of water households lead to a significant growth of production. Jäger (1987) proved that the main growth of production function was between 1950 and 1980. Körschens et al. (1994) identified in according to Jäger (1987) an increase of grain production with 100% between 1902 and 1992.

However, these practices of intensively-used agricultural land led to strong impacts in soil and groundwater ecology because of soil erosion and soil degradation. Bork et al. (1998) postulated for the same time period the increase of soil erosion and soil degradation in several other European regions as well. In order to clarify the situation of the soil productivity function, the Prussian Taxation of real estate (1864) and the German Soil Inventory from 1937 give the soil and land use status before and without the intensive changes from extensive use to intensively-used agricultural land in the second half of the 20th century. However, the comparison of the two soil assessments by this study indicates steps of change. The natural soil productivity decreased to a larger area of soil in a lower group of usability (*Table 3*).

We distinguish two main periods of the production function development in the investigated area during the last 150 years. We found a first period from 1864 to 1960 with relative stability in comparison to other phases since the middle of 18th century. The distribution of land use types was stable and the changes in natural soil productivity in accordance with the investigated soil assessments were without high amplitude (Jäger 1987). The second active period up to 1960 were characterized by new management practices like melioration, fertilisation and mechanical soil management (Jäger 1987). The increase of the production function (e. g. in the production of cereals) is accompanied with the degradation of natural potential to produce biomass on several fields, because of erosion, soil accumulation, soil compaction and other changes of physical and chemical soil characteristics. To conclude the comparison of the two soil assessments we can say that the natural soil productivity has not significantly changed between the middle of the 19th century and the beginning of the collectivisation (1960). *Figure 6* shows the development of natural productivity and the crop production. Furthermore, the main driving forces that influenced this development were shown in context of the time scale.

The increasing landscape dynamics by land use practices and land use changes are in the same time essentially for the development of the production function.

The changes in management practices and the new agrarian objectives of the society have strong influences on the production function. The result of these developments is a highly productive agricultural land use. The adaptation of the landscape structure and the monofunctional land use by preference of the production function is the result of the economic optimisation. This economically optimised land use recently goes on with the ongoing height human input of energy and substances. Thus, the today's stability of the production function depends directly and mainly on the inputs of the farmers. It follows that the ecological equilibrium of the man-managed land is increasingly unstable and vulnerable against such disturbances as natural hazards (Steinhardt 2005). Dabbert (1994) points to the enhanced organic management practices developed in modern agriculture with nutrient balances and increasing soil fertility since the 19th century. Meyer (1997) proved for the investigated study area that the regulation functions as a term of the landscape household of landscapes is still in decline from the collectivisation period.

The biodiversity heavily decreased after the "collectivisation" by the intensively-used agricultural land and the changes of landscape structure (Waldhardt et al. 2003, Baessler – Klotz 2006). In comparison with that the less intensive agricultural land use directly after Word War II promoted high spatial heterogeneity and the richness species (Baessler – Klotz 2006). The biodiversity increase is described for the time period until the mid-19th century for cultural landscape followed by a decrease since the beginning of industrialisation of agriculture (Plachter 2001).

4. CONCLUSION

Similar to most European countries, the landscape structure changes described in this study follow the comparable fundamental changes especially for the time period after 1960. Landscape structural changes and the development of production function should be seen and combined with results of other disciplines like the studies on climate change, the investigations about the loss of biodiversity, the degradation of arable land and the desertification problem. Furthermore, the results show the linkage between human land use, and landscape structures and functions. The interdependency between landscape structural changes and the development of production function is also demonstrated in this case study. Follow-up impairments, for example soil degradation, soil erosion and the total loss of soil productivity, the society will confront with economic, ecological and social problems with probably high costs.

Thus, for a target-oriented, based on the principles of sustainability and landscape functions to produce ecosystem services land use planning, the historical information demonstrated in this study can help to bridge the gap between economic and ecological interests. Aspects of historical land management practices confront the discussion with examples how to manage the landscape and that the satisfaction of human needs can be brought in line with ecological interests. This balance between human productive needs and techniques, and the ecological basis is necessary for a sustainable future. The methods to analyse the changes of landscape structure and soil production function induced by land use since the 18th century in North Saxony demonstrated in this study should help to bring the historical information/the data of historical maps in the context of modern methods of landscape analysis.

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CHARACTERISTICS OF THE FLOW REGIME ALONG THE REGULATED TISZA RIVER REACH DOWNSTREAM OF TISZAFÜRED

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Abstract

In this paper, an attempt is presented at clearing the reasons of some uncommon flow phenomena observed over the Tisza reach downstream of Tiszafüred, and at pointing to the practical significance of the results obtained. Over six hundred thousand daily stage data were selected from the more than six million (!) water level data, registered from 1876 to 2009 (on the gauges between Tiszafüred and Novi Bečej (Törökbecse)). Taking the data of ground water wells into consideration, the conclusions arrived at are believed to be of interest to theoretical fluvial hydrologists, yet also to river engineers engaged in designing and operating (when needed) flood control schemes.

Key words: low-water, high-water, ground water, hysteresis function, water level drop, backwater, barrage, permanence

INTRODUCTION

The comprehensive reclamation project conceived by Pál Vásárhelyi and implemented under the management of Károly Herrich has changed flow conditions of the River Tisza and those of the tributaries substantially. Flood peaks rose by 3 to 4, and low waters dropped by 2 to 3 metres in the bed, which was shortened by 32 % of the original length. The steeper slope has increased the average flow velocities river $\sqrt{1,6}$ = 1.26 times at medium stages. The coincidence pattern and extent of interaction with the tributaries have also undergone changes (Vágás 2007).

Owing to drainage accelerated by roughly 26% in the main river and to the loss of storage space in the severed oxbows (Vázsonyi 1973), the spring and early summer flood waves travelled downriver faster and were followed by longer arid summers and longer low water periods. After up to 20 to 40 rainless days, most of the flow consists of groundwater drained by the river (Szalay 2000). Groundwater is depleted further by withdrawals for human uses (Csatári et al. 2001, Völgyesi 2005, 2009), thus lowering the ground water table (Rakonczai 2006).

The project has started hydrologic processes, which conflicted with traditional laws of fluvial engineering, and which failed to explain several of the phenomena and processes actually observed. These include the dropping low-water levels (Iványi 1948, Dunka et al. 1996, Konecsny 2010), the changes in the ground water table and the flow regime of rivers (Rónai 1985, Tóth 1995, Tóth – Almási 2001, Rakonczai 2001, Bozán – Köröspart 2005, Völgyesi 2005, 2009, Pálfai 2005, 2011, Szalai – Lakatos 2007, Marton 2010), the rising high-water water levels and the effects of the barrages (Koncz 1999, Stegăroiu 1999, Schmutz et al. 1995, Giesecke – Mosonyi 2005). More recent studies have attributed these to changes in the state of the flood bed flanked by the levees (silting and vegetation growth) and in the channel geometry (Nagy et al. 2001, Schweitzer 2001, Gábris et al. 2002, Sándor – Kiss 2006). Without intending to question the potential local significance of these effects, the hydrological phenomena dealt with below (viz., flattening flow profiles, effect of barrages and the actual hydrologic interactions between the recipient and the tributary rivers, as well as the ground water) are considered more general and substantial in nature.

Flood waves starting form the Upstream Tisza have been observed repeatedly to overtake each other before entering the middle reach. Some of such flood waves have been observed more recently to split again on the lower reach. Backwater, respectively drawdown, by the major recipients has been offered as explanation for these phenomena (Vágás 1982). The flood waves entering from the tributaries Maros and Hármas-Körös may coincide with rising or falling stages in the recipient Tisza River and raise, or lower the peaks of the latter. The actual stage in the Danube, the ultimate recipient, may also back up, or draw down the Tisza water level and even start a peak spreading upstream in the Tisza River. Such random flood waves may become perceptible as the cause of important changes in the flow regime in the Tisza River, owing to the extremely flat slope of the latter. The discharge measurements of growing frequency over the past decades have revealed that together with the gauge reading, the slope of the surface profile must also be allowed for when estimating the actual discharge (Dombrádi 2004).

The 133 years long record of flows and floods in the River Tisza has revealed that the normal velocity and direction of flow differ markedly from the velocity and direction of the flow registered during the flood peaks (Vágás – Simády 1983). The flow velocity is determined normally by the discharge, bed- and surface slope conditions of the river in accordance with the conventional laws of hydraulics, whereas the velocity of the flood peaks depends highly on the actual backwater and/or drawdown caused by the tributaries, or the main recipient (the Danube). The peak stage may spread upstream against the direction of flow over long river sections. Flood waves starting over the upper reach have been observed repeatedly to flatten over the middle, or lower reach, before entering the Danube. Although more in-depth studies on the aforementioned phenomena have been started but recently, their correlation seems obvious.

The general opinion of Huszár (1985), Bogdánfy (1906), Erdős (1920), Tellyesniczky (1923), Korbély (1909), Iványi (1948), Lászlóffy (1982), Vágás and Simády (1983) was that not all flood waves travelling down the River Tisza, but only some of them peaked earlier at upper gauging stations than one of the downstream ones, and ended "regularly" at the mouth to the Danube. An appreciable number of Tisza floods were affected on one of the middle or lower sections (not necessarily the same in every case) by backwater of a flood on the Danube or one of the Tisza tributaries – especially the rivers Maros or Körös Rivers, or drawdown in the case of their recession, so that the peak occurred earlier at the lower gauging station than at one of the upstream ones.

A hydrological phenomenon observed long ago on the Tisza River is the hysteresis loop, viz., a curve displaying the discharge of a flood wave versus the corresponding stage (Bogdán-ffy 1906, Korbély 1937, Németh 1954). Its substantial feature is a peak stage residing over the same section for a longer period of time (several days). As a consequence of these irregularities the relationships based on steady flow velocity and surface slope are limited in their validity and usefulness.

OBJECTIVES

The aim was to identify and offer theoretical and practical solutions to issues as yet not fully cleared in the Tisza River section downstream of Tiszafüred. Over six hundred thousand daily stage data were selected from the over six million water levels registered from 1876 to 2009 (on the gauges between Tiszafüred and Novi Bečej (Törökbecse).

The more specific objective was to correlate streamflow and progress of flood waves, to analyse their likelihood along the river section and in time, their statistical characteristics and to discover the hydrological and geographical reasons leading to their occurrence in the Tisza section downstream of Tiszafüred and to identify those considered extraordinary relative to other rivers.

An attempt was made at shedding new light on areas of scientific interest believed to merit further study in order to improve flood control measures by drawing on lessons learned during floods of recent decades, and made possible by latest advances in computerised analysis. The impact of the tributaries and the main recipient – the Danube – on the Tisza was the most important question, which has not received adequate attention thus far. Surface profiles in river networks comprising tributaries and recipients are prominent areas in this respect. In such networks the distinction between the velocity of river flow and that of the flood peak is believed important enough to study more in depth. The phenomenon of flood peaks spreading opposite to the direction of flow is believed unique in global fluvial hydrology.

Accelerated drainage in the wake of the Tisza Valley Reclamation Project has depleted the water resources also along the Tisza reach downstream of Tiszafüred. The extent thereof in periods of low precipitation was demonstrated on the basis of the data of ground water level detection that had started in the beginning of 1930's.

Weirs were studied for their impact on groundwater, river flow and water regime.

METHODS AND AREA OF ANALYSIS

Tisza water levels registered daily after regulation from 1876 up to 2009 on the gauging stations between Tiszafüred and Novi Bečej (Törökbecse) were processed. Surface slopes were determined as the difference in water levels registered simultaneously on two adjacent stations and divided by the distance between the respective stations. The surface slopes determined in this way were then evaluated statistically. The following river sections were studied: Tiszafüred, Taksony, Tiszabő, Szolnok, Martfű, Tiszaug, Mindszent, Csongrád, Algyő, Szeged in Hungary, and Novi Kneževac (Törökkanizsa), Senta (Zenta), Novi Bečej (Törökbecse) in Serbia. The gauge readings were divided into metre-ranges and the slopes obtained were entered in the appropriate range. The 133 years long record was also subdivided into periods.

The daily surface profiles of the Tisza were plotted and the annual lowest-, mean- and highest stages were identified. Any change over time in these water levels was examined for events and interference with the life of the river, which have actually or potentially affected the flow regime.

The annual duration of water levels below the gauge "0" and above the "600 cm mark" was noted, as well as the actual duration in the higher-than 600 cm range of the major flood waves. The flood waves travelling normally downriver, that is peaking successively at each gauging station and showing no backwater evidence were analysed. The temporal changes of the annual low level in the groundwater observation wells were compared to the low stages in the rivers. A few flood-loops were plotted making use of the scarce streamflow measurements and the corresponding gauge readings. For the same cases the conventional gauge relation curves were also drawn.

REVIEW OF THE FINDINGS

By detailed scrutiny of the over 130 years long record of river stages in conjunction with over 80 years of groundwater readings, with due allowance for human interferences in the catchment, as well as for changes in rainfall pattern, the following conclusions have been arrived at:

The major drop of low-water levels over the Martfű–Mindszent Tisza section is attributable to the substantial reduction of the runoff from, and exhaustion of, the storage opportunities in the Körös catchment. The major drop has taken place in two steps: In the 1841-1842 low-water period considered relevant for setting the elevation of the “0”point of the gauges, the combined flow in the three Körös branches was large enough to feed the Tisza section involved, so that the gauge readings were higher. Subsequent developments in the Körös catchment have depleted the low-water yield and thus reduced the discharge to the Tisza materially. The reduced low-water discharge from the Körös catchment has flattened the former bulge on the low-water surface profile on the affected section (*Fig. 1*).

The low-water surface profiles react promptly to changes in the tributary discharges. Reduced inflow from the Körös catchment has reduced the low-water streamflow in the recipient Tisza downstream of Csongrád. This, in turn, has allowed more pronounced effect of the backwater caused by discharge of the tributary Maros. As the consequence thereof, the surface slopes decreased from the Maros mouth upstream as far as Csongrád. On the other hand, upstream of the Körös mouth the surface slope became steeper again, because the low inflow from the Körös causes no backwater in the Tisza (Bezdán 2010a, 2010b).

Completion of the Tiszalök Dam in 1957 and of the Eastern Main Canal in 1965 has relieved dry-weather water shortage in the region and raised low-water flows in the river section studied. Additional supplies to the region were channelled from the Kisköre Dam and the Western Main Canal. The low-water surface profiles became even smoother thanks to the backwater of the Novi Bečej Dam (1976).

Flood waves travel downriver with different surface slopes. The average slopes on the various sections were calculated from widely scattered data. In terms of percentages the differences are formidable and play a significant role in changing the water levels. When compiling stage forecasts, local distribution of rainfalls must also be allowed for (Bezdán 2010a, 2010b).

Except for river sections impounded also at low-water, surface slopes become steeper with falling depth. At mean water the surface slope is flatter than at low water. The cause of this phenomenon is that downstream of the mouth of a tributary, the discharge thereof is added to that of the recipient Tisza, the water level in the latter rises with a steep surface slope. On the other hand, upstream of the mouth the flow in the recipient is backed up, the water level is raised, while the surface slope becomes flatter and may assume even negative values. Over the section affected peaking is delayed and an inverted flood loop occurs. Such reversed flood loops develop on river section(s) upstream of backwaters. Immediately downstream of tributary mouths normal flood loops may be expected. In cases where the backwater effect of the recipient, or a tributary, or a weir extends upstream beyond the mouth of a recipient, the sense of the flood loop downstream of the mouth will depend on the actual discharge of the tributary (Bezdán 1997, 1998, 1999, 2008, 2010a, 2010b).

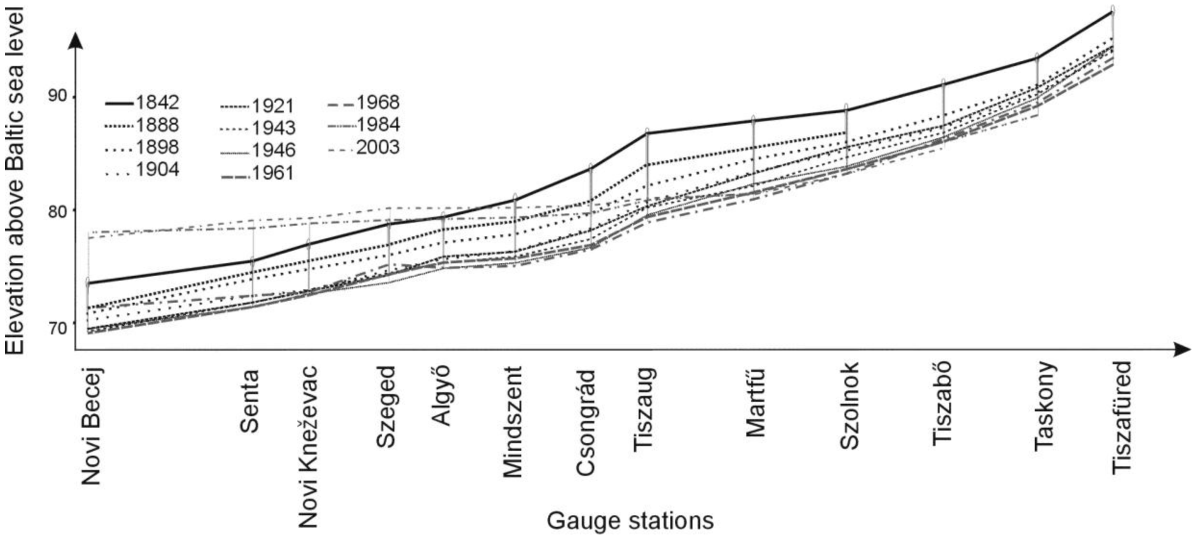

Fig. 1 Surface profiles of lowest low-waters in the years indicated

Over 70% of the Tisza flood waves were backed up by one of the tributaries or the Danube during the 1876 to 1975 period. More than 90% of the flood waves peaking with stages above the 600 cm range belonged to this category. Since the Novi Bečej Dam was commissioned in 1976, backwater has raised 80% of the flood waves and 95% of those with overbank stages. Conveyance of virtually all high floods is affected also by the fact that these are under the combined influence of two or more tributaries and since 1976 also of the Novi Bečej Dam. The most often backed up river section in the high-water ranges are those between Tiszaug and Algyő. Since the dams were commissioned, flood waves were backed up repeatedly along these sections. Flood waves peaking within the banks in the pre-dams period were backed up by the Danube beyond Szeged in 25% of the cases, this percentage having grown to 48% since the Novi Bečej Dam started operating. Of the overbank floods backed up beyond Szeged, 25% were registered before 1976 and 20% thereafter. This information is of paramount interest in forecasting and fighting floods. The number of flood waves peaking in "reversed order" decreases with distance from the river causing them. The number of peaks attributable to the Danube backwater decreases with distance from the Tisza mouth, but owing to the clearly undistinguishable simultaneous influence of the Körös and Maros tributaries, the relationship is not a straightforward one. The unbalanced distribution of the occurrence of all "reversed" flood waves may be influenced by the possibility of interference between several gauging stations (Bezdán 1999, 2008).

Owing to backwater from the recipient, some flood peaks occur upstream of the mouth of a tributary. Thus 40% of the Tisza flood waves since 1876 and peaking at all gauging stations terminated upstream of Senta. This figure is 54% for flood waves peaking above the 600 cm mark. Since 1976, when the Novi Bečej Dam started operating, 58% of the flood waves terminated at one of the stations upstream of Senta, whereas formerly this figure was 28%. Of the flood waves peaking in the higher-than 600 cm range those advancing farthest downstream occurred most frequently between the stations Martfű and Szolnok during the 1876-1975 period. After 1976 most flood waves peaked latest along the Martfű, Tiszaug and Mindszent section. For the apparent "retardation" of the Tisza flood waves described by several authors, random changes of the actual hydrologic conditions in the catchment are believed responsible, rather than spontaneous, or artificial hydromorphological changes in the river bed. This information should be remembered when contemplating levee reinforcement projects (Bezdán 1999, 2002).

During the 1976-2009 period, over the Tisza sections influenced by dams and weirs the low-water surface slopes decreased, while their statistical scatter widened. The high-water-slopes, on the other hand, became steeper with a narrower scattering range (Bezdán 2010a, 2010b).

Downstream of the Kisköre Dam commissioned in 1973 the lowest low-water levels dropped until the year 2009 by more than 100 cm at Taskony, 50 cm at Tiszabő, 20 cm at Szolnok and 10 cm at Martfű, Parallel thereto, the duration of low water levels has grown.

Novi Bečej (Törökbecse) Dam commissioned in 1976 has created a backwater reach extending normally upstream to Csongrád (in the range of lowest low-waters up to Tiszaug) and raising the low-water level at Tiszaug by 55 cm, at Csongrád by 105 cm, at Mindszent by 150 cm, at Algyő by 170 cm, at Szeged by 200 cm, Novi Kneževac by 270 cm, at Senta by 300 cm, while at the dam itself by 385 cm on the average. This means that at lowest low-water the average readings on the same gauging stations became -240, -135, -25, 50, 70, 140, 205 and 270 cm, respectively. The dam has thus actually eliminated low-waters in its vicinity, reducing flow velocities virtually to zero.

Releases of low and medium flows are thus completely controlled by the dam. This implies at the same time that the channel along the backwater reach has no influence any more on the flow regime and functions actually as an impounded system, which stores the water until it is released as scheduled by the dam operator (Bezdán 1994).

Upstream of Kisköre Dam the lowest backwater level has increased by more than one metre since the nineties. Silting has raised the lowest backwater by 30-50 cm also upstream of Novi Bečej Dam. The water levels at high flows are influenced by the dams and weirs, as well as by the discharges of tributaries. Kisköre Dam influences the flow regime by the water stored behind it in that any arriving flood wave spills over a raised water level rather than over a low one, changing the original conditions. Flood levels may then be raised substantially downstream as far as the southern national boundary, especially in then event of simultaneous flood discharges from the aforementioned two major tributaries (the Maros and the three Körös branches).

At times of major flood waves, the backwater upstream of the Novi Bečej Dam merges the former gauge relation curves as far upstream as Tiszaug. Traces of the historic gauge relations are difficult to recognise even at times of high Maros floods. This means that river flows are controlled by the Novi Bečej Dam also during high-water periods, in that releases depend on the conveying capacity of structure. The arriving flood flows are thus necessarily stored and raise the water level in the limited flood-bed volume enclosed by the flood levees up to the Kisköre Dam. The rate of release at the mouth depends not necessarily on the rate of the original inflow, but on the conveying capacity and hydrologic state of the recipient streambed comprising the dam. During the pre-dam period the traditional gauge relation curves have clearly revealed any backwater and substituted the flood loops representing the stage-discharge relation and offered partial compensation for the scarcity of discharge measurements (Bezdán 1994).

Besides backwater, dams are prone to raising also the groundwater table. Owing to the local topography and soil conditions, this impact is especially pronounced in the surroundings of the Novi Bečej Dam, where the groundwater never sinks below a certain elevation. Higher groundwater under large areas in low-water periods has reduced the water absorbing capacity of the soil relative to the former, natural conditions. Infiltration from the storage ponds built in the elevated parts of the catchment has also raised the groundwater table. The resultant impact consists of shorter low water periods and longer duration of medium- and high waters. The lowest water tables sustained by the dams are also higher than those prior to the construction of the storage ponds, which prevent the groundwater from sinking below a certain level even in dry periods. Flood waves entering the Hungarian reaches from the headwaters encounter drastically changed conditions, in that backwater raises base water levels in the rivers possibly without higher streamflow rates controlled by dams.

CONCLUSIONS

Any statistics of water levels, sediment transport and channel morphology compiled on the Tisza River will be necessarily misleading without allowance for the fact that dams cause fundamental changes in hydrologic and sediment transport processes alike. This is why however long historical records and such created after the commissioning of dams must be considered separately.

Csongrád Dam postponed repeatedly, would be an important link in the canalised Tisza River. In a sequence of dams in which the backwater of a downstream one extends to the tailwater of the one upstream, silting in the headwater and erosion in the tailwater are much less pronounced than in more loosely spaced schemes. Yet the river strives to attain equilibrium conditions so that high rates of sediment transport are attenuated gradually. According to experiences gained thus far, dams change the flow regime, raise the low-, medium- and high water levels, reduce flow velocity and cause silting.

Over the Tisza reaches downstream of Kisköre Dam frequent and occasionally conspicuous natural and man-made backwaters (caused by the Körös and Maros tributaries, the Novi Bečej (Törökbecse) Dam and the Danube) raise strong doubts as regards the effectiveness of emergency reservoirs upstream. Higher levels of safety against floods of higher peaks and longer durations would be achieved by raising and strengthening appropriately the existing defences.

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CREATING EXCESS WATER INUNDATION MAPS BY SUB-PIXEL CLASSIFICATION OF MEDIUM RESOLUTION SATELLITE IMAGES

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Abstract

Excess water frequency factor, which indicates the number of inundations in the area under study within a certain period of time, is the most dynamic variable among the parameters applied in the complex methodology of excess water hazard mapping. Creating excess water inundation maps, representing the situation in the most realistic way, was hitherto a critical moment in excess water hazard mapping. Instead of field measurements, since the database of Landsat satellite images became accessible in 2009, it is possible to process satellite images taken from the year 1985, with using new, non-traditional methods different from the pixel-based classification. These methods are mainly sub-pixel based classifications and they are applied principally on images taken in periods of extended excess water inundation, under clear weather conditions. In our research project, medium-scale mapping was supported principally by hand-held or mounted multispectral (the bands of visible and infrared light) digital aerial photography. The photo-taking process, depending on the actual meteorological conditions, can be flexibly accomplished in the most extended inundation period, thus it is possible to create excess water maps at the scale of 1:10000.

INTRODUCTION

Excess water frequency factor, which indicates the number of inundations in the area under study within a certain period of time, is the most dynamic variable among the parameters applied in the complex methodology of excess water hazard mapping (Pálfai et al., 2004). Creating excess water inundation maps, representing the situation in the most realistic way, was hitherto a critical moment in excess water hazard mapping, since the creation of an excess water map via traditional methods and field survey is time-consuming and contains several possibilities for committing errors (Licskó B., 2009). One of the major problems regarding field mapping is that the determination of the shape of an extended excess water area is uncertain from a close-to-surface point, owing to the low angle of vision. It is also difficult to determine the extension of the patches by walking round their boundary using kinematic GPS. This method gives particularly indefinite results, because there is a continuous transition between the open water surface, the slightly saturated soil and the dry soil, therefore their classification is problematic.

While mapping excess water inundation, efforts should be made to cover a large area, and to create large-scale thematic maps in a cost effective way. This way, not only the open water surfaces, but also the transitional areas could be mapped. Large-scale mapping is supported principally by hand-held or mounted multispectral (the bands of visible and infrared light) digital aerial photography. The photo-taking process, depending on the actual meteorological conditions, can be flexibly accomplished in the most extended inundation period, thus it is possible to create excess water maps at the scale of 1:10000 (Licskó B., 2009). However, the survey of vast areas is expensive and requires considerable post-processing.

The mapping of excess water inundation is more economical if the inundation map derives from remote sensing data covering vast areas. Excess water inundation maps based on satellite images have been created by the Institute of Geodesy, Cartography and Remote Sensing (FÖMI) since 1998. A significant number of maps were created in the years 1999 and 2000, when the inundation was very extended (Csornai G. et al., 2000). By means of 0.1 ha resolution thematic excess water maps derived from high-resolution satellite images, not only the open excess water surfaces could be detected and delineated, but also the vegetation in water and the highly saturated soil, which is very destructive to agricultural cultivation. During the pixel-based classification of satellite images taken by the sensors of the applied SPOT, Landsat and IRS-1C/1D LISS-III satellites, the determination of the sample areas might run into difficulties as the great number of the spectrally heterogeneous pixels might cause inaccuracy concerning the classification of the transitional areas.

In case of satellites revolving in a Sun-synchronous orbit, optical satellite images are taken at a well-determined point in time, however, in these spectral bands cloud cover frequently inhibits image-taking. Thus, the images of microwave imaging sensors (ENVISAT, MERIS, ASAR, RADARSAT and ERS) are effectively applicable for flood and excess water mapping, as well as in operative works (Csekő Á., 2003). However, by excess water maps based on radar data only the open water surfaces and the saturated soil areas could be delineated. Regarding the images of the year 2000, the radar data by themselves were limitedly suitable for high-resolution excess water mapping, however, they complete the data derived from the optical systems well.

Since the Landsat image database became accessible in 2009, it is possible to process satellite images taken from the year 1985, with using new, non-traditional methods different from the pixel-based classi-

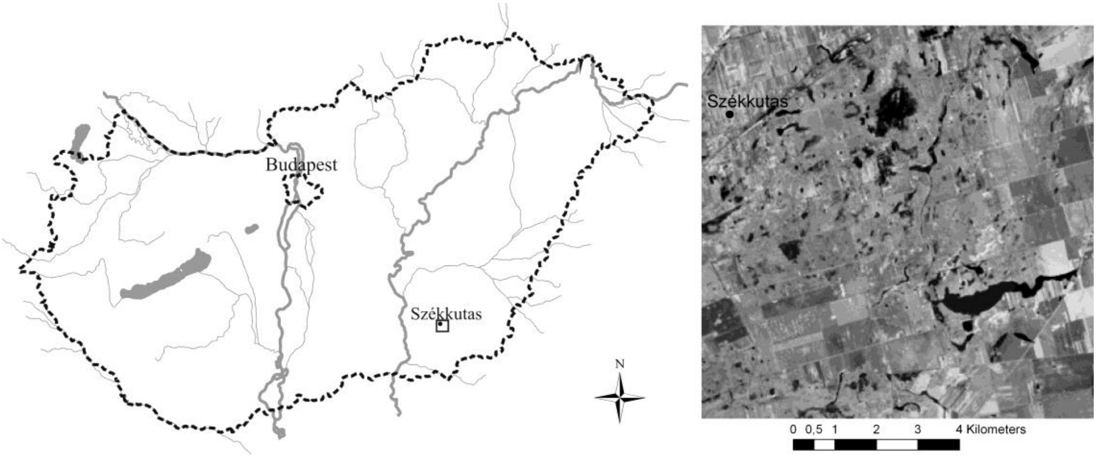

Fig. 1 The area under study

fication. These methods are mainly sub-pixel based classifications and they are applied principally on images taken in periods of extended excess water inundation, under clear weather conditions.

THE STUDY AREA

The area under study is situated in the south-eastern part of the Great Hungarian Plain, in the vicinity of the settlement Székkutas. Regarding land use, it is characterized by agricultural lands and protected areas belonging to the Körös-Maros National Park. The designated study area is 86 km^2 and is on the boundary of Csongrád and Békés counties. In terms of excess water hazard, it belongs to the 'medium hazard' category (Pálfai I. et al., 2004). The relief differences are minimal; the elevation values are between 81 m and 89 m.

DATA APPLIED AND THEIR PREPARATION FOR PROCESSING

During the survey, two years characterised by excess water inundation were chosen and one image taken in each year respectively have been analysed. Excess water inundation was considerable in the year 1986, while it was extreme in the year 2000 (Pálfai I., 2006). In these two years satellite images taken in early spring and early summer were selected, which were not disturbed by clouds. The time of the image-taking was as near to the period of the largest excess water inundation as possible. Data were downloaded from the web database (http://glovis.usgs.gov) of the U. S. Geological Survey (USGS). The area under study was also covered by the medium resolution images of the satellites Landsat-5 and Landsat-7, the catalogue numbers of which are 186/028 and 187/028. Thus, more images of the area became available and their time resolution was not only 16 days, but also 7 and 9 days.

A Landsat-5 TM image (row 187/coloumn 28) taken on 16th April 1986 and a Landsat-7 ETM+ image (row 186/coloumn 28) taken on 23rd April 2000 were selected, both of which were transformed to UTM projection system (WGS 84, zone 34).

Via atmospheric correction, the intensity values of the Landsat-5 TM and Landsat-7 ETM+ were transformed to reflectance values using an ERDAS IMAGINE model (Chavez P. S., 1996; Chander G.-Markham B. L., 2003).

To carry out accuracy estimation, the one-meter resolution colour infrared aerial photographs taken on 23rd April 2000 were available as reference data. In addition the digital database provided by the field survey of the Directorate for Environmental Protection and Water Management of Lower Tisza District (ATIKÖVIZIG) was also applied, which includes the patches of excess water in the inundated areas for the years characterized by inundation.

METHODS

Spectral mixture analysis

The significant advantages of the medium resolution (30 m) TM and ETM+ images of Landsat satellites revolving in a Sun-synchronous orbit are, that they are multispectral images covering vast areas (185*185 km) and they can be transformed with high accuracy to medium scale (approx. 1:100000) land cover maps by traditional pixel-based classification. However, their disadvantage is, that if the reflectance features of the area change on a greater scale in the space (the smallest elements, patches of the landscape pattern are smaller), than the spatial resolution of the satellite image, numerous so-called spectrally mixed pixels can be found in the image. One of the basic problems of excess water mapping is that the open water surfaces might be relatively small in area, therefore these surfaces, as well as the soil surfaces in the transitional areas and the areas covered by vegetation are difficult to classify owing to the numerous spectrally mixed pixels. For the classification of the spectrally mixed pixels the so-called Spectral Mixture Analysis method was developed (Roberts et al., 1998).

The aim of Spectral Mixture Analysis (SMA) is to determine the spatial ratio of the spectrally homogeneous land cover types, the so-called *endmembers*, within a pixel. Each endmember specifies an unmixed, pure land cover type. The Linear Spectral Mixture Analysis (LSMA) is the improvement of the SMA method, by which the ratio of land cover types can be determined by using minimum two, in case of an LTM picture six, endmembers. In order to be able to solve the linear system of equations (1), the number of the endmembers has to be less than the number of the spectral bands of the image.

$$R_b = \sum_{i=1}^{N} f_i \cdot R_{i,b} + \varepsilon_b \tag{1}$$

R_b: the reflectance value of the image in band b;
N: the number of endmembers;
f_i: the ratio factor of endmember i;
R_{ib}: the reflectance value of the i^{th} endmember in band b;
ε_b: residual error.

The sum of the ratio factors of the endmembers equals 1 in every pixel and $f_i \geq 0$.

$$\sum_{k=1}^{n} f_{i,k} = 1 \tag{2}$$

The suitability of the model can be determined on the basis of the ε_b residual error or on the basis of the value of the root mean square error (RMSE) for each band of the image.

$$RMSE = \frac{\sqrt{\sum_{i=1}^{n} \varepsilon_i^2}}{n} \tag{3}$$

The endmembers are usually selected from the different bands of the satellite images or 2D scatter plots worked out from the bands (Rashed T. et al., 2001). By Principal Component Analysis (PCA), the endmembers are easier to determine, since it assembles almost 90 % of the data variance into the first two or three bands and reduces the correlation between the bands to a minimum (Smith M. O. et al., 1985). The other frequently applied transformation, which is also applied in this present research, is the minimum noise fraction (MNF) method. It consists of two main steps: (1) in the first step the noise fractions of the database are decorrelated and rescaled on the basis of an estimated noise covariance matrix and transformed data is provided, in which the noise has unit variance and there is no correlation between the bands; (2) in the second step a traditional PCA is carried out (Green A. A. et al., 1988).

The Pixel Purity Index (PPI), that selects the spectrally most pure (extreme) pixels from multispectral or hyperspectral images, was also applied to specify the endmembers. Employing iterative methods, the PPI creates N-dimensional spectral spaces on randomly chosen unit vectors. This procedure determines the extreme pixels (those that are at the end of the unit vector) in each projection, and records how many times the given pixel was specified as extreme. The value of each pixel in the resulting image is equal to this number (Broadman J. W. et al., 1994).

In the first step, MNF images were created for the Landsat TM image taken on 16th April 1986, which resulted in another 6 bands. The information content of the images is continuously decreasing after one another, thus the first three bands contain 89.5% of the total information content. The last bands predominantly contain only noise. The MNF images were used as input data for the PPI calculation, during which process the extreme pixels were defined by the algorithm after 1000 repetition.

On the basis of the first three MNF images and the resulting image of the PPI, three endmembers were defined for the linear spectral mixture: (1) the water surfaces, (2) the vegetation, and (3) the soil. These endmembers were pointed out in the spectral space formed by the first three MNF-bands and were detected at the margins and peaks of the 2D scatter plot.

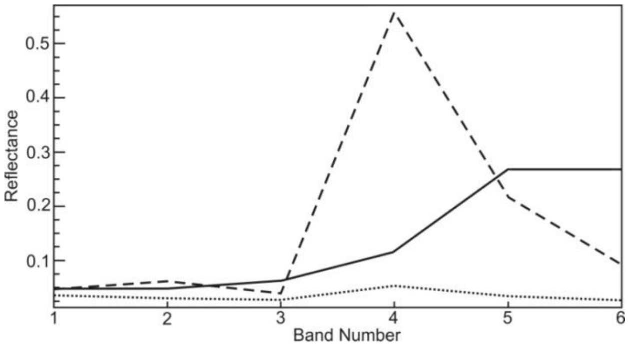

Fig. 2 The reflectance curves of soil, vegetation and water surfaces

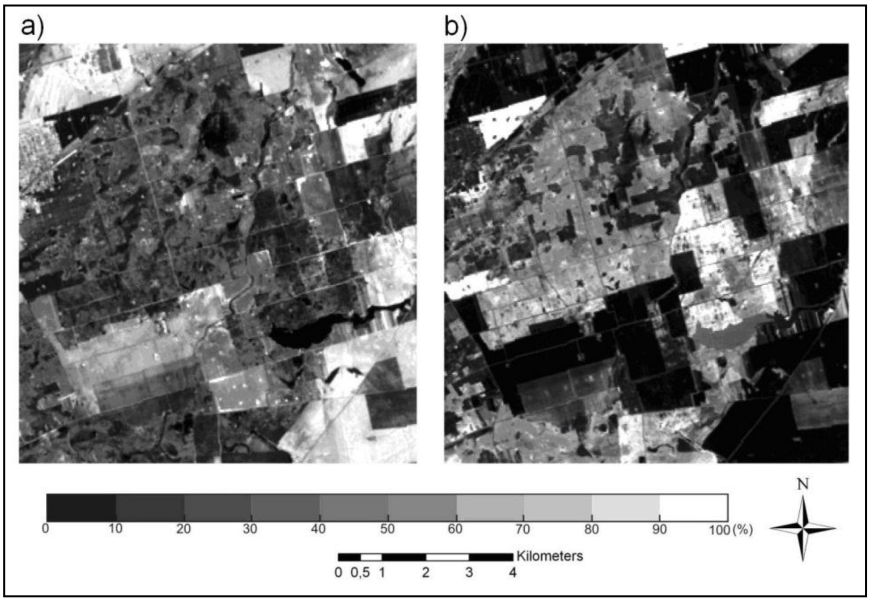

Fig.3 The ratio map of (a) the soil and (b) the vegetation based on the Landsat TM image taken on 16th April 1986.

DEFINING THE LAND COVER RATIO OF THE PIXELS

The outcomes of the LSMA are the maps showing the ratio of endmembers (soil, vegetation and water) within a pixel. The three maps represent the spatial distribution of the aforementioned land cover types for each pixel. The value of the pixels varies between 0 and 1. If the value equals 1, the ratio of a certain land cover type within the pixel is 100 % (*Fig. 3*).

On the gray-scale ratio map of the soil fractions (*Fig. 3a*), the open soil surfaces, are marked with light grey colour, where their ratio is 80-100%. The ratio of vegetation varies between 70 and 100 % on the arable lands, grasslands and pastures (*Fig. 3b*).

The open areas covered with excess water are marked with white and light grey colours on the gray-scale ratio map of water surfaces (*Fig. 4*) where the ratio of the water covered surface is about 70-100 % within a pixel. The Lake Fehér near to the settlement Kardoskút stretches along as a light grey patch on the south-eastern part of the area. Furthermore the excess water in abandoned riverbeds and on arable lands also has high fractional values on the ratio maps. The grey coloured territories are wet soils (saturated soils) and vegetation in water, where the ratio of surface water varies between 30 and 70 %.

Similarly, maps representing the land cover ratio within the pixels were created based on the Landsat ETM+ images taken on 23rd April 2000 (*Fig. 5*). By the analysis of the ratio maps of the water surfaces, the extent of inundation at the two dates can be examined, the total area covered with excess water can be determined and the spatial pattern of the patches of excess water can be compared.

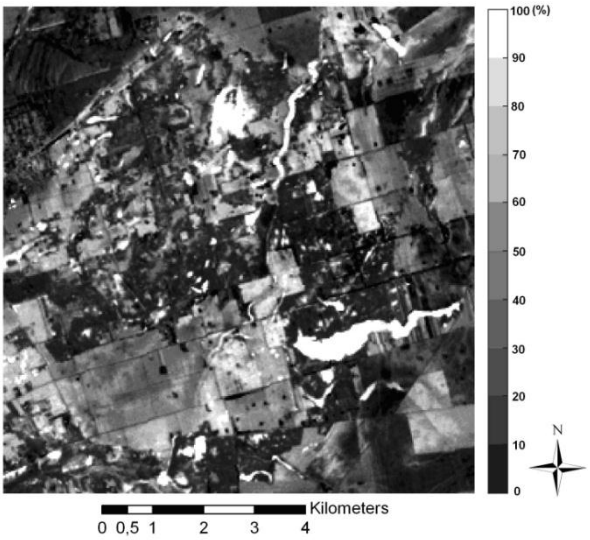

Fig. 4 The ratio map of water surfaces based on the Landsat TM image taken on 16th April 1986.

5. RESULTS AND ACCURACY ESTIMATION

The classification of land cover ratio maps by using supervised classification

A supervised classification was carried out on the 3-band image (1: soil, 2: vegetation, 3: water ratio map), which was the result of the LSMA. Based on the three endmembers seven classes were created. Three of the

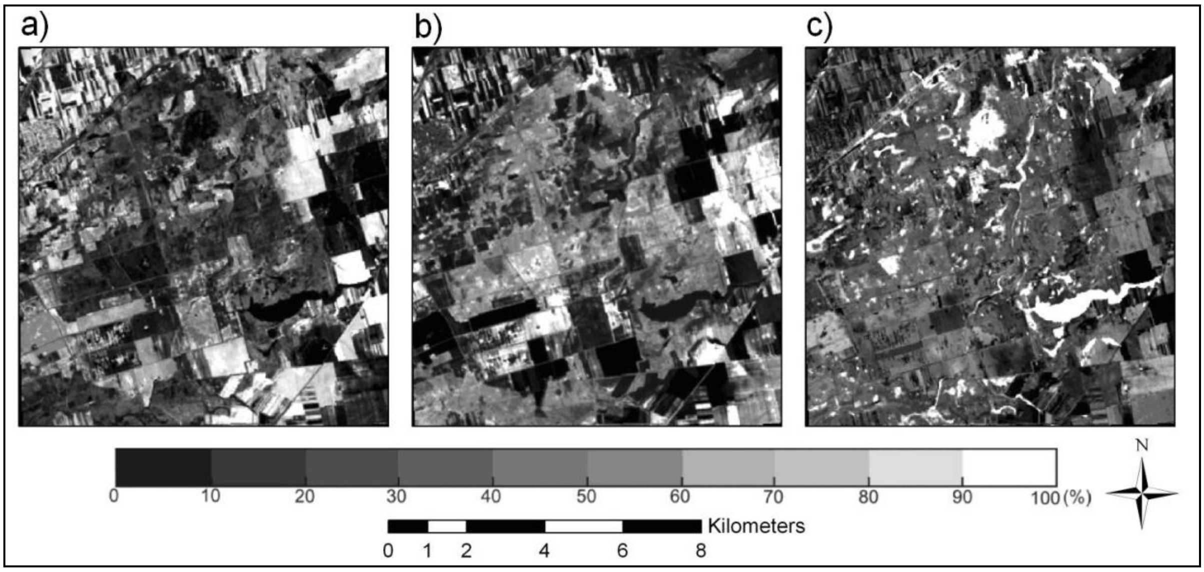

Fig. 5 The ratio maps of land cover types based on the Landsat ETM+ image taken on 23rd April 2000.
a) soil, b) vegetation, c) water surfaces

seven classes mainly contain one land cover type, another three classes contain two land cover types and there is one more class that includes all the three land cover types nearly in equal proportion.

When the study area was selected, the upper and lower limits of soil, vegetation and open water surfaces were defined. On the basis of this, the following seven classes were defined: (1) open water surfaces, (2) vegetation, (3) open soil surfaces, (4) saturated soil, (5) vegetation in water, (6) soils covered with vegetation and (7) other. The classes are represented in a triangle diagram (*Fig. 6*). During the supervised classification the parallelepiped decision rule was applied. In case of overlapped areas, the certain pixels were assigned to one of the classes by using the minimum distance method.

Similarly, the supervised classification was carried out on the Landsat ETM+ image taken on 23rd April 2000, which resulted in a thematic map with the same 7 classes. The water covered surfaces marked with black colour, the saturated soils and the wet soils can be easily distinguished on the map (*Fig. 7-8*).

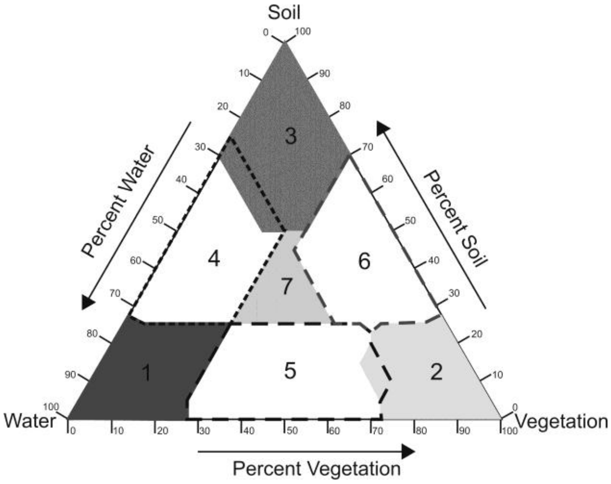

Fig.6 The triangle diagram representing the seven land cover types

	Lower_1	Upper_1	Lower_2	Upper_2	Lower_3	Upper_3	Lower_4	Upper_4
Soil	0%	27.5%	0%	27.5%	50%	100%	25%	75%
Vegetation	0%	27.5%	60%	100%	0%	30%	0%	25%
Water	50%	100%	0%	27.5%	0%	30%	25%	72.5%

	Lower_5	Upper_5	Lower_6	Upper_6	Lower_7	Upper_7
Soil	0%	25%	25%	75%	25%	50%
Vegetation	27.5%	75%	30%	70%	25%	50%
Water	20%	70%	0%	25%	25%	50%

Table 1 The upper and lower limits of the land cover types according to the endmembers

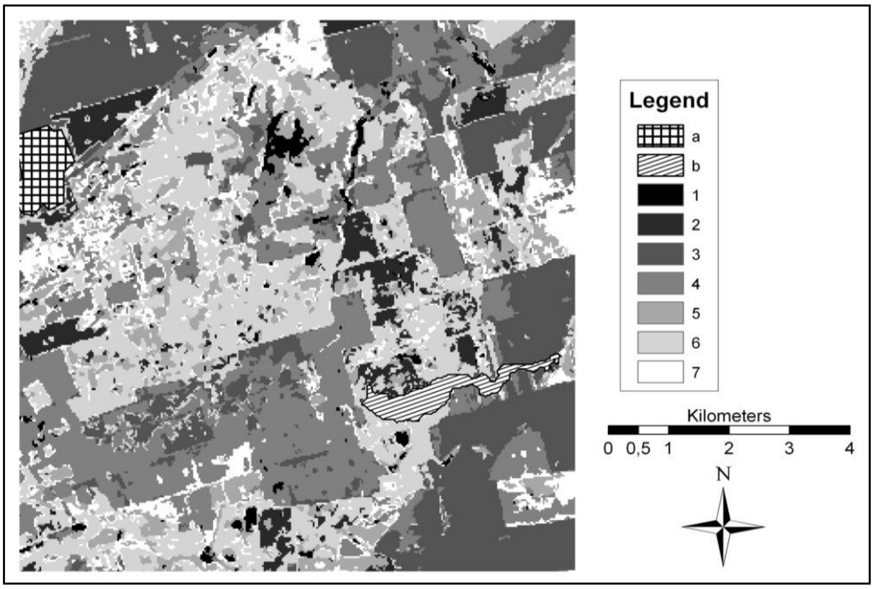

Fig. 7 Thematic map based on the endmember ratios of the Landsat TM satellite image taken on 16th .April 1986.
(a) Székkutas, (b) Lake Fehér, (1) open water surfaces, (2) vegetation, (3) open soil surfaces, (4) saturated soil(5) vegetation in water (6) soils covered with vegetation, (7) other

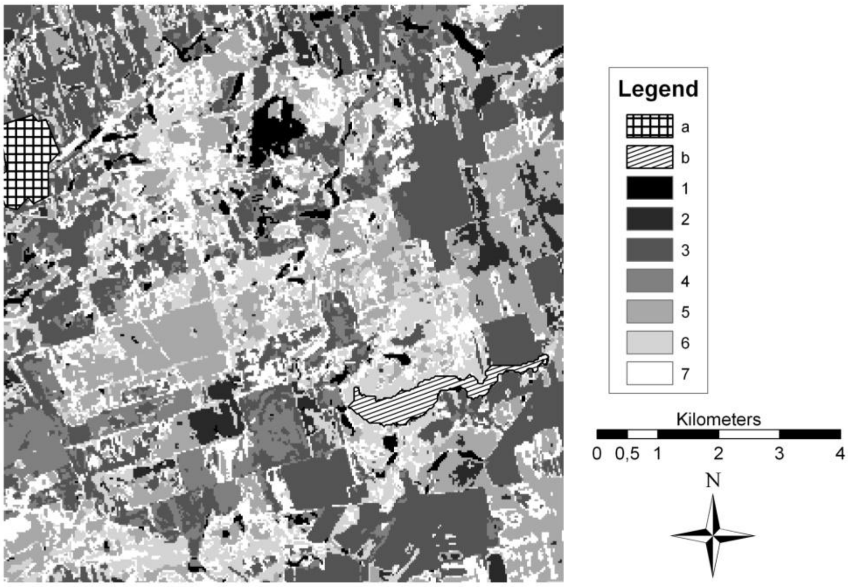

Fig. 8 Thematic map based on the endmember ratios of the Landsat ETM+ satellite image taken on 23rd April 2000.
(a) Székkutas, (b) Lake Fehér, (1) open water surfaces, (2) vegetation, (3) open soil surfaces, (4) saturated soil, (5) vegetation in water, (6) soils covered with vegetation, (7) other

By comparing the open water surface classes of the two examined dates, the location of the patches of excess water and the total extent of excess water coverage can be defined (*Fig 9*). It can be concluded that the patches of excess water occupy similar locations on the two images, however, there is a difference regarding their extension. The total surface of the patches was 1.52 km^2 in 1986, a year characterised by considerable excess water inundation and it was 2.63 km^2 in 2000, a year characterised by extreme excess water inundation.

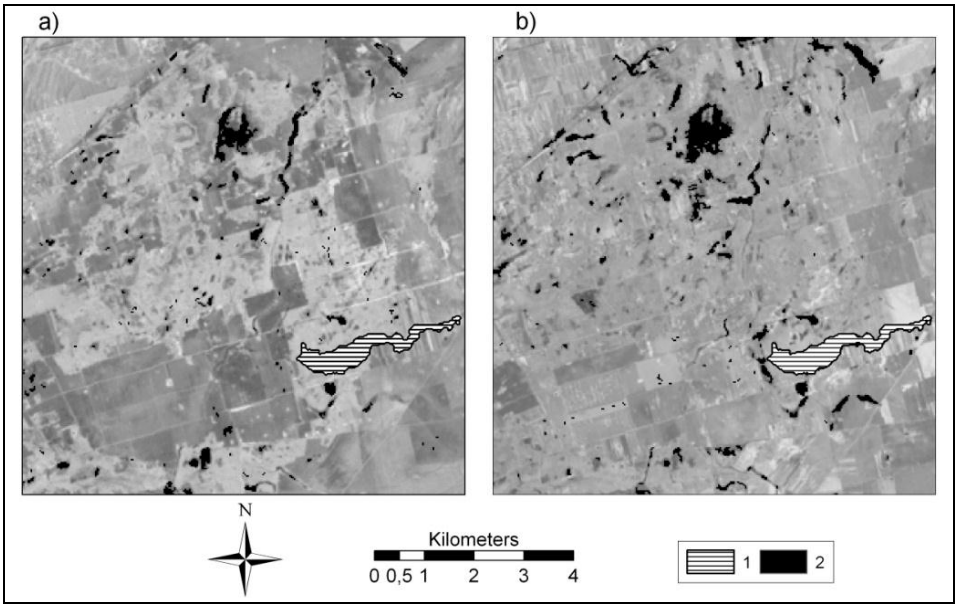

Fig. 9 The comparison of the patches of excess water on the images taken on 16th April 1986 (a) and 23rd April 2000 (b) (1) Lake Fehér (2) open water patches

Accuracy estimation

In the first step the results of the classification were compared with the data produced by the field surveys of the Directorate for Environmental Protection and Water Management of Lower-Tisza District (ATIKÖVIZIG). Our classes of the open water surfaces, the saturated soil and the inundated vegetation were compared with the excess water polygons as references (*Fig. 10*). On the basis of the comparison it can be concluded that due to their smaller scale, the field surveys are less detailed. There are some patches of excess water on the satellite images that can be detected without any image processing method, but they are in areas that are difficult to approach, hard to walk round, thus these patches are missing from the results of the field surveys. The classification based on satellite images is also favourable, as this way the saturated soils can be differentiated from the vegetation in water, while field surveys do not produce such descriptive data.

Other available data that can be used as reference to estimate the accuracy of the classification are the aerial photographs taken of the Tiszántúl, in the vicinity of Székkutas on 23rd March 2000 (*Fig. 11*). Although the photographs with 1 m geometrical resolution are appropriate for the visual determination of the land cover types, the precise separation and classification of certain water surfaces on the 3 band photos are hard to carry out with automatic image processing methods.

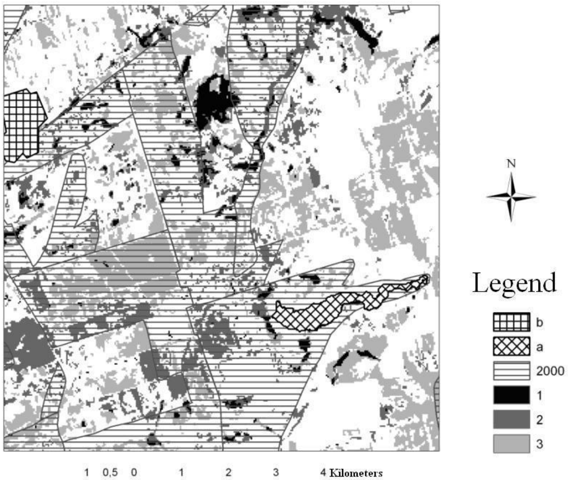

Fig. 10 The comparison of the patches of excess water of the three classes of the thematic layer and the field survey (a) Székkutas, (b) Lake Fehér, (1) open water surfaces, (2) saturated soils, (3) vegetation in water

In order to prove the importance of the SMA-classification, the created thematic layer was compared with the results of a traditional pixel-based classification. ISODATA classification was carried out on the Landsat ETM+ 6 band image taken on 23rd April 2000 (*Fig. 12*), during which process 7 output classes were set. Subsequently the 7 land cover classes of the thematic layer were compared with the adequate classes of the ISODATA clustering by using the cross-tabulation method (*Table 2*).

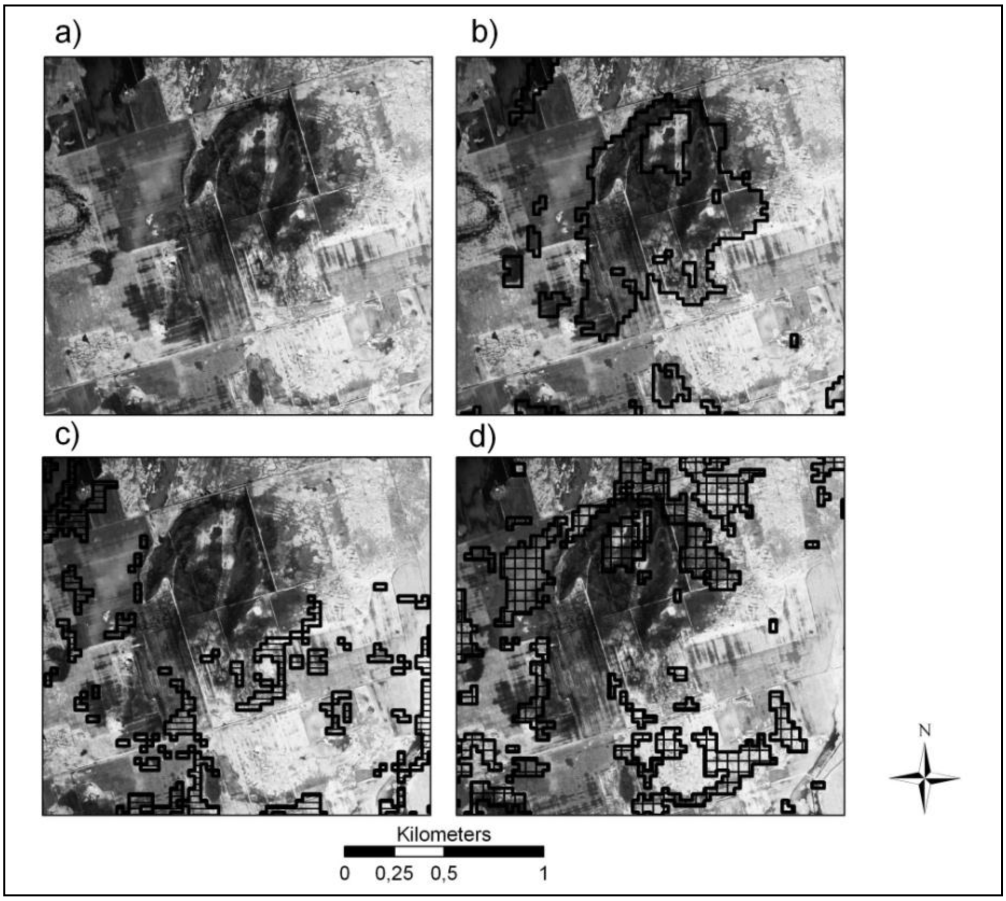

Fig. 11 The aerial photograph (a) and the polygons of the certain classes: (b) open water surface, (c) wet (saturated) soil (d) vegetation in water

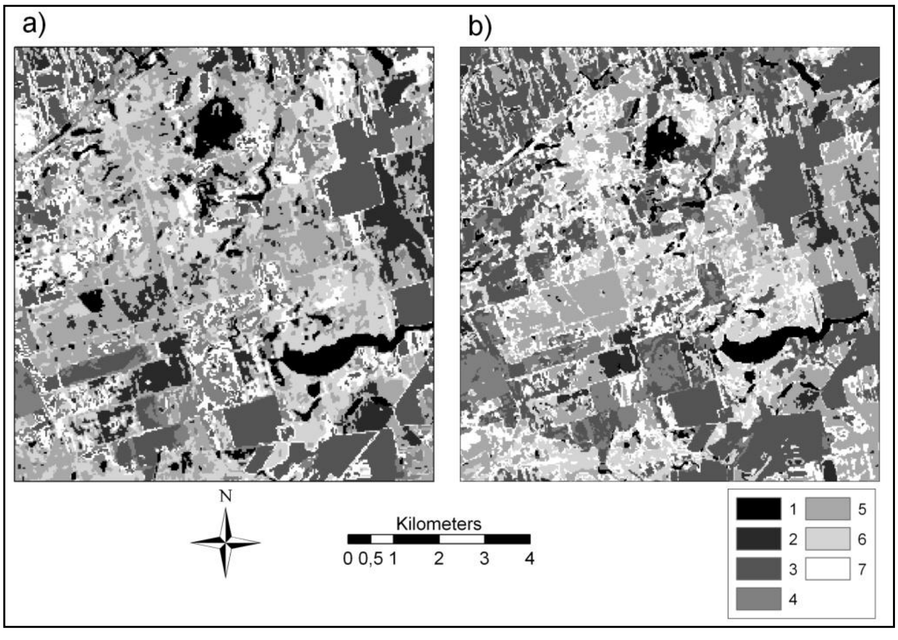

Fig. 12 Images based on the ISODATA classification (a) and the SMA-image classification (b)
(1) open water surfaces, (2) vegetation, (3) open soil surfaces, (4) saturated soil, (5) vegetation in water, (6) soil covered with vegetation, (7) other

		ISODATA classes						
		1	2	3	4	5	6	7
SMA- image classes	Open water surfaces	67.3%	0.5%	-	0.4%	0.1%	-	-
	Vegetation	-	41.8%	-	-	0.1%	-	-
	Open soil surfaces	0.1%	0.2%	92.5%	7.2%	0.3%	3.2%	92.0%
	Saturated soil	9.6%	-	6.6%	59.6%	-	1.4%	4.4%
	Inundated vegetation	22.4%	54.0%	-	3.0%	66.0%	0.5%	-
	Soil covered with vegetation	-	3.2%	0.8%	0.3%	10.8%	53.0%	3.1%
	Other	0.7%	0.1%	0.1%	29.5%	22.7%	41.9%	0.5%

Table 2 The comparison of the ISODATA classification and the SMA-image classification using the cross-tabulation method

On the basis of these, the open water surface class of the ISODATA classification shows a 67.3% concordance with the water surfaces gained following the SMA classification. Furthermore, 22.4% and the 9.6% of the open water surface class of the ISODATA classification have been classified as vegetation in water and as saturated soils, respectively. The class of vegetation shows a 41.8% concordance with the SMA classification, however, 54% have been classified as vegetation in water. The soil surfaces show 92.5% concordance. There has been a 59.6% and 66% concordance regarding the wet (saturated) soil and the vegetation in water, respectively.

6. CONCLUSIONS

On the basis of our research it can be concluded that by using a sub-pixel based classification, the medium resolution satellite images are suitable for mapping excess water. The satellite images being available since the mid-1980s provide an opportunity to create excess water hazard maps. The classes of the thematic maps created by the linear spectral mixture analysis are able to provide more detailed results than the traditional pixel-based classifications. The excess water patches of the earlier field surveys are precisely identifiable and by the help of the applied methods the creation of these maps can be made automatic.

Acknowledgement

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