Journal of Env. Geogr. Vol. III. No. 1-4. pp. 1-9.

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-

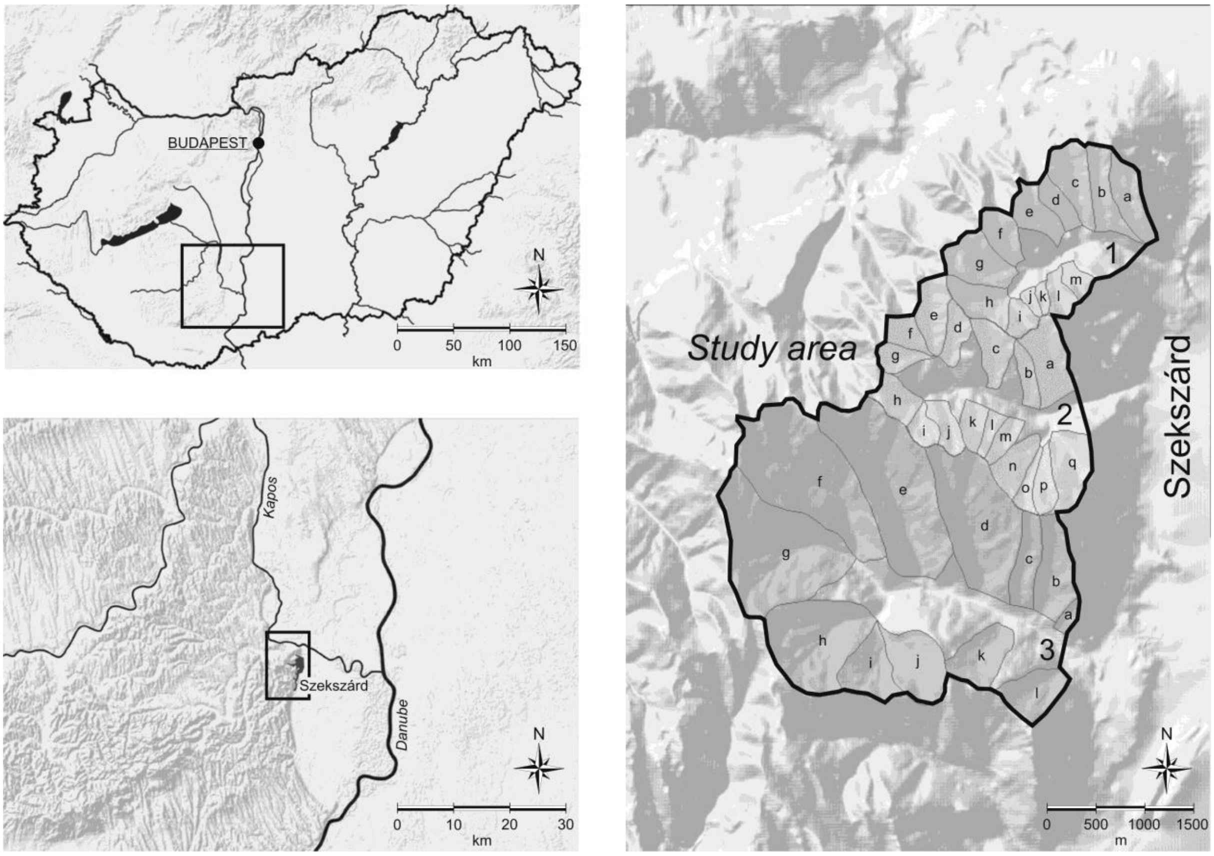

Fig. 1 Location of the study area

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

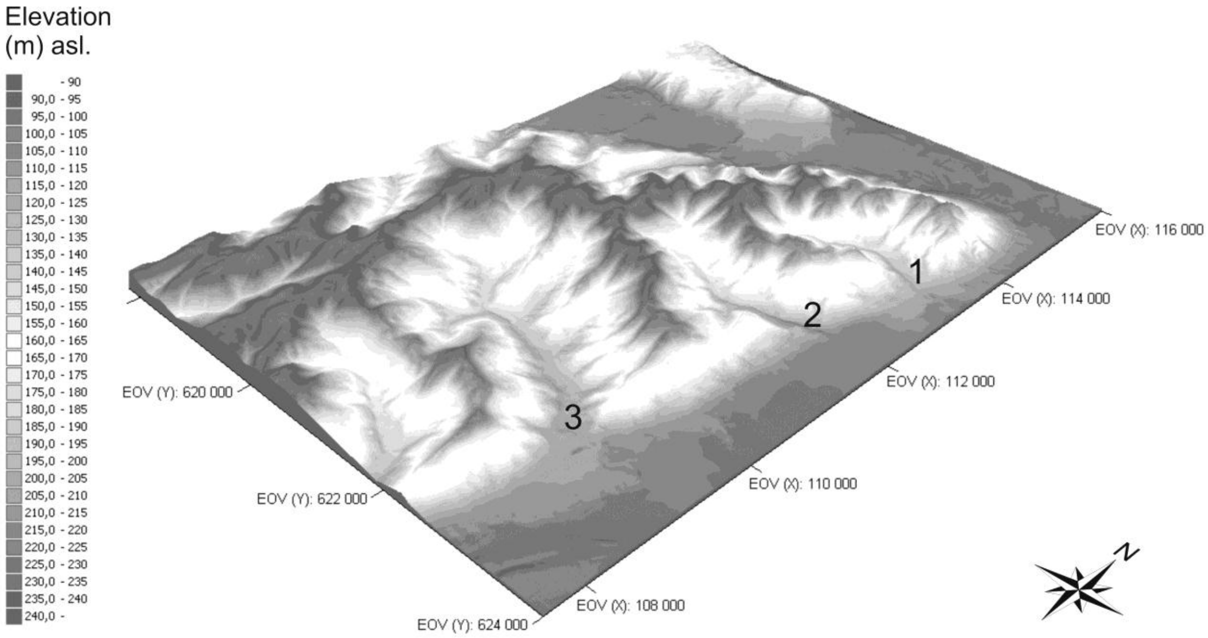

Fig. 2 3D-view of the sub-catchments

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.

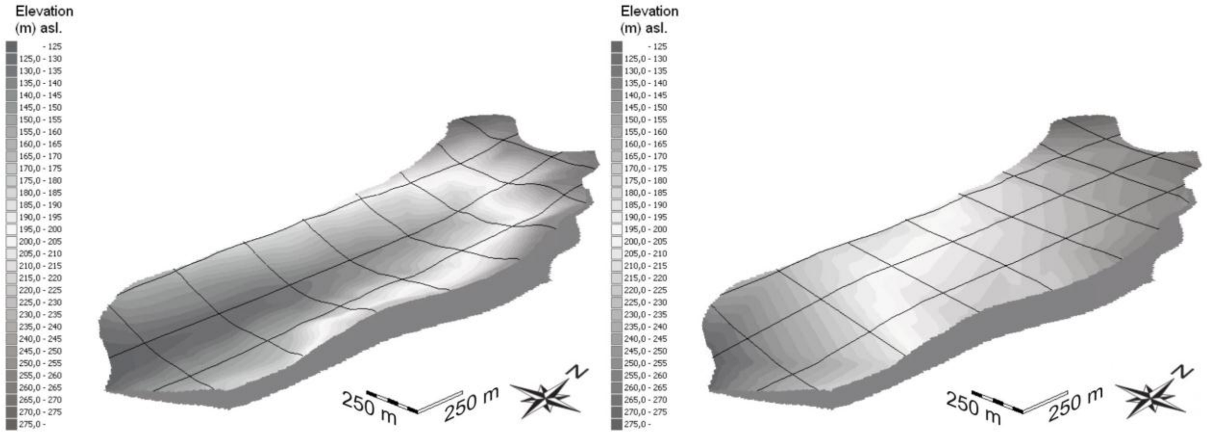

Fig. 3 Present-day and potential relief of a sub-catchment

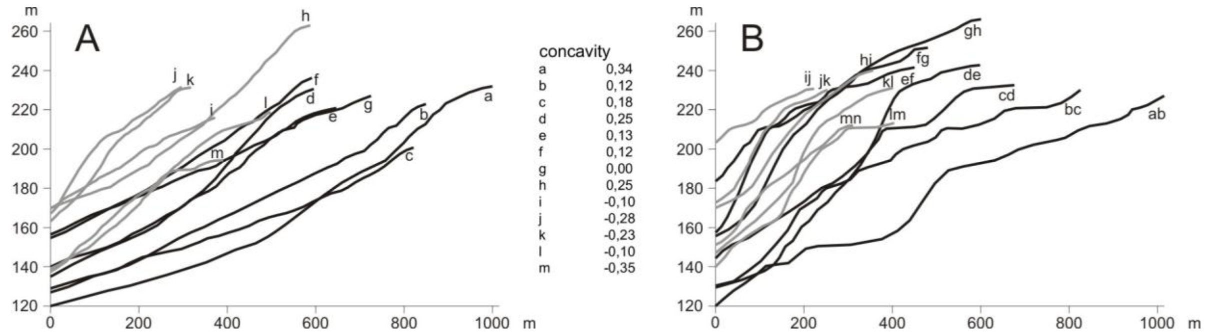

Fig. 4 Longitudinal profiles of the valley floors (A) and the intercollin ridges (B) in case of No.1. catchment (black lines: southern exposure; grey lines: northern exposure)

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

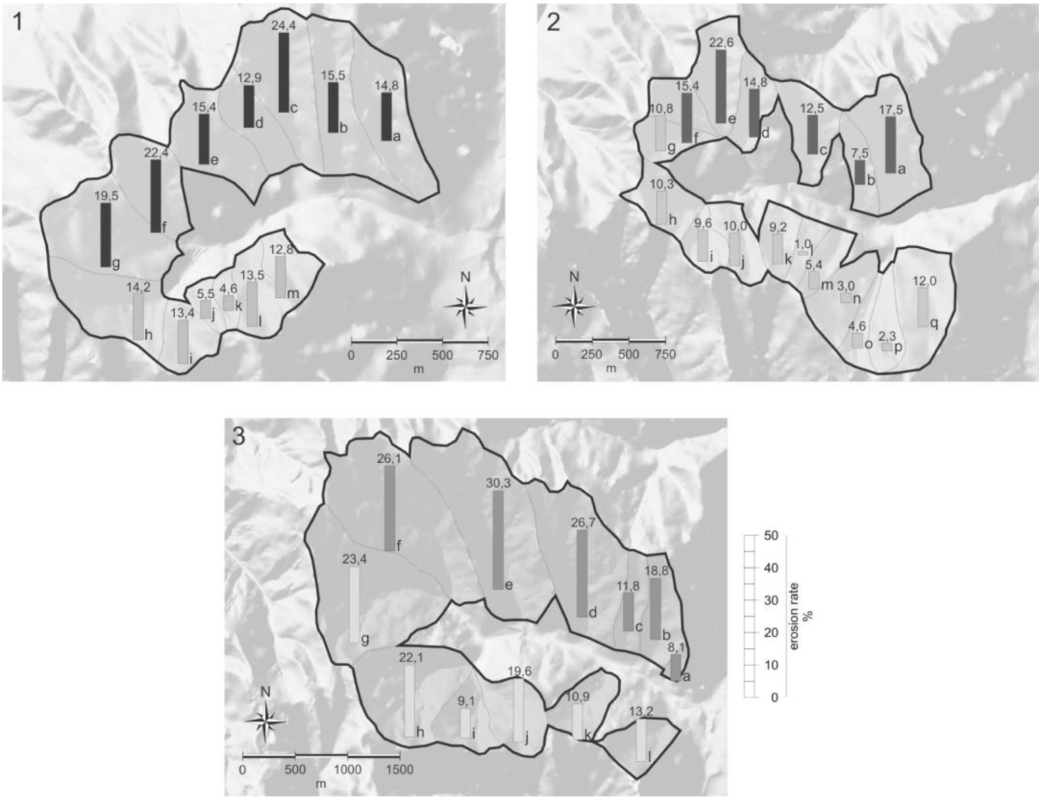

Fig. 5 Calculated net-erosion of the sub-catchments. (The main catchments are numbered 1-3, the sub-catchments are labelled a-q counter-clockwise)

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.

References

Ádám L. 1964. A Szekszárdi-dombvidék kialakulása és morfológiája. *Földrajzi Tanulmányok* 2: 69

Ádám L. 1969. A Tolnai-dombság kialakulása és felszínalaktana. *Földrajzi Tanulmányok* 10: 186

Balassa I. 1982. Magyar néprajz. Budapest: Corvina Kiadó, 214-216

Davis M. B. 1976. Erosion rates and land-use history in Southern Michigan. *Environmental Conversation* 3/2: 139-148

Kaczián J. 2004. Szekszárd – A nemes borok és a művészetek városa. Szekszárd: Palatinus-Séd Nyomda, 19-23

Kerényi A. 1991. Talajerózió. Budapest: Akadémiai Kiadó, 15-34

Knighton D. 1998. Fluvial forms and processes. London: Arnold Publ., 242-245

Marosi S. 1990. Magyarország kistájainak katasztere II. Budapest: MTA FKI, 564-568

Máté A. 2001. A Szekszárdi borvidék rendszerváltozás utáni gazdasági helyzete. Magyar Földrajzi Konferencia, Szeged, CD-publication

Pataki J. 1961. Az antropogén morfológia és a gyakorlati élet. *Földrajzi Közlemények* 4: 301-306

Pécsi M. 1981. A Dunántúli-dombság. Budapest: Akadémiai Kiadó, 121-124

Pinczés Z. 1980. A művelési ágak és módok hatása a talajerózióra. Közlemények a debreceni KLTE Földrajzi Intézetéből, Budapest: Akadémiai Nyomda 357-379

Stolte J. 2003. Modelling water flow and sediment processes in a small gully system on the Loess Plateau in China. *Catena* 54: 117-130

Summerfield M. 1991. Global geomorphology. Singapore: Longman Publishers, 184-185

Szabó J. 2006. Antropogén geomorfológia. Debrecen: Kossuth Egyetemi Kiadó, 64-70

Töttős G. 2008. Szekszárd: mesélő útikönyv. Szekszárd–Paks: Demeter Dél-Mezőföld Természetbarát Egyesület, 133-152

White I. D. – Mottershead, D. N. – Harrison S. J. 1984. Environmental systems. London: Allan&Unwin, 436-469