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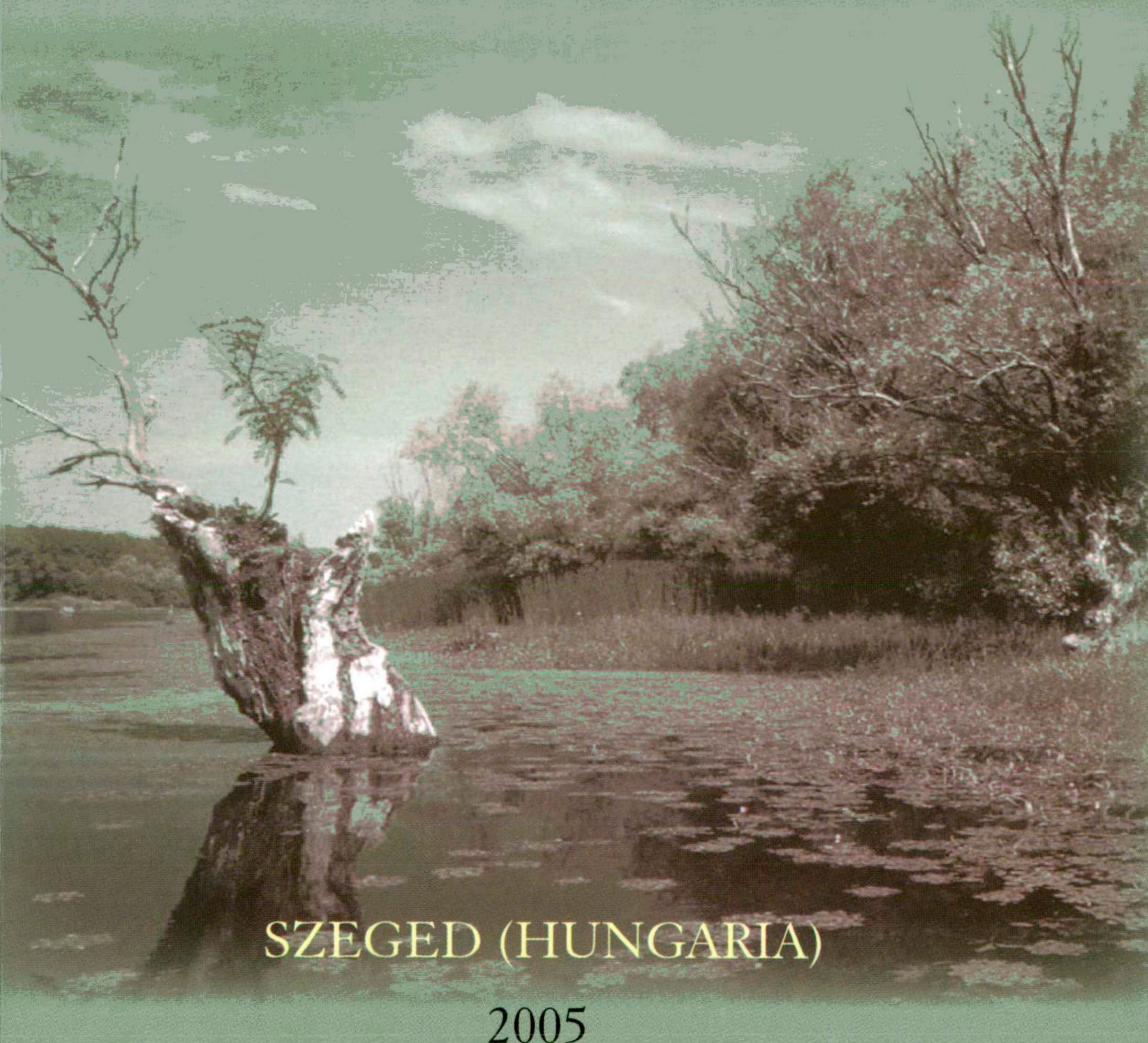

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INVESTIGATIONS OF CHANNEL DYNAMICS ON THE GREAT HUNGARIAN PLAIN SECTION OF RIVER MAROS

KISS, Tímea – SIPOS, György

Abstract

The present paper is concerned with the study of a 20 km segment of river Maros near the Hungarian border. The major goal of this study was to shed light on the geomorphological changes occurring in the section under investigation, created by close-to-natural and semi-anthropogenic processes since the implementation of the river control works with a special attention to the period of the past 50 years, focusing mainly on a single distinguished morphological unit: the point-bar and island system of Apátfalva within the extent of this reach. With the help of the revealed dynamic morphological changes of the channel, an assumption was made to evaluate the stability and state of equilibrium of the composing units of the section at different scales.

Introduction

Though river Maros is the largest tributary of the river Tisza, it has received far less attention from geomorphological research dealing with its channel dynamics and the variety of geomorphological forms present within the riverbed. Nevertheless, the analyzed section of river Maros offers ideal conditions to investigate and evaluate the influences of close-to-natural processes in an area, which was exposed to intensive human activities and anthropogenic influences in the past.

The major goal of the present investigations was to shed light on how this river section, as a complex system, being relatively undisturbed since the 19th century river control, responded to various human influences and intervention. In order to achieve this, several methods and approaches have been utilized for the evaluation, beginning from revealing the dynamic processes present in the island and point-bar channel system of river below Apátfalva, and reaching to the evaluation of stability and equilibrium of this 20-km-long river section.

Preliminaries in the literature

Though the questions of morphological stability, equilibrium and sensitivity within fluvial systems are widely discussed in the literature, only a few studies are concerned with the analysis of the relationship between the various natural forms of the riverbed and changes in its state of equilibrium.

The first statements related to the state of equilibrium in these systems are found in the works of LEOPOLD and WOLMAN (1957). According to their interpretation, the state of equilibrium within the fluvial systems is equal to a long-term stable phase or, in other words, during this phase the nature of the course remains unaltered for a longer time, considering meandering as the ideal morphological type.

However, they also showed that the braided or anastomising morphologies, which had been considered to represent a disturbed state earlier, represent a state of equilibrium after all as well, it also represents a stable phase maintainable for a longer period of time, only assuming a different energy level; i. e. different hydrological and load characteristics.

According to GREGORY and WALLLING (1973) and later HOWARD (1982), the state of equilibrium can be represented by a "function of the inputs and outputs of a geomorphological system with relatively unchanged values for a certain period of time". In other words, we can speak about disturbance when the output variables, in this case the bed forms, undergo significant change. Naturally we must account for some buffering effect in the system as well, only responding with a change of the forms after an action of certain strength. Furthermore, the time as a separate factor should also be taken into account during the course of equilibrium evaluation; i.e. the time needed to balance the influences affecting the system (RICHARDS, 1982).

The states of equilibrium are not to be schematized allowing for different responses from the side of the system following the loss of stability (WERRITTY – LEYS, 2001). Consequently, two major types are known for the state of equilibrium in fluvial systems in the literature: (1) there is a lower energy level, a so-called robust state when the system is capable to adapt to the influences affecting it via only minor modifications, preserving its original morphology; (2) and there is a so-called sensitive state, characterized by increased energy levels and a significant response to external influences represented by permanent or long-lasting alteration of the morphology, like that of the channel pattern.

The introduction of the notion of geomorphological threshold into the literature is linked to SCHUMM (1973). According to him, the majority of morphological changes are related to sudden events, when the energies affecting the system exceed a certain value; the so-called threshold value, above which the system becomes unstable. Consequently, the sensitivity of a geomorphological system equals to its resistive competency providing for the preservation and maintenance of its balance (BRUNDSEN, 2001).

Changes in intrinsic or extrinsic parameters of the system may lead to surpass of the threshold (LEWIN – BREWER, 2001). After this, the system reaches a newer state of equilibrium providing lower or higher stability compared to the previous state depending on the circumstances. The time needed for the emergence of this new state of equilibrium equals to the response time of the system.

The high complexity of the fluvial systems; i.e. a river is made up of several reaches with several bends within the reaches and different bed forms within the individual bends, further complicates the problematics of threshold value determination in fluvial environments. The stability of the different composing elements is both spatially and temporally variant, thus this factor must be accounted for when setting the values of threshold (KERN, 1998; CARSON, 1984a,b). In certain cases it is only the subsystems that are displaced from their state of equilibrium. However, in other cases when more subsystems collectively become unstable, e.g. as a result of a catastrophic event, it may result in the unstability of a structure at a higher level of hierarchy as well.

Thet pilot area

The river Maros is the largest tributary stream of the river Tisza with a length of 749 km, and an estimated area of discharge of 30.000 km^2 comprising about 20% of the total discharge area of the river Tisza. It's a rather flashy stream with a discharge of 1600 m^3/s at high water, that of 161 m^3/s at mean water and that of only 21 m^3/s at low water; i.e. there is an almost 80-fold difference between the rate of high and low waters. The slope of the river in the area of the reach under investigation was 14 cm/km before the implementation of the river controlling works increasing to 28 cm/km afterwards. The rate of sediment transport is quite significant. Consequently, in case of the river Maros one must account for intensive channel forming processes, both as a result of the suddenly changing discharges, as well as the amount of sediment transported, and the stream power.

Our investigations concentrated on the near-border section of the river Maros between Apátfalva and Nagylak (**Fig.1.**). This unit, located between the fluvial kms of 31 and 50 is made up of four major bends, with an individual length of 2-3 kms, in the upper part (40.5-50 fluvial kms). In the lower part (between 40-31 fkm), the river occupies an almost straight and highly widened channel with a width of 200-300 m and forms near-bank and mid-channel point bars and islands.

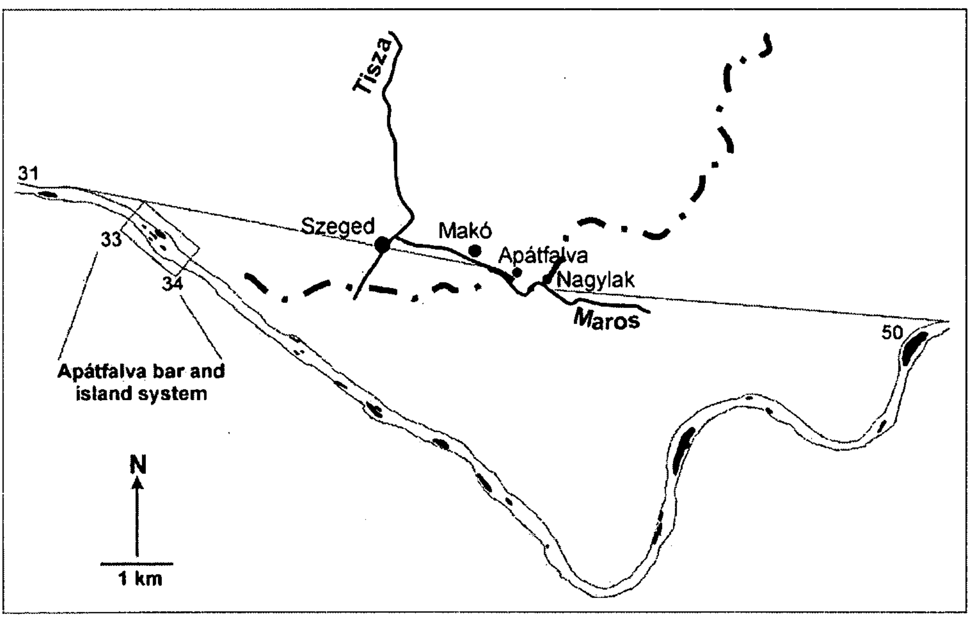

Figure 1. The location of the studied area

The river is dominantly aggrading in the section under investigation with a meandering and braided morphology. As the reach of the river between Nagylak and Makó is practically abandoned since the implementation of the Trianon treaty, the semi-anthropogenic processes deriving from the preceding river controlling works are highly accentuated.

Within the above mentioned 20 km section, a single node located downstream of Apátfalva (33-34 fkm) was analyzed in details (**Fig.1.**). The chosen morphological unit is an 800 m-long system of islands and point-bars, covering an area of 9 ha at low water. Data collected here and the deductions made from the analysis of these give the basis of the majority of statements related to the conditions of the wider section.

Materials and methods

The geoinformatical analysis was carried out in two stages at different scales. As a first step, spatial alterations occurring during the past 50 years were determined with the help of three aerial photographs (1950, 1964, 1991), a topographic map of 1:25.000 (1981) and GPS data collection (2001). Spatial data deriving from five different time periods enabled a comprehensive analysis of the area and the determination of the directions and tendencies of the major changes.

First the geocorrection of the aerial photos and the maps was carried out transforming them into the EOV map system with the help of the software ERDAS Imagine 8.4. Then the surficial forms (islands and the banks) were digitized as vectors with the help of Arcview GIS 3.2 software and the raster and vector data were overlapped. The gained composite was utilized for measuring the changes in the position of the bank and the migration of the islands and bars. The influence of the different water levels was negligible on the pictural sizes of the islands, despite the fact that the photos were taken at low-and medium water, as the sides of the islands are generally highly steep, thus the deducted movements are much greater than the possible size differences resulting from the nature of the photography.

The second stage of the analysis involved the discovery of greater interrelations in this 20 km reach. Maps and aerial photographs, or better to say a sequence of these, deriving from 6 different times were used as a starting point in the work. The oldest map was a 1914 reworked edition of an earlier map of 1: 75.000 prepared during the 3rd military survey. This has been adjusted to two mosaicized topographic map series of 1:10.000 (1969, 1982). The aerial photos were taken in 1951, 1981 and 1991, respectively. GPS data collected in 2002 provided information on the most recent changes.

Results

The island and bar system of Apátfalva

The island and bar system of Apátfalva occupies a node[1] within the riverbed of the Maros. This form can be linked to the channel patterns of the braided rivers (LEOPOLD – WOLMAN, 1957). The highly varying bar forms, as well as the five largest islands, make this node the most developed and most complex out of the ones observable within the section analyzed.

The location of the islands and the course of the banks could have been analyzed at five different times within this island system.

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[1] Node is a widening section of rivers with more or less straight channels, where usually bars and islands are formed within the active channel resulting in the development of a braided pattern (Leopold et al. 1957).

According to the comparison of the results gained, the most intensive changes occurred before the 1960s in the area, resulting in highly significant displacement of the islands as well as the the banks.

From the 1960s onwards, only minor changes could have been inferred, however, they still indicate significant annual displacement at the scale of several meters (**Table 1.**). The following intensive island formation processes could have been reconstructed for the pilot area: At the first time of the analysis, in 1950, the Maros formed a slight left bend with the largest width of the riverbed located in this section (275 m) and being significantly narrower upstream and downstream (140-148 m). In order to counterbalance this increased width of the riverbed, a dozen of minor islands were formed by the river resulting in a decrease of size of the active channel (to a degree of 80% of the original width but a still impressive 220 m).

Table 1. The rate of erosion and accumulation in terms of the Apátfalva node islands

	Island 1.	Island 2.	Island 3.	Island 4.	Island 5.	days above 200 cm	days above 350 cm
	The rate of retreat at the upstream end of islands (m/y)						
1950-64	1	*	0,4	*	7,8	457	73
1964-81	2,1	2,7	1,2	3,7	3,5	978	156
1981-91	0,3	0,3	1,1	1,6	0,6	235	8
1991-01	0	0	0	6,5	1	161	43
	The rate of growth at the downstream end of islands (m/y)						
1950-64	*	*	2,2	*	2,2		
1964-81	1,9	1,5	0,5	2,2	0,7		
1981-91	5,3	1,7	2,1	1,6	0,9		
1991-01	0	0,5	1,8	11,3	4,7		

* the island did nort exist in 1953

This stage represents an aging node, where the islands are so much crushed up together close to the left banks (**Fig. 2/A-B**), which allows for the pass of a very low velocity course only in between. This foreshadowed the future plugging of the anabranches just as it had happened in case of the right bank areas among similar conditions. In case of this latter part, a wide sandy area, attached much more to the floodplain than the active riverbed, emerged in the 1950s where waters could pass over during the event of high waters only.

On the next aerial photograph (1964) a rejuvenated node (**Fig. 2/A-B**) can be seen with increased channel widths, the largest one being around 300 m. The hydraulic conditions have also changed within the active channel allowing for the formation of mid-channel bars and new island cores, islands within the channel. This was the time when the five islands observable even today, though in a somewhat altered form, were born. If we compare the fluvial morphological changes of this time period with the length of the floods between 1950-1964, we can clearly see that the number of days with water levels higher than the mean 200 cm (on the basis of the fluviometer at Makó, where the LWL: -107cm and the HWL: 625 cm) was relatively low

(9% of the total period) with even fewer floods resulting in an overbank flow (1.3%). Consequently, the mean water conditions play a crucial role in the formation of islands, starting off from point-bars, partly as a result of the prevailing accumulation processes and the stabilizing effect of the vegetation settling onto the surfaces of the bars.

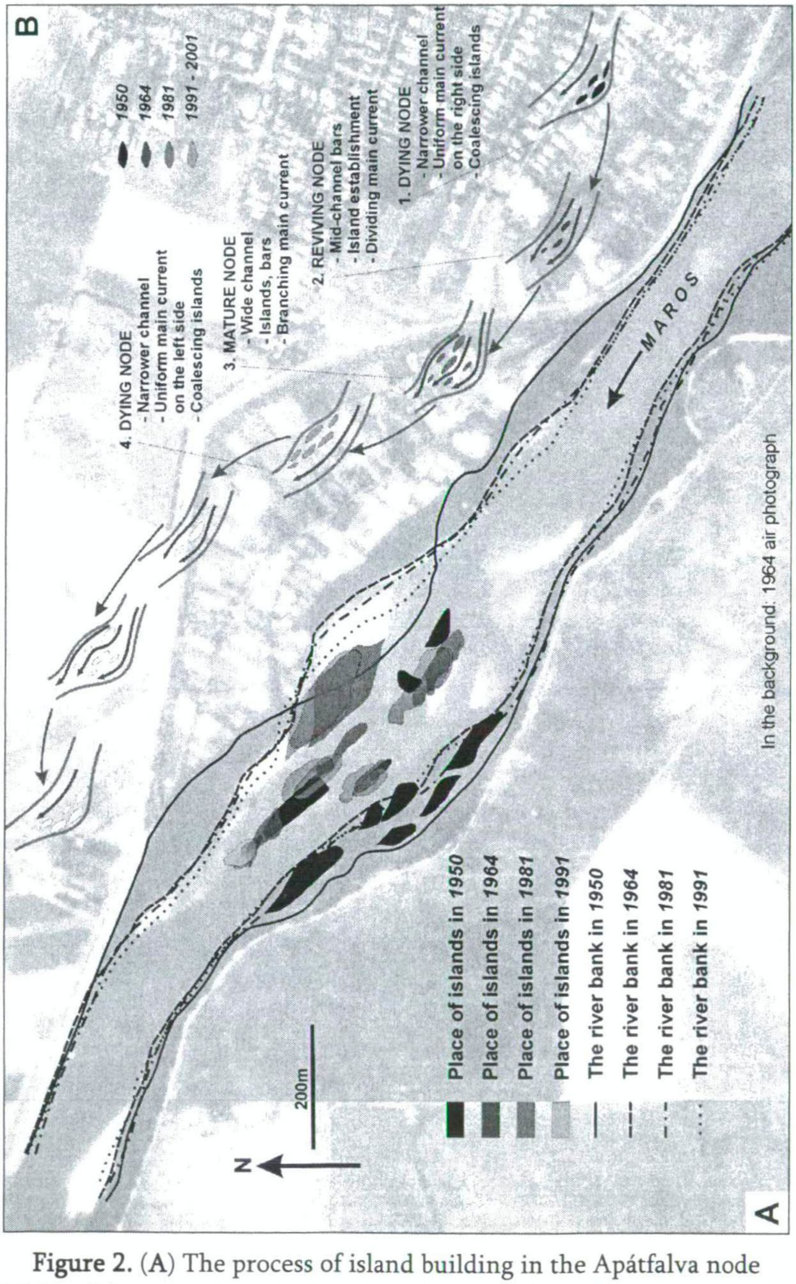

Figure 2. (A) The process of island building in the Apátfalva node
(B) The life cycle of a node, based on the example of the Apátfalva node

Only minor changes could have been observed up till 1981 showing that the node reached a mature state, consuming most of the river's energy. There is hardly any change in the course and location of the banks with an initiating downstream migration of the former islands (**Fig. 2/A**). During the 17 years between 1964 and 1981, the upper end of the islands recessed 50-60 m with a downstream growth of only 30-40 m. This corresponds to an average annual change of 3-3.5 and 1.8-2.3 m, respectively.

All these changes were by no means gradual, but rather can be linked to one or two significant events, thus we can speak about highly considerable individual displacements. This time period must have brought about the destruction of the islands with the prevalence of frequent high waters (15% of the total period) and floods (2.5 % of the total period). This was also the time when the highest record-breaking water levels were recorded on the Maros in 1970 and 1975, repectively (with values of 624 and 625 cm at Makó).

While there was no significant alteration in the course of the left banks, by 1991 the channel has become 50 m narrower on the right side compared to the previous conditions. The area of the islands also increased considerably (**Fig. 2/A**), as their lower ends underwent a 20-50 m growth compared to the 5-10 m destruction of their upper ends. The islands occupied 21% of the largest width of the node. However, the width of the active channel on the lower part was only 59% of the original. Besides the downstream movement and growth, a lot more sediment accumulated on the downstream right side of the islands during this time as a result of the left-hand displacement of the channel line. The above mentioned pace of island building during this time can be explained by the lower frequency of mean and high waters compared to the previous periods (this was also the time when the lowest water levels in 50 years were recorded).

The results of GPS measurements carried out in the pilot area indicate the continuation of the above mentioned tendencies and processes, the underlying result of which might be the further increase in the frequency of mean and high waters (only 5.5%). The extension of the No. I-II-III. islands hardly changed. On the other hand, the No. IV. and V. islands have become largely elongated while performing a retreat. The islands become gradually longer and narrower downsteam, and most likely will be completely consumed in the end. The underlying factor of this might be that as the islands are restricted to a more and more confined area at the lower ending of the node (occupying only 41% of the total cross section in 1991), this results in an increase of the velocity, and a destruction of not only their upper ends but the sides as well.

As it can be clearly seen from the above-mentioned statements, highly dynamic morphological changes occurred in out pilot area within a relatively short period of time (**Fig. 2/A**). The location of the islands gradually changed during the 50 years of time analyzed, with such changes as clustering, migration towards the left and the right banks as well while moving downstream parallely. During one or two extreme periods, their upstream edges might have eroded as much as 6 m annually with a parallel even 11 m annual increase of their downstream ones.

Meanwhile, during these 50 years, the node once earlier had reached a state, when the majority of the islands melted into the banks, resulting in a temporary cessation of the node within the channel.

However, two remaining island cores in the middle of the channel enabled the redivision of the channel line and the rejuvenation, and widening of the braided unit enabling the formation of newer islands as well. As there was no human intervention in the area during this time; i.e. no control works influenced the processes in the channel, the direction and tendency of morphological change seems to follow a cyclic trend within the present node with the easily identifiable recurrent stages.

As such, three major node developmental stages can be distinguished within a single cycle: reviving, mature and aging (**Fig. 2/B**). The continuous recurrence of these represent a dynamic state of equilibrium, making the unit seemingly uniform from the outside; changes in the picture from the outside do not even reach the rate of intrinsic changes. However, one can not exclude the possibility on the basis of the left or right disposition of the main channel line, that this disposition within an aging node can lead to the ultimate distruction of the island system within the channel, which on the other hand would respresent a change in the morphological state of equilibrium.

The reach between Apátfalva and Nagylak

Islands

The next stage of our analysis involved the investigation of the processes of the whole reach embedding the node analyzed earlier at length, thus the scale of our investigations has changed significantly granting a different character and degree of the observed phenomena as well (**Fig. 3.**).

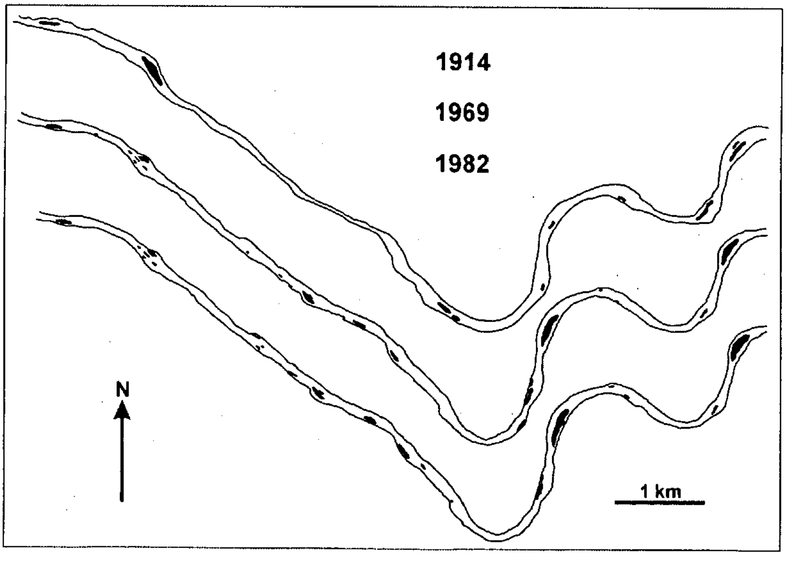

Figure 3. The islands of the studied reach in 1914, 1969 and 1982

Changes between 1914 and 2002 for the reach between Apátfalva and Nagylak were quatified at this stage complemented with the results of observations made in the bar and island system of Apátfalva.

In this 20 km section, both the number and the area of the islands underwent a gradual increase: with a rate of 19% between 1914 and 1969, and a further 16% by 2002 (**Table 2.**). Similar conclusions could have been made for the island system of Apátfalva on the basis of the analysis of aerial photos (1953, 1964 és 1991). The underlying factors might be on one hand the sediment stabilization effect of the vegetation, as well as the alterations in the certain hydraulic parameters of the river (discharge, quality and quatitiy of transported load, cross section of the riverbed), resulting in periodic relatively large-scale sediment accumulations. When the percentages of the total areas of the islands are taken collectively in comparison to the open-water areas, this provides further evidences of intensive island formation in the section under investigation (**Table 2.**) This also implies a gradual aggradation of the channel within this reach of the Maros.

Table 2. The growth of the number and area of islands located in the Apátfalva node

date	number of islands	total area of islands	growth of total area compared to the previous date	total area compared to the open water surface of the channel
On the studied 20 km reach				
1914	10	185 000 m²	-	5,65 %
1969	22	220 000 m²	19 %	6,73%
1982	27	255 000 m²	16 %	7,74%
In the Apátfalva node				
1953	5	15 900 m²	-	10,07 %
1964	5	17 500 m²	10 %	11,74 %
1991	5	20 200 m²	15 %	15,85%

Nodes

Twelve significant nodes could have been identified in the 20 km section analyzed considering the 2002 conditions (**Fig. 4**).

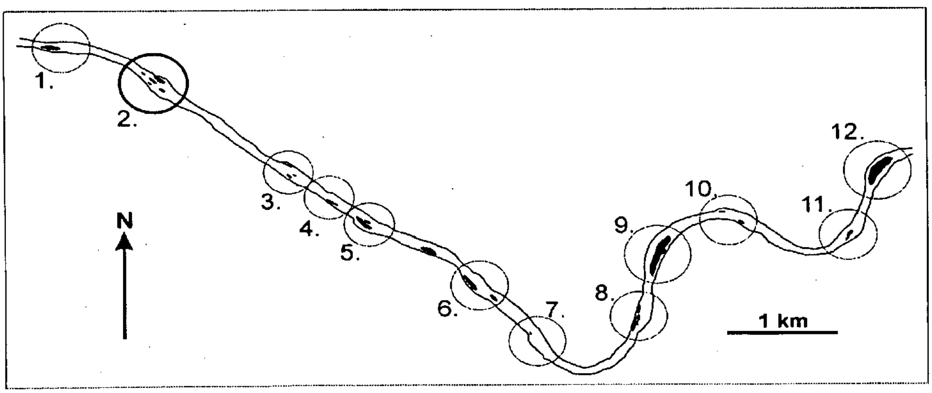

Figure 4. The nodes identified on the studied reach

Their lengths are between 300-800 m with widths varying between 230-300 m. The most mature and complex of these was the No. II node located downstream of Apátfalva. The evaluation of the prevailing processes in this node allowed for the classification of the other nodes of the reach as well on the basis of their developmental stages within the certain time periods; i.e. we can speak about nodes in their reviving, mature and aging phases. The certain characteristics of the different nodes for the periods examined are given in **Table 3**. From the lowest part of the pilot area, the No. III, IV., and V. nodes must by all means be mentioned, as these are not depicted on the 1914 military survey maps (**Fig.4.**).

The channel is relatively narrow with a width of 70-100 m, representing a stage developed right after the river control works. On the 1969 map well-developed nodes can be identified in this section with mature and aging nodes present on the 2002 maps. The most dynamic changes could have been observed in the No. III. node. Here, while we can find only an island core on the 1969 photo, 30 years later three mature islands could be spotted. Besides, the latest GPS measurements indicate surprisingly great displacements as well (85 m accumulational growth in case of the central islands). On the whole, the lower, straight part of the reach under investigation, articulated with pseudo-bends, gave birth to several new nodes experiencing dynamic changes afterwards, which implies a certain degree of instability within the system.

The second major group of nodes (VII. – XII.) is linked to the meanders of Nagylak (**Fig.4.**). They tend to be generally more stable and static; i.e. the island systems embedded have hardly changed at all lately, and all of them are depicted on the 1914 map as well. This sort of stability is also relative, as in the majority of the cases there is a significant growth in the area of the islands and a disposition of the islands from one side to the other at certain nodes (VIII, XI) (**Fig.3.**). The nodes located in the bends tended to move downstream as well with the pass of time at a collective rate of approximately 250-300 m.

The whole reach

As the two groups of nodes are linked to well-distinguishable sections of the channel, the general analysis of these two sections was also desirable in order to see how much change happened in the morphological pattern of the river Maros during the analyzed period of 90 years. A slight downstream movement of the meanders is observable in the upper part of the reach. The meandering pattern can be considered as a stable and permanent one for the period analyzed. On the other hand, the presence of well-developed nodes and islands in the bends refer to higher energy conditions in this case as well, as it was shown in other fluvial systems earlier (LEOPOLD – WOLMAN, 1957; RICHARDS, 1982; GREGORY – WALLING, 1973; WEST, 1978).

However, significant changes happened in the morphological type of the lower part of the reach. Here, the average width of the channel experienced a significant increase, in case of the newly born nodes with a value of even 100 m while on other parts with a value of 50-60 m from 1914, and the former straight channel pattern was replaced by a braided one.

Table 3. States of development in terms of the identified nodes

	Node		1914	1953	1969	1982	1991	2002
lower, straightened section	1.	islands	1 large rb*	1 large lb*	1 large, lb	getting closer to lb.	merging into lb.	merging into lb.
		state	*mature*	*mature*	*mature*	*dying*	*dying*	*dying*
	2.	islands	1 large	3 large, 4 small, lb.	5 mature islands	5 islands moving right	5 islands	reviving branch
		state	*mature*	*dying*	*mature*	*dying*	*mature*	*mature*
	3.	islands	no island	1 huge bar	1 island core lb.	3 islands	3 islands	significant migration
		state	-	*reviving*	*reviving*	*mature*	*mature*	*mature*
	4.	islands	no island	1 small lb.	1 small, 1 large merging into lb.	1 growing	1 merging into lb.	1 merging into lb.
		state	-	*reviving*	*reviving*	*mature*	*dying*	*dying*
	5.	islands	no island	2 large, 2 small, lb.	1 lage, 1 small, toward lb.	1 large, 1 small, toward lb.	2 coalescing islands	1 island, merging into lb.
		state	-	*reviving*	*mature*	*mature*	*mature*	*dying*
	6.	islands	no island	2 islands lb.	1 island lb.	1 large island merging into lb., 1 small	1 large island merging into lb., 1 small	slight change
		state	*widened channel*	*mature*	*dying*	*reviving*	*reviving*	*reviving*
upper, meandering section	7.	islands	2 islands	2 small lb.	no island	1 small mid-channel	1 small mid-channel	the island elongated
		state	*mature*	*reviving*	*widened channel*	*reviving*	*reviving*	*reviving*
	8.	islands	1 island mid-channel	no island	1 large, 3 small, rb.	3 islands merging into rb.	1 large, 1 small merging into rb.	no island
		state	*reviving - mature*	*reviving*	*dying*	*dying*	*dying*	*widened channel*
	9.	islands	1 small mid-channel	1 growing island	1 large lb.	1 large, 1 small blocking branch	1 large merging into lb.	slight change
		state	*reviving - mature*	*mature*	*dying*	*dying*	*dying*	*dying*
	10.	islands	1 small lb.	1 island lb., huge bars	2 island cores	2 growing islands	1 active rb., 1 merging into lb.	1 island rb.
		state	*mature*	*reviving*	*reviving*	*reviving*	*mature*	*mature*
	11.	islands	1 large lb.	2 small lb.	1 large mid channel	1 large moving left	1 island lb.	1 island lb.
		state	*dying*	*reviving*	*mature*	*mature*	*mature*	*mature*
	12.	islands	2 islands mid-channel	1 growing island mid channel	1 large mid-channel	1 large mid-channel	1 large mid-channel	1 large moving right
		state	*mature*	*mature*	*mature*	*mature*	*mature*	-

* rb.: right bank, lb.: left bank

This gradual widening is quite evident for the period between 1969 and 2002, thus might be accounted for in the future as well. The widening and the development of nodes must be the result of not the alterations of the hydrological conditions of the river, but can be explained as a return from the pattern forced onto this fluvial system by the river control works into the original morphological type. Thus, it might be a sort of forerunner of the development of new nodes, and the rejuvenation of the former meanders in case of the bar and island system of Apátfalva.

Changes confined to the lower part of the section analyzed refer to an unstable phase of an artificially created system, though the rate of change here is not as rapid as the processes prevailing in the individual subunits of the system.

Evaluation of the stability of the present channel

According to the above mentioned results, the nodes located in the lower part of the reach analyzed emerged after the river control works as an unwanted morphological side-effect of these artificial interventions. In contrast to the general expectations in connection with the prevailing relationship between the process and forms, changes of the morphological forms resulted in a modification of sediment accumulation and the processes responsible for the shaping of the channel in our case in this reach not vice versa. The changes in the location of the channel line, its divisions, displacements and periodical unifications tends to indicate a border-line case between the braided and the meandering pattern for the lower parts of the system. However, one can expect a further development and migration of the meanders in the upper parts of the system. The geomorphological forms experience highly considerable alterations in certain parts of the reach analyzed, which do not result in a disruption of the equilibrium but imply a certain degree of instability within the system.

The state of equilibrium is characterized by a periodic consistence of the characteristics of the forms. Thus, the island and bar system of Apátfalva has been in a state of equilibrium lately as no significant changes resulting in the disintegration of the unity of the system occurred here during the 52 years period of the analysis. However, the emergence of the bar system surmise the disintegration of balance, created by the river control works in the 19th century, when the formerly meandering channel was straightened, and this morphological change favored the development of a braided pattern. This is also true for the whole of the lower parts, where the nodes proved to be highly active in creating a braided pattern in this area of the reach analyzed. Thus the forms of this system, which emerged right after the river control works, refer to a disintegration of the state of equilibrium. At this scale however, changes in the whole reach were not as significant as the ones observed within the individual nodes. In case of the upper parts, when the course of the channel and the changes in the pattern are considered alone, we may discover the presence of a state of equilibrium during the period analyzed.

Thus, most likely this upper part was capable to buffer the effects of a much smaller intervention, thus preserving the original energy level with a robust response. Conversely, the lower part was unable to outrule the effects of much more drastic transformations getting into a higher energy level with a sensitive response.

Consequently, one can expect another sensitive response to newer minor changes as well in this case in the future. The major displacements of the islands can be linked to catastrophic events; i.e. floods, in case of the islands system of Apátfalva and the analogous nodes as well. Such events may result in the obstruction of certain anabranches within the nodes or the expansion or widening of the nodes.

As even the minor floods can result in considerable changes in the nodes analyzed, e.g the displacement of the channel line, the more extreme floods may result in the total loss of the state of equilibrium of the generalized system. This can initiate further changes in the sections downstream the nodes.

Summary

According to the results of geoinformatical analysis, considerable dynamic morphological alterations took place in the island system of Apátfalva in case of the islands located in the nodes within a relatively short period of time, with an annual displacement rate of even 5-10 m. Furthermore, the direction and the mode of morphological change in the above mentioned node, analyzed in details, seem to have been following a cyclic pattern lately (reviving, mature and aging stage), thus reflecting the presence of a dynamic balance, where the intrinsic processes do not exceed the threshold value, which would otherwise result in the expansion of the node or the initiation of significant channel transformations.

The gradual development of newer islands for the whole of the section analyzed may refer to the aggradation of the channel as well. The identified nodes can be classified into two major groups within the 20 km section analyzed: dynamically transforming ones characteristic of the lower parts and more permanent, static ones characteristic for the upper parts.

According to the results of the analysis of the subunits (islands, nodes), the reach under investigation can be divided into two major units different in their characteristics, with a stable meandering upper part, and a straight lower part, where changes refer to unstable conditions. The nodes analyzed became dominant after the river control works, in some cases their emergence is directly linked to the effects of these.

On the whole within this dual reach a robust state of equilibrium emerged in the upper part and a sensitive state of equilibrium developed in the lower part within the channel. Thus several minor or one extreme event may lead to the loss of equilibrium in case of the lower parts in the future.

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INVESTIGATIONS ON THE RATE OF FLOODPLAIN SEDIMENT ACCUMULATION IN THE MÁRTÉLY EMBAYMENT OF THE LOWER TISZA

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Introduction

Recently, floods with record-breaking highs are encountered in the river Tisza more and more frequently. Usually, several factors, acting either separately or collectively reinforcing each other, are blamed for contributing to these extraordinary floods such as (SZLÁVIK, 2001; SOMOGYI, 2000; RAKONCZAI, 2000):

- Changes in the landscape utilization of the active floodplains, as well as general landscape planning in the watershed area.
- The spatial and temporal alterations in the quantities and intensities of rainfall.
- The gradual silting-up of the active floodplain.
- The water retaining effect of the tributaries and the river Danube
- The low gradient of the river and the irregularity of the riverbed.
- The changing distances between the dikes on the banks along the course.
- The unexpected side-effects from the use of out of the country reservoirs.
- The increase in paved surfaces.

The present work is restricted to the analysis of a single factor of the above mentioned ones, namely the possible effects of the general silting-up of the active floodplain in the creation of these increasingly higher level floods, and the determination of the amount of sediment, which have accumulated on the active floodplain since the river controlling works of the 19th century. The Mártély embayment of the Lower Tisza region was chosen as the pilot area of our investigations. The degree of sediment accumulation and silting-up was recorded at two sites: (1) a morphological feature of known age acting as a reference (2) a site on the active floodplain always known to be exclusively a part of the floodplain.

Preliminaries

More and more workers are engaged in studying the geological processes of the active floodplain of the river Tisza and its tributaries, including the degree of sediment accumulation on and silting-up of the active floodplain, using various methods and approaches. According to calculations done by KÁROLYI (1960), in places lacking active channel displacement and cutoffs point bars are in a relatively elevated position being located sometimes even 2 m higher than the adjacent areas. Meanwhile, silting-up in the narrow active floodplains can reach even higher degree, an increase of 0.3-1.6 m.

Analyzing a digital elevation model of the Tisza catchment area, GÁBRIS et al. (2002) inferred a 0.23-0.6 m sediment accumulation rate in the reach between the mouth of the Sajó and Tiszadob from the time of the 19th century river regulations. SZLÁVIK (2001), utilizing hydrological records, could successfully quantify the degree of silting-up observable on the active floodplain, the littoral parts and the point bars in the Middle and Upper Tisza region. According to the recorded values, the average annual sediment accumulation on the active floodplain of the Lower Tisza was 1 cm for the period between 1976 and 1983. The same value was 5 cm for the areas of the point bars and the 30-50 m wide near-bank areas, though occasionally even annual deposits with a thickness of 60-80 cm were also recorded on the point bars.

Direct sediment accumulation measurements were carried out in the area of the Szatmár Lowlands by BORSY (1972), on the active floodplain of the Szamos, after the cessation of the 1970 spring floods. According to his observations, the largest rate of sediment accumulation was restricted to the areas adjacent to the banks (0.2-0.3 m). There was a rapid drop in the thickness of the accumulated deposits at successively larger distances from the riverbed, while the presence of only a thin coating could have been identified at the foot of the artificial levees.

SCHWEITZER using various sedimentological tools and methods managed to quantify the degree of sediment accumulation on the active floodplains of the river Körös and the Middle Tisza region. According to his findings, the floodplain was heightened by about 1.6-1.8 m in the vicinity of Békésszentandrás from the time of the 19th century river regulations (SCHWEITZER, 2001). While recently, a unique 10 cm/flood sediment accumulation rate could have been inferred for a point bar in the Tisza near Szolnok (SCHWEITZER et al., 2002). According to NAGY et al. (2001), there was a silting up of 1-1.5 m in certain narrow active floodplains of the Middle Tisza region from the time of the river regulations. However, in case of an active point bar the ratio of sediment accumulation can be even as high as 10-45 cm during major floods.

KISS et al. (2002) determined the average thickness of the sediments accumulated in the Lower Tisza between 1998 and 2001 to be 2 cm, pointing out that sediment accumulation on the point bars could have reached even higher rates during this time (0.7 m). Though, this value was only 1-5 cm in the 10-20 m wide near-bank areas.

The study area

The pilot area of our work is situated on the left banks of the river in the largest floodplain embayment of the Lower Tisza region, NW of the city of Hódmezővásárhely, between the 209.5 and 198 fluvial kms (**Fig.1.**), in the area of the Mártély Natural Preserve. The dikes in the study area were constructed in 1882 followed by a cutoff of the channel in 1889 (Ányás-Mártély) (IHRING, 1972). After the regulations, the length of the Ányás bend was shortened to 2.6 km from the original 5.4 km. While the original 1.5 cm /km gradient increased to 2.5 cm/km (LÁSZLÓFFY, 1982).

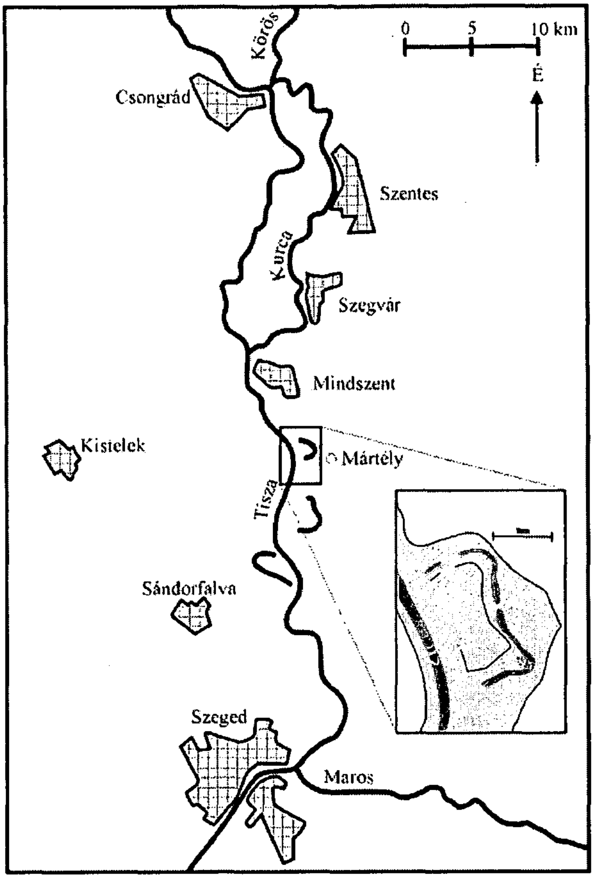

Figure 1. The location of the study area

Samples were collected from the Ányás island, bordered by the river Tisza and the Dead Tisza of Mártély. Here, the 850-2600 m wide active floodplain is located at 78-82 m ASL. Remnants of the ancient dike system, as well as numerous point bars and natural levees are elevated above the floor of the flat embayment (**Fig. 2.**).

The highest floodwaters (1000 cm) affecting the study area were recorded during the spring of 2000 in the Mindszent floodometer. Low waters are restricted to the fall and winter parts of the year, with the lowest values (-280 cm) recorded in October 1946. In a normal year floodwaters tend to cover sometimes even as wide as 4 km areas of the Mártély embayment, seemingly reflecting the original conditions, which might have prevailed on the floodplain preceding the 19th century river regulations. The area of the Ányás island, located between the dead arm of Mártély and the Tisza are generally covered by planted stands of poplar and mixed oak woodlands. Occassionally even the oldest stands were preserved in some areas as well as abandoned orchards and wetlands, offering ideal habitats for various species (RAKONCZAY, 1987).

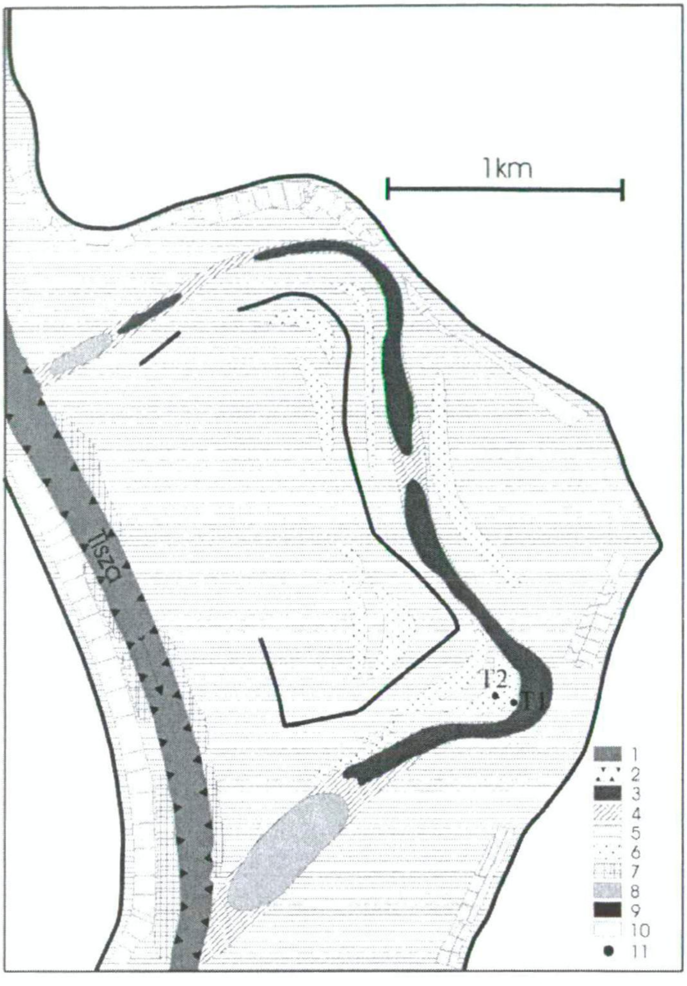

Figure 2. The geomorphological map of the studied area with the location of the sampling sites marked

1: modern active riverbed, 2: river cliff, 3:formerly active riverbed, 4: formerly active riverbed with water coverage, 5: alluvium, 6: former point bar, 7: near-shore bar, 8: point bar, 9: dike, 10: earthwork ditch, 11: sampling site

Material and methods

Two test pits were dug in the study area. One of these (T1) is located on the right banks of the cutoff channel of Mártély, corresponding to the inner convex sandy side of the former river bend of the Tisza; the other pit (T2) is located on the active floodplain between the cutoff channel and the active riverbed. Samples were collected at 2 cm intervals. As the goal was to infer the thickness of sediments accumulated since the river regulations, the T1 pit was deepened and sampled only to the horizon of the sandy beds, which must correspond to the point bar deposits of the formerly active riverbed preceding the regulations.

Accordingly samples from the T2 pit were taken to a depth of only 1 m, as no larger sediment accumulation rates could have been presumed for the higher parts of the active floodplain on the basis of observations made at T1.

The collected samples were subjected to grain-size analysis using the Köhn type pipette method and dry sieving. The grain-size classes were determined after Miháltz. The carbonate content of the samples was measured by Scheibler-type calcimetry. After pretreatment with potassium bichromate, the organic content was determined by spectrophotometry. The collected samples were also subjected to heavy metal analysis for the elements of Cd, Ni, Zn, Cu, Pb after total digestion with aqua regia using an AAS type Perkin Elmer 3110. The values received are given in ppm. Samples from T2 were subjected to magnetic susceptibility studies in the SAS laboratory of the University of Wolverhampton using a device type Bartington MS2B. The final results were graphically depicted using the software packages TILIA and TILIA Graph. During the course of evaluation, ratio of sediment accumulation in the pit deepened in the inner parts of the active floodplain (T2) was determined on the basis of the results of the reference samples of T1 taken from a morphological unit of known age.

Results

1. The timing and length of floods between 1901-2001

Via utilizing the hydrological data of the ATIVIZIG for the period of 1901 and 2001, the highest water level values (HWV) as well as the intra-annual extent of flooding and water cover in the floodplain was studied in details. The utilized data were all recorded on the floodometer of Mindszent, located closest to the study area of Mártély. For the determination of the length of flooding two water levels were taken into account: (1) the river tends to leave its course at a water level of 520 cm; the forms of the floodplain are not univocally covered by water until the level of 630 cm; (2) at levels exceeding 630 cm the point bars and even the highest parts of the floodplain become flooded as well. The profile of T2 is located at 80 m ASL on the active floodplain, while that of T1 occupies a formerly active point bar, preceding the river regulations, at 79 m ASL. Consequently, the area of T1 must have experienced more and longer-lasting flooding than that of T2 (**Fig. 3.**). Via using the HWV and the values of the intra-annual extent of flooding on the active floodplain 6 major floods could have been identified for the past 100 years in the study area, on the basis of the prevalence of short-term or long-term flooding (**Table 1.**).

2. The description of the individual profiles

A. The profile corresponding to the formerly active point bar (T1)

The inner convex sandy side of the former river bend of the Tisza is located closer to the cutoff channel and must have experienced longer water coverage during the floods located 1 m below the horizon of the inner parts of the active floodplain, where the other profile was created (about 79 m ASL). The profiles were divided into zones and units, with samples having similar features grouped into a single zone (**Fig. 4.**).

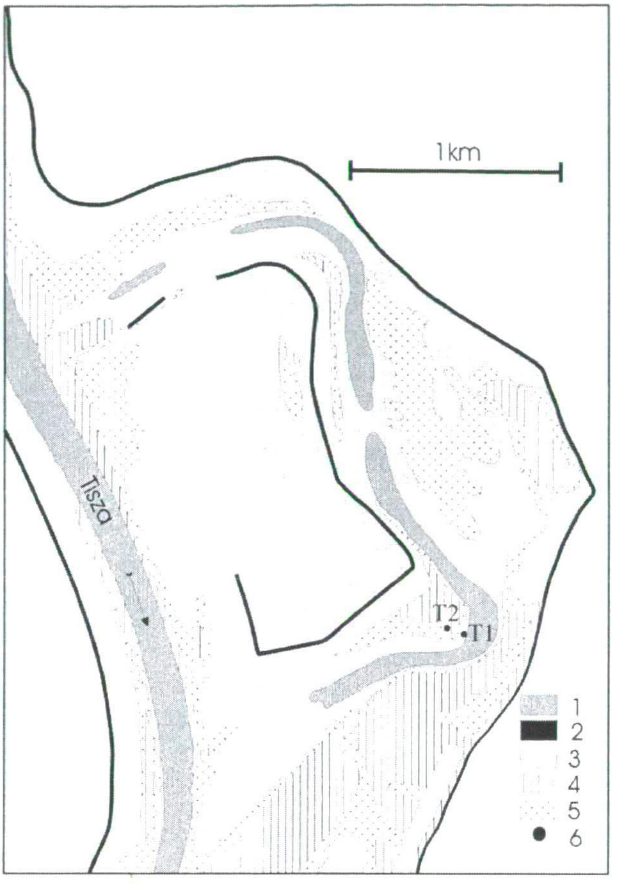

Figure 3. The elevation characteristics of the study area
1: water, 2: dike , 3: <79m, 4. 79.5-80.5m, 5: >80.5m, 6: sampling site

Table 1. The characteristics of the inferred flood periods with the highest recorded water level values (HWV) marked

Period	Length	The duration of floods (above the water level of 630 cm)		HWV cm (year)
		Within the period (%)	During the year with the longest extent of flooding (%)	
1.	1912-1919	14	23.5 (1916)	951 (1919)
2.	1922-1926	8	14.8 (1924)	910 (1924)
3.	1940-1945	25	40.27 (1941)	974 (1944)
4.	1962-1970	9	30.4 (1970)	982 (1970)
5.	1974-1981	13	15.6 (1979)	892 (1981)
6.	1998-2001	13	21.1 (1999)	1000 (2000)

Zone I. (88-94 cm):

In these samples the highest sand values were recorded (above 90%), implying that this material must correspond to the deposits of the formerly active point bar, preceding the 19th century river regulations. In order to back up this assumption, grain-size composition of samples taken from a modern active point bar at Mindszent was also determined and compared. There the recorded total sand fraction was around 92. 2%, which seems to be congruent with the value received for the lowermost part of the T1 profile. Minor peaks of Cd and Ni could have been identified in this zone between the depths of 90-92 cm.

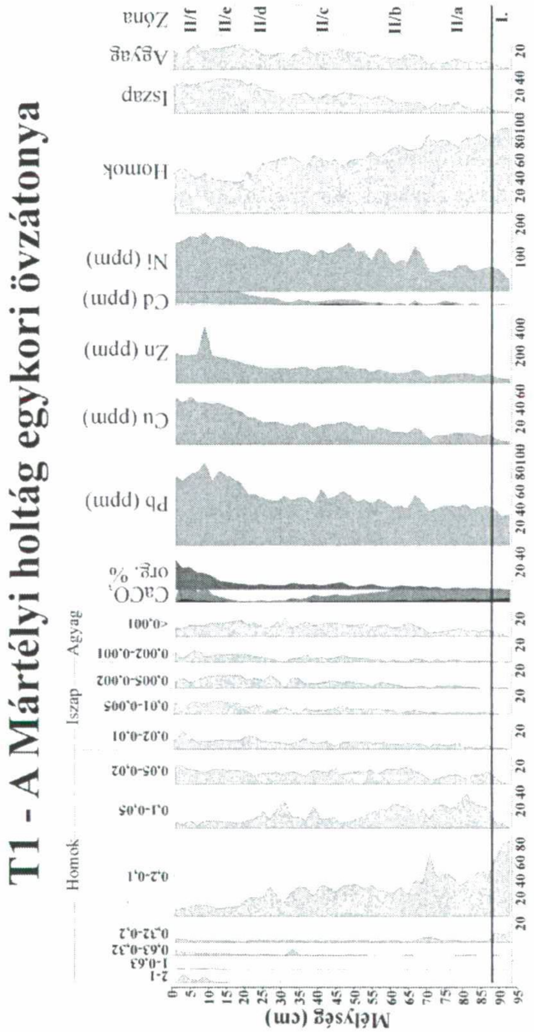

Figure 4. The chemical and physical properties of the samples taken from the profile created on the former point bar of the Mártély cutoff channel (T1)

Zone II. (0-88 cm):

This zone from a depth of 88 cm upwards must represent the material, which accumulated after the river regulations of 1889. The sequence is upward fining, with a gradual upward decrease in the sand content, accompanied by an increase in the silt and clay content. This zone was further subdivided into units or subzones on the basis of marked changes in the general sedimentary features.

In unit II./a (70-88 cm) the sand content goes below 90%, but the dominant sand fraction is alternating with the depth (e.g. very fine sands are 52.8% between 84-86 cm; fine sands are 37.8% between 80-82 cm etc.) The total amount of silt and clay in these layers is around 20%. The lowermost boundary of this unit was determined by the clearly observable peak of all five heavy metal elements (86-88 cm). While an increase in the sand fraction (approx. 90%) marks the uppermost boundary of this unit between the depths of 70-72 cm. The four major peaks in fine and medium sands must correspond to the major floods between 1912-19.

The generally decreasing trend in the sand content is observable in unit II./b (54-70 cm) as well. Although there are two major peaks observable in the sand content between 54-56 cm and 62-64 cm (76.8% and 69.2%, respectively), attributable to an increase in the medium, fine and very fine sands in the layers. These two peaks must correspond to the two largest floods of the period between 1922 and 1926. There is an increase in the silt and clay content with relatively high values between the depths of 56-58 cm (> 15%). This also holds for samples taken from the depths of 64-66 and 66-68 cm as well. These samples with a higher clay and silt content are all characterized by high values of all studied heavy metal elements. Conversely, only three elements have high values (Pb, Cd, Ni) between the depths of 62-64 cm.

In the samples of unit II./c (30-54 cm) three major sand peaks could have been identified between the depths of 32-34, 38-40 and 44-46 cm, respectively. Here the sand fraction exceeds 60% in the samples with a dominance of fine and very fine sands. The floods between 1940-1945 seem to correspond to this part of the section. Similarly three major peaks with values exceeding 20% can be observed in the silt and clay content in this part of the profile (36-38 cm, 46-48 cm, 52-54 cm). In these samples there is an increase in the amounts of Pb, Cu, Zn, plus that of Ni in the sample taken from a depth pf 52-54 cm.

The upward fining trend is also observable in unit II./d (20-30 cm) where the sand fraction is below 50% in samples between 20-22 and 22-24 cm. Several minor peaks in the sand content are observable in this part of the profile, which must correspond to numerous floods between 1962 and 1970. The peak values of silt and clay were recorded between the depths of 22-24 cm (clay 22.7%, silt 35%) with a concomitant increase in the amount of Pb, Cu and Ni.

A relatively peaceful period characterizes the next unit of II./e (10-20 cm) (1974-81?) without any outstanding values in the sand, silt or peak contents. However, there is an upward increase here in the sand content, accompanied by a decrease in the clay content.

The ratio of the sand and silt is around 35-40% while that of the clay is below 30%. However, all studied heavy metal elements have high values at the depth of 12-14 cm with the exception of Zn.

In the final unit of II./f (0-10 cm) there is an upward increase in the coarse and medium sands (8-10, and 2-4 cm, respectively), probably marking the record high floods from 1998. Here the total silt content manages to remain above 30%. While there are two major peaks in the clay content (0-2 cm and 6-8 cm, respectively). All studied heavy metals tend to have a peak value in the layer between 8-10 cm. This seems to be congruent with the findings of the study of NAGY et al. (2001) in the Middle Tisza region, where also an increase in the Zn and a dual peak of Pb was recorded in the uppermost samples, just like in our case.

B. The active floodplain profile (T2)

The next profile is located in the inner parts of the active floodplain (**Fig. 5.**), approximately 1 m higher than the T1 profile. Consequently, this area was affected by floods with water levels higher than 630 cm only. So the amount of sediments, which accumulated after the river regulations, must be also lower here. In case of the T1 profile, the actual thickness of deposits, which accumulated after the river regulations, can be determined with high accuracy as we are dealing with a geomorphological feature of known age. Conversely, these works by no means result significant alterations in the grain-size composition in the inner parts of the active floodplain, as is the case with the T2 profile. In order to elucidate the accumulated sediments for the past more than 100 years, the marker zones or units identified in the profile of T1 have been utilized for correlation.

On the basis of its grain-size composition and general heavy metal content the T2 profile can be divided into two major units or zones:

Zone I. (32-100 cm):

The deposits of this zone are characterized by a high sand content, relatively low heavy metal and organic content, and also high carbonate content. The concentration of magnetic minerals is also low here with a dominance of coarse grained MD ferromagnetic grains and a significant paramagnetic mineral fraction.

In the lowermost sample of unit I./a (94-100 cm) the proportions of all three grain-size fractions (sand, silt, clay) exceed 30%, with a dominance of the clay fraction (37%).

There is an increase in the sand content to 65% in the uppermost sample of the unit (94-96 cm), with a dominance of fine sands (> 35%). The proportions of clay and silt are below 20% here. The highest amount of Pb, Cu, Ni, Zn were recorded in the lowermost sample (98-100 cm) with a general upward decreasing trend in the horizon. However, no traceable amounts of Cd could have been identified in this unit.

In unit I./b (68-94 cm) the proportion of sand in the samples is high (almost always exceeding 75%), with peak values in samples taken from the depths of 72-74, 82-84 and 92-94 cm, respectively. Conversely, there is an increase in the amount of clay and silt in the samples deriving from the depths of 68-70 and 78-80 cm, with a concomitant peak in the recorded heavy metals as well.

The proportion of sand in the samples of unit I./c (48-68 cm) is also very high (around 90%), with a significant proportion of fine sands between the depths of 50-52, 54-56, 58-60 and 62-64 cm, respectively. Very fine sands have a value of 20% in three samples deriving from the depths of 56-58, 60-62 and 66-68 cm. From the heavy metals, only Cu and Zn were present in measurable proportions, plus Ni in two additional cases.

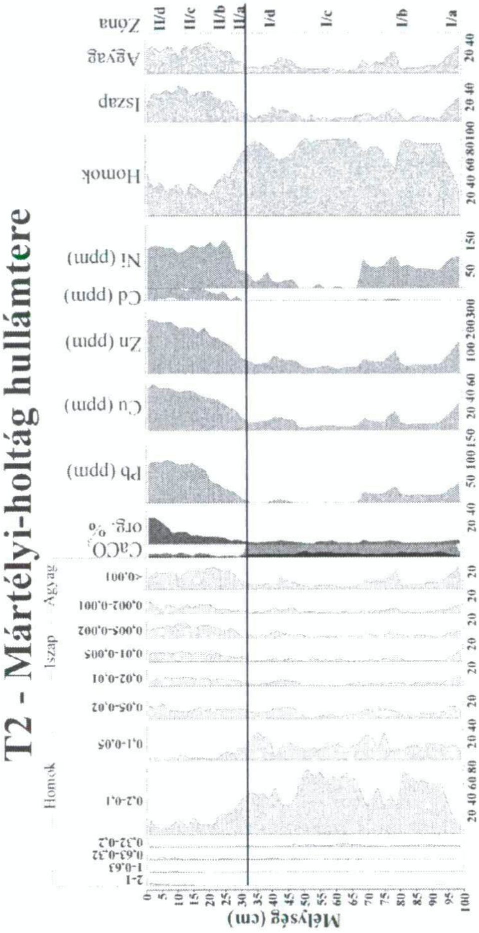

Figure 5. The chemical and physical properties of the samples taken from the profile created on the active floodplain (T2)

In the lowermost part (40-48 cm) of unit I./d (32-48 cm) there is a decrease in the sand content with a concomitant increase in the silt and clay (20-20%), as well as heavy metal content of the deposits (40-42 and 42-44 cm). Then in the samples between 32-40 cm, there is another increase in the sand content with a peak value recorded at 34-36 cm (89%). Cd was not traceable here. Pb was measurable only in three samples. The high carbonate content accompanied by a low heavy metal and psephite content marked the uppermost boundary of this unit and Zone I as well.

Zone II. (0-32 cm):

Here, there is a significant increase in the clay and silt content, concomitantly with a remarkable rise in the amount of the heavy metals as well. In parallel, the proportion of sands and carbonates in the sample experienced a major drop.

There is a gradual decrease in the sand content in unit II./a (28-32 cm), with a still impressive proportion exceeding 60%, and a concomitant increase in the silt and clay content in the samples. The heavy metals also experience a rise here with a maximum of the element of Cd only in this unit between 28-30 cm. On the basis of these features, this unit can be correlated with the II/a unit of the T1 profile.

There is a further decrease in the sand content in unit II./b (20-28 cm) as well with one peak value recorded between 24-26 cm (51%). This is accompanied by a steady increase in the proportions of clay and silt in the samples with two peaks recorded between 20-22 and 26-28 cm, respectively. In the second case both fractions are above 35% in the sample. The heavy metals also experience a further rise with two maximum values of Ni recorded between the depths of 20-22 and 24-26 cm, respectively. The barely noticeable peaks of Pb, Cu and Zn assumes a correlation of this unit with the units of II./b and II./c of the T1 profile. The concentrations of magnetic minerals in units II/a-b are also low . However, there is a gradual increase in the ARM/χ and χ_{ARM} values of the samples. In unit II./c (10-20 cm) the clay and silt content is high, above 60%. There are two increases in the sand content in samples taken from the depths of 10-12 and 14-16 cm. However, it always remains below 40%. The amount of the heavy metals is outstanding for almost all studied elements between 14-16 cm. Zn has peak values even in the lowermost samples of this unit as well (18-20 cm). Similarly high values were recorded in the II/d unit of the T1 profile.

There are two peaks in the sand content in unit II./d (0-10 cm) preceded by peaks of the finer fractions, just like in the uppermost two units of T1. Similar high values of the studied heavy metals (Pb, Cu, Ni, Cd, Zn) were recorded in the lowermost samples of this unit as in those of the II/e unit of T1, connected to floods between 1974 and 1981. During the first half of the 1990s, this area was free of floods, due to the low maximum level of the floodwaters, which prevented sediment accumulation in this part of the active floodplain during the inferred time period (1990-1995). In the uppermost samples of this horizon the studied heavy metals are present also in peak amounts, except for Cd, as in the II/f unit of T1. So these layers must have been deposited after 1998. Units II/c-d are also characterized by outstanding magnetic susceptibility values as well (χ, SIRM, SIRM/χ).

Summary of results

The following general conclusions can be made in connection with the two studied profiles:

1. As the area of the T2 site experienced shorter water coverage and less flooding events than that of T1, the accumulation of fluvial deposits was also lower there. Conversely, the area of the T1 site, experiencing flooding almost every single year must have been the site of greater sediment deposition.

The amount of sediment accumulation from the time of the 19th century river regulations was 88 cm at the T1 site and 32 cm at the T2 site, respectively. This assumption is also justified by the altered magnetic susceptibility of the uppermost samples of the T2 profile (0-32 cm), reflecting intensified soil erosion in the watershed area, as well as intensive accumulation (OLDFIELD 1991).

2. The calculated annual rate of sediment accumulation in the T1 profile after 1889 was 0.79 cm/ year. While it was only 0.29 cm/ year in case of the T2 site.

3. The presence of outstanding coarse grained fractions in the profile served as clear indicators of record high floodwaters and long-lasting flooding events.

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THE ANALYSIS OF SEDIMENT ACCUMULATION AND SILTING-UP OF A CUTOFF CHANNEL ON RIVER MAROS NEAR THE CITY OF MAKÓ

OROSZI, Viktor György – KISS, Tímea

Introduction

During the quest of reasons underlying the extraordinary floods on the rivers of the Great Hungarian Plain, which occurred in the past few years, investigations of the processes and changes prevailing on the floodplain has become more and more important. On the one hand, these involve the understanding of the process es, and degree of sediment accumulation on the floodplains and the silting-up of the cutoff channels. Because of the different degree of sediment accumulation on the active and protected floodplains, the cutoff meanders located behind the artificial levees on the protected inactive floodplain still dominantly form open-water oxbow lakes with differential characteristics. Meanwhile their counterparts, located on the active floodplain in front of the artificial levees are sometimes entirely filled up. A good example of these filled up oxbow lakes can be found at the city of Szolnok in the form of a part of the cutoff channel of the Tisza of Alcs, which is located on the active floodplain in front of the artificial levees (SOMOGYI, 2000). Nevertheless, the oxbow lakes of river Maros and cutoff meander at Szeged also belong to this latter group.

The major aim of our investigations involved the analysis and reconstruction of the process and speed of sediment accumulation and silting-up in an artificial cutoff channel created during the river control works, and located on the floodplain of river Maros near the city of Makó. The reconstructions were mainly based on the historical analysis and interpretations of maps from the area, as well as the application of pollen analytical methods. A special type of pollen analysis, aimed at the determination of the pollens of invasive plant species with a known date of appearance and frequent occurrence, has been utilized in order to determine the relative age of the individual sediment horizons in the sedimentary profile, and thus the annual rate of sediment accumulation and silting-up.

During the course of our investigations presented herein, we were seeking answer to the following questions:

1. What sort of environmental changes and transformations occurred during the past 300 years in the pilot area?
2. What is the degree of silting-up in the cutoff meander?
3. Is the application of the pollen analysis of invasive plant species suitable for absolute age determination of recent sedimentary profiles?

The found answers to these questions might help us to enhance our understanding of the processes and changes prevailing on the active floodplain, and their indirect influences on flooding as well.

The pilot area and the methods applied

The pilot area of our study is located on the right banks of river Maros SE of the city of Makó between fluvial kms 27-30. The area forms a tiny embayment on the active floodplain with a width of approximately 1 km (**Fig. 1.**) This area was placed under protection within the framework of the Körös-Maros National Park in 1999. The former overdeveloped meander, known as the Goszpod bend was cut off between 1842-1850. Since then the cutoff channel has been completely filled up and is surrounded by the floodplain and point bars. The discharge of the river Maros at the profile of Makó is 40 m^3/s at low water, while it can reach a rate of 1800 m^3/s during flooding (VÍZRAJZI ÉVKÖNYV). The average annual deposit transportation capability is 2.73 million t, the largest rates during the highest waters may reach as much as 6000-12000 kg/s as well.

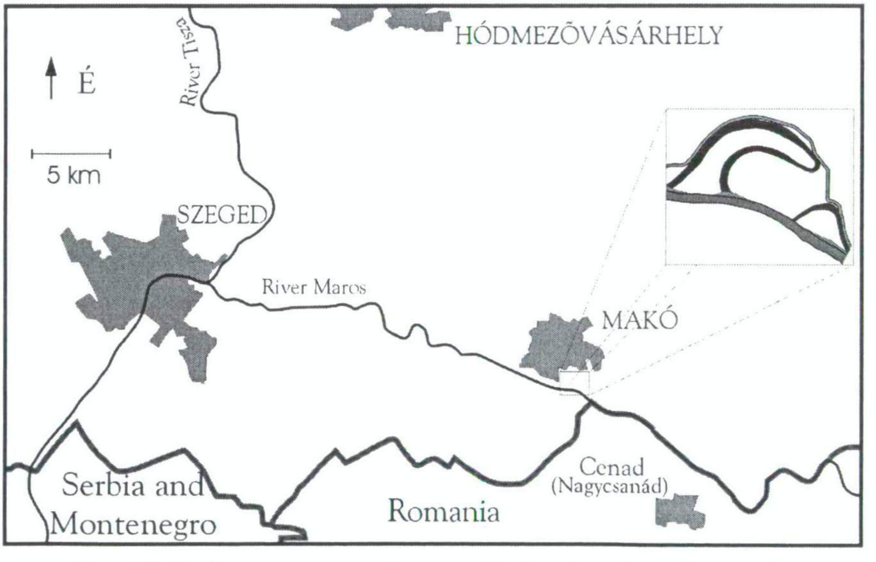

Figure 1. The location of the pilot area with the site of sampling marked

As a first step in our investigations the relevant maps and detailed descriptions published have been collected (TÓTH, 1972, 1988, 1992). In parallel, sediment samples were taken at an interval of 10 cms from the former bed of the Goszpod bend with a hand-driven Földváry type auger until the coarser material of the active channel was reached (420 cm).

The collected samples were analyzed for grain-size composition via simple sieving and using a Köhn pipette. The carbonate content of the samples was determined by Scheibler calcimetry. Finally, the organic content was determined by spectrophotometry following a digestion with sulphuric-acid and potassium-bromate.

During pollen analysis, the Zólyomi-Erdtman zinc chloride acetylation method was utilized for sample preparation followed by the determination of the sporomorphs under the microscope at a magnification of 400-600 times (FAEGRI–IVERSEN, 1988). The obtained results were used for the construction of pollen diagrams depicting percentage and absolute values with the help of the softwares Tilia and Tilia Graph 3.0.

Results

Maps and descriptions

The first map of the area under investigation was prepared by WALTNER in 1699 (**Fig. 2/A**). In this map, the river Maros is characterized by several branches and islands above the village of Nagycsanád, however below the settlement there are numerous meanders. The author speaks about arboraceous vegetation prevailing along the river bends.

The 1753 map of Steinlein depicts an arboraceous, marshland vegetation in the area of the Goszpod bend along with two islands within the riverbed of Maros. The tracks of the artificial levees protecting the city of Makó are well traceable along the western side of the meander. The thin line on the eastern side running into the meander may represent a drainage channel referred to later on as the „Pallagi-fokja" ("Pallagi crevasse").

The following maps more or less depict the general conditions of a given period: the map of J., Vertics (1778); the map of the first military survey (1784). Another, professional river navigation map prepared in the late 1780s can be attributed to Vertics as well. In these there are no signs of the formerly mentioned islands above the Goszpod bend, even though only two or three decades had passed since their first mentioning. As depicted in the map of the first military survey the left banks of the river are covered by arboraceous vegetation.

The city of Makó was surrounded by woodlands at a larger distance, which turned into vineyards and hemp fields closer to the city. The earlier depicted site of crevasse is missing, a drinking site is indicated instead.

There are six ship mills on the river Maros in the 1804 map of Horváth, the meander neck is cut through by an artificial levee. The arboraceous vegetation was displaced by grassland areas in the area of the Goszpod bend and that south of it.

The site of the same crevasse splay is depicted again on the 1805 map of Vertics on the "inner pasturelands of Makó", which might be a rejuvenation of the 1753 crevasse event and is also referred to as the „Pallagi Fokja" ("Pallagi crevasse"). The planned sites of cutoff are clearly observable on the 1:28 800 maps created in preparation for the river control works on Maros in 1827.

The narrow meander of the Baranya bend necessitated their implementation. A description dated from 1835-36 tells about scant willow-poplar woodlands and sporadic hardwood areas with intercalated gardens and orchards.

The spring floods of 1838 and 1841 enhanced the negotiations on the necessity of control works due to the high vulnerability of Makó. A supplement of the 1842 report of Mátéffy on the progress of the river control works is depicted on **Fig. 2/B**

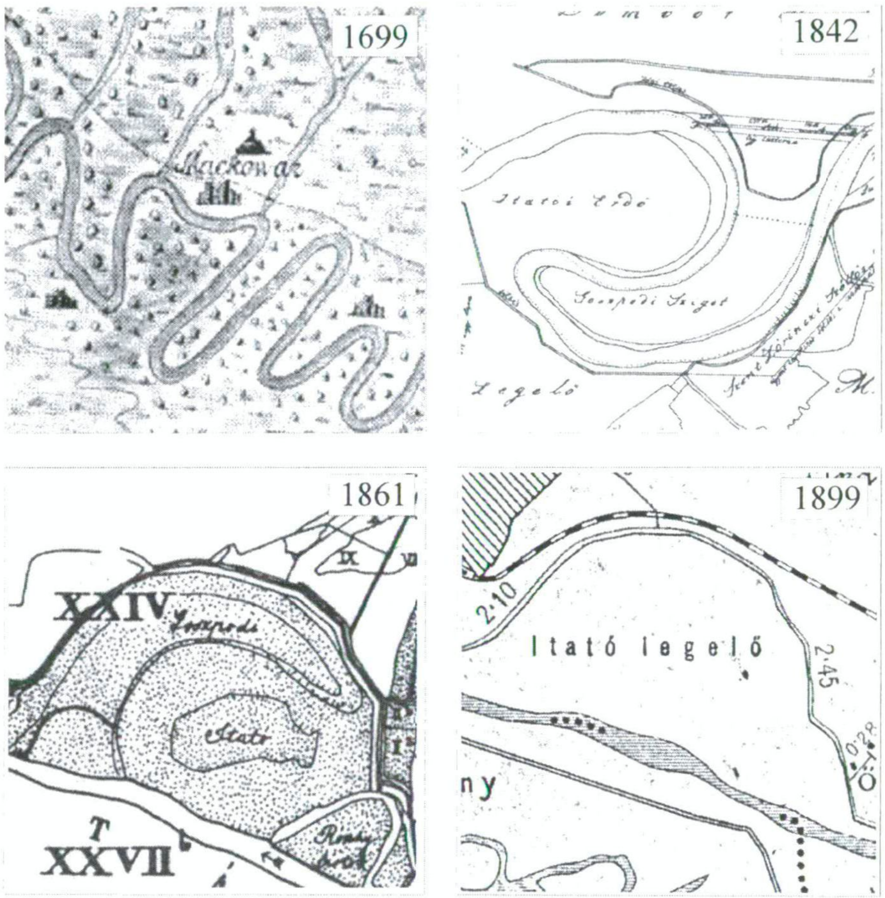

Figure 2. Changes in the environment of the pilot area based on maps
A: 1699, B: 1842, C:1861, D: 1899

Though the majority of the work was complete, it took some time for the natural river to occupy its new artificial bed (TÓTH, 1992). Following the implementation of the cutoffs, finished by 1850, the establishment of artificial levees and other flood protection work started.

The pilot area has been referred to as Dead Maros on a general field survey map from 1854 (unknown scale and author) for the first time. According to Tóth (1992), a series of lime-burning furnaces were located near the willow woodlands of Lúdvár in 1860, not too far from our pilot area. Furthermore, a shallow-draught steamboat, the „Kaiser Ebersdorf" was a means of transprtotation between the cities of Szeged and Arad from 1852 onwards. The produced ash might have been preserved in the sediments as shown by pollen analyis. The 1861 map of Breuer G. with a scale of 1:14 000 depcits the distribution of the inner pasturelands of the city of Makó (**Fig. 2/C**). On this map the branch of the Goszpod bend located closer to the active riverbed is narrower in contrast to the other one. This narrow section must have acted as some sort of a sediment trap for the finer deposits reaching the area during flooding since this was the first deep trench on the floodplain from the direction of the channel. Conversely, water movement in the other branch located closer to the artificial levee must have been reduced resulting in the accumulation and deposition of less sediment to that area.

According to the 1899 map from the area (**Fig. 2/D**), the cutoff channel was totally infilled during a period of about 50 years (bw. 1850–1899). The important differences in the relief were soon leveled off thanks to the large carrying capacity and volume of load of the river Maros since there are no open water areas in the pilot area on this map, however even the network of minor creeks is depicted on the other side of the Maros as well. The disappearance of the oxbow-lake resulted in a complete melting of the Goszpod bend with the former „Itató" (Watering place). The floodplain of the Maros becomes narrower downstream the pilot area and widens up again afterwards damming up waters again resulting in increased accumulation rates.

There were no significant changes in the pilot area up to 1914, characterized by pasturelands and sweep pole wells and trees lining the margin of the artificial levees. Traces of initiating bar and island formation in the active riverbed can be observed as well. According to a detailed map from 1970 the area is between 81 and 84.5 m asl., with the deepest point being the holes dug by the groundmen. Wet meadows and willow woodlands occupy the lower-lying areas while apple orchards and pastures can be found in the higher regions.

The results of the analysis of the sedimentary profile

A. Grain-size composition

The prepared diagram depicts the percentages of sand (2-0.02 mm), silt (0.02-0.002 mm) and clay fractions (0.002> mm) in the sediment along with their cumulative values (**Fig. 3.**). The amount of ash along with the carbonate and organic matter content is also depicted here. The profile can be divided into three major units according to the characteristics observed on the diagram:

Unit 1: (420-380 cm) This unit is dominantly made up of sand (77-92%), with the appearance of medium sized sands at a considerable amount alone here throughout the profile (0.63-0.2 mm). The proportions of clay and silt fractions are minimal. These samples correspond to the the coarser, sandy deposits of the active channel of the Maros with a high ash content and low organic matter content as the deposition of organic materials was not possible within the active riverbed.

Unit 2: (380-170 cm) This unit is characterized by alternating layers rich in sands (40-75 %) and clayey-silty beds. The ash content is still very high between 230-340 cm following an initial fluctuation. The organic matter is highly fluctuating as well its peaks corresponding to the ones of the clay and silt fractions.

Unit 3: (170-0 cm) Here the amount of sand is reduced to a rate of 30-50%. The clay content is very often around 50-55% with hardly any changes in the silt fraction. This unit is characterized by a significant drop in the ash content accompanied by a slight increase in the carbonate content, but still with rates of 3-4% only. The humus content is not so capricious regarding its former peak values here, however it reaches considerable amounts in the upper 40 cm of the section.

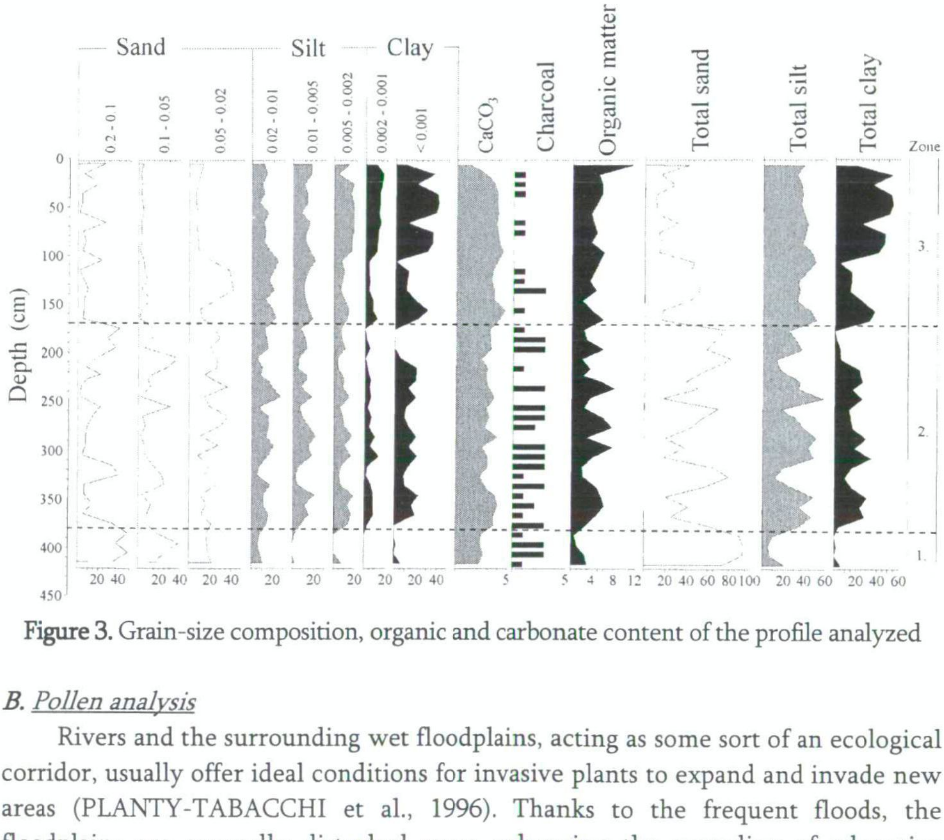

Figure 3. Grain-size composition, organic and carbonate content of the profile analyzed

B. Pollen analysis

Rivers and the surrounding wet floodplains, acting as some sort of an ecological corridor, usually offer ideal conditions for invasive plants to expand and invade new areas (PLANTY-TABACCHI et al., 1996). Thanks to the frequent floods, the floodplains are generally disturbed areas enhancing the spreading of adventive plants as well. Thus the identification of invasive species via pollen analysis, with a known date of appearance, might be utilized as an absolute dating method for determining the speed and rate of silting-up and sediment accumulation on the floodplains.

A multipurpose selection of, as well as the determination of the exact date of appearance of these invasive species in Hungary is important prerequisites of the analysis. The most promising species are those, whose known distribution areas overlap with the lower reach of the river Maros. Furthermore, they must be capable to expand to the woodlands, high-weed areas, mud vegetation areas, marshlands and dry and wet meadows of the floodplain, based on their ecological needs and habitat preferences (SOÓ, 1973). As a second step, we have to determine how massive the species is regarding its appearance, and how many close relatives or non-invasive subspecies it has in Hungary. These factors highly influence their ease of determination.

The following species have been utilized after multi-level selection with the first date of Hungarian occurrence marked (PRISZTER, 1960, 1997):

1870	water-weed	*Elodea canadensis*
1872	negundo	*Acer negundo*
1880	water breeze	*Wolffia arrhiza*
1889	marsh-mallow	*Althea officinalis subsp. pseudarmeniaca*
1904	echinocystis	*Echinocystis lobata*
1907	amorpha	*Amorpha fruticosa*
1908	helianthus	*Helianthus decapethalus*
1916	erucastrum	*Erucastrum nasturtiifolium*
1922	Italian bur-weed	*Xanthium italicum*
1932		*Typha laxmannii*

However, these dates of PRISZTER (1997) do not necessarily indicate the first date of immigration or appearance, but rather the first date these species are mentioned in the literature, or the first specimen from a botanic garden. Thus on one hand, there is a chance that some species had immigrated to Hungary well before they were found and mentioned in the literature. On the other hand it might be also possible that certain species had been described at a given date, however they appeared on the floodplain of the maros only at a later time many years or even decades afterwards. In order to somewhat eliminate these errors, the results of botanical analysis carried out in the pilot area have also been utilized in our work (HALÁSZ, 1889; TÍMÁR, 1948, 1950; TÓTH ,1967; MAKRA, 2002; OBRADOVIC et al, 1979)

When preparing the diagram a new clustering method was used, different from the traditional approaches, to make the process of evaluation easier. The determined species were clustered into groups following the plant coenological classification of SIMON (1994). Arboreal pollens were divied into two groups (AP): *allochtonous* deriving from the larger discharge area of the Maros, and the local species of the pilot area (*autochtonous*). Then the remaining non-arboreal pollens were determined (NAP): tangle plants (*Lemnetea*), marshland vegetation (*Phragmitetea*), plants of the wet meadows (*Molinio-Juncetea*), dry pastureland vegetation and arable weeds (*Festuco-Brometea + Chenopodietea*), the group of non-arboreal plants characteristic of the willow woodlands (*Salicetea NAP*), and finally the invasive and allochtonous NAPs. As the number of pollens was not statistically evaluable in all of the samples an absulote value pollen diagram has been constructed. According to this, the profile can be divided into four major units (**Fig. 4.**).

Unit 1: (420-380 cm) This unit is characterized by the presence of tree pollens and those of water plants, as welll as spores. The plants of wet meadows and dry pasturelands are not typical here and no invasive forms have been found. However, the large amount of allochtonous NAPs and APs deriving from larger distances (*Juniperus, Pinus, Abies* and its corroded version) is quite conspicuous.

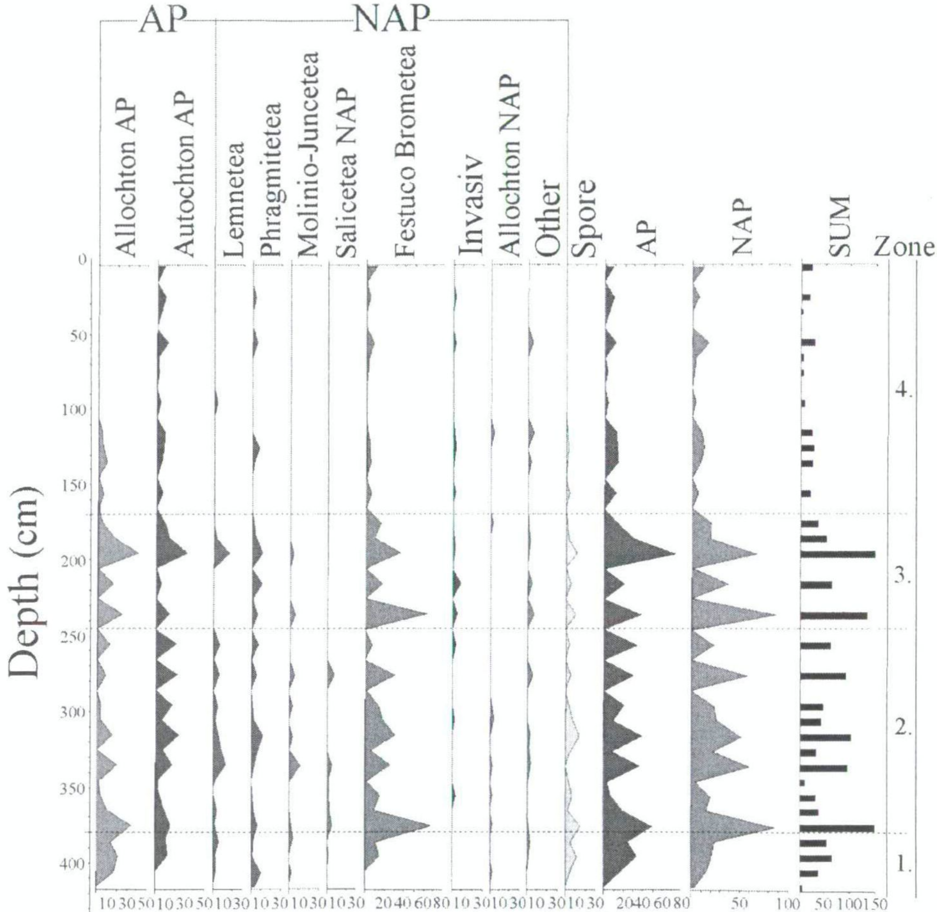

Figure 4. Cummulative absolute pollen diagram for the profile analyzed

From the local trees the species of willow (*Salix*) oak (*Quercus*) as well as hazelnut (*Corylus*) are dominant. The proportion of these local APs is lower compared to the allochtonous ones. All these seem to indicate the presence of an active channel and fluvial processes in the area. This is how the pollens of plants indigenous to Transylvania could reach the area, very often in a corroded form. A dominance of gallery forests characterized the floodplain at this stage.

Unit 2: (380-240 cm) The appearance of allochtonous APs is not continuous but the autochtonous APs become gradually dominant in this unit, mostly those of willow, oak and hazelnut as well as poplar (*Populus*) and elm (*Ulmus*). From the NAPs the species *Lemnetea* appear here (*Myriophyllum, Potamogeton, Nymphea).* Besides these, marshland plants are also frequent in this unit (*Carex).* The appearance of NAPs characteristic for the gallery forests is restricted to this zone alone. From the plants of dry pasturelands the family of gramineae and plantain (*Plantago*) indicating signs of treading in the area, as well as the arable weeds (*Chenopodium*) are present here in larger quantities. The spores are dominantly *Pteridophytae*. From the sporadic appearances of invasive plants, the first occurrence of negundo (*Acer negundo*) (260 cm) occurred here, whose appearance in Hungary is dated to 1872 by PRISZTER (1997). This appears in the 1889 species list of HALÁSZ, meaning that its spreading period may correspond to these two decades.

This unit most likely represents an open-water cutoff channel, created by the river control works, slowly silting up turning into a marshland and thus offering ideal conditions for the trapping and preservation of pollens. Its direct neighborhood is characterized by the presence of gallery forests and arables, as well as pasturelands. Pollens deriving from larger distances on the discharge area of the Maros must have been deposited during the floods. The high ash concentrations observable in several horizons (340-230 cm) may refer to the activities of lime burners mentioned from 1860 in the area.

Unit 3: (240-170 cm) A short periodic maximum of allochtonous APs related to floods is observable in this unit as well. The local woodlands were composed of oak, willow, hazelnut and poplar howver APs are no longer dominant compared to NAPs. The tangle vegetation is only dominant periodically, rather the representatives of the marshland vegetation are prevailing (*Caltha, Carex, Lycopus*). The pollens of cereals, goose-foot (*Chenopodium*), choke-weed (*Orobanche*), plantain (*Plantago*), and Artemisia (*Artemisia*) deriving from dryer areas under cultivation indicate an increasing human activity and influence in the area. The spores are dominantly *Pteridophytae* here as well. From the invasive species the pollens of *Amorpha fruticosa* appear between the depths of 240-250 cm, its first appearance in Hungary is dated for 1907 (PRISZTER, 1997).

This unit represents a marshy, swampy area with shallow water coverage and the inwash of coarser material on top of the finer clayey sediments of the cutoff channel during floods, as a result of increased water velocity and capacity. The presence of *allochtonous AP* and the species *Lemnetea* indicate still-water conditions following the floods.

Unit 4: (170-0 cm) The number of pollens is significantly decreased in this zone. The autochtonous APs appear only sporadically and the tangle (*Lemnetea*) as well as the marshland vegetation almost compelety disappear here. Among the NAPs of pasturelands the pollens of the following species appear with other dry pastureland preferring forms: *Gramineae, Orobanche, Trifolium.* The spores are almost totally missing in this zone. From the invasive species the first appearance of ragweed (*Ambrosia artemisiifolia*) is observable from a depth of 140 cm in several horizons. Further invasive species can be identified from a depth of 130 cm like robinia (*Robinia pseudo-acacia*) and sweet-flag (*Acorus*). The presence of ragweed along the river Maros is not indicated in the 1967 work of TÓTH, however JÁRAINÉ-KOMLÓDI (1999) puts its first appearance in this area into the 1960s. The pollens of robinia (*Robinia pseudo-acacia*) and sweet-flag (*Acorus*)are not suitable for chronological purposes in our case as their first Hungarian appearances date back to times preceding the river control works.

The drastical changes in the pilot area's vegetation can be explained by a gradual aridification of the area resulting in the complete disappearance or periodic emergence of habitats suitable for hygrophilous species. No permanent water coverage is present in the cutoff channel, the short periods of water coverage are linked to the floods greatly reducing the pollen trapping and preserving capacity of the system. In the neighborhood of the infilled cutoff channel gallery forests could have been found at a larger distance with pasturelands and arables under cultivation in the direct neighborhood.

Summary

The following environmental changes can be summed up for the area of the analyzed cutoff channel (**Fig. 5**.): The pilot area used to form an overdeveloped bend of the river Maros before the river control works thus the primitive system of levees along the rivebed were not able to prevent waters from reaching the floodplain during floods. Thus, this bend was cut off between 1842 and 1850 because of the increasing insecurity of the city of Makó from floods. The area referred to as the "Goszpodi-hajlás" (Goszpod bend) was covered with gallery forests up to the beginning of the 19th century. However, these gallery forests were present along the Maros afterwards as well. Later these extensive gallery forests were gradually exchanged for pasturelands, meadows and orchards. This was a period when many allochtonous pollens were transported into the pilot area by the river.

The pilot area formed a part of the active floodplain of the Maros even after the river control works as well and started rapidly silting-up thanks to the large load-carrying capacity of the river into this area during floods. As the amount of sediment deposited by the river on the floodplain is decreasing with increasing distances from the active riverbed the branch of the cutoff channel located closer to the riverbed was more rapidly and significantly infilled, serving as a sedimentary trap of coarser materials. The deposition of finer sediments was dominant among still-water conditions after the floods on the floodplain. The periods of floods marked the accumulation of allochtonous, while the intermittent periods marked the preservation of local or autochtonous pollens.

The final stage of aggradation can be placed to the beginning of the 19th century, when the cutoff channel was almost completely silted-up with only period water coverage and soon fully drying out. The former channel was used for grazing in the first half of the 20th century, then it was turned into a hayfield, thus the pollen trapping and preserving capacity of the original cutoff channel was greatly reduced.

The rate of silting-up for this cutoff channel was determined with the help of the collective evaluation of map data and the results of pollen analysis of invasive plants as well as the grain-size analysis of the deposits.

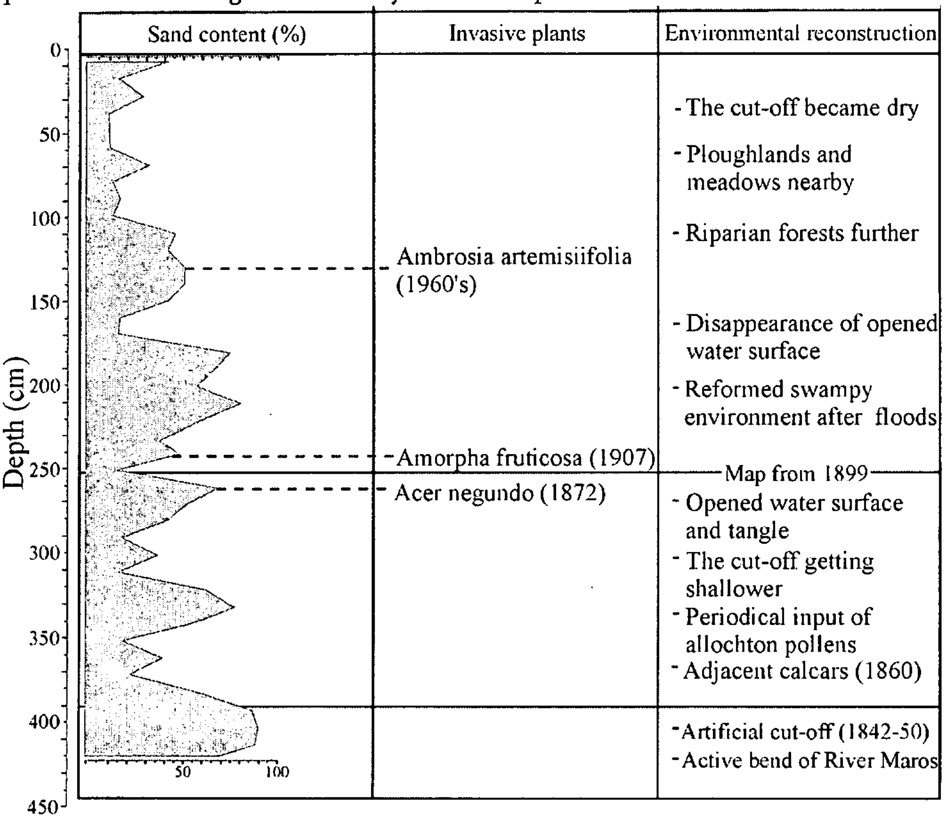

Figure 5. Correlations of the results of the analyses

The annual rate of deposition and silting-up following the cutoff (1842-50) and lasting about the almost complete silting-up of the channel (1899) was 2.5 cm/year. Afterwards the deposition of the remaining sediments (240 cm) lasted approximately 100 years which corresponds to an annual rate of sediment accumulation of 2.4 cm/annum. The rate of deposition was only slightly reduced following the large-scale silting-up of the channel; however there might be significant differences in this period (if we accept the date proposed by JÁRAINÉ (1999) for the first appearance of ragweed in the area then the average annual silting-up must have been around 3.5 cm/year for the past 40 years. This latter must be the outcome of partly a smaller degree of compaction or the changes of the carrying capacity of the Maros, or even the larger environmental changes on the greater discharge area)

An attempt was made for the absolute dating of sediments deposited in the channel, as well as the determination of the rate of silting-up by the collective evaluation of grain-size, geochemical data and results of a pollen analytical method rarely used in Hungary. For this only three invasive plant species with a known date of first Hungarian appearance were suitable: ragweed from the 1960s (*Ambrosia artemisiifolia*), amorpha (*Amorpha fruticosa*) from 1907 and finally negundo (*Acer negundo*), from 1872. This pollen analytical method is suitable for absolute dating, however only collectively with other methods and for areas with permanent water coverage (cutoff channels, interbar depressions).

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UTILIZATION OF THE INUNDATION AREA OF LAKE FERTŐ BEFORE REGULATION WORKS: EXAMPLE OF SARRÓD AND ITS SURROUNDINGS

KISS, Andrea

Abstract

Due to its extreme shallowness, the basin of Lake Fertő/Neusiedl was exploited well before the regulation works which took place especially from the second half of the 19th century. Before regulation works, utilization of the primary lake basin and the secondary basin or inundation area was mainly dependent on the actual waterlevels. Located at the shallow, southeastern edge of the lake, probably the most typical sample area of temporal inundation sites is the one which belongs to the village of Sarród. Based on contemporary (partly late medieval, but mainly early modern, modern) written sources, maps as well as archaeological evidence, in the present study an attempt is made to provide some forms of a simple reconstruction on the utilization of the lake basin. While the basic utilization types depended on the actual waterlevel conditions, due to historical, economic reasons and perhaps climatic variabilities and change, other utilization variants as well appeared in time. The available contemporary information can be divided into three major groups related to the low-very low, medium-high waterlevels of the lake. The third group of evidence is connected to the special utilization types of islands located in the basin. Applying a simplified utilization 'model' related to the coastal wetlands of Western Europe, the analysis and results of the present study can be used as an example for source analysis in the whole Fertő area as well as other wetlands connected to lakes.
Keywords: historical land use, inundation area, waterlevel changes

At the edge in between: lake and wetland environment

Before the late 19th-century regulation works, the landscape and land use of the area were fundamentally different than today. Not only the landscape but also the hydrological regime of the alkaline Lake Fertő/Neusiedl and the connected wetlands of the Hanság/Waasen looked basically different: they all took part of a larger hydrological system of such main rivers of Northwestern Hungary as the Répce, Rába and Rábca, and through the last one the lake, but especially the wetlands had indirect connection to the Danube. Apart from the indirect supply coming from the mentioned rivers through the former wetlands of the Hanság, the extremely shallow Lake Fertő had direct water income from the Ikva river, too. At the southern edge of the lake basin, an extensive area belongs to the inundation area which in fact is still part of the lake basin. This inundation area reaches its greatest extent at the southeastern edge, at the village of Sarród, where it comprises a transition towards the wetland areas of the Hanság. Similar to the area of the neighbouring settlements of our investigation, the village boundaries, far extended into the basin, reflect a typical edge-of-an-inundation-area location: as such, most of its lands are located in the inundation area or secondary (and partly also in the primary) basin of the lake (MAKSAY, 1974). Depending on the actual waterlevel of the lake, this inundation area looks different: while in case of high waterlevel it is partly flooded, in case of low waterlevel of the lake it is a pasture with some brooks and deeper bogs and mires around.

The present study area belongs to a village of medieval origin; unlike today, before the 20th century most of its lands located in the secondary basin of the lake (hereafter called 'inundation area'), while its eastern boundaries were already in the direct neighbourhood of the extended wetlands of the Hanság. Due to the afore-mentioned environmental conditions, one can recognise a double land use of the study area: economy and income of the village lied upon different bases in case of different waterlevels. Today most of the area belongs to the Fertő-Hanság National Park. The National Park takes the responsibility of habitat reconstructions and the creation of 'quasi-natural' sites where they try to establish an ecologically balanced system. In order to make this work the most effective, they need an adequate background of how the area 'traditionally' looked like in the last hundreds of years. As we will see later, the best and largest material to this work comes from the time immedately before water regulation works started, namely from the 18th century.

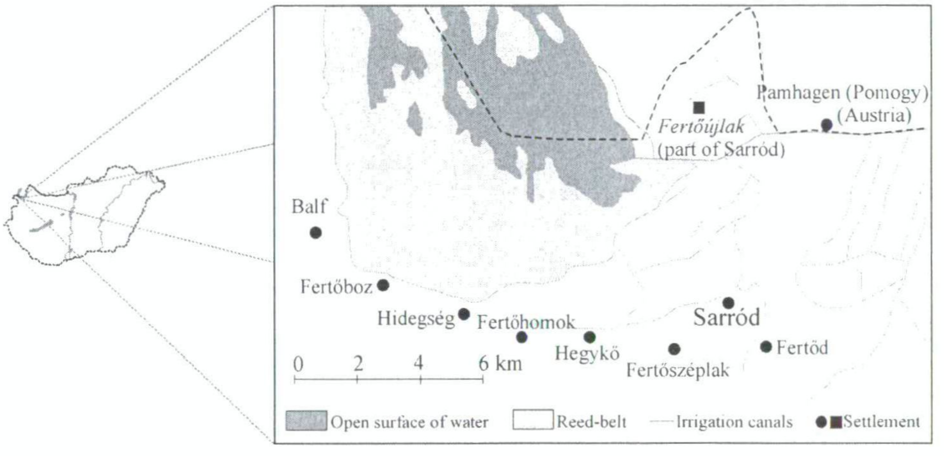


Figure 1. Settlements of the southern Fertő area

Past waterlevels – is there a possibility for any reliable reconstruction?

The past landscape as well as the land use of the secondary basin together with its changes could be influenced and altered by human activity, but also natural environmental changes such as the actual waterlevel of Lake Fertő had primary importance. This waterlevel, nevertheless, varied not only for some days or weeks due to prevailing northern or southern wind directions, but it also had significant seasonal and longer-term changes (KOPF, 1963; BÁRDOSI, 1994; KALMÁR, 1982). From the late 16th, but especially from the 17th century there is more and more information available (descriptions, legal documents, perambulations, etc) to the reconstruction of possible waterlevels of the lake.

As we could already see, from the viewpoint of reconstruction possibilities the most significant period is the 18th century. This is the time when the lake has not yet been regulated but already enough documents (e.g. detailed maps, diaries, scientific descriptions – among the most interesting and detailed ones, see for example KIS, 1797,

1816) can be found to follow the most significant changes. Official documents (for a good example, see the collection in ALB) and then the measurement of the waterlevel became relevant only in the 19th century, but reliable results of systematical observations are available only for the 20th century (KOPF, 1963, 1974; ZORKÓCZY, 1975; KALMÁR, 1982).

At present, only one "official" reconstruction of the Austrian hydrologist, Fritz Kopf (KOPF, 1963) is available on the typical waterlevels and the changes of the last approximately four hundred years (**Fig. 2.**). Although this reconstruction is widely used and accepted in Hungary, there are some questionable points concerning its database; this fact warns us to apply the graph with caution.

Therefore, un connection with the reconstruction of Fritz Kopf, we have to rise attention to some uncertainties: the author did not give any information concerning the source material of his reconstruction, or – if it is not his database – then who made the reconstruction itself. Thus, it is not really possible to decide on the reliability and contemporanity of his sources. Another problem is the fact that in his graph he uses continuous line to present the historical waterlevel changes (see **Fig. 2.**), while on the basis of our present knowledge referring to the source material of the region, it is not really possible to show the whole course (even if decadal) of waterlevel changes in such a detailed way.

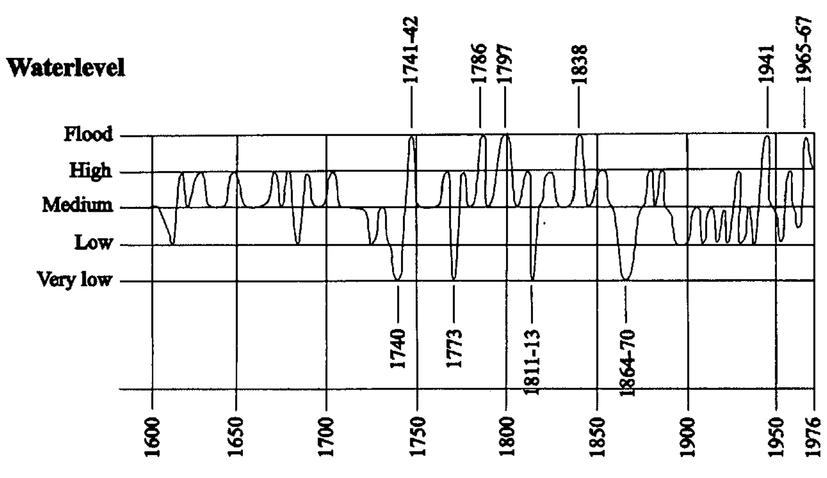


Figure 2. The waterlevel changes of Lake Fertő in the last four hundred years, reconstructed by Fritz Kopf (KOPF, 1963; 20th-century update: ZORKÓCZI, 1975)

As a consequence, he either applied significantly more contemporary original sources than what we know up to now, or he simply connected the known waterlevels, and in this way 'created' a continuous line of reconstruction. While in many cases it was possible to find original contemporary sources to his graph, there are some cases when the connection between the presumable original source is not that clear or it is not yet possible to find the contemporary evidence.

Based on the above-mentioned reasons, I do not apply the graph of Fritz Kopf as a direct source of information concerning past waterlevels of the lake.

Being the only available reconstruction on the waterlevel changes of the lake at the moment, it is still important because in the long run it clearly represents the great variability and frequent changes of the waterlevel as well as the tendencies of these changes in the last four hundred years.

Shoreline changes and the inundation area

Due to the shallowness of the lake (today the average depth is 0.5-0.7 m) and the smothness of the lake basin, little changes in hydrology can cause significant losses of extension. This means in practice that 1 cm change in waterlevel means approximately 3 km^2 change in water surface (PANNONHALMI, 1997). Although conditions were partly different before regulation works, the main characteristics, for example the extreme shallowness and the flatness of lake basin did not change fundamentaly (see, e. g. KOPF, 1967).

The repeated changes of salt content, caused by the waterlevel changes in great dry periods of the lake, can be clearly followed in the sediments (today dry) parts of the lake basin (the secondary lake basin or inundation area of the lake), for example near the village of Sarród (Lászlómajor – see e. g. the analysis of SZABOLCS – ÁBRAHÁM, 1957). After the lake has left the inundation area in the neighbourhood of the village of Sarród the "soil," according to the survey carried out at the turn of the last (19th and 20th) century, was "of medium quality" (SZONTAGH, 1903: map in the appendix).

The inundation area, in case of medium or high waterlevel, could be a wet or even swampy plain, while in case of low waterlevel it was a pasture, meadow for mowing or both, in some places interrupted by bogs, mires or small lakes as well as waterflows (**Fig. 3.**). According to the '*Conscriptio*' of Sarród village in 1727-8, the extension of the "*Pascua*" (pasture) was 3.5 times larger in case of dry conditions compared to the situation in wet periods (CR 1727-8/Sarród). From the 16th century on, the meadows and pastures of the area were used in grazing cattle and horse (for medieval and later evidence, see KISS, 2001; modern evidence: e.g. TÓTH, 1998; ÉLŐ, 1937. etc; see later the 17-18th-century unpublished reambulation material).

While a valuable model of the utilization of the inundation areas along the Tisza river and the lowlands of northeastern Hungary was made by Sándor Frisnyák (concluded in FRISNYÁK, 1995), this – as a compact model – works on the lake inundation area only with certain restrictions. Moreover, differences in forms of utilization and intensity in time can be detected as well. In certain aspects, medieval utilization of actual land pieces at the Lake could be more intensive then in later periods. In order to represent these differences in an easily understandable way, I also counted with the parallels of see-shore areas in Western-Northwestern Europe. Consequently, as the basis of a simplified representation of lake-(secondary)basin utilization, a series of drawings – similar to the ones found in the book of Stephan Rippon referring to the Dutch and British shorelines – were applied here (see RIPPON, 2000).

The aim of application of this simplified 'model' is to provide an example of (secondary) lake basin utilization, which can later be a basis for further representation. This is especially valid and an interesting task for the early period (up to the late 18th century) when no adequate maps are yet available, on the other hand we have some detailed descriptions on the land use of (certain pieces of) the inundation area. Since the inundation area belonging to the village of Sarród is located at the edge of the wetlands of the Hanság and Lake Fertő, the 'model' can be extended to other "hany" (mixed wetland) type of inundation areas of lakes.

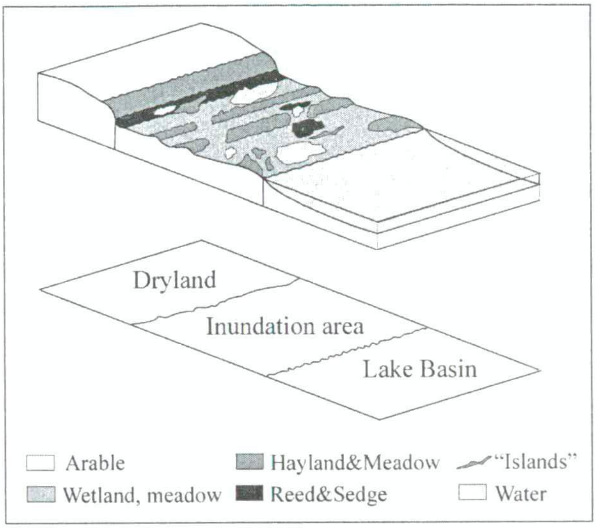


Figure 3. Simplified picture of land use at the southeastern shoreline in the modern times

Utilization of the lake basin before water regulation works

The utilization of waters, fishery and the fishing industry itself can be divided into two larger groups: on one hand the fishery of the Lake and that of the inundation area. Moreover, the utilization of the vegetation (reed, sedge, bulrush) also provided an additional income for the inhabitants. While there is more information available about the fishery of the lake at this particular place, we know relatively little about the actual fishery of the inundation area. Nevertheless, on the basis of close parallels (the almost neighbouring villages of Fertőhomok and Hidegség), we have to count with some similar utilization of not only the lake but also that of the inundation area, already in the Middle Ages (see e. g. 1281: LINDECK-POZZA et al, 1985).

However, taking morphological conditions into account, the sentence of Márta Belényesy – referring to the conditions of the 14th-century Hungarian fishery – can be true also for our research area, namely that "The water remaining in the deeper hollows were excellent places for creating fishponds" (BELÉNYESY, 1953). Although we do not have such a direct information concerning fishponds in the inundation area, a somewhat indirect source is available referring to the fishponds of a local landowner in Fertő, in 1575 (SOÓS, 1937). Another indirect example is when, in the middle of the 16th century, the powerful landlords of the area, the Nádasdy family transported baby fishes from Fertő to their (artificially created) fishponds (e.g. HERMAN, 1887; 1533: SZAMOTA – ZOLNAY, 1906). The actual extention, 'quality' and utilization of the vegetation in the litoral area also primarily depend on the waterlevel: changes of this "reed-sedge" belt can mainly be detected in the 18th-century sources (see e.g. CR, CL references and maps).

In addition, the ford between the villages of Pomogy/Pamhagen and Sarród (also dividing the basins of Lake Fertő and Hanság) had special importance in fishing industry, documented from the 14th century (see e.g. 1365, 1558: NAGY, 1889; LUKÁCS, 1953; BÁRDOSI, 1994; KISS, 2001). From the middle of the 16th century (see the abundant correspondence of the Nádasdy family: KÁROLYI – SZALAY, 1882; MÁLYUSZ, 1929), through the late 16th-17th-century economic sources such as conscriptions and *urbaria* (see MIKÓ, 1992; and the UetC reference material) up to the cartographic evidence of the late 18th-early 19th centuries, the main characteristics of the environment remained the same more or less: depending on dry or wet conditions, one could cross at the ford in water or on foot. The most typical examples of the applied cartographic evidence are the results of 'ford- and shoreline mapping' (e.g. 1782: MOL S12 Div. XVI. No. 8, 10; S 12 Div. XI. 34/2, 5), 'military-mapping' (KF/1-3) as well as 'regulation-mapping' (e.g. MOL S 12 Div. XIII. 295/1) – all connected to medium and high waterlevels of the late 18th century.

Utilization of the inundation area at medium and high waterlevels

Concerning utilization of the inundation area, in case of medium and high waterlevels, most of our information is available only from the (16-18th centuries (See e.g. KÁROLYI – SZALAY, 1882; UetC 12:42/3, 4, 6, 56/33-36; MIKÓ, 1992; MOL, P 623/124; referred CR and CL material). The utilization at that time took place from the direction of the villages located outside of the basin, and thus, this utilization (except for, of course, the almost ever-flourishing fishing industry) was concentrated mainly to the litoral region (and the 'islands') (**Fig. 4.**). Significant changes occurred only with the great drought of the lake basin in 1865-8, followed by the intensive regulation works.

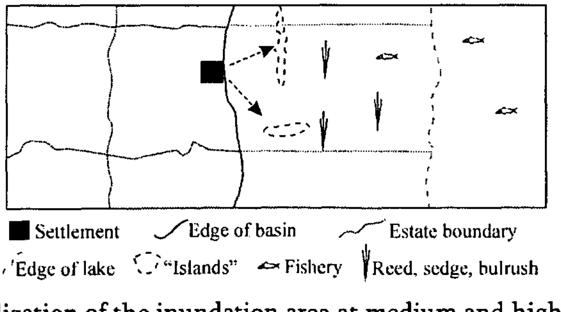


Figure 4. Utilization of the inundation area at medium and high waterlevels

The inundation area – due to the higher waterlevel – is covered partly by shallow but open surface of water, partly by reedy-swampy area and bogs, while some higher parts (the 'islands') still keep acting as places for mowing or grazing animals (mainly oxen). According to the urbarial conscriptions of 1767, the herds of oxen of the village reached the remaining pastures by swimming (TÓTH, 1998).

In case of high and medium waterlevels, fishing also plays a rather important role, while high and very high waterlevels did not support further extension of reed and sedge.

Utilization of the inundation area and the primary lake basin at low waterlevels

The basin utilization in case of low and very low waterlevels, represented in **Fig. 5.**, is less homogenious compared to the previous cases. Here the main source of information is the extensive legal material of perambulation and reambulation documents (descriptions and questionaires on waterlevel changes, current utilization and exact location of boundaries, environmental conditions) and cartographic evidence (early maps and sketches), dated from the late 17th century up to the mid-19th century (e.g. MOL UetC 12:42/3, 4, 6; CL, CR reference material). Interestingly enough, this situation is depicted on very few of the early local, high-quality maps, produced by professional map-makers; due to the contemporary high waterlevel conditions at that time, most of the late 18th-century maps provided information for medium and high waterlevels. Only a little amount, and predominantly lower-quality maps or sketches (of both earlier and later periods) are available, mainly in the legal material (reambulation procedure: MOL P 623/124, P 108/111-2, Processus appellati 5/5211, etc). More information appears only with the already good-quality mid-19th-century catasther material for the reconstruction of low waterlevel environments (for the late 17th-early 19th-century period, MOL P 623/124, P 108/111-2; cadaster conscriptions: 1855-6: MOL S 79. Sarród, Süttör, etc).

Even if the majority of sources provide an overview on the prevailing conditions of the 17-18th centuries, in some cases medieval examples can be cited as well. According to this set of early evidence, the meadows '*in Ferteu*' were utilized and had a high value already in the (13-)14th century (KISS, 2001): thus, here the importance of grazing has to be emphasised. The area was utilized as pasture, meadow for mowing, whereas also acted as an important set of row materials (partly or entirely free of taxation!) such as reed (e. g. for covering house, heating and the young sprouds for feeding the animals while drought), bulrush and sedge (KISS, 2001; TÓTH, 1998; making equipments of everyday use – sometimes also for market purposes: CL, CR evidence, for later evidence, see ÉLŐ, 1937). Utilization took place continuously from the dryland settlements nearby (**Fig. 5/A**): in our case from the village of Sarród and the domain of Sárvár and Kapuvár, later of Süttör (Süttör is today part of Fertőd village).

Many of the 18th-century legal cases took place because of the controversies on the (former) "zone" of common pastures or commonly used areas belonging to the village(s) of our sample region (the most famous cases were between Sarród, Süttör, Pomogy/Pamhagen and Széplak; see e.g. MOL P623/124; P108/111-2; Processus appellati 5/5211), predominantly in the inundation area. Here in case of long-lasting dry periods such as the one in the first half of the 18th century, parts of the inundation area in the village boundary zones were clearly used by the herds of other villages, too (**Fig. 5/B**), which fact caused the above-mentioned controversies on clarification of the exact boundary line.

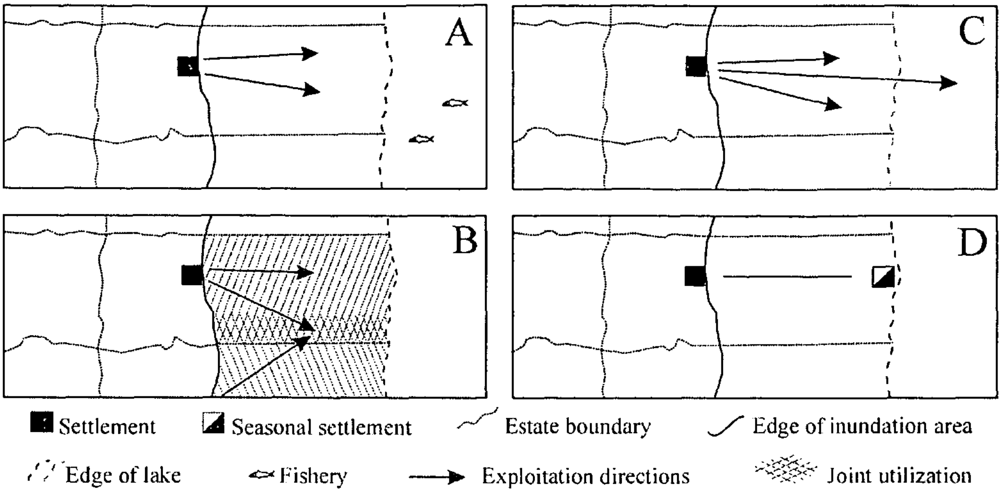
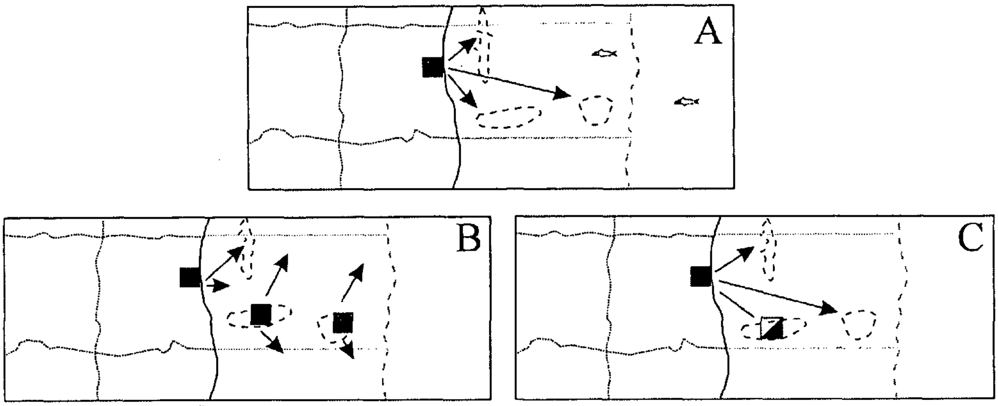


Figure 5. Main types of utilization in lake basins at low waterlevels

Still, no matter how low the actual waterlevel was, some parts of the inundation area – due to the existence of waterflows as well as small ponds and bogs – remained wet predominantly in the first half of the 18th century. In case of very low waterlevels of the lake, nevertheless, not only the inundation area but also part of the primary lake basin dried up and, therefore, became available for direct utilization (**Fig. 5/C**). In **Fig. 5/D** a probably quite usual, though before regulation works rarely mentioned case is represented: on the higher terrains - where later, after regulation works most of the manors were located - temporal settlements appeared in summer (thus, oxen could be kept and gathered without taking them back to the dryland – see KF/3; cadaster maps and conscriptions: MOL S 78, 79 Sarród, etc). After water regulation works, these temporal settlements rose as new economic centres in the newly created drylands, first in the form of manors; later these manors became, however, real permanent settlements in the former inundation area (e.g. Nyárosmajor, Mexikó/Fertőújlak).

Utilization of the 'islands'

Due to their importance in utilization, special attention should be taken to the 'islands' (ÉLŐ, 1937; MIHÁLY, 1971). In spite of the fact that in the whole neighbourhood there is only one such island (called Jakabsziget, today belonging to the neighbouring village of Süttör) which is frequently and exclusively mentioned in sources as a separate island throughout the early modern and modern period, on the basis of cartographic and some indirect written (urbarial conscriptions of 1767) as well as archaeological evidence we can certainly presume that many other 'real' islands and the so-called islands took significant role in the utilization of the inundation areas. The island-peninsula appearance depended on the waterlevel: they looked like real islands and/or peninsulas mainly in case of medium and high waterlevels (**Fig. 6/A**).



■ Settlement ◪ Seasonal settlement Estate boundary Edge of inundation area

Edge of lake ⟶ Directions of possible exploitation Fishery

Figure 6. Utilization of the 'islands'

In reality, at least in the 19th century, under the name of an 'island' we have to count with at least two types of formations: one is the group of 'real' islands, entirely surrounded by water in case of medium and high waterlevels, while the other, so-called islands were probably rather peninsulas, lands with some direct connections to the mainland, but still looking as islands from the direction of the mainland (ÉLŐ, 1937). Nevertheless, these 'islands' could loose their typical features in case of waters lower than medium level. Based on charter- and archaeological evidence (e.g. MNMRA XVIII. 272; MIHÁLY, 1971 – archaeological survey of the islands; KISS – PASZTERNÁK, 2000 – complex survey of Urkony-Jakabsziget) we can say that the utilization of islands and probably their surroundings was the most intensive in the 13-15th centuries when (permanently inhabited) settlements were located there (**Fig. 6/B**). Some of these settlements later (from the 15th - early 16th centuries) became the place of temporal settlings (**Fig. 6/B**), while most of their territories then belonged to the neighbouring villages such as Süttör (today Fertőd) (Urkony-Jakabsziget; Feketebokor, etc) (**Fig. 6/C**). In the modern times, utilization was mainly characterised by meadows for mowing and pasture or in some cases arable lands as well (**Fig. 6/A**). For this latter case, we can cite examples based on written documents only from the 18th century (e. g. mainly in the Hanság basin), but especially from the mid- and late 19th century. Whereas in some cases still temporal settling places remained on the islands in the modern times (e.g. Jakabsziget), in many other cases no trace of later settlings (e. g. the islands east to the ford) were found (e. g. Feketebokor). After the great drought of 1865-8, followed by the regulation works, these 'islands' were the first places where new manors appeared (e. g. Mexikópuszta-Fertőújlak, Lászlómajor, Nyárosmajor), but some of them remained uninhabited, and later perished due to decades of deep-ploughing (e. g. Jakabsziget).

Abbreviations

ALB – Allgemeine Landestopographie des Burgenlandes
MOL – Magyar Országos Levéltár/Hungarian National Archives
SLt – Soproni Levéltár/Sopron Archives
MNMRA – Magyar Nemzeti Múzeum Régészeti Adattára/Archaeological Database of the Hungarian National Museum
UetC – Urbaria és Conscriptiones
CR – Conscriptiones Regnicolaris
CL – Conscriptiones Localis
KF – Katonai Felmérés/Military Survey

Maps

First Military Survey (KF1): Col. V. Sec. 11. (1782) – M 1:28800; Second Military Survey (KF2): Col. XXIII. Sec. 49. (1845) – M 1:28800; Third Military Survey (KF3): 4957/2, 4958/1. (1880) – M 1:25000.

MOL, Map Collection:

S 12. Div. XI. No. 34/2, 5 (turn of 18-19th c.?): Fertő lacus mappa originalis qua pars mappa Arabonis generalis originalis. Ms; pedel; mpa; cb; 300x98 cm; o: NW.

S 12 Div. XVI. No. 8. (1782?): Olay, Franciscus jur. Geom. (Exam. Hegedüss, Joannes com. geom.): In Wiesselburger Comitat hat der neu errichtete Damm mit Inbegrief der Brücken 1838 ... M 1:25920.

S 12 Div. XVI. No. 10. (1782): Laab, Casparus com. jur. geom.: Mappa demonstrans situm paludum et localitatum aggeris Pomogyiensis in quantum terreno .... Comitatus hujus Mossoniensis ingremiatus furet, versus Eszterház ducentis .... M 1:19200.; 52,5x84 cm; o: N.

S 12 Div. XIII. No. 295:1. (Joannes Nep. Hegedüs com. Ord. Geom., Georgius Király ord. geom., Casparus Láb com. ord. geom.): Mappa Geometria exhibens Lacum Ferto(e) Palude Hansagh, et Districtum Tóko(e)zeiensem, una cum Projecto de demissione Lacus et exsiccatione Paludum exhibito MDCCLXXXI. (1781) 65x43,5 cm; M 1:108000.

S 78 Cadaster maps of the village of Sarród and Süttör (1856-7) – M 1:2880.

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SOME EXAMPLES OF BENCH EROSION FROM THE GREAT HUNGARIAN PLAIN

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The technical improvements of the past few decades opened up new possibilities for researchers engaged in the investigation of modern geomorphological processes. Methods like the application of various remote sensing and high resolution field mapping techniques, as well as those of absolute dating and modern material science can elucidate information on environmental changes, which previously had been regarded as unattainable. Improvements in computer science and technology opened up new gates for geoinformatics. The increasing accuracy of measurements on the other hand enabled the identification of even short-term changes and events as well. It was mainly this latter factor that gave an impetus for our work in initiating an investigation on the characteristics of the process of a special lowland bench erosion from the second half of the 1990s. With the help of the recorded data embedding 7 years, marked changes can be clearly identified.

Benches introduce some sort of versatility into the relatively uniform landscape of the Great Hungarian Plain. These geomorphological features are generally restricted to areas, which were frequently flooded before the water regulations. But they appear in connection to various landscape management measures as well (road and channel constructions). The characteristic, 10-30 cm high microforms are mostly restricted to alkaline areas. However, as our research results indicate, although alkaline soils may largely contribute to their development, they are not an exclusive prerequisite of bench formation and erosion.

In Hungarian practice the area of the Great Hungarian Plain was generally considered to be not prone to erosion hazards up to quite recently. Areas of this region are not depicted on any maps displaying erosion hazards (e.g. The National Atlas of Hungary, 1989), and not even present in statistical evaluations of the environment (KSH 1986: Environmental conditions and protection measures). Bench surfaces formerly received less scientific attention. However, a detailed investigation of these areas may open up new, more adequate evaluation possibilities in determining the degree of lowland erosion. Frankly, the degree of soil erosion in the Great Hungarian Plain is far more below the value experienced in hilly areas (BARTA, 2001). However, its potentials must not be underestimated. This unique type of erosion, complemented by a gradually increasing aridity, may cause significant transformations in the soil and the environment.

The definition and geomorphological characteristics of lowland benches

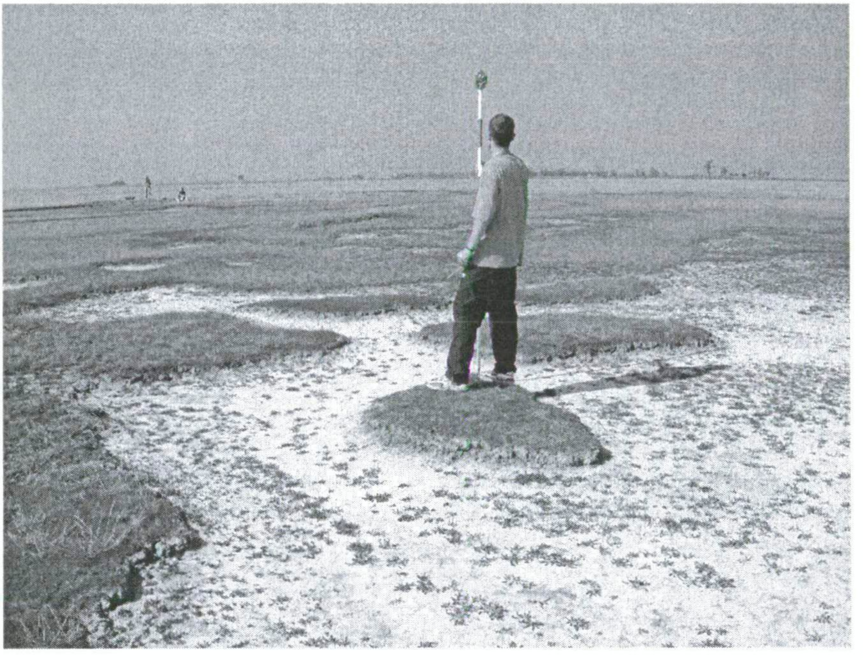
Despite the extensive nature of areas effected by lowland bench erosion in the Great Hungarian Plain being almost a general feature of the *pusztas* of the national parks of this area and mentioned in certain works dealing with the process of alkalinization as well, up to 1970 only a single study dealt with the detailed description of this unique geomorphological feature (STRÖMPL, 1931). Here, the very first attempts to interpret the development of this micromorphological complex have been made, along with the possible roles of water (dissolution, scouring) in their formation.

In our work, it was during the middle part of the 1970s through the course of preliminary investigations preceding the protection of the *puszta* of Szabadkígyós (Körös-Maros National Park) that we actually realized the problems deriving from the lack of adequate studies and descriptions of this unique feature. Our morphological and pedological investigations made it rather apparent (DÖVÉNYI et al, 1977) that the formerly established terminology is out of date and requires revision. Furthermore, an acceptable explanation for the development of these microforms could also have been advocated. Frankly, during this early stage the process of bench formation was linked to the alkaline soils, thus the original terminology used formerly was partly preserved in our future works.

The starting main form of bench erosion is the *alkaline bench*, which is a continuously changing feature complex. Thus their components can hardly be interpreted on their own. This bench is composed of various sub-features such as the *bench top*, corresponding to the original surface, the *eroded alkaline flat*, from which the topsoil has been removed, and finally the continuously migrating *bench margin*, as a result of the progressive erosion (**Pic. 1.**). Very often this margin appears as a linear feature. At other times it composes several meter long transition surfaces.

Picture 1. Destruction of bench margin by retrogressive erosion (near Tótkomlós)

During the process of bench erosion the original surface becomes dissected yielding island- and peninsula-like microforms of large variety (**Pic. 2.**). During the whole process the dissoluble salts either infiltrate into the ground or precipitate on the surface. The resulting rock fragments end up either in the fractures, which form during the arid summers and termed as *alkaline veins* (**Pic. 3.**) or are transported away from the surface by the winds.



Picture 2. Isolated bench islands (near Tótkomlós)

The process of bench destruction

The process of bench erosion must be divided into two stages for practical reasons. The first stage involves the actual development of the benches, while the second one is the destruction of these bench surfaces.

The majority of resources in the literature univocally mention the development of differences in the relief as a prerequisite of bench formation and bench erosion in lowland areas. Sometimes this can be even in the cm range. However, there might be several reasons for the emergence of differences in the topography. One of the most commonly appearing cases is when a natural dip in the surface is attributable to the presence of infilled ancient riverbeds and adjacent natural levees in a formerly fluvial landscape. But human activities creating different relief conditions (channels, ditches running along the roads, cart tracks) are almost just as important. However, bench formation may initiate even in totally flat and smooth surfaces as well as a result of soil shrinkage attributable to arid conditions and the formation of extensive cracks in the ground.

Picture 3. Alkaline veins (near Tótkomlós)

The further developmental path of these bench areas is primarily influenced by the relief conditions and the soil structure. But the degree and type of vegetation cover might also be influential.

The solonetz alkaline areas with a well-deformed soil structure tend to give the typical sites for bench erosion yielding benches of the size of 10-30 cm via the erosional removal of the topsoil. Based on his research implemented of what is the most well-known *pusztas* of Hungary, the Hortobágy. TÓTH (2003) managed to classify the erosion types into the following groups: areal, linear, retrogressive and anthropogenic erosion. His findings are more or less congruent with our results. However, according to our findings for extensive areas several other important types are also observable. Conversely, the separate treatment of the anthropogenic type is strictly refused by us for several reasons. On the one hand, the majority of bench erosion is initially connected to some sort of human intervention, the exact type of which can not be fully determined due to the elapsed time. On the other hand, erosion triggered by human influences can be classified into the other groups as well. Like for example along the channels we can observe mainly retrogressive erosion causing bench destruction, while in the case of cart tracks the process is rather linear. If we take these factors into consideration as well then 4 major types of bench erosion could be identified in the area of the Great Hungarian Plain.

a) *Retrogressive erosion.* According to our field observations, this type tends to be the most commonly occurring with continuous soil erosion along an irregular line at the margin of the bench usually lacking surficial vegetation (see **Pic. 1.** and **2.**). During the process the soil is almost dissected into its basic components and transported away that way from the site. In case of the solonetz areas, the basic type of retrogressive erosion results in the complete loss of the A horizon, exposing the underlying saline layers, which host only salt tolerant vegetation.

If the erosion process decelerates for some reason, the marginal areas of the bench can be widened to such a degree, when changes are observable in the alteration of the vegetation types alone, related to the resulting differential dissolved salt content of the underlying soils (RAKONCZAI, 1986).

b) *Break-away erosion.* This more spectacular and easily divisible type of bench erosion can develop in areas with large relative differences in the relief. This type of erosion could have been observed in Miklapuszta, a former floodplain of the ancient Danube now belonging to the territory of the Kiskunság National Park (RAKONCZAI–KOVÁCS, 2000.). The 60-100 cm thick benches can break off in blocks of several ms (sometimes even 10 m) together with the surficial vegetation as a result of scouring by waters, which accumulated in the low-lying areas (**Pic. 4**).

Picture 4. Broken-off bench margin (Kiskunság National Park, Mikla-puszta)

In this case the soil aggregates of several dm^3 fall apart into their basic grain components only at a later stage. The differential chemical properties of the removed soil blocks also result in initially a transformation then in most cases the complete perishment of the surficial vegetation (**Pic. 5.**).

Picture 5. Lowered surface of broken-off bench remains with vegetation under transformation

c) *Linear erosion.* This erosion type is mostly constrained to the block dissection of the bench surfaces. Very often we can also come across signs of the processes (cart tracks, animal paths) which initiated this type of erosion (**Pic. 6.**). As a result of this process the greater benches are transformed into island- or peninsula-like forms, their gradually increasing marginal areas progressively accelerating the erosion process as well. Sometimes alkaline veins, promoting a fast movement of surficial waters may also develop in these longitudinal forms.

Picture 6. Linear erosion launched by vehicles (Kiskunság National Park, Mikla-puszta)

d) *Areal erosion.* In several cases the erosion of the benches and the removal of the constituting rocks happened not from the direction of the bench margins, but rather from the top downwards as a result of slow material transportation. The presence of grasses in the margin as well as the generally loose structure of the soil covering the benches must have an important role in this process, even though this role is still partly enigmatic to us. As a result of this erosion process the surface of the original bench gradually becomes morphologically uniform with the adjacent lower-lying areas of the salt flats, though to a certain degree these two forms can be easily told apart via careful observation of the surficial vegetation. We have managed to record such transformation of 20-30 cm thick and 10-15 m wide benches in the *puszta* of Szabadkígyós (**Pic. 7.**), which embedded about 25 years.

Picture 7. Former benches lowered by areal erosion (Körös-Maros National Park, Szabadkígyós)

The methods applied for recording erosion

Measuring and quantifying modern geomorphological transformations is a very complex problem. One of the major problems comes from the possibilities for generalizing short-term transformations, observed during the field measurements. Another major problem derives from the accuracy of the measurements, since in these short-term cases we are dealing with small values. Thus for our work a complex array of various methods have been collectively utilized considering the characteristics of the pilot areas, the available past data and the reliability of the measuring instruments. In places, where thanks to the special characteristics of the topography maps from former military surveys were also available, there was a chance of temporally extending the scope of our investigations.

On the whole it must be stated that our investigations on the process of bench erosion were based on different annual data sources, containing data collected with different methods and resolutions. Although the final conclusions were drawn from the analysis of long-term data, the findings on the degree of transformations should by all means be treated with necessary caution and must be improved by further continuous field measurements to consider them fully reliable in the future.

Traditional field measurements started as early as the 1970s in one of the alkaline areas of the Tiszántúl, the *puszta* of Szabadkígyós (SZÖŐR-RAKONCZAI-DÖVÉNYI, 1978).

These were then extended to other areas, bearing different characteristics (the vicinity of Tótkomlós, Miklapuszta) and complemented by the use of more advanced methods and instruments for both data recording (GPS, geodesic stations) and data processing (GIS) from the 1990s onwards (KOVÁCS, 1999; RAKONCZAI-KOVÁCS, 2000).

Another possibility for a comprehensive evaluation of the degree of bench erosion might be the transformation of the data recorded in different times and in different mapping systems into a uniform system. This approach was best suited for the analysis of the erosion of benches with a relatively large size, something what we have encountered in the pilot area of Miklapuszta. As a first step here data maps with a scale of 1:25.000 deriving from the 3rd Military Survey of 1883, as well as that from 1981 with a scale of 1:10.000 was looked at in details. Then in order to capture the modern transformations field measurements were taken using a GPS from 1997, and then a complex geodesic data recording device from 2003. The 1972 panochromatic Corona satellite photos with a geometric resolution of 2.5 m, as well as the 1994 black and white aerial photos on the area with a resolution of 2m, plus the color aerial photos of 2000 with a geometric resolution of 65 cm were also used in our work.

In order to capture the erosion of the low-lying benches field measurements were implemented. In case of the most important sites a direct comparison of the measured values of the recorded sites using the devices of a monitoring station or a GPS enables the attainment of a resolution at a cm scale. Lines prepared via connecting such data points may give the most reliable results on the transformations of the spatial extent of benches. Field measurements happened with the use of a GPS in the first stage of the work (TOPCON Turbo-S II., Trimble Basic+) via the application of a relative spot and go method, requiring a measuring time of 4-5 min before moving onto the next point. Consequently, only the most characteristic sites have been measured at this stage. Field measurements carried out in 2003 were relying on a much more accurate instrument of SOKKIA Set310 geodesic station. The accuracy of angle measurement with this device was 3", while that of the distance measurements was +/- 2 mm + 2ppm /2700 m. The presence of quartic triangular points assigned to the higher areas in the vicinity of our pilot area has offered ideal stand points for our measurements easing our work to a large degree. This latter method offers not only significantly better resolution and reliability, but requires less time for data recording as well, only a couple of seconds. Thanks to this data collection could have taken place in shorter intervals on the field yielding lines representing better the natural conditions in our GIS analysis.

The recorded degree of bench erosion in different type of pilot areas

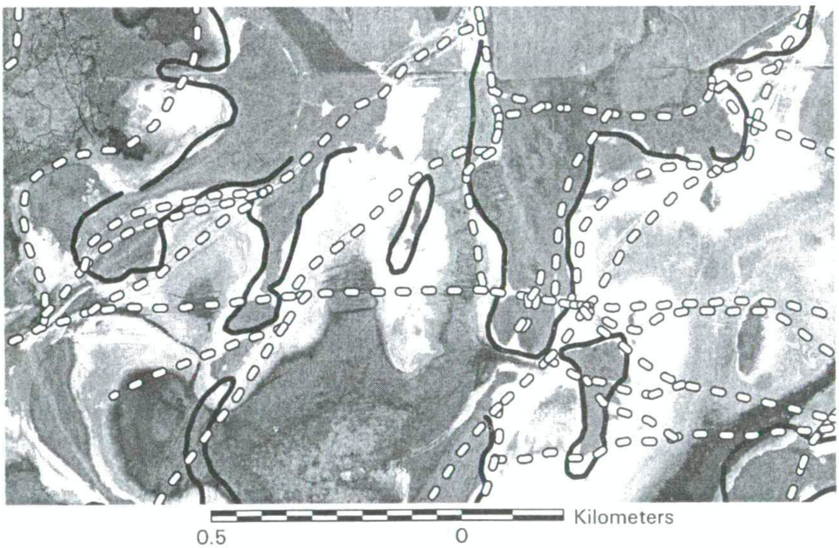
Erosion of large benches with a chernozem soil (Miklapuszta)

The solonchak alkaline pilot area located in the northern part of Miklapuszta forms one of the most spectacular alkaline bench areas in Europe with " giant" benches of a height sometimes exceeding even 1 m. Although the location of the alkaline benches was not congruent on the map of the 3rd military survey transformed into the uniform national projection system (EOV) with their modern position, with the help of their unique shape and the surrounding environment they could have been easily fitted into our new system.

During the comparative analysis spanning a period of approximately 100 years, the borderline of the benches was determined in case of the map of 1981 with data complemented from the 2000 aerial photo of the area as well.

The calculated average annual rate of retrogression was extremely high: 10-15 cm! The degree of erosion for the individual benches compared to the data on the map of the 3rd military survey was 40% at an average. So while about 100 years ago approximately 21% of the 340 ha pilot areas was covered by benches, today this ratio is only 12%. This data seems to refer an annual rate of erosion of 1520 m^3 calculated for a realistic bench height of 50 cm.

Another characteristic feature in the pilot area was the dissection of the bench ridges by roads and flock paths leading to the formation of new isolated bench islands. At the given resolution there was a one-third increase in the number of these separate bench islands in the area during the past 100 years, with several extensive benches are lacking in the modern maps (**Fig. 1.**).



thick line: margins of alkaline benches (3rd Military Survey Map)
broken line: roads, paths and channels (map 1981, aerial photo 2000)

Figure 1. The effects of landscape utilization in bench erosion
(background: aerial photo 2000.)

The first step of higher resolution evaluations was the investigations of data and changes for the last 30 years with the help of the Corona satellite photos (**Fig. 2.**). The secondary polynomic transformation of the photo with the help of a topographic map had an RMS error of 0.5. The calculated loss of bench islands of 4% /decade using the topographic maps was only 2%/ decade using the satellite photo. Nevertheless the annual rate of retrogression was 8 cm, which is congruent with the values calculated in the long-term analysis.

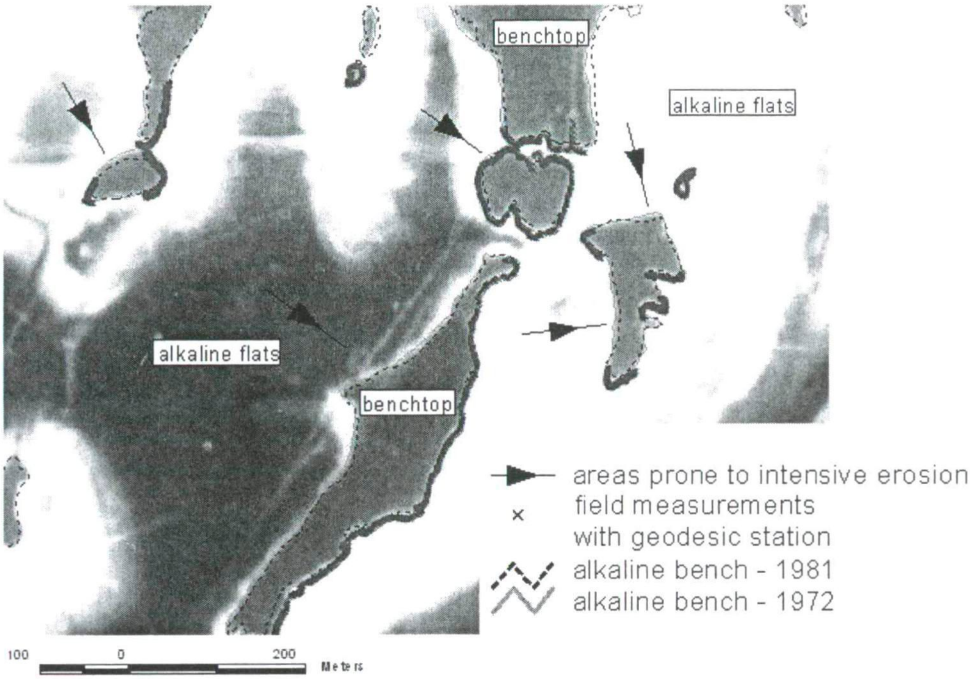


Figure 2. Interpreted bench margins and the comparative analysis of the results of 2003 field topographic survey (background: Corona satellite photo)

The bench erosion of solonetz alkaline areas (Tótkomlós)

10-20 cm high benches emerged as a result of the complete removal of the topsoil (A horizon) in the alkaline steppes SW of Tótkomlós. Here the construction of drainage channels and the ditches running along the roads must be unambiguously blamed for the initiation of the erosion process. Field surveys were carried out in this pilot area from the summer of 1997. In the initial phase the position of the borderline of some characteristic benches were recorded using a GPS like in the former case followed by the implementation of comparative field surveys using a geodesic measurement station from 2003.

According to our findings, here the retrogressive type was the prevalent form of erosion with an approximately 0-15 cm degree per 6 years. Unfortunately, the density of data points recorded during the GPS measurements did not meet the requirements of a high resolution analysis, thus the final results drawn from these data can be regarded as preliminary and informative only. There can be assumed some sort of an aerial erosion as well in several island-like microforms. However, as no elevation values were recorded during the initial survey, as the GPS is unable to trace and record small-scale differences, the relative lowering of these surfaces can be justified only by the photos alone.

The aerial erosion of solonetz alkaline areas (Szabadkígyós)

Detailed topographic mapping using a theodolite and accessory network was carried out in the alkaline *puszta* between Szabadkígyós and Kétegyháza in 1977, preceding the protection of the microforms (**Fig. 3.**). During this time the microforms were bounded by sharp bench margins of 20-30 cm. The vegetation cover of the bench tops and alkaline flats were also clearly different. When we returned to the area during the summer of 2003, we have come across a completely altered landscape. The alkaline flat covered by halophyte plants formerly now had a uniform grass cover, the extensive benches completely disappeared, and the margins of them were hardly discernible.

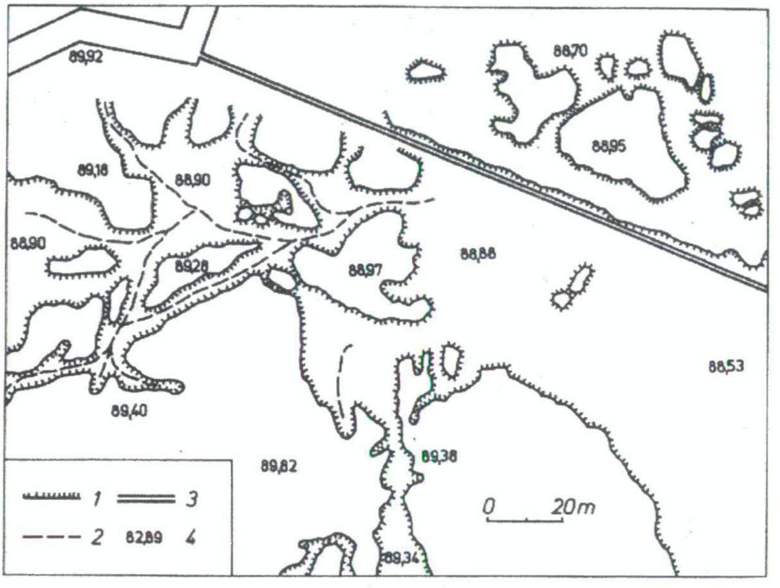


Figure 3. Micro-relief of the "*puszta*" at Szabadkígyós in 1978 (Szöőr-Rakonczai-Dövényi, 1978)

Legend: 1: boundary between natron bench and natron plain, 2: natron stream, 3: canal, 4: elevation above sea level (m)

There were two important environmental changes, which affected the area during the past 25 years. As a side effect of the gradual increase in aridity and drop in the groundwater level the alkaline soils and the vegetation was largely transformed, just like the original bench microforms. The most spectacular changes from a morphological point of view was observable on several benches, which could have been clearly mapped and identified in 1977.

The former morphologies were reflected only in their different vegetation cover without any discernible deviations in the topography. In the place of these former benches we have come across saline spots (Limonium Gmelini) or even fresh meadows (see **Pic. 7.**).

All this seems to pint to the transformation of the formerly retrogressive type of erosion into an aerial type. Since in case of a retrogressive erosion the size of the resulting soil patches would be smaller than the original size of the bench. However, due to the lack comprehensive, continuous field surveys in the pilot area the possible links between the increasing aridity and the transformation in the type of the erosion could only be assumed and not clearly justified.

The consequences of the erosion process

In the light of our findings it can be clearly seen that the process of bench erosion is a relatively rapid landscape transformation factor, restricted mostly to lowland areas utilized as pasturelands or meadows. Since the rate of erosion is in the cm scale, the effects of the process are rather considerable even within the span of a couple of decades. There are two important consequences of the process cited. On the one hand it causes significant soil erosion. On the other hand it also brings about a destruction of the protected microforms even in a natural, preserved setting without leaving any possibilities for actual preservation even among the highest measures. Transformations in the groundwater levels related to climate change, and the concomitant soil and vegetation changes may also play a role in the transformation of the erosional forms.

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THE ANALYSIS OF CONTAMINATION DERIVING FROM THE LEAKAGE OF SUBSURFACE PIPELINE NETWORKS USING REMOTE SENSING

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Abstract

Patches of melted snow on the surface can serve for the easy detection of underground oil or thermal water pipeline networks. This thermal effect can be recognized during the spring as well when vegetation tends to grow more rapidly over the pipeline than in its surroundings. Old pipelines may be fractured or leaking due to different physical and chemical processes and the soil and underground water can become contaminated by natural oil, gasoline and other waste materials. The aim of the research group (Department of Physical Geography and Geoinformatics, University of Szeged, Hungary; A.A. Stádium Ltd. and ERMI-2000 Ltd.) was to develop a methodology for discovering pipeline leakage at a very early stage based on aerial thermal and video images. The GPS coordinates were added to the images and these data were processed in a GIS platform (self-developed ESRI ArcMap extension). An FLIR SC 2000 thermal camera was used; the spatial resolution of the captured images was 30 cm. The video images were less useful than the thermal images in pipeline detection during the spring and the summer when land use changes due to vegetation transformation, and during the winter when a thick snow covers the ground. Due to the spatial and thermal resolution, small spots of leakage on the surface could be recognized on the thermal images. Spatial coordinates of the leakage quickly identified its location and this was a great benefit in allowing for rapid environmental rehabilitation. We hope that the developed methods can be used to monitor the pipeline network on the largest oil field in southern Hungary on a daily basis (or for flood risk assessment or forest fire localization).

Introduction

The fracture or leakage of pipelines very often leads to critical situations, just think about the some last years' rupture of main large-diameter water pipelines in Budapest. The illegal tapping of transportation pipelines via drilling may lead to not only significant contamination at the site but this wanton behavior often claims lives as well. Several hundreds or even thousands of kilometers of subsurface pipeline networks are present in the neighborhood of producing oil and gas fields. The continuous track line monitoring of old pipes is highly desirable, especially in case of the subsurface pipelines established several decades ago, due to the more and more frequent natural ruptures and leakages. The aim of our research was to develop a new remote sensing method, based on the already available technologies, which enables the discovery and localization of leakages at an early stage on the field, well before the appearance of the first signs on the surface. Furthermore, it makes the identification of the type of leakage possible as well. With the help of various measurements carried out on the field, we tried to verify that heat emission from these subsurface pipes causes measurable temperature variations on the surface, making the use of aerial remote sensing devices feasible for the detection of such lines.

Our goal was to assign geographical coordinates to the captured aerial video and thermal images enabling the processing of the acquired data within a GIS platform.

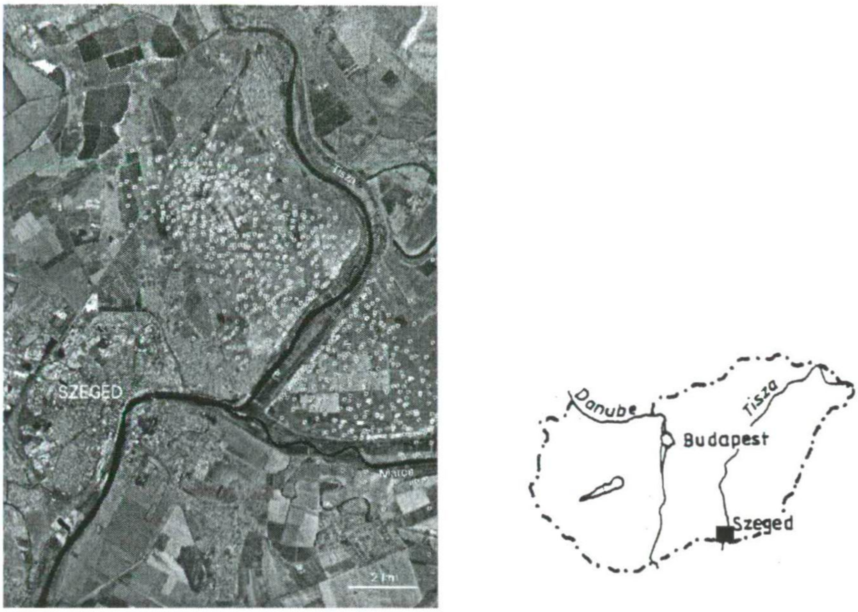

Figure 1. The geographical location of the investigated area and vector coverage of the sites of oil, gas and thermal water wells on a Landsat TM 453 (RGB) satellite image

The resulting self-developed environment-monitoring and decision support system was tested for various surfaces, vegetation types regarding usability and efficiency. The implementation of this idea was greatly assisted by the support from a successful project of the Department of Physical Geography and Geoinformatics, University of Szeged handed in for the IKTA-3 KÉPI-2000 tender of the R+D Secretariat at the Ministry of Education in 2000 under the title "The development of a thermal image recording and processing system (TEKER)". Two local enterprises also took part in the tender, namely A.A. Stádium Ltd. and ERMI-2000 Ltd. The producing gas and oil fields of the MOL Hungarian Oil and Gas Plc., located north of Szeged were selected as pilot area in our study; the necessary papers and documents were obtained from the owner for the execution of the flights and research.

Methods

More than 1000 producing wells and a system of approximately 1700 km-long subsurface pipelines can be found in the producing field of Algyő.

Petroleum prospecting and exploitation beginning in the 1960's has significantly altered the former agricultural landscape. The walls of the different pipes (oil, gas, thermal water pipelines) are subjected to intensive thinning via corrosion with the pass of time. This degradation may finally lead to rupture or leakage caused by physical, chemical or possibly anthropogenic impact and the seepage of the transported material into the soil or groundwater in the pipe's surroundings.

However because of the buried past riverbeds, and the interconnections among the present hydrological systems and River Tisza the material seeping from the pipelines may damage larger areas, possibly living waters as well.

The produced oil, gas and thermal water is transported to the collectors from the wells and then to the main collector in pipes. Following several observation flights carried out in February and May 2000 (MUCSI, 2001a; MUCSI, 2001b; MUCSI–VARGA-FERENCZY, 2001c) it became quite obvious that these pipelines significantly influence the temperature of their direct neighborhood, the outcome of which is observable even with the naked eye. The heat surplus deriving from the pipes enables the rapid growth of vegetation during early spring, however it also leads to desiccation of the soils and vegetation during early summer as well (see **Fig. 2-3.**).

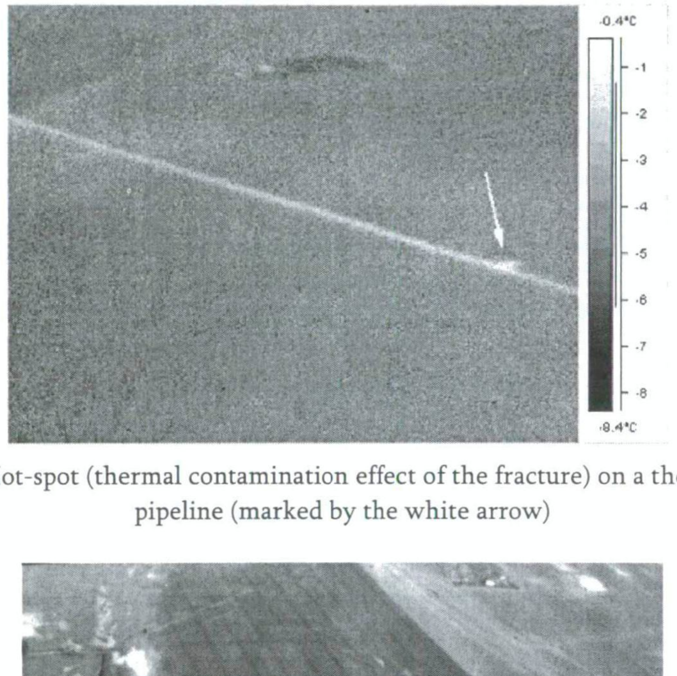

Figure 2. Hot-spot (thermal contamination effect of the fracture) on a thermal water pipeline (marked by the white arrow)

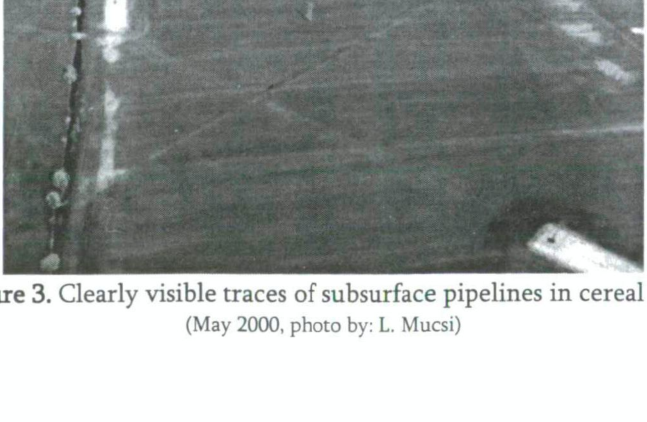

Figure 3. Clearly visible traces of subsurface pipelines in cereal ploughfields
(May 2000, photo by: L. Mucsi)

Figure 4. Patches of melted snow clearly indicate the path of subsurface pipes as photographed on the 26th of November 2000 (by: M. Dzsupin)

The thin layer of snow covering the ground during winter very often melts above the pipelines as it can be seen on the photograph taken in 2000 (**Fig. 4**).

There are several possibilities for monitoring pipeline networks based on domestic and international experiences. A controlling-measuring system (DiTEST) (e. g. fiber-optic cables) can be installed below the pipelines during piping. Continuous monitoring of pressure within the pipes (FLEXIM), acoustic monitoring (SHIFENG, 2000), or feeding radioactive materials into the pipes followed by the measurement of γ radiation (DEVELOPMENT…) may all serve as possible tools for discovering small leakages. The hydrocarbon content present in the air in the soil can also be traced with a suitable device like the German KAMINA (KAMINA), which is, after programming, capable to identify various hydrocarbons (digital nose). Several approaches are known in aerial monitoring as well ranging from the evaluation of simple color aerial photographs (GEOPLACE), to the application of thermal cameras, 3D seismic measurements (FUGRO), or even aerial flame spectroscopic devices analyzing HC compounds (AET).

Aerial pipeline monitoring is carried out on a daily basis in our pilot area, however the success is greatly dependent on the experience and expertise of the monitoring staff. Digital cameras and video cameras are used for documentation. No other devices or systems support the recognition of leakage.

Ruptures and the accompanying leakages are very often recognized too late in this producing field, covering about 150 km^2, and in such cases the expenses of rehabilitation and decontamination may reach several 10 million forints.

Pressure monitoring used besides aerial monitoring of pipes cannot successfully identify minor pressure losses caused by smaller leakages.

Furthermore, even when the pressure loss is identified the precise location of the rupture can not be determined. Based on the governing physical laws and our personal experiences, utilization of thermal cameras of appropriate sensitivity and resolution, and the processing of acquired thermal images in a GIS platform may enable the recognition of such accidents even in their initial stage. This early recognition could greatly reduce damages to the environment as well as the cost of rehabilitation efforts.

Results

A, Soil temperature measurements on the field to determine the spatial distribution of excess heat

Up till now it was unknown exactly to what extent do the subsurface pipelines influence the surrounding temperatures. Thus as a first step, it was analyzed whether or not any temperature difference can be traced in the neighborhood of active pipelines. A soil temperature recording system was designed which enables continuous data recording and digital data storage. The requirements of the system consisting of 16 soil thermometers had been conceptualized, and Astrum 2000 Ltd. was asked for the technical implementation and the development of downloading and conversion software.

A short description of the system:

a, 16 soil thermometers with a 5 m wire link to the data recording unit	**b**, 0.1-0.2 °C accuracy, data recorded with two decimal places	**c**, data recorded every 10 minutes
d, storage capacity is 6-8 weeks	**e**, data read with „Szonda" software via RS-232 port	**f**, power supply of 220 V, with a 2 weeks UPS backup.

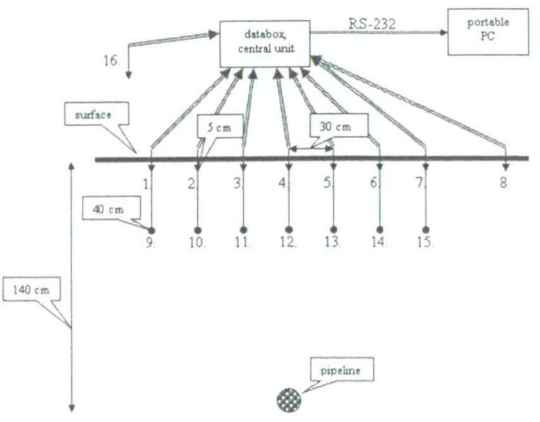

Figure 5. A schematic of the location for soil thermometers – 16-channel soil temperature recording system after installation

The system was installed to the SZT-5 collector station of the pilot area. The thermometers were placed above the pipeline at a distance of 30 cm, 7 of them at a depth of 40 cm, and 7 at a depth of 5 cm in the ground. A single thermometer was placed 5 cm deep into the ground at a distance of 1.7 m away from the pipe, and the last one was settled 2 m above the surface to capture air temperatures (**Fig. 5.**). The installation took place on 30/10/2001.

Data series recorded between 30/10/2001 and 09/01/2002 are depicted on **Fig. 6.** After evaluation the following conclusions can be drawn:

a, there is a decrease in soil temperatures during the winter months, temperatures are well above zero with a well-observable daily cycle

b, the highest temperatures were recorded by the thermometer located directly above the pipeline in all cases

c, the marginal thermometers recorded successively lower values their distances from the pipe increased

d, there was an average difference of 2° C between the central (12.) and marginal (15.) thermometers (located at a distance of 90 cm)

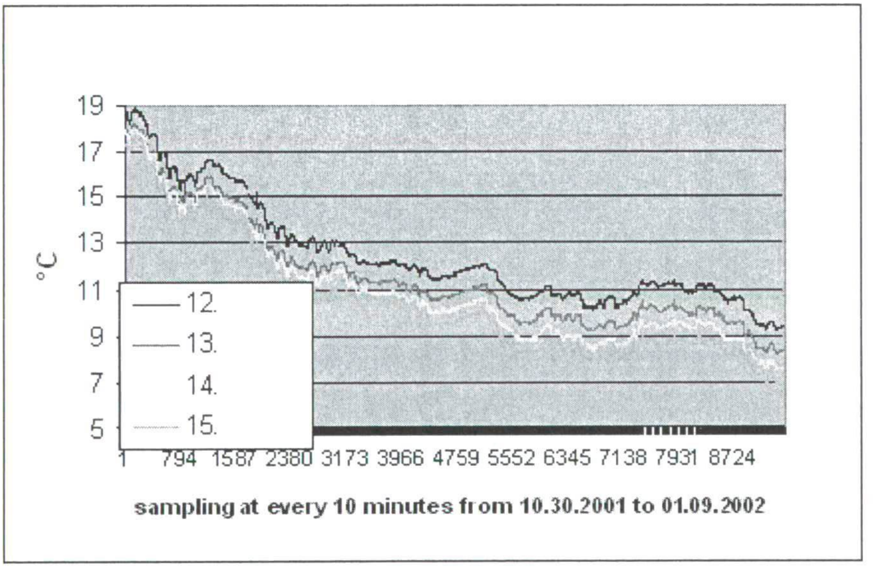

Figure 6. Soil temperatures at a depth of 40 cm on the right hand side of the pipeline

B, Determining the geometric resolution of the thermal camera

The sensitivity of the thermal camera used was rather high (0.1 °C, see **Table 1.**), thus temperature differences reaching larger values than this in the zone above the pipe can be identified at sufficient geometric resolution. However, the distances, inside which further temperature differences can be observed on the right or left side of the pipeline, were also unknown before soil temperature measurement.

The extent of this zone of varying temperatures, a specific field of view (FOV) (α = 24°) and the FPA panel size (320*240 pixel) determine the flight height required for the achievement of sufficient geometric resolution during the flights. If the camera is fixed in a way that the shorter side of the thermal image is parallel to the direction of flight then the resolution of the acquired image can be calculated from the parameters of flight height (h), FOV (α) and the number of FPA rows (240) with the following equation:

Resolution (r) = (2 * h * tg α/2)/240

if h = 240 m (about 800 feet), α = 24° then r = 31 cm.

With such resolution the whole image covers an area of 115x81 m. Considering flight speed of 150 km/h (41.6 m/s), and images being recorded every second, then the outcome is images overlapping with a ratio of 50%. If the camera is perpendicular to the original state then this overlap between the successive images is even larger, 63 %.

Table.1. Technical data for the thermal camera FLIR SC2000

Type:	FLIR SC 2000
Accuracy:	± 2 % of the whole range or 2 °C
Thermal sensitivity:	< 0,15 °C
Angle of view:	24°×18°
Focus:	0,5 m - ∞
Detector type:	Focal Plane Array (FPA), non-cooling microbolometer 320×240 pixel
Spectral range:	7,5 – 13 μm
PC card:	PCMCIA II. or III. FLASH, or ATA compatible Hard Disk
Image storage:	14 bit full dynamic

C, The integration of image data into a self-developed GIS extension

In addition to the thermal camera a digital video camera has also been used. The primary aim was to determine the efficiency of the thermal camera in comparison to video images recorded in visible light. However the larger FOV together with the higher spatial resolution of video images enabled better localization of the leakage.

The acquired images for the same areas deriving from different sources in different formats (video - AVI, thermal camera from IMG to JPG) were synchronized on the ground and registered with GPS data recorded cinematically on the plane with a Topcon Turbo-SII GPS and were processed at a later stage.

The recorded images, GPS data and the orthophoto maps prepared earlier (Aerial photography of Hungary project, 2000) were stored and processed in a GIS platform capable of processing and viewing motion picture as well image is displayed (**Fig. 7.**), while the lower left window contains the thermal images recorded every second with the central coordinates and the time of image capture indicated. This self-developed program is an extension of the ESRI ArcGIS platform, thus its use requires the installation of the ArcView 8 software package.

One of the greatest advantages of using this GIS framework is the availability of all its viewing and processing functions within the extension, granting a wide spectrum of viewing and analyzing possibilities to the researcher.

The system is made up of three individual units displayed in three windows enabling individual positioning on the screen according to the analyzer's will.

One possible arrangement of these windows is seen on **Fig. 7.**. In this case the map of the area is placed in the larger window on the right. In this window, along with the other coverages placed over the original ortho-photograph, a continuously moving symbol indicates the location of the plane or the captured image.

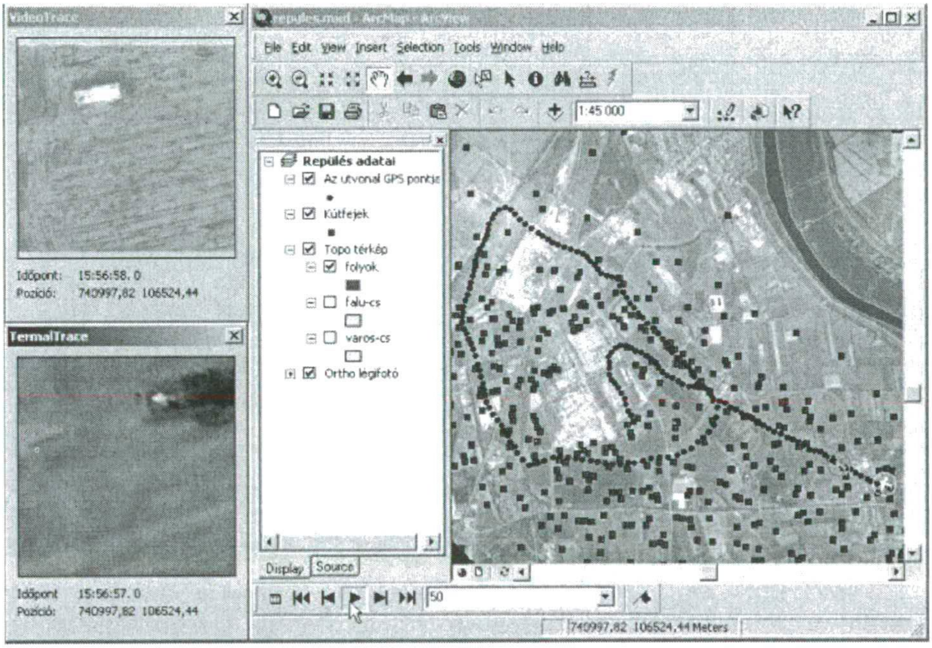

Figure 7. Application view of ArcMap for viewing and analysis of image and spatial data

The menu on the upper side of the window along with the tool buttons are used for the initiation of various geoinformatical commands like zooming-in and out, picture flip and rotation, query of, modification, load and save of attribute data, etc. In the upper left window the video

D, The filtering of thermal images with a self-developed program

The visual evaluation of thermal images is as easy as one, two, three for the professional eye, however the processing software coming with the camera (ThermaCAM Researcher 2000™) makes the evaluation of the images feasible on an individual base as well. In case of our device the acquired images needed to be filtered before processing, because relatively small temperature differences appeared as a veil-like noise on the images, which was quite disturbing during further analysis (**Fig. 8.**).

E, Comparative analysis of video and thermal images

According to our observations made during the flights, the traces of pipelines can be easily followed on the thermal images even in areas with dense vegetation.

Temperature differences were around 2 °C in the zone of 3-4 m above the pipelines during the time of analysis. Maximum temperatures were recorded above the lines as seen on the temperature profiles with a gradual decrease towards the sides.

Changes in soil structure can be observed on barren surfaces, but the traces are a lot sharper on the thermal images. If the trackline is complex or more pipelines are running next to each other, the application of thermal imagery is even more successful (see **Fig. 9.**).

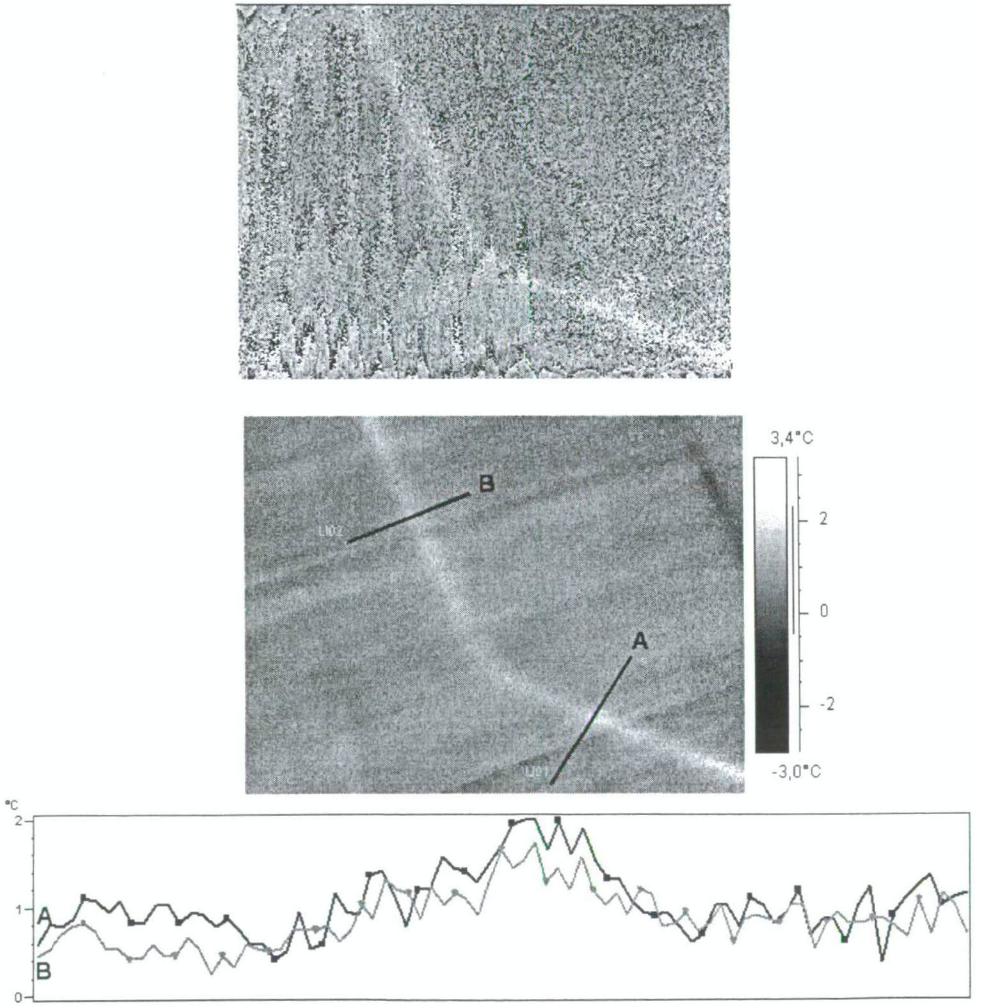

Figure 8. Original and filtered images of a hot thermal pipeline with two observed temperature profiles

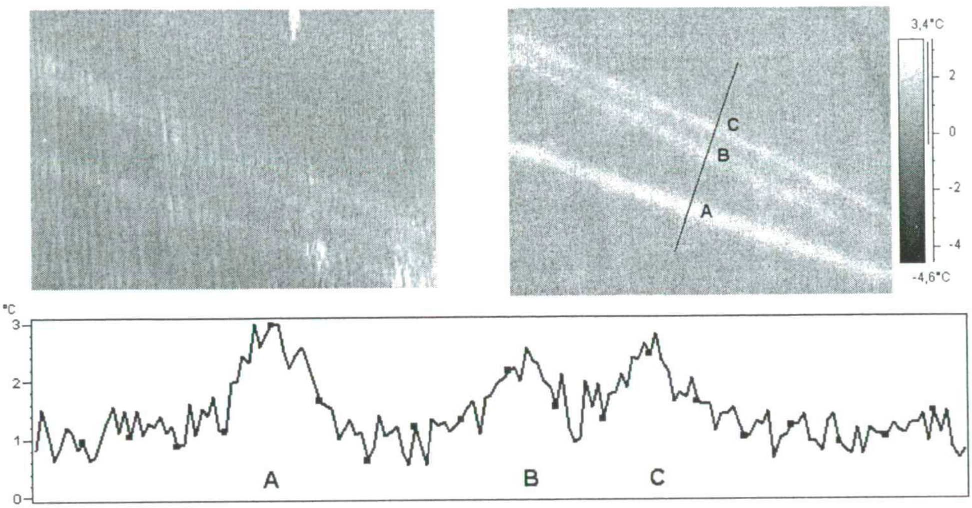

Figure 9. The trackline of three pipelines on video and thermal images and the observed temperature profile

Thirty flights have been carried out as part of the project yielding the discovery of some leakages. In the following few examples for the leakage of cold- (**Fig. 10.**), and hot (**Fig.11.**) pipes can be observed.

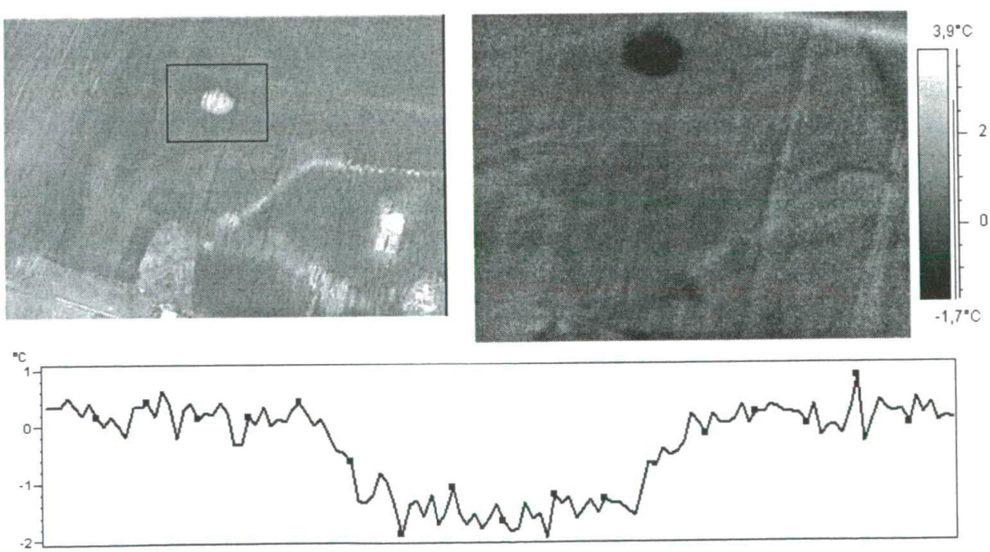

Figure 10. The spot of a leakage in cold (gas) pipe on a video and a thermal image with an observed temperature profile

The spot of leakage in case of the hot pipe (oil) is almost undetectable on the video image but it is clearly observable on the thermal image (**Fig. 11.**).

The diameter of the light patch, in the circle on **Fig. 11.**, is about 1,5 m. As it can be seen on the temperature profile there is a steep increase in surface temperatures towards the center of the leakage with a 5 °C higher value in the center of the spot than in the surroundings of the pipe (the normal difference was around 2 °C).

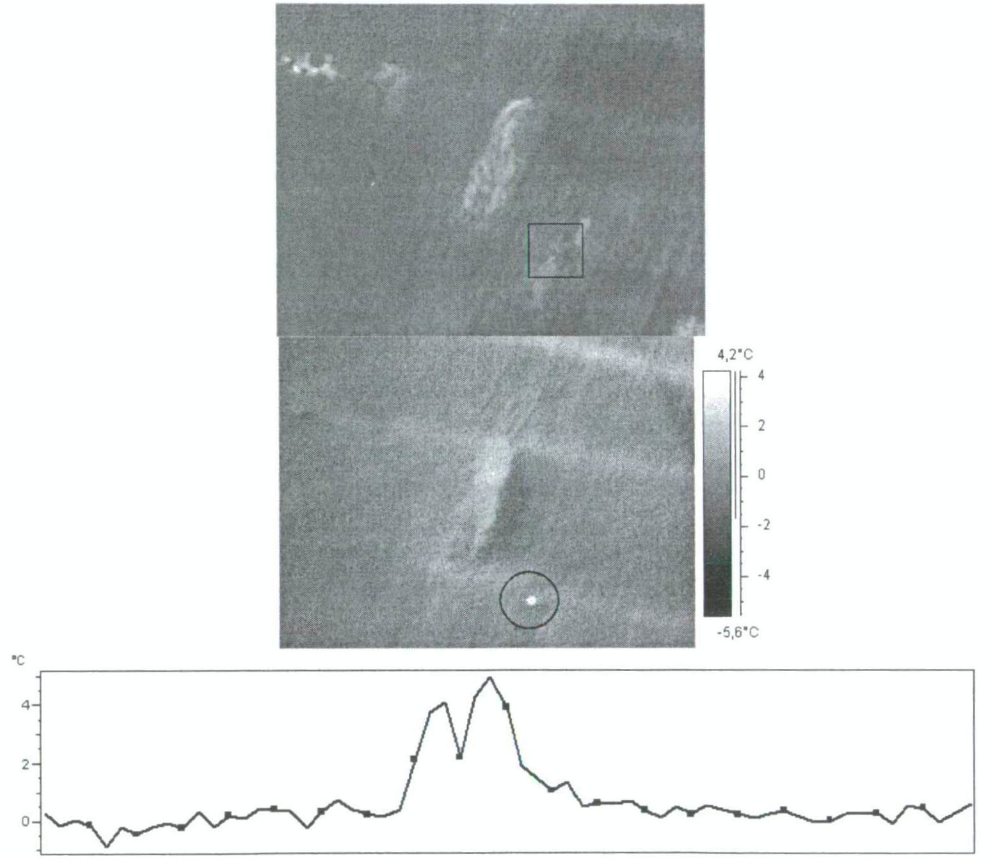

Figure 11. The spot of a leakage in hot pipe on a video and a thermal image with an observed temperature profile

F, Further processing of thermal images

The thermal images can be processed further by the application of various filters and image analysis procedures making the spots of leakages more accentuated in the images, more contrastive compared to their neighborhood as it can be seen on the 3D image of **Fig. 12.** or the filtered images of **Fig. 13**, (the image on Fig. 11. was further filtered with a Sobel filter).

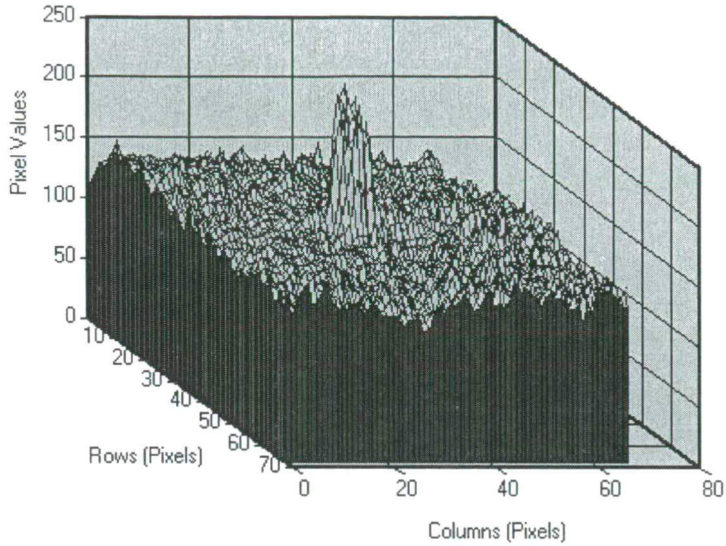

Figure 12. 3D view of the thermal image of the leakage depicted on Fig. 11

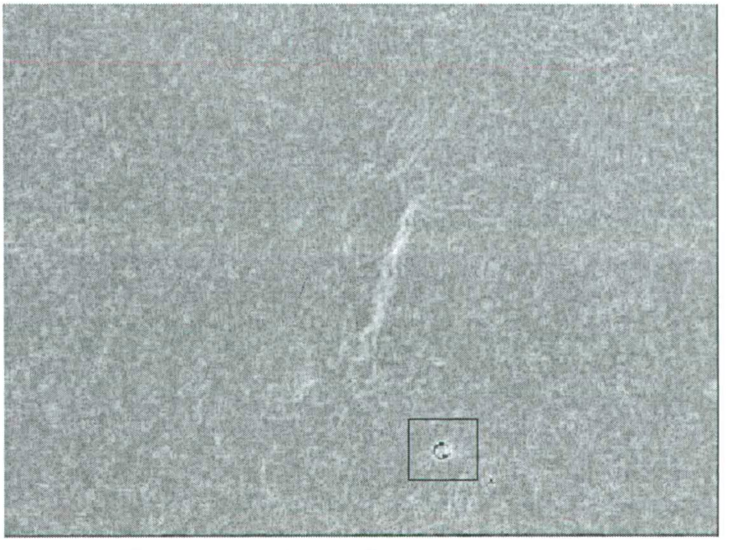

Figure 13. The image on Fig. 11. further filtered with a Sobel filter (darker spot marking the site of leakage)

Summary

According to our findings, the active subsurface pipelines significantly alter the temperature of their surroundings, especially during the winter season. The field analysis of the extents of the affected zone enabled the calculation of parameters necessary for the successful aerial imaging of these pipeline networks (flight height, geometric resolution).

The image data recorded on the plane was integrated into a self-developed GIS platform based on the captured GPS coordinates enabling further visual processing and evaluation of the data for the more accurate localization of the sites of leakage. The analysis of thermal images enabled not only the determination of the exact site of leakage but also its type (hot or cold pipes) along with the possible spatial extent of the contaminant plume.

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THE GENERAL CHARACTERISTICS OF EXCESS SURFACE WATERS IN THE LOWER TISZA REGION, HUNGARY

KOZÁK, Péter

Abstract

Excess surface waters termed as inland waters are uniquely Hungarian phenomena. Their spatial distribution is characterized with the help of numeric and topographic data. The latest survey and comprehensive analysis of the distribution of these inland waters was concerned with observations up to 1980. Several excess surface waters have developed in the study area, which may serve as standards since the implementation of the survey. The aim of the present study on the one hand was to analyze the data of this extended study period. Furthermore, we were to test whether the so-called congregation or accumulation theory is applicable for the sizing of a planned drainage system. Our final results contributed to a more accurate understanding of the development of inland waters as well as a better evaluation.

The aim of the study

Excess surface waters termed as inland waters are uniquely Hungarian phenomena, with serious impact on the productivity of agriculture in its temporary developmental timing. No wonder their developmental mechanism, spatial distribution as well as questions of a proper definition have received much attention in Hungary since the beginning of the 1940s. The latest comprehensive spatial evaluation, embracing the period up to 1980, is from the hands of PÁLFAI (1994). He was also the one, who managed to come up with a complex overview surrounding the rather controversial definitions of the phenomenon (PÁLFAI, 2001).

The observed inland waters at the end of the 1990s and in 2000 called for an extension of the original study period regarding the frequency of inland water development. The present study involves the compilation of the results for the whole spectrum of data available for the Lower Tisza Region.

The process of inland water development

Struggle against water hazards in lowland areas generally involves uniquely special lowland measures, the so-called protection against inland waters. This activity is of crucial importance, as about 60% of the cultivated areas in Hungary are prone to temporary flooding by inland waters, affecting approximately more than 4 million hectars.

The major task of these protection measures is to prevent hazards resulting from unwanted water surplus on the lands. As natural ditches and other natural drainage channels, enabling the drainage of surface and seepage waters are generally lacking in lowland areas, surplus waters unable to infiltrate into the ground usually either accumulate in one place on the surface, or are collected in minor depressions lacking drainage.

In the 19th century, via the river regulation works, rivers were forced between artificial dikes enabling a control of the floodwaters and a gradual cessation or reduction of floods from that time onwards. However, with the cessation of one type of water hazard another one turned up: inland waters.

This term was collectively applied to waters, which accumulated on the protected flood free plains lacking free drainage because of the flood protection dikes. The problem was somewhat eased by first the construction of flood gates in the dikes, and later on that of pumping stations from 1878.

This way the inland waters could have been driven into the rivers, even in times of high waters in the riverbed constrained between the dikes, during the floods. However, due to the natural endowments of the lowlands and the special topographic setting (low relief, many closed drainage areas.), and the lack of a comprehensive artificial drainage system the efforts of driving these inland waters away from the affected areas into the rivers could not keep up with the pace of their development resulting in extensive flooded areas experiencing shorter-longer inland water coverage.

Unfortunately, not only the protected low-lying floodplain areas were affected by these inland waters, but the adjacent higher areas as well. Thus waters affecting these elevated areas are also referred to as inland waters. When these inland waters managed to filtrate into the lower-lying areas, they have significantly increased the floodwater coverage.

Regarding their hazardous effects, to put it short, inland waters are practically flood waters affecting lowland areas and resulting from a high watertable perching the surface of the ground. Similarly to the floodwaters of rivers, inland waters also derive from rainfall (melting snow or rain).

However, excess waters unable to infiltrate into the ground are not drained on the spot but accumulate in the minor depressions of this low relief area, and by being stored there for shorter or longer periods causes inland water inundations.

Excess surface waters can also develop as a result of a high watertable perching the ground surface in areas where the hydrology and geomorphology allows. Nevertheless, the source of these waters in this case is also rainfall.

If we consider this latter developmental mode of the excess surface waters as well, we can give the following definition of the phenomenon: *excess surface waters are surficial waters either temporary inundating lowland areas in lack of any natural mode of drainage or develop as a result of a high watertable perching the surface of the ground.*

Studies dealing with the occurrences of excess surfaces waters were usually put forth and advocated after major inundation events. The most recent survey on the whole area of the Great Hungarian Plains was implemented during the first half of the 1980s following the major inundations of the second half of the 1970s (PÁLFAI,. 1984).

However, the more recent considerable inundation events by these excess surface waters called for the complementation and reevaluation of these former data and results.

The data sources used in the study

Due to the extensive nature of hazards attributed to excess surface waters, the monitoring and recording process of the spatial distribution of these inundation events was implemented by several different monitoring organizations yielding data of different resolution and quality, thanks to differences in the methods applied during data collections and evaluations.

The units of water conservancy in Hungary have been continuously collecting hydrological data regarding the actual conditions of the watershed areas and those on the development of excess surface waters. While the units of agricultural administration (Regional County Agricultural Offices, Water Conservacy Units) were collecting data only in areas under their direct authority. Local governments were also dealing with cases in their areas. CD organizations recorded information on excess surface waters only in case of actual crisis. Data collected by these authorities were used primarily for developing operative defense plans and taking accurate measures. However, research institutes were more interested in using these data for elucidating the backgrounds of the development of excess surface waters along with the more accurate determination of the extension of affected areas, which might be helpful in future protection measures (e.g. BAUKÓ et al., 1981).

This slight difference must be the result of the deviations observable in the methods applied for data collection in operative defense work using surficial field data, and those applied in scientific work relying more and more on remote sensing data for an earlier event (RAKONCZAI et al., 2001). Unfortunately, these latter works are generally concerned with relatively recent data, hampering the availability of long-term data series. Furthermore, use of data from other resources is rather limited in these investigations.

Relatively uniform and continuous data for a longer time period (say more than 50 years) on these excess surface waters is available from the water conservancy authorities exclusively including such details as the proportion of runoff from these waters, the size and spatial distribution of inundated areas and other important hydrological parameters like temperature, rainfall, ground frosts etc. Consequently, all the information in this database was used as a major starting point in our investigations.

In water conservancy practice the initial evaluation of the excess water hazard events determines the possible effects of these excess waters accumulated in an area on the local hydrological measures. The following situations are generally considered to be excess water hazard events:

- In times when high water levels in the natural outlet streams of the watershed area (rivers, creeks etc) prevent the natural gravitational transportation of the excess waters into them (in these cases stable or mobile pumps located next to the influx serve to pump these waters into the outlet), *or*
- Excess surface waters inundate larger areas.

Besides the quantitative numeric parameters of these excess surface waters, the approximate spatial extension of the inundations is also continuously monitored and recorded just like any changes by the local experts of the water conservancy authorities.

Surface monitoring and data collection generally involves field measurements and predictions as well as the systematic use of cadastre maps, during the course of which data on the approximate distribution of these excess surface waters and the inundated areas are applied to maps of 1:10000 and 1:25000 in relation to clearly identifiable objects.

After the cessation of the hazard event, the locally collected map data regarding maximum extension of inundations is applied onto a collective comprehensive map.

The resolution of the maps is in accordance with the expected resolutions required by the given protection measures. For the times preceding the 1950s, maps depicting the spatial distribution of inundated areas by excess surface waters are generally lacking with only recorded numeric information available.

The available maps depict the most significant inundation events in the country with the exception of the years 1941-42, which otherwise were the mostly affected periods in modern history. From the second half of the 1950s maps depicting maximum inundation are readily available in the hydrological archives. So these were primarily used in our investigations.

Methods applied

As a first step the available maps were converted into a raster digital format via scanning and the contours of the inundated areas were digitized. After the necessary topographic transformations, the resulting vector data was depicted in a cumulative map of unified national projection system (EOV).

From the resulting maps and database containing information on annual inundations the frequency of excess surface water inundation events was determined with the help of geoinformatical tools and methods for the areas monitored by the Lower Tisza Region Water Conservancy Authority (ATIVIZIG) (**Fig.1.**).

The resolution of the digital database was fundamentally determined by the original scales of the paper maps being between 1:50000–1:100000. The layer embedding vector information on the hydrography of the area was applied onto the received working map.

A major problem we had to face derived from the fact, that in several cases a single map contained multiple information on a single inundation event, but with different contours of the borderline of inundated areas in certain cases..

The resolution of the prepared final map hampered the possibility of drawing local, high resolution conclusions at the scale of plots. However, these maps are generally adequate for strategic planning in hazard protection measures.

Consequently, our evaluations were restricted to the files with events of the period for the past 50 years (1957-1959, 1962-1963, 1965, 1967-1982, 1986-1987, 1991, 1993, 1999-2001).

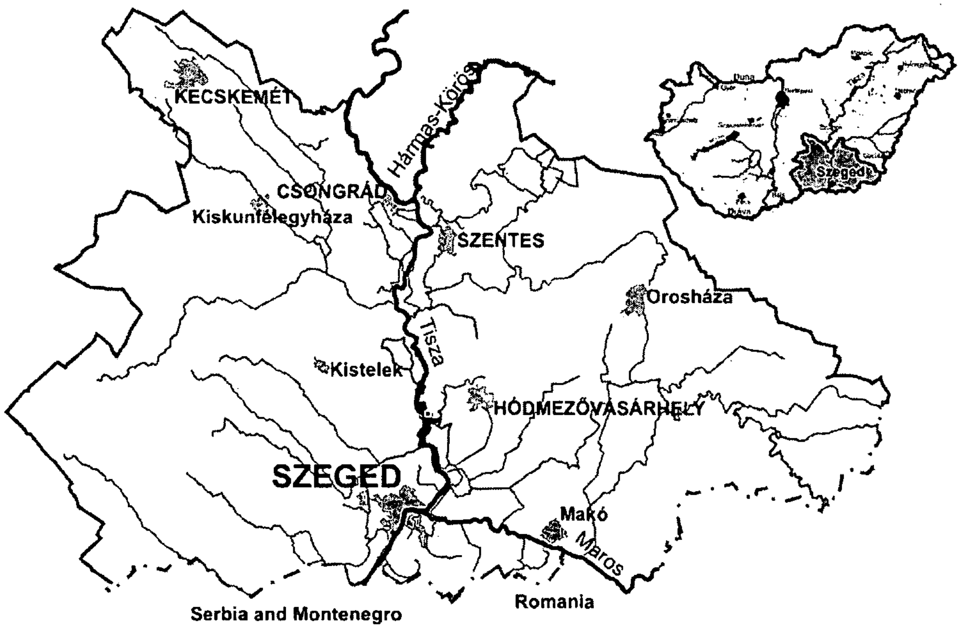

Figure 1. The areas monitored by the Lower Tisza Region Water Conservation Authority (ATIKÖVIZIG)

Results

According to our findings the area of the Lower Tisza Region can be subdivided into three, well-distinguished subregions, characterized by differing excess surface water parameters (areas on the right banks of the river Tisza, those on the left banks including the[1] alluvial fan of the river Maros, and the Torontál). This subdivision is not congruent with the actual spatial extension of the mentioned landscape areas in all cases, but seems to be adequate from the point of view of our investigation results.

In case of the areas located on the right banks of the Tisza excess surface waters generally accumulate and are being stored *in natural depressions.* In this area runoff coming from the direction of the Danube-Tisza Interfluve ridge is collected in the valleys hosting the outlet streams and generally inundate the areas adjacent these outlets. The most frequently inundated areas are those at Gátér-Fehér Pond, Sós Pond plus their vicinities, as well as the drainage channel network Percsora. It is important to note, however the areas of Gátér-Fehér Pond, Sós Pond were included in the drainage network as potential storage areas.

Thus channels usually drive runoff from the upper parts of the watershed into these reservoirs until the development of favorable hydrological conditions. Possibilities preventing the drainage of these waters are generally low here.

[1] Collection of excess surface water data is restricted to separate watershed areas. In order to get a comprehensive view, these pieces of information are sometimes unified involving data deriving from several adjacent watersheds, and the term inland water landscape unit is applied.

The process of water accumulation is well-suited for analysis thanks to the favorable topography of the studied area. The frequency and value for the development of excess surface waters in areas located larger distances from the drainage channels is uniform and low. Thus the collection of these waters can be explained by the traditional accumulation theory as far as the rim of the channels (**Fig. 2.**). However, the areas running along the channels are much more frequently inundated than their more distant counterparts, which can not be fully explained by the traditional accumulation theory alone.

Rather the so-called "line up theory" should be applied onto these cases (VÁGÁS, 1989). According to this, the drainage capacity and directions is determined by not the quantities of the accumulated excess waters, but the storage and carrying capacity as well as general hydrological conditions of the outlet. When too much water arrives at the outlet, the volumetric difference will be stored in the vicinity of the influx points starting out from the first point upstream along the drainage channel.

This clearly explains the greater frequency of inundations along the drainage channels, and is especially true to the mouth areas of streams.

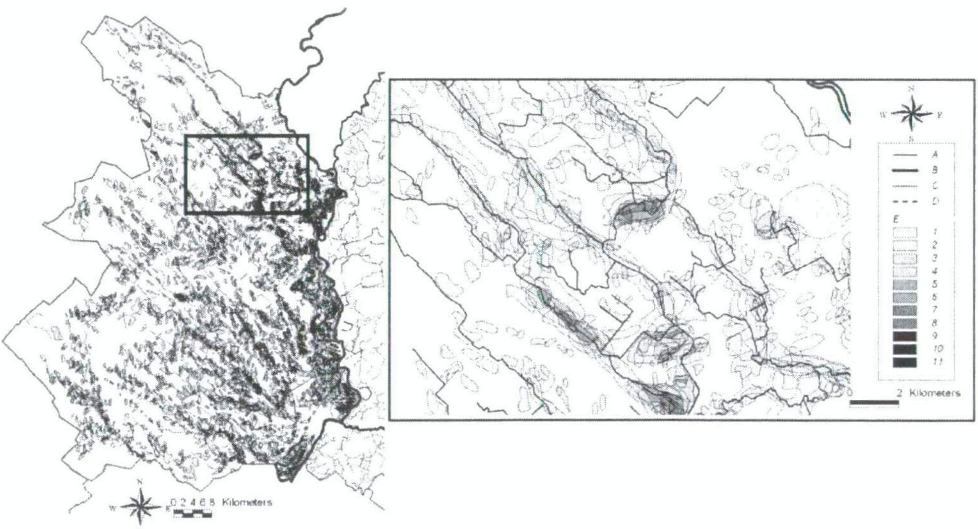

Figure 2. The frequency of inundations by excess surface waters in the monitored region on the right banks of the river Tisza

Legend: **A** – channel network; **B** – rivers; **C** – boundaries of administration units; **D** – operational area boundary of ATIKÖVIZIG; **E** – categories of frequency of excess surface water

Another characteristic feature of this area is the increase in the relative frequency of inundations in the areas adjacent to the river Tisza parallely with its course. The first adequate explanation of this phenomenon can be found in the work of SALAMIN (1942): the high waters during floods are of crucial importance in the formation of inland waters along the rivers, as these waters may infiltrate through or below the dikes into the adjacent protected areas causing inundations.

By applying the "line-up theory" this explanation of SALAMIN (1942) can be complemented as follows: *the development of inland waters is determined primarily not by seepage through the dikes in areas adjacent to rivers, but rather the upper limit of the carrying capacities of pumps located at the influx of the drainage channels into the outlet stream. The range of inland waters deriving from seepage through the dikes is only about 100-300 m.*

Three areas most affected by inundations could have been identified in the region *in the left banks of the river Tisza* (**Fig.3.**): northeast of the city of Szentes, south of the cities of Orosháza and Hódmezővásárhely. In this unit *there is no characteristic increase in the frequency of inundations and excess surface waters along the drainage channels.* This must be attributed to the fact that runoff waters tend not to rush directly into the drainage outlets due to a lower relief.

Conversely, this lower relief also limits the carrying capacity of the drainage channels.

The affected area in the vicinity of Orosháza is located at the end point of the drainage network, where the carrying and storage capacity of the system is generally low.

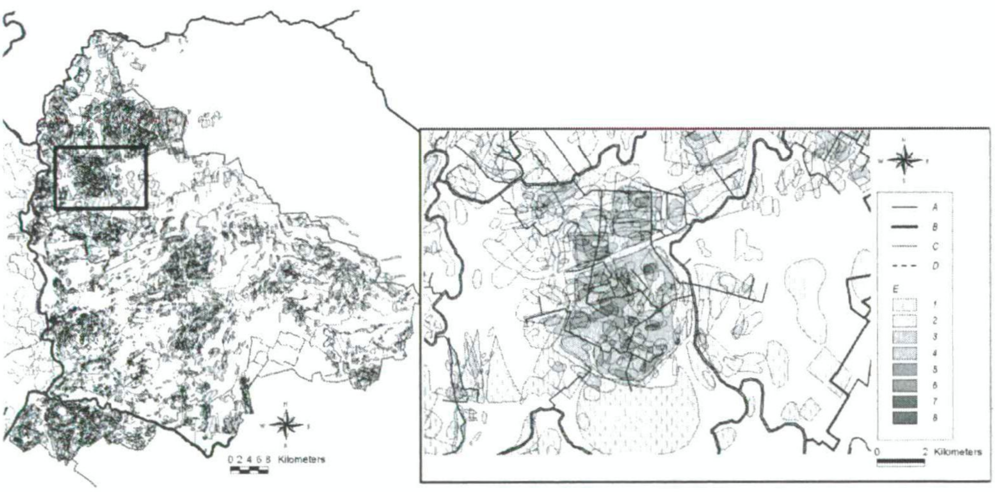

Figure 3. The frequency of inundations by excess surface waters in the monitored region on the left banks of the river Tisza

Legend: **A** – channel network; **B** – rivers; **C** – boundaries of administration units; **D** – operational area boundary of ATIKÖVIZIG; **E** – categories of frequency of excess surface water

In case of the examples from the vicinities of Szentes just like the measured regional maximum of Hódmezővásárhely, the reduced carrying capacity of the channels deriving from the low relief must be blamed for the higher frequency of inland water inundations. Here, the area of the alluvial fan of the river Maros must be separately mentioned, as excess surface waters also tend to have an underground source there (from groundwaters).

It must be noted, that higher frequencies in inundation were observable in areas running along the major watercourse, the river Tisza only. While such an increase in case of the two other marginal watercourses of the Hármas-Körös and Maros was not so unambiguous.

In case of the area of the *Torontál* (**Fig.4.**) inundations by excess surface waters tend to be more frequent than in case of the two former studied areas, *in a relatively homogenous distribution for the whole region*. The storage capacity of the drainage system has very low future resources, with inundated areas often appearing adjacently to the drainage channels as well. This must be attributed to the fact, that this landscape unit is the one with the lowest elevation in Hungary. The frequency of inundations along the rivers can not be clearly differentiated from other distant parts of the mentioned area.

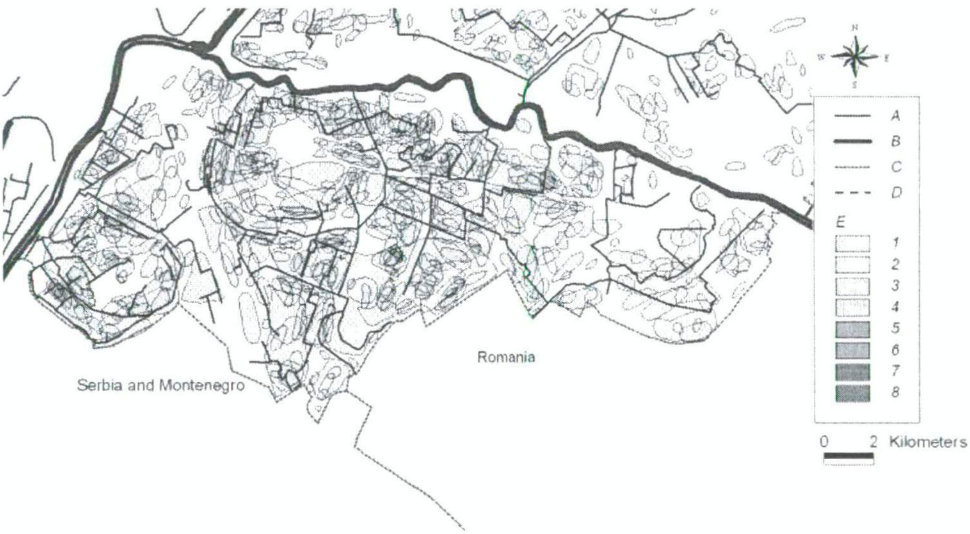

Figure 4. The frequency of inundations by excess surface waters in the Torontál landscape unit

Legend: **A** – channel network; **B** – rivers; **C** – boundaries of administration units; **D** – operational area boundary of ATIKÖVIZIG; **E** – categories of frequency of excess surface water

Possibilities for practical usage

Since the exact delineation of the areas inundated by excess surface waters is a factor of the geomorphological characteristics of the studied landscape primarily, as well as the technical background used in the surveys (RAKONCZAI et al., 2001), the application of modern remote sensing techniques besides the regular surficial field monitoring would be highly desirable. The resulting data by the application of these new analytical methods would largely increase the accuracy of the prepared database, as well as the reliability of the evaluations. Thus the utilization of these modern remote sensing methods (satellite and aerial photos) during the field surveys is highly advocated. This way on the one hand, more accurate maps could be prepared.

On the other hand, it also gives a possibility for the calibration of these extensive, and rapidly available survey data from remote sensing with those actually recorded on the field.

During the improvement of the drainage network not only the water carrying capacities of the channel systems should be improved, but their storage capacities as well, especially in areas highly prone to inundation by excess surface waters. This is especially applicable to areas located on the left banks of the river Tisza and the Torontál. An increase in the storage capacity of these systems would largely reduce maintenance costs, as the construction of new drainage channels into the original system would require higher financial resources than the expenditures related to increasing the storage capacity of the present system.

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THE EVALUATION OF WIND EROSION HAZARD FOR THE AREA OF THE DANUBE-TISZA INTERFLUVE USING THE REVISED WIND EROSION EQUATION (RWEQ)

SZATMÁRI, József

Summary

Detailed wind erosion studies were implemented on a pilot area in the Danube-Tisza Interfluve between 1995-2000. With the help of the recorded values, we were to test the applicability of the USDA RWEQ (Revised Wind Erosion Equation [United States Dept. of Agriculture (USDA) Wind Erosion & Water Conservation Service (WEWC): http://www.lbk.ars.usda.gov/wewc/]. to Hungarian sites and examples. The pilot studies yielded a standard deviation of less than 20% from the average for dry barren sandy surfaces affected by heavy gusts (15-22 m/s) with the largest recorded value of erosion at 880 tons/ha; and the largest predicted value of the same variant at 960 tons/ha. In the next step, a wind erosion hazard map was prepared for the area of the Danube-Tisza Interfluve using remote sensing techniques in the evaluation of satellite images, which was then compared to the Potential Wind Erosion Map of Hungary (LÓKI, 2003). According to the calculated values of soil moisture (Landsat5 TM-SWI), and the received erosion rates taken from the RWEQ model, 20-45% of the pilot area could be considered as potentially violated by wind erosion.

Introduction

The gradual increase observable in aridity values, and the increasing susceptibility to heavy droughts in Hungary should be attributed to a possible climate change (MIKA, 1995; WEIDINGER et al., 2000.) affecting primarily the area of the Great Hungarian Plain, and most heavily the region of the Danube-Tisza Interfluve included.

The observed trends of rising temperatures, decreasing precipitation rates, as well as the gradual drop in soil moisture and groundwater levels recorded in regional studies all tend to influence the potential susceptibility of an area to deflation as well (KERTÉSZ et al., 2001.; RAKONCZAI et al., 2001; LÓKI, 2003.; KOVÁCS, 2004.).

One of the major goals of our wind erosion studies was to develop a database, which might be not only useful in directing the attention of decision makers to the potential hazards of wind erosion in the agriculture (MUCSI-SZATMÁRI, 1998.; SZATMÁRI, 2000), but to an important and very serious environmental and public health problem observable in several cities and villages of the Great Hungarian Plain: dust pollution of the air.

Dust pollution observable in the settlements of the Southern Great Hungarian Plain well exceeds the limit of emission, with the largest recorded value present (RAKONCZAI et al., 2000.). The main source of the floating dust particles present in the air can be linked to agricultural dusting of arables, which could be significantly cut back by forestation or grassing of the abandoned arable lands.

Hopefully, the joining of Hungary to the European Union will open up new financial resources to the country, and will also contribute to the initiation of large-scale landscape management in the future. We would like to contribute to the theoretical and practical base of this work with our research results. Detailed wind erosion studies were implemented on a pilot area in the Danube-Tisza Interfluve during the second half of the 1990s (MEZŐSI-SZATMÁRI, 1998.). The present paper discusses the applicability of the USDA wind erosion model to Hungarian examples based on the utilization of our recorded values as input into the model. Furthermore, a detailed wind erosion hazard map has been prepared via the evaluation of satellite images and aerial photographs of the studied area for the period investigated.

Material and methods

In order to record the amount of sand exposed to aeolian transportation, a 50x50 m pilot area was outlined on the sand ridge of Kiskunmajsa-Dorozsma in the vicinity of the hydrometeorological station (**Fig. 1.**). Sand movement was measured with the help of measuring rods at weekly and fortnightly intervals. The pilot area was systematically plowed and exposed to chemical weed control to sustain a surface with scant vegetation cover. This surface is considered to be potentially liable to deflation during the spring and the fall in great extention in the area of the Danube-Tisza Interfluve.

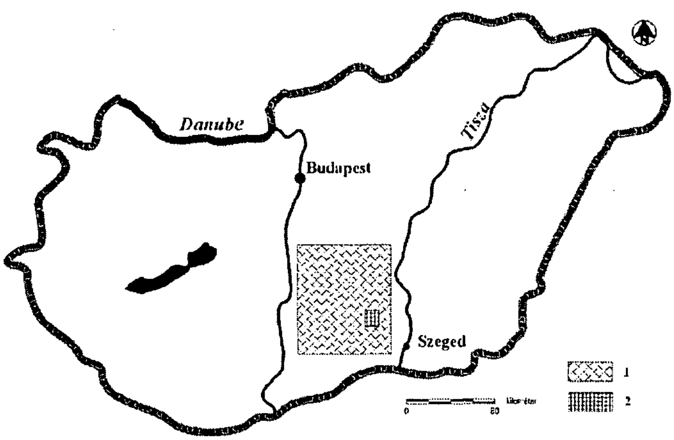

Figure 1. The location of the pilot area.

1: the studied region of the Danube-Tisza Interfluve via remote sensing methods; the area covered by the wind erosion hazard map; **2**: the location of the pilot area and studied lot on the sand ridge of Kiskunmajsa-Dorozsma

The meteorological parameters were recorded both with the help of on-site devices and with those located at the nearby meteorological station. Furthermore, the highly detailed database of the Szeged and Kistelek stations of the Hungarian Meteorological Survey (OMSZ) has also been adopted to our work, and the maximum wind speed values presented in the daily reports of the OMSZ between April 1997 and 2000 for the cities of Szeged, Kecskemét and Kiskunhalas have also been used.

As the second step in our work, an area covering approximately 64 km^2 (**Fig. 1.**) was delineated on the sand ridge with the studied lot in the center. The natural vegetation and landscape utilization of the region located between the cities of Kiskunmajsa and Kistelek are rather versatile.

Geomorphologically speaking, the alternation of sand ridges, interdune depressions and flats characterize this southern part of the Danube-Tisza Interfluve. Soil samples were collected from different sites of the studied area, which were characterized by differing soil conditions and landscape utilization. The sites which are most sensitive to wind erosion have also been identified in the course of multiple field mapping. The most important physical properties of the collected soil samples, especially from the side of deflation processes, were determined in the laboratory. These included the carbonate and organic material content as well as the grain-size composition of the samples.

LANDSAT5 TM multi-spectral satellite images have been utilized for the remote sensing analysis with the values of NDVI (Normalised Vegetation Index) which is the most frequently and widely used index for net produced biomass. The different classes of wind erosion hazard potential were set up for the 6420 km^2 area of the Danube-Tisza Interfluve with the help of the soil wetness index (SWI) derived from LANDSAT images, taken on 14th April 1997 and 22nd April 2000, respectively (**Fig. 1.**). Field reference data for the studied time period used in the classification procedure comes from the recorded soil moisture values at the site near Kömpöc, where according to our personal observations, the emergence of a potential wind erosion hazard is connected to the interval of 0-6% soil wetness.

Ours was one of the very first Hungarian work focusing on wind erosion processes, which applied a test of wind erosion models as well. It must be mentioned however, that these computer based models are user-oriented beta versions prepared by American researchers and come with a built-in meteorological database.

Thus in the vast majority of our work we had to concentrate on developing a suitable meteorological database for use as an input into the model. The most important step involved was setting up a suitable algorithm necessary for wind statistical analyses from the detailed field data available (maximal wind speed and direction values recorded at 10 minute intervals between 1997 and 2000).

Institutes enjoying subsidy from the US Department of Agriculture (USDA), namely the WEWC in Texas and WERU (Wind Erosion Research Unit) in Kansas managed to develop two highly different wind erosion models during the past two decades, working independently from each other.

We had a chance to gain access to and try out these models utilizing our field data with the permission and help of the experts working at these institutes. The present study discusses the testing of the RWEQ model, which predicts soil erosion along a line crosscutting an isolated rectangular lot giving medium to long-range average predictions with low temporal resolution and without any bootstrap of the prevailing processes.

In order to assess accurately the data on the Landsat TM5 images of the region of the Danube-Tisza Interfluve, field data have been collected at 34 points in the pilot area located between Kiskunmajsa and Kistelek including such parameters as vegetation cover percentages, soil samples with determined physical parameters of grain-size composition, carbonate and organic matter content. Areas potentially liable to wind erosion were delineated with the help of the data retained from the satellite images (vegetation and soil wetness index values) and the measured field parameters. The parameters deriving from the field sampling were used as an input in the „soil submodel" of the RWEQ.

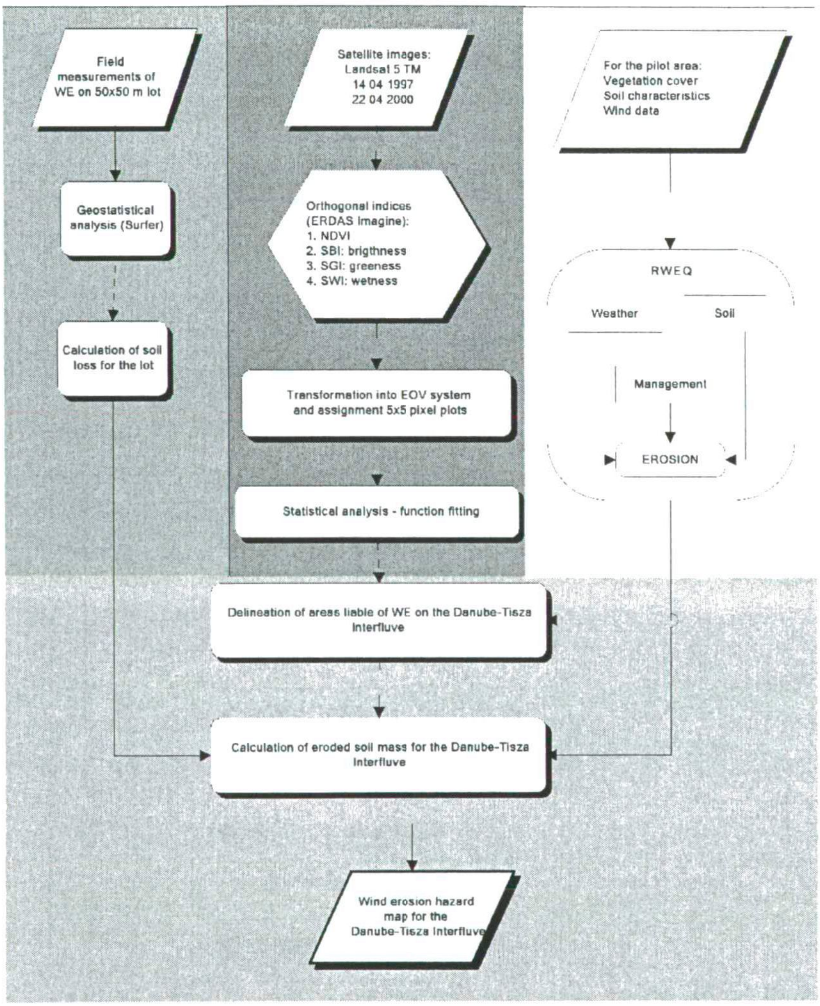

Figure 2. Flowchart of wind erosion measurement steps.
Integration into a complex model.

During the testing process, meteorological data recorded and calculated for the spring of 1997 have been utilized, as this period witnessed the highest values of eroded material due to a relatively intensive deflation lasting for several weeks in the pilot area.

Data coming from different sources, including field measurements and calculated values from remote sensing analyses, as well as general model algorithms, have been integrated into a single system (**Fig. 2.**).

Results and discussion

1. The findings of field measurements in the pilot area

The recorded values for the period of 1995-2000 are depicted on **Fig. 3.**

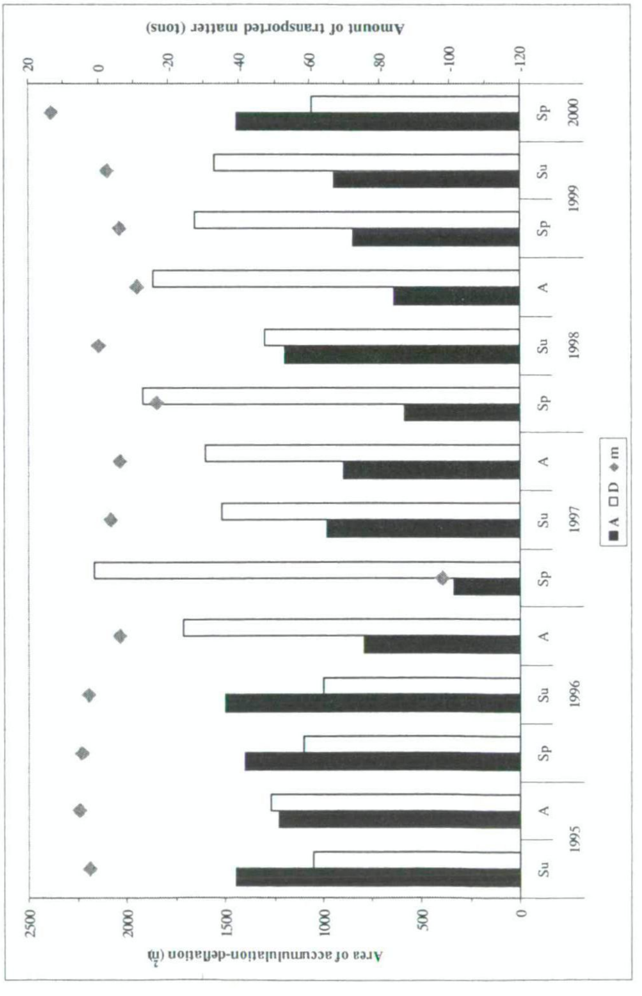

Figure 3. The results of field measurements between 1995-2000 summarized for seasons. A: accumulation (m^2); D: deflation (m^2); m: the amount of transported matter (tons)

The most intensive sand movement could be observed during the springs of 1997 and 1998, when the amount of monthly total transported sand exceeded 200 tons (equaling approximately the removal of 3 cm soil), and 50 tons for the one-quarter hectare of the lot.

No relevant sand movement could be measured or identified in the spring of 2000, when the recording of field data and the second satellite image was taken of the studied area. Our data were then compared to those of DIKKEH (2004.), recorded via utilizing sand traps and measuring stakes on a 1 ha lot near the city of Kecskemét. According to the latter, the rate of soil erosion recorded during a 10 hour and a 20 hour measurement series during the middle of April in 1988 were 59 m^3/ha and 56 m^3/ha (corresponding to a total of 150-160 t/ha eroded soil amount). As the wind speed values were very similar during this time and the first two studied weeks of April 1997, it can be generally stated that strong gusts with a speed exceeding 5-6 m/s are capable to move several hundred tons/hectare of sand from one place to an other within only a couple of hours on a dry, barren sand surface, free of vegetation cover.

2. The outcomes of the RWEQ erosion submodel run

According to our findings (**Table 1.**) the differences between the measured (920 t/ha) values of deflation on a vegetation free lot and those calculated from the model (e.g. Sample M33: 788 t/ha; or Sample M6: 644 t/ha) were less than 25%, which is acceptable. Researchers R. VAN PELT and T.M. ZOBECK investigated the relationship between the deflation values recorded at six stations and the ones predicted by the RWEQ model in details. According to their findings, the correlation of the predicted and actually measured values was between 0.6-0.7, implying the underestimation of the actual deflation values in the model (R. VAN PELT et al., 2002.). The deflation values recorded by us on a lot with vegetation cover (fall wheat) were significantly different from the ones calculated by the model, the underlying reasons of which might be revealed by further program runs only. Naturally no long-term verification statements could be drawn regarding the model as we have only dealt with data for a single event and a single area only so far.

3. The evaluation of wind erosion hazard for the area of the Danube-Tisza Interfluve

The studied area is classified into the category of 99% liable to risk according to the „Potential wind erosion hazard map of Hungary" (LÓKI, 2003.), with a total area under heavily endangered exceeds 50%. From the calculated soil wetness index (SWI) we can draw conclusions reflecting our recorded values for the two spring periods. The April of 1997 was relatively poor in rainfall with frequently recurring strong gusts, also yielding the highest erosion rates on our pilot area during the 6 year of the study (about 900 t/ha/month). Based on the classification prepared via the analysis of the satellite images the regions potentially liable to wind erosion exceeded 40% of the total area of the Danube-Tisza Interfluve, 9% of which was moderately and highly affected by wind erosion (**Fig. 4.**; **Table 2.**).

The RWEQ model yielded a monthly average erosion rate of 640t/ha for the moderately and strongly affected dry, barren sand surfaces, and a rate of 150 t/ha for the weakly affected areas. Based on the values for April 2000 2% of the total area belong to the class of highly endangered by erosion and 17% was only weakly affected (**Table 3.**).

Table 1. The actual measured values at the sampling points and the ones calculated from the LANDSAT TM5 images taken on 14th April 1997 (**) and 22nd April 2000 (*)

Type of vegetation cover*	Percentage of covered area* (%)	No. of soil sample*	SWI**	NDVI**	Calculated RWEQ erosion rate (t/2500 m²)
Woodland	100	M11	-14.98	0.36	0
	15	M26	-48.10	0.25	53
Wheatland	75	M27	-41.52	0.37	2
	70	M8	-37.98	0.30	3
	50	M10	-1.65	0.63	8
	50	M30	-30.71	0.37	5
	47	M29	-37.25	0.37	9
	45	M5	-19.28	0.48	15
	37	M32	-19.77	0.51	15
	35	M34	-26.14	0.43	16
	30	M1	-32.4	0.29	21
	25	M24	-27.15	0.47	34
	25	M25	-61.17	0.11	27
	23	M15	-43.63	0.21	35
	17	M36	-55.30	0.21	47
	16	M19	-34.62	0.31	75
	13	M16	-31.38	0.32	67
Orchard	2	M14	-56.47	0.13	173
	0	M17	-58.83	0.08	241
Reed	100	M7	-21.91	0.14	0
Fallow	75	M23	-39.62	0.31	2
	50	M31	-39.07	0.18	8
Meadow	70	M35	-14.22	0.52	3
	50	M28	-29.89	0.41	5
	7	M3	-60.39	0.11	91
Interdune depressions	100	M18	-30.73	0.36	0
	100	M22	-27.81	0.33	0
Arables without plants	4	M12	-46.12	0.16	138
	2	M2	-60.3	0.13	150
	3	M6	-20.72	0.47	161
	1	M20	-59.06	0.21	142
	0	M33	-64.68	0.13	197
Vineyard	90	M4	-58.08	0.08	1
	50	M21	-46.37	0.18	8

Table 2. The evaluation of deflation hazard based on classification for the Landsat5 TM image taken on 14th April 1997

SWI	risk	pixel (30 m / pc.)	area (km²)	percentage (%)
(-120, -80)	high	23062	20,8	0,32
(-80, -60)	moderate	595336	535,8	8,34
(-60, -20)	weak	2528430	2275,6	35,41
(-20, 60)	no	3966697	3570,0	55,54
unclassified		27895	25,1	0,39
Total		7141420	6427,3	100,00

Table 3. The evaluation of deflation hazard based on classification for the Landsat5 TM image taken on 22nd April 2000

SWI	risk	pixel (30 m / pc.)	area (km²)	percentage (%)
(-120, -80)	high	270	0,2	0,00
(-80, -60)	moderate	138920	125,0	1,95
(-60, -20)	weak	1232837	1109,6	17,26
(-20, 60)	no	5690499	5121,4	79,68
unclassified		78894	71,0	1,10
Total		7141420	6427,3	100,00

If these values are taken approximately as the real values at least in their magnitude, then during April 1997 at least a total of 70 million tons of sand must have suffered transportation in the area of the Danube-Tisza Interfluve (**Table 4.**). As it can be clearly seen in **Table 3.**, this mass of transported sand could have been 70-80% less in April 2000 assuming similar wind conditions due to the higher rates of moisture of upper soil layer. However, as we have noted in the section of field measurements no wind action could be detected for this period.

Table 4. The amount of wind-blown sand for the area of the Danube-Tisza Interfluve based on classification for the Landsat5 TM image taken on 14th April 1997 and the calculations of the RWEQ model

risk	area (km²)	percentage (%)	Erosion (thousand of tons)
high	21	0,3	35620
moderate	536	8,3	
weak	2276	35,4	34134
Total	2833	44	69754

According to KARÁCSONY (1992.) and MOHAMMAD D. (1991.), in case of a natural wind erosion process 10-20% of the total transported matter is given by dust particles.

Based on this value approximately 7-14 million tons of dust could become airborne during our studied period causing significant air quality problems in the nearby settlements.

Summary

This paper presents a method for the accurate and complex treatment and evaluation of field data, those gained from the evaluation of satellite images and the soil erosion values predicted by a wind erosion model as a first step in deflation studies. The final outcome of this work is a wind erosion hazard map of the area on the one hand.

Furthermore, the amount of airborne dust causing air pollution problems could also be predicted for a two-week period of wind erosion.

Our very first findings were rather promising, thus the initial testing and verification of the model utilizing Hungarian site data were worthy, and call for a continuation. This is by no means surprising, considering the long-standing research experiences of the USDA working groups for the development of the tested model.

We shall also carry on our database development for the area of the Great Hungarian Plain via the collection and evaluation of satellite images and aerial photographs utilizing remote sensing approaches, as this database is of primary importance in several ongoing researches, including our wind erosion studies as well.

The most effective and reliable source of landscape utilization, vegetation cover data, and those on soil conditions are materials used in remote sensing.

In order to gain better and more reliable information on wind erosion regarding such parameters as critical wind speed, and soil conditions, we plan to extend our research to other areas of the Great Hungarian Plain potentially liable to wind erosion (Nyírség, the Körös-Maros Interfluve), along with the further refinement of our research methods.

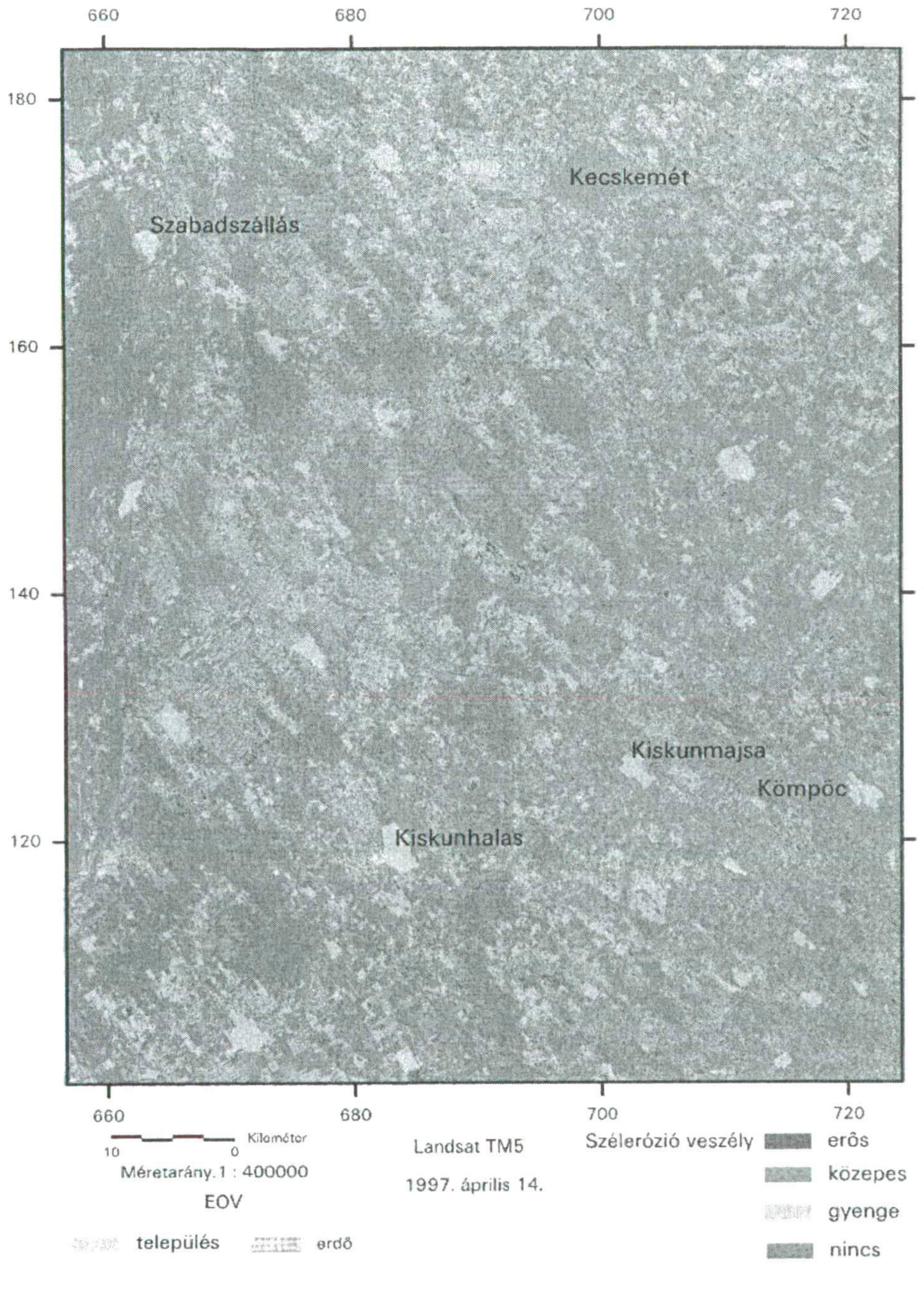

Figure 4. Wind erosion hazard classes
(erős: high, közepes: moderate, gyenge: weak, nincs: no hazard)

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SPATIAL AND TEMPORAL ANALYSIS OF THE AVAILABLE NUTRIENTS OF THE TOPSOIL IN A PILOT AREA: MACRO- AND MICROELEMENTS AS INDICATORS OF EROSION

FARSANG, Andrea – RÁCZ, Péter – HORVÁTH, Dénes

Abstract

The aim of the present study was to shed light on the laws governing the spatial and temporal variations of available nutrients in the topsoil in a pilot parcel located in a subbasin of the catchment area of Lake Velence. The choice of the site is based on the utilization of the lake as a recreation area. The majority of the land in the catchment area is in agricultural use and the water quality of the lake is highly sensitive to the intensive exploitation of the soils due to the relatively large catchment area compared to the size of the water body.

The following tasks were to be carried out as part of the present study:

- the recording of the distribution of micro and macro elements along with the major soil characteristics on the pilot parcel at three different times;
- the analysis of the potential correlations between the soil parameters and the element content with the help of statistical tools;
- the modeling of erosion for a given slope segment with the help of an erosion modeling software (Erosion 2D) in order to distinguish the slope areas where accumulation or intensive erosion is present;
- finally these erosion and accumulation segments were compared to the nutrient profiles in order to determine the group of elements most suitable as indicators of erosion.

Introduction

The hypothesis according to which the "fate of a lake is in the hands of its catchment area" is especially true for Lake Velence. Agricultural production on the catchment area along with the intensity of fertilization as well as the implementation of water- and soil-friendly approaches in the agricultural production and fertilization play a crucial role in the deceleration of eutrophization and the improvement of water qualities within a lake system used mainly for recreation as Lake Velence. The catchment area of the lake covering approximately 602.4 km^2 is about 23 times of the water surface. An estimated 713,000 t of soil is eroded from the catchment area annually, 20% of which gets into streams and reservoirs; i. e. approximately 143,000 t/year. The reservoirs of Zámoly and Pátka capture about 60,000 t of the above, yielding a final load of 83,000 t transported into Lake Velence every year (KARÁSZI K., 1984). The lack of any natural obstacles on the catchment area enables practically undisturbed transportation for the sprinkled nutrients towards the base of erosion because water flows down the slopes carrying soil and sediments into the creeks, since the wet meadows adjacent to the creeks were put under agricultural production in the 1970s. These 50-70-m-wide wet habitats served as some sort of physical and chemical traps for the eroded nutrients. In order to create larger parcels, suitable for production using high-capacity machines (BÓDIS - DORMÁNY, 2000), shelter belts were eradicated.

These have also served as erosion traps for eroded soil particles in case of sloping parcels, thus enabling the preservation of water quality in Lake Velence in addition to soil protection.

Several researchers have recognized the potential dangers resulting from the loss of nutrients in the topsoil of lands under agricultural production via erosion and sheet flow. DÉRI (1986) developed a method for estimating the rate of N and P discharge and erosion with regards to the vegetation cover by investigating the 14 subbasins of the catchment area of Lake Balaton. According to his observations the decrease of the ration of woodlands below 30-40% of the total vegetation cover results a sudden increase in nutrient discharge and erosion. As DEBRECZENI et al. (1983) have pointed out in their lysimeter investigations the following factors are of crucial importance in the transportation and loss of nutrients: type, physical composition and pH of the soil. HEATHWAITE et al. (2003) have developed a method for the estimation of P loss in case of the soils of minor catchment areas and ploughfields covering a couple of hectares. DUTTMANN (1999) and Isringhausen (1997) after modeling the process of soil erosion in several minor catchment basins using Erosion 3D and AGNPS software models, created maps of P redeposition based on their findings. The potential role of morphology concerning the distribution of heavy metals within the soil for a minor catchment was investigated by KERÉNYI and SZABÓ (1997).

The present study involved the analysis and discussion of several aspects in relation to the catchment area of the Cibulka creek, covering an area of approximately 14 km^2. This is a subregion of the catchment of the Vereb-Pázmánd waterflow, which is largely responsible for the contamination of Lake Velence. The following aspects were considered (**Fig.1.**):

- to shed light onto the spatial and temporal variations of the nutrition cycle of soils in the area;
- to investigate how the morphology, the organic content as well as the cohesion of the soils influence the spatial variance;
- to decide which micro- or macroelements can be considered as indicators of soil erosion;
- to determine those slope segments, which are most exposed to soil erosion, nutrition leaching, and accumulation in the pilot area, running parallel with the slopes and utilized for vine growing and acting as a major source of nutrition contamination to the lake;
- to correlate the erosion and accumulation slope segments, received as an output from the modeling software Erosion 2D, with the variations of the metal content along the slope.

The area under investigation

A *150 x 300-m-parcel was chosen as the site of a detailed, high resolution analysis* on the catchment of Cibulka creek. The aspect of the parcel was north-eastern, with an average slope angle of 4°, 1° and 6°.

The mean annual precipitation at the site is between 550-600 mm, 50-55 % of which comes during the summer (MAROSI - SOMOGYI, 1990), very often as heavy thunderstorms. The *genetic soil type* of the parcel is forest-residued chernozom developed on a loess bedrock (**Fig. 2.**), , which belongs to the category of average or weakly eroded considering the rate of erosion. The *thickness of the productive topsoil* exceeds 150 cm. The pH of the topsoil is slightly alkaline with values ranging between 7.21–8.5. Vegetation cover, one of the key factors influencing soil erosion in the area, was around 35% in average during the period of the analysis. The pilot parcel was selected carefully in order to represent an area where landscape utilization is similar to that of the slopes of the catchment area; namely, where large-scale vineyards are present.

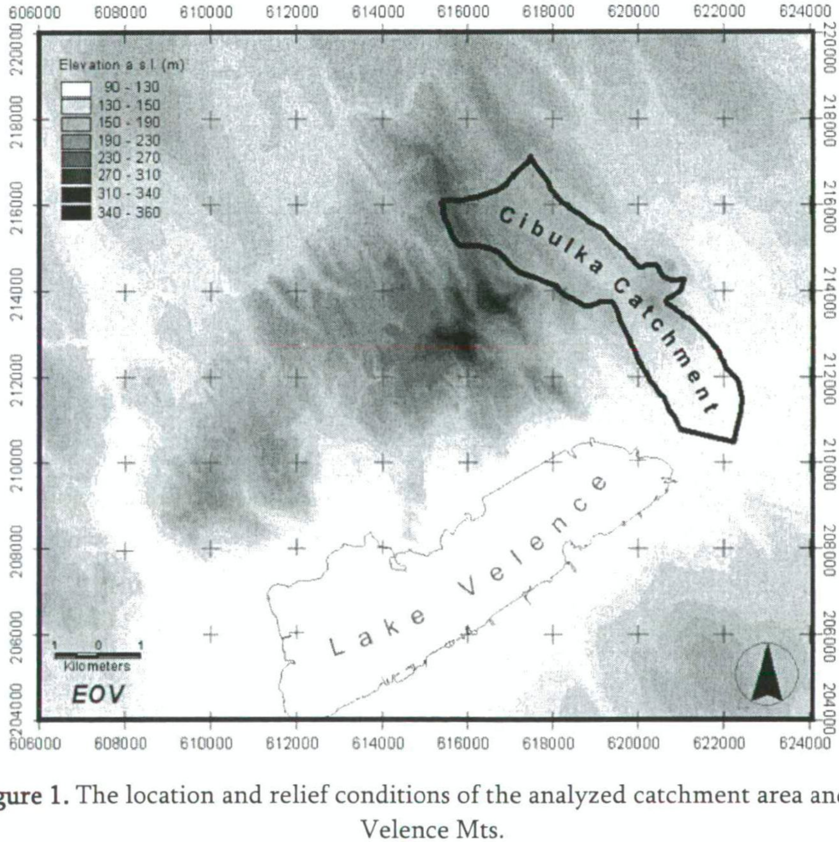


Figure 1. The location and relief conditions of the analyzed catchment area and the Velence Mts.

Among the changes of landscape utilization on the catchment of Cibulka creek during the past 20 years the transformation of ploughfields into vineyards was of primary importance. The Hungarovin viticulture (Pázmánd) purchased arable lands in several steps from the Agromark Producer's Cooperative in the late 1980s, early 1990s and planted vine-stocks into the newly gained areas, introducing large-scale intensive production.

These changes in the landscape utilization resulted in an increase of vine-stock covered areas, influencing the rate of soil erosion and the amount of discharged nutrients as well by changing the ration of vegetation cover. According to our measurement data concerning vegetation cover (collected from 14 different parcels of the catchment between April and October) the ratio of annual vegetation cover is lower in the area of parcel No. 7, similar to other vine-growing areas, compared to other parcels with a different landscape utilization (**Table 1.**). This vegetation cover data has been also used for the calibration of our model for the pilot parcel in the soil erosion modeling system Erosion 2D/3D.

Table 1. The rate of vegetation cover for the major land types on the catchment between April-October 2001.

Plants grown on the given parcels	The ratio of vegetation cover in percentage				
	April	*May*	*June*	*August*	*October*
1. fallow	53	62	98	99	100
2. winter wheat	46.6	98	100	89.6 (stubble field)	100 (stubble field)
3. winter wheat	88	100	100	2 (ploughfield)	65 (sugar beet)
4. winter wheat	65.6	100	100	96 (stubble field)	100 (stubble field)
5. winter wheat	65.6	100	100	56.3	25
6. grape	51	51.3	55.6	47	100
7. grape	**41**	**35.6**	**52.6**	**59**	**49.3**
8.corn	-	24.6	74.6	100	100
9. corn	-	14.6	46.3	100	100
10. hay	-	98	99	100	100
11. corn	-	16	63.6	100	100
12. oat	-	78	98	22.6 (stubble field)	58.6
13.grape	16	16.3	22	51	50
14. corn	-	15.3	40,3	100	100

Sampling and analysis material and methods

Detailed sampling and the laboratory analysis of the collected samples for the selected pilot parcel (**Fig. 2.**) was carried out in three steps: samples were collected on two occasions in 2001 (May and June) and once in May 2003 for each slope segment. Sampling was carried out in a 25 by 25 meter grid. The exact location of the sampling sites was recorded with theodolite in order to help repeated sampling. Sampling was performed by taking average samples for the uppermost 10 cm of the topsoil. The following soil parameters and nutrients have been examined in detail:

pH(KCl), **K_A** (Arany-type cohesion index), **$CaCO_3$**, **humus** content (%) and **available micro- and macroelements** (NO_2-NO_3-N, P_2O_5, K_2O, Na, Mg, Ca, Mn, Zn, Cu, Fe, Mo, B, Al, As, Cd, Co, Cr, Hg, Ni, Pb).

The analysis of nutrients was constrained only to those retrievable by plants. After extraction with acetic acid solution of ammonium-lactate for macroelements, and Lakanen Erviö extraction for the microelements, measurements were performed with an ICP Thermo Jarell Ash ICAP 61E device (BÚZÁS, 1988).

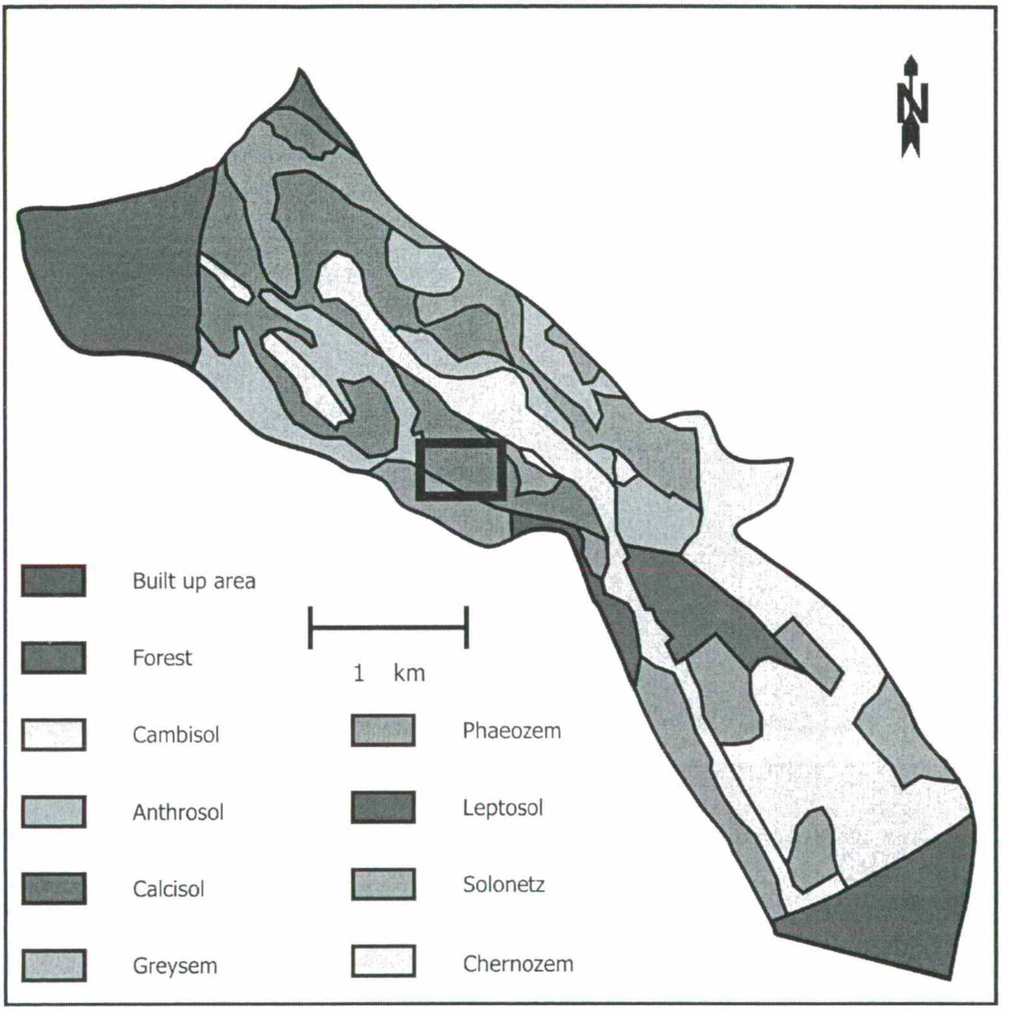


Figure 2. The prevailing soil types of the catchment basin with the pilot parcel marked

In order to determine the variations in the rate of soil erosion, and the accumulation segments along the slope, we used soil erosion modeling software Erosion 2D (SCHMIDT, 1996), which was developed in Germany.

The system is made up of three submodels: the first submodel captures topography and slope angles; the second is an infiltration submodel, while the third captures the rates of soil erosion and accumulation.

The slope profile for the analysis can be determined in the first submodel from the watershed boundary down to the valley floor in such a way, so that even minor topographic feaures and linear elements (road cuts, ditches) could be considered as well during the simulation. In describing the process of erosion two important subprocesses are distinguished in the model. One of these captures the governing rules and equations necessary for the movement, while the other captures those that are necessary for the transportation of the surface grains.

The model, parallel to the slope, simulates soil erosion occurring from a single rainfall event (MICHAEL, 2000). This *model requires less input parameters* compared to other similar modeling systems however the reliability of the output is highly sensitive to the accuracy of the input. The input involves three major categories: relief type data (height of the slope and the length of the slope base), parameters reflecting the conditions of the topsoil (bulk density, amount of organic C, erodability, surface roughness, soil moisture, vegetation cover), and finally data characterizing the intensity and temporal distribution of rainfall. Measurements of the above mentioned relief and soil parameters as well as the sampling, was carried out in May 2003 for the individual slope segments. All samples taken from a 25 × 25 m grid have been analyzed for grain-size distribution, physical properties as well as humus content. The model was run for a single rainfall event, which occurred in the area under investigation in May 2001 (duration: 1 hour, intensity: 19.3 mm/h). Data for this event was obtained from pluviometer measurements of a local meteorological station.

Results

The spatial and temporal variations of the nutrition content available to the topsoil

Based on its *physical properties* the soil in the pilot parcel can be classified as sandy loam with an Arany-type cohesion index of 32-41 (**Fig. 3.**). Regardless of regional differences, the parcel under investigation as a whole is medium or poor quality in terms of nutrition supply. The amount of organic matter, used as an indicator for the available N content, ranged between 0.8% and 2.8%. The P and K content in certain areas (e. g. the NW margin) is extremely high in all samples taken at different times (P_2O_5: 350-400 ppm, K_2O: 250-300 ppm) despite the collection of average samples. The mean macroelement content for P was 70-100 ppm, while for K it was between 100-150 ppm (Fig. 5-6.). The above-mentioned area is characterized by several extreme values for some microelements as well like e. g. Zn, Cd, Co, and Ni. None of the microelements reaches the temporary limit value (B value) (KÁDÁR, 1998), established for the characterization of the available nutrition content of the plough horizon. The available nutrition content exceeds the „A" value, i. e. the contamination background concentration (10 ppm), only in case of Cu.

The spatial distributions and variances in the micro- and macroelement concentrations of the topsoil are similar for the individual elements in the two close-timed sampling occasions (May and June 2001). The major accumulation zones can be clearly distinguished. Based on the dominant spatial variance patterns, two element groups can be identified.

The spatial distributions of P, K, Pb, Zn, Ni, Pb, Cd, and Co follow a similar pattern (**Fig.** 5-6.). The remaining group of elements does not display any similarities in their spatial distribution; i. e. while in some areas the concentration increases this is accompanied by decrease in other areas.

These elements are N, Ca, Na, Al, Fe, Cu, and Mg. The spatial distributions of the first group of elements display a close correlation with those of the humus content and the physical properties of the soils.

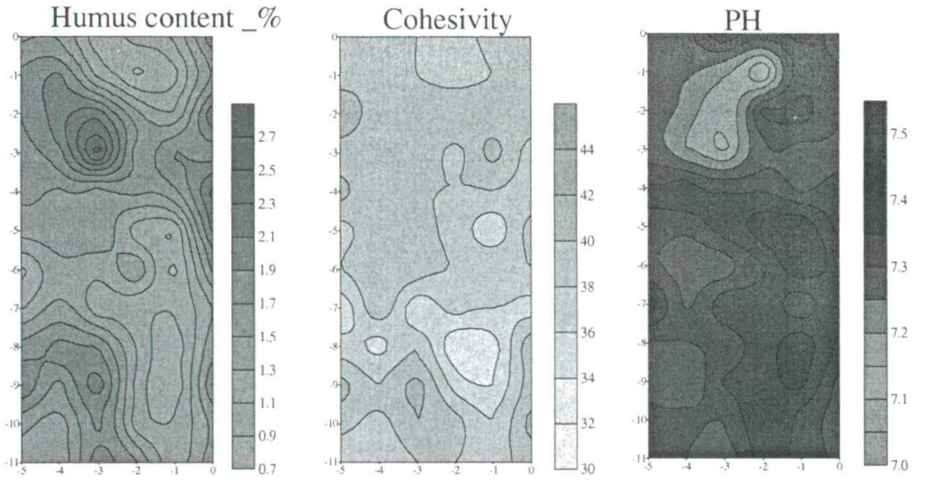


Figure 3. The spatial distribution of humus content, cohesion and pH of the soils in the pilot parcel

Macro- and microelements as indicators of erosion

Before the plantation of vine-stocks in the area (1990), the nutrition supply was even in the whole area of the pilot parcel, but there has been a major rearrangement in nutrition content during the past 10 years. The *rearrangement patterns and tendencies are different* for the individual analyzed elements, depending mainly on their chemical properties. The elements adhered to grain surfaces or to organic particles in the soil (e. g. P, K, Pb, Cd, Ni), follow a spatial distribution pattern corresponding to the variations of cohesion, and humus content of the topsoil. As changes in microrelief fundamentally determine transportation and movement of the soil grains and the topsoil, which is the richest in organic matter, the spatial distribution pattern of the latter elements is very similar to that of the relief. These correlations are depicted in Table 2. It can be clearly observed that the concentrations of the elements mentioned above are positively correlated with the organic content of the soil (r^2: 0.626-0.808), and cohesion. The other major group of elements is discharged from the topsoil following their dispersal and is transported horizontally on the soil along the profile in a soluble form (e. g. N, and Ca). The concentrations of all elements are negatively correlated with the alkalinity of the soil, because the decrease of the pH results in an increase of the available elements.

Table 2. The correlation matrix of the soil properties and the available macro- and microelement contents

	pH	Clay content	Corg	P	K	Cd	Ni	Pb	Co	Al	Cu	Zn	N
pH	1.00	-.396	-.491	-.263	-.334	-.396	-.477	-.431	-.441	-.502	-.120	-.299	-.201
Clay content	-	1.000	.533	.280	.382	.371	.326	.353	.071	.148	-.055	.279	.254
Corg	-	-	1.000	.631	.808	.739	.803	.626	.489	.426	-.061	.571	.377
P	-	-	-	1.00	.742	.649	.570	.733	.237	.066	-.279	.537	.375
K	-	-	-	-	1.00	.614	.703	.582	.415	.344	-.005	.635	.585
Cd	-	-	-	-	-	1.00	.667	.701	.356	.303	-.160	.516	.262
Ni	-	-	-	-	-	-	1.00	.550	.667	.580	-.175	.410	.273
Pb	-	-	-	-	-	-	-	1.00	.339	.188	-.253	.508	.310
Co	-	-	-	-	-	-	-	-	1.00	.800	.184	.274	.192
Al	-	-	-	-	-	-	-	-	-	1.00	.334	.149	.137
Cu	-	-	-	-	-	-	-	-	-	-	1.00	.247	.224
Zn	-	-	-	-	-	-	-	-	-	-	-	1.00	.656
N	-	-	-	-	-	-	-	-	-	-	-	-	1.000

The rearrangement and the local increases and decreases of nutrition content can be linked to the *microrelief* of the pilot parcel, indicating the initiation of a valley being formed. The markings in **figure 4.** indicate the steeper areas more susceptible for erosion (where profiles indicate degradation as far as the loessy bedrock), which were identified by field measurements (profile-degradation readings) and confirmed by detailed topographic analysis.

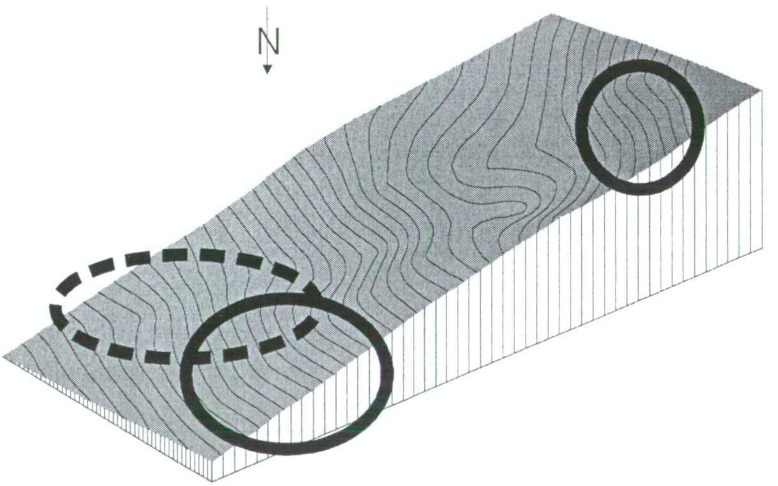


Figure 4. Relief conditions of the pilot parcel (150-300) with the areas exposed to erosion (continuous line) and accumulation (dashed line) marked (based on field observations, contour interval: 0.5 m)

Both these and the flattening areas capable of accumulation are clearly demonstrated by the spatial distribution of the individual elements (**Fig. 5-6.**).

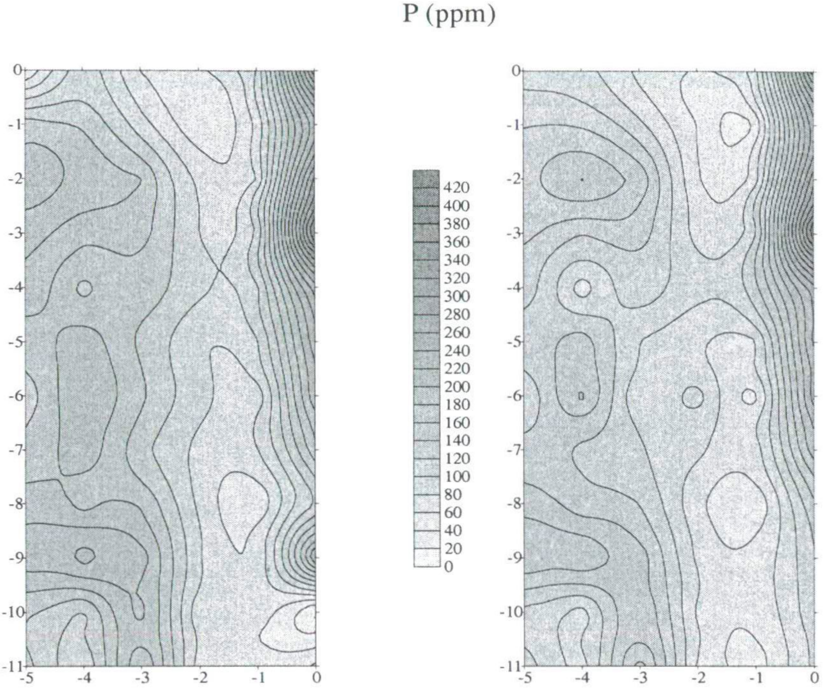


Figure 5. The spatial and temporal variations of the available P content (May and June 2001)

This is valid for both the macro- (P, K), and the microelements (Zn, Cd, Ni, Pb). In addition to the changes in microrelief, intensive ploughing in the direction of the slope also influences the spatial variations and distribution pattern of the physical properties, humus content as well as the macro- and microelement content of the soil.

Erosion modeling software Erosion 2D was run for a given slope segment of the pilot parcel in order to separate the areas exposed to intensive erosion (the curve is negative, resulting in soil removal) and those characterized by possible deposition and accumulation (with positive values of the curve). According to the output results, in two areas positive material transport (at a distance of 70-80 m, and 210-220 m from the base of the slope), and in one area (at a distance of approx. 160 m from the base of the slope) intensive erosion could have been predicted (about 1 t/ha). The area under investigation in the model has a 100% vegetation cover composed of woodlands, excluding the possibility of significant input concerning either soil particles or nutrients.

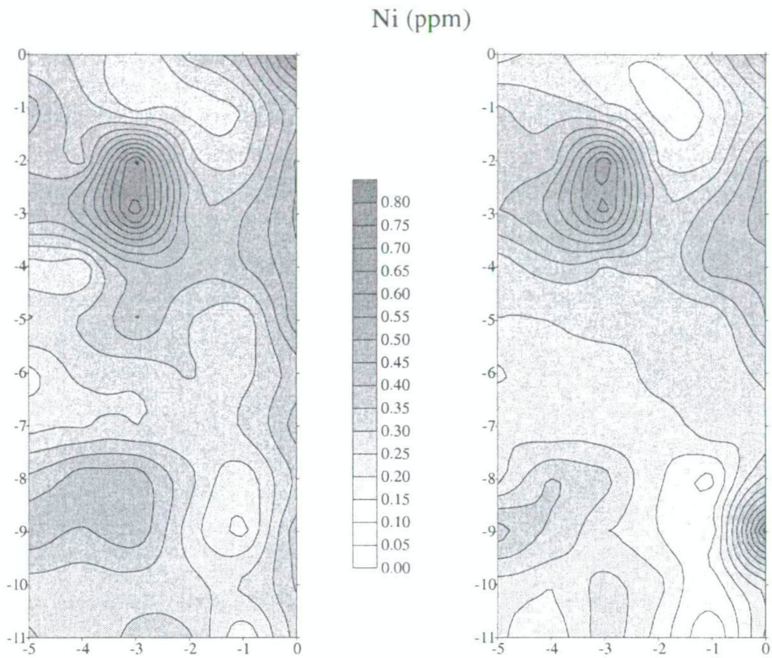
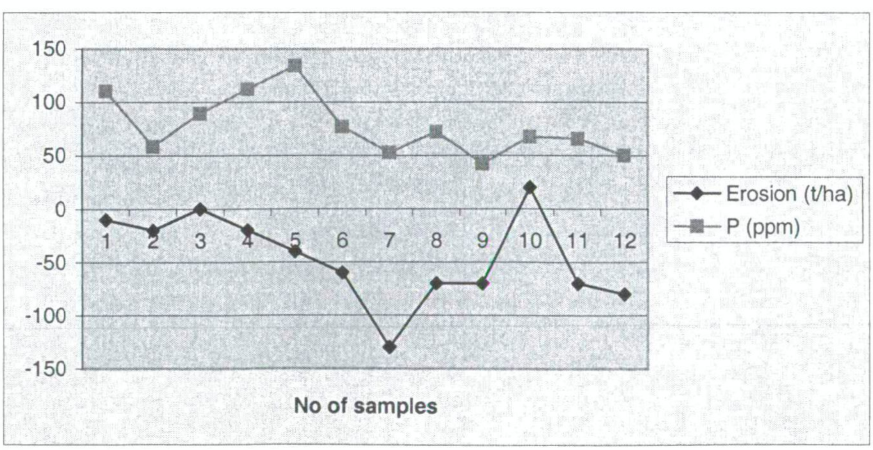


Figure 6. The spatial and temporal variations of the available Ni content (May and June 2001)

Finally these erosion and accumulation segments determined with by the model were compared to the nutrient profiles of the individual segments in order to see whether the tendencies of the elements considered as erosion indicators correspond to the results of the model (**Fig. 7-8.**).



(Values indicating soil erosion are 10x exaggerated)

Figure 7. Variations of the P content of the topsoil and the erosion-accumulation segments along the slope (the distance between the sampling sites is 25 m)

According to our findings, elements P and K from the macroelements, and Cu from the microelements appeared to be characterized by a distribution pattern along the slope similar to the one predicted by the model.

Based on the analysis of temporal variations of the nutrient profiles for individual segments (May 2001 – June 2003), the following statements can be made. After a uniform nutrient supply 13 years ago (no further fertilization or nutrient supply occurred in the area afterwards) a spatial differentiation of the nutrition content of the topsoil was initiated. This resulted in an erosion transportation of elements difficultly solved (e. g. P), adhered to the grains along the profile.

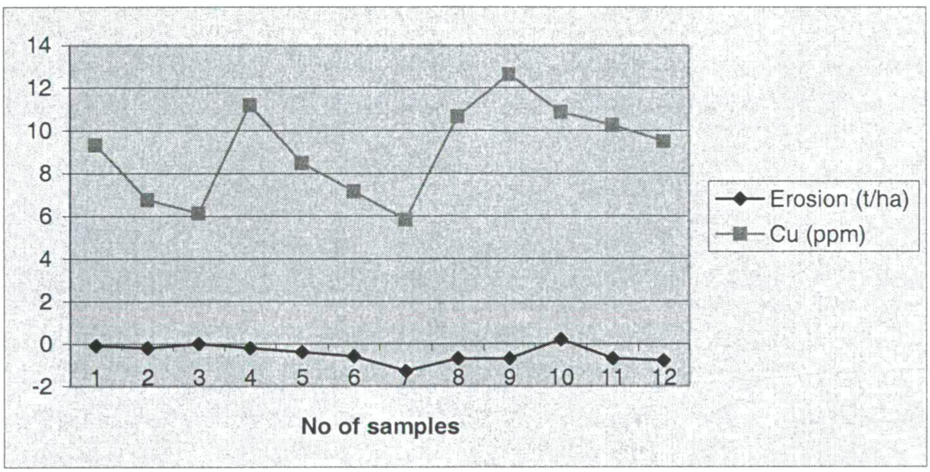


Figure 8. Variations of the Cu content of the topsoil and the erosion-accumulation segments along the slope (the distance between the sampling sites is 25 m)

According to the analysis of the P content for three consecutive sampling periods (**Fig. 9.**) the initial even distribution of nutrients along the slope starts differentiating with the pass of time; namely displaying a decrease in the segments exposed to erosion and an increase in those where accumulation occurs.

Following an artificially set up uniform nutrient supply, a state of equilibrium is reached as a result of the surface processes. This varies from slope to slope and is influenced by factors such as slope profile and other important features influencing soil erosion.

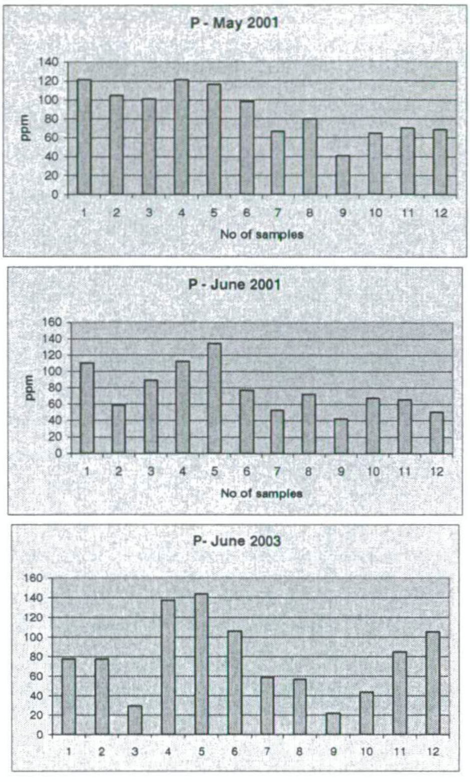


Figure 9. The temporal variations of available P content in the topsoil along the slope between May 2001 and June 2003.

Summary

The major aim of our investigations was to determine a group of elements from the micro- and macronutrients suitable to serve as indicators of soil erosion on the example of a pilot parcel selected on a sub-catchment of Lake Velence. To achieve this the following objectives were achieved:

- Distribution of macro- and microelements was mapped at two different times on the pilot parcel.
- Possible correlations of the individual soil properties and the elements were statistically evaluated. The elements correlated with the organic content and cohesion of the soil (e. g. P, K, Pb, Cd, Ni) follow a spatial distribution pattern corresponding to the variations of these latter parameters.
- Erosion was simulated for a selected slope segment with the help of the software Erosion 2D; from the output two accumulation zones and one segment suffering extensive erosion could have been identified. These erosion and accumulation segments were compared to the nutrient profiles of the individual segments.

- The group of elements most suitable as indicators of erosion was determined: these are P, K as macroelements and Cu as a microelement; their variations along the slope correspond to the results predicted by the model.
- Based on the analysis of the temporal variations of nutrient profiles for the individual segments (May 2001 – June 2003) the temporal differentiation of these elements is also well traceable, enabling the determination of the profile of equilibrium for the analyzed slope segment.

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MODELING RUNOFF AND INFILTRATION ON PLOUGH FIELDS

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Abstract

Erosional investigations have a very important role in soil conservation. There are dozens of infiltration and erosion models attempting to describe these processes more and more accurately. The aim of the present paper is to introduce a dynamic mathematical model, which is suitable for modeling the effects of a rainfall event on infiltration and runoff at the scale of parcels. As a theoretical base, the most typical and simple conditions were chosen that we are faced with on a plough field. Namely the model is applicable to soils with two different layers; i.e. a cultivated topsoil, and a more compacted plough-pan beneath. The model consists of three submodels. The vegetation submodel determines the net rainfall reaching the surface directly, or through the vegetation. The infiltration one can show the temporal distribution of the net rainfall between the infiltration and the runoff. Finally the runoff submodel describes the runoff intensity in space and time. The model can compute with equalizing the water amounts needed to fill the soil layers until field capacity, and the maximum soil moisture with definite integrations derived from the Horton's equation. It determines the following points of time: the start of surface runoff, the wetting front reaching the plough-pan, the plough-pan damming back water, the topsoil becoming saturated. All intervals between these moments can be ordered to different functions of the infiltration and the runoff. Programming was done in Maple 8.

Introduction

Understanding and controlling the hydrodynamic processes of the Hungarian arable lands is of primary importance, regarding both the conservation of soil quality, as well as the plants cultivated. The most important factors determining the physical properties and the quality of soils are the water absorbing capacity and permeability of soils, influencing potential infiltration and runoff. Furthermore, they are an important asset, mostly via runoff, to one of the most significant erosion process: soil degradation. Several theoretical and practical models have been proposed for determining infiltration, runoff and the degree of the resulting soil degradation so far (WISCHMEIER et al., 1978; KIRKBY et al., 1980; GRAYSON et al., 1992; MORGAN et al., 1993; YOUNG, 1994; FLANAGAN, 1994; BEVEN, et al., 1995).

These models included abstract mathematical approaches, empirical equations for inter-relationships and display a large-scale variety regarding the spatial and temporal extensions of the modeled area. Unfortunately, even the most commonly used soil models carry a large degree of uncertainty and error deriving from the high spatial and temporal variance of the soil properties and the hardships encountered during the quantification; i. e. the measurement of these as well (QUINTON, 1997; VEIHE et al., 2000). Measurements of soil erosion and the adaptation of soil erosion models are quite relevant at several Hungarian institutes today (VERŐNÉ, 1996; HUSZÁR T., 1998; CSEPINSZKY et al., 1999; CENTERI, 2002).

Testing and calibrations of the EUROSEM soil erosion modeling system (MORGAN et al. 1993, 1998) started in 1998 at our department (BARTA, 2001). This work has revealed several problems in the algorithm of the EUROSEM which prevented the appropriate calibration. In order to eliminate these errors, the development of a new model was initiated.

The aim of the present paper is to introduce a dynamic mathematical model which is suitable for modeling the amount of surface water deriving from the rainfall and irrigation, as well as its distribution between infiltration and runoff at the scale of parcels.

Since the final goal is the development of a complete soil erosion modeling system, via the enhancement of the previously mentioned mathematical model, the spatial distribution of surface runoff was determined as accurately as possible even at this stage.

The theoretical basis and the input parameters of the model

As a first step, a model was developed for rainfall events with permanent intensity (I1, mm/min). The intensity of surface runoff is calculated with the help of three distinct, yet closely interdependent submodels (**Figure 1.**). Consequently, the parameters used in the models can be divided into three distinct groups as well:

1. Vegetation parameters: determine the amount of "net rainfall"; the actual amount of precipitation reaching the surface in case of a rainfall event with permanent intensity.
2. Soil parameters: determine the distribution of net rainfall between infiltration and runoff.

The calculation of the rate of infiltration was carried out with the help of the Horton's equation (HORTON, 1933). At this stage our model is applicable only for the most simple and typical conditions we are faced with on ploughlands, not a comprehensive situation involving an arbitrary number of soil layers. Namely, for soils with two different layers; i.e. cultivated topsoil and a more compacted plough-pan beneath, characterized by less favorable hydrological properties.

Since normally we can find layers with higher hydraulic conductivity beneath this latter horizon, presuming their homogeneity, only the two uppermost layers should be considered in our model. As the development began on the basis of soil erosion investigations, the capillary effects of the groundwater were neglected in this model.

In contrast to previous infiltration models describing the total water absorption of soils with the help of a single equation, a new aspect of our model is that here absorption and discharge is calculated for the individual soil layers. Furthermore, only such parameters were utilized as an input which can actually be measured or calculated.

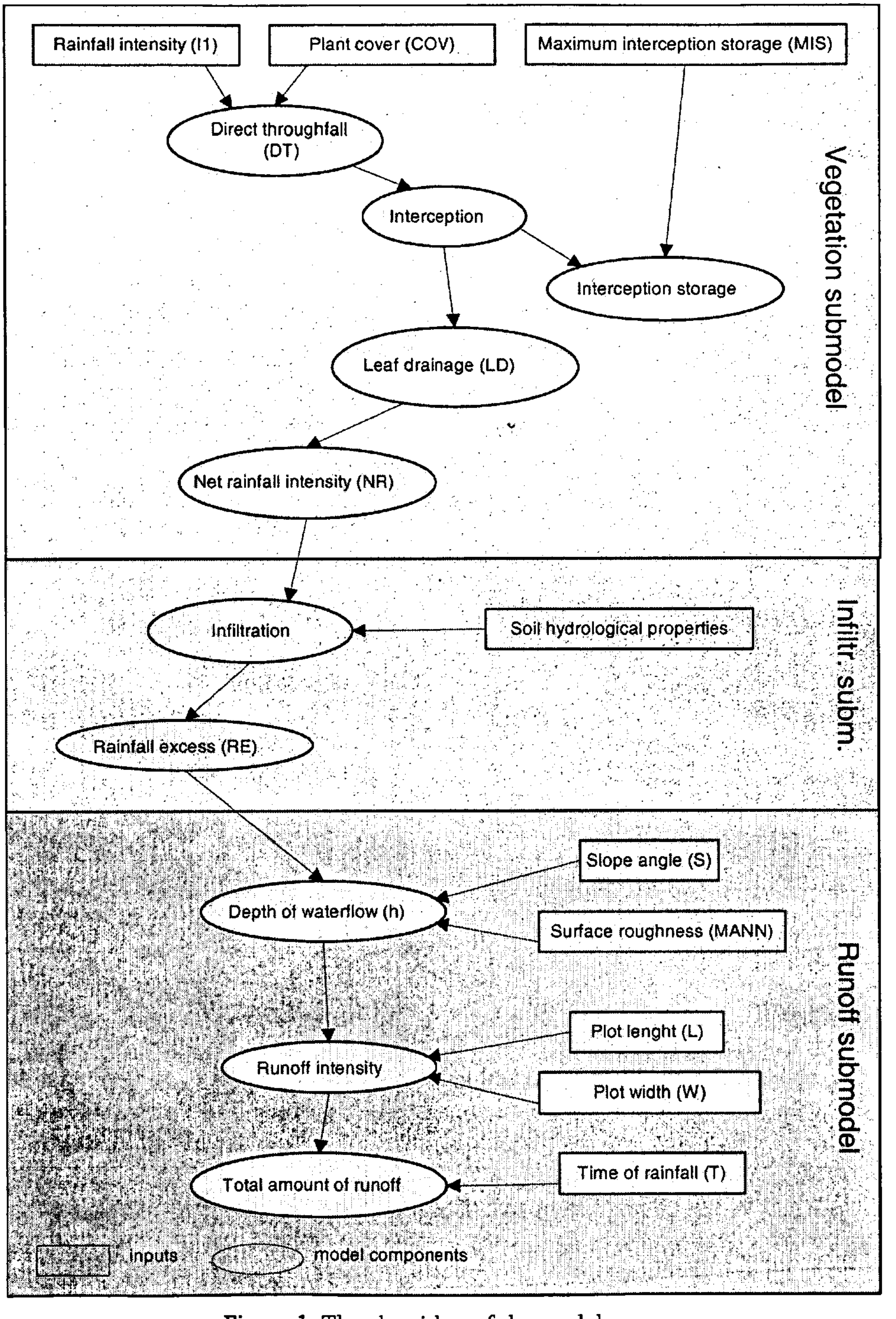

Figure 1. The algorithm of the model

3. Micro-relief parameters: determine the intensity, velocity and capacity of sheet wash among given relief conditions, i. e. the temporal distribution of runoff in the area.

The following vegetation parameters have been utilized:

- Surface vegetation cover (COV),
- The maximum interception storage of the vegetation (MIS, mm).

The following physical and hydrological properties should be taken into account as inputs for both soil layers under investigation:

- layer thickness(D, cm),
- maximum water content (P, v/v),
- field capacity (KP, v/v),
- gravity pore space (GP = P-KP, v/v),
- initial average soil moisture (M, v/v),
- saturated hydraulic conductivity (Kc, mm/min),
- the function of water absorption-permeability for the given soil layer.

This latter is given by the Horton's equation (DE ROO et al., 1992; SCHRÖDER, 2000):

$$K(t) = K_c + (K_0 - K_c)\, e^{-At} \qquad (1)$$

where

K(t): is the water absorption capacity and the hydraulic conductivity of the soil layer in relation to time (t, min) measured from the initiation of saturation (mm/min)

K_0: the initial water absorption (mm/min)

A: a constant parameter characteristic for the soil layer

Hereunder parameters related to the top cultivated soil are marked with a subscript 1 in the text, while those related to the plough-pan are marked with a subscript 2.

The calculation of the K(t) functions are carried out on the field with the help of a double-framed hydraulic conductivity meter upon the surface of the individual soil layers. Naturally the implementation of this 6-hour measuring process is not feasible preceding all rainfall events. Therefore, measurements should take place among conditions characterized with the lowest achievable water content in the soil, in order to be able to widen the scale of applicability of the function. Knowing such a function enables the control of the intensity of water absorption from the state of actual initial water content. It is supposed that the zero point of the function represents the state of actual initial water content.

The following micro-relief parameters have been utilized:

- the length of the plot (L, m),
- the width of the plot (W, m),
- the slope of the plot (S, m/m),
- the Manning value representing the roughness of the surface (MANN, $m^{1/6}$).

The vegetation submodel

Several equations are used to describe the process of how rainfall reaches the surface; i. e. the intensity of net rainfall (WISCHMEIER, 1978; KIRKBY et al., 1980; MORGAN et al., 1993; BERGSMA, 1996). The intensity of net rainfall, as a result of the process depicted in **Figure 1.**, can be calculated in relation to time with the help of the following equation adopted from the EUROSEM model (modified after MORGAN et al., 1998):

$$NR(t) = I1 \times (1 - e^{-I1 \times t/(MIS \times COV)}) \quad (2)$$

where NR(t) marks the net rainfall intensity in mm/min. Several practical tables have been prepared for capturing the maximum interception capacity of the vegetation (WISCHMEIER et al., 1978; KIRKBY et al., 1980; MORGAN et al., 1993). Unfortunately, the majority of these do not give any details on the rate of surface vegetation cover considered. Thus it should be noted here that equation (2) is applicable for the calculation of maximum interception capacity only if the vegetation cover is 100%. Without this, the *COV* component should be neglected in the denominator of the exponent of *e* in equation (2).

The final outcome of the vegetation model, i. e. NR(t) is taken as the input for the infiltration submodel.

The infiltration submodel

This submodel is a completely new development without any elements adopted from other models. In order to create a dynamic model, infiltration was determined in relation to time in all cases. Rainfall starts at time t = 0, and the following significant time periods could have been distinguished in the fluctuations of infiltration and runoff:

T_1: the increasing values of NR(t) exceed the decreasing values of $K_1(t)$, i. e. water absorption is reduced below the net rainfall intensity. This results in a rainfall excess (RE(t), mm/min) on the surface and the initiation of surface runoff.

T_2: as a result of water absorption the topsoil reaches the limit of field capacity. It bears no effect on the amount of rainfall excess however, the lower plough-pan starts taking up water from this time onwards

T_3: The rapidly decreasing water adsorption of the plough-pan becomes less intensive than the hydraulic conductivity of the topsoil. This results in the saturation of the gravity-pore space of the cultivated layer thanks to the backwater effect of the plough-pan.

T_4: The topsoil reaches the limit of saturation. From this point on surface runoff is determined by the water absorption capacity and hydraulic conductivity of the plough pan.

The order of the above-mentioned events is only theoretical, there might be certain discrepancies. In reality T_1 very often equals 0, i. e. surface runoff is induced even at the initial stage of absorption. Even more frequently, the hydraulic conductivity of the cultivated soil exceeds the rate of initial water absorption of the plough-pan, resulting in the elimination of T_3.

In order to determine the above mentioned T time periods, the total water volumes necessary for reaching the given rates of field moisture were calculated in two different ways for the two soil layers:

1. based on layer thickness, water content, plough field capacities and porosity and
2. with the help of integrals derived from the Horton's equation.

In this latter case the upper limits of the integral ranges define the unknown T-s, thus by solving the equations received by the equalization of the two different types of calculations the T values could be determined.

Calculation of the volumetric water content

The amount of water necessary for reaching the state of initial field moisture, field capacity and maximal rate of saturation was given in mm, i. e. l/m^2.

The parameter of initial field moisture given in mm (MT) is not considered in the present version of the model. It will be significant at the correction of the function for water absorption later on during the process (see earlier):

$$MT = 10 \times D \times M \tag{3}$$

The amount of water (KT, mm) necessary for reaching the state of field capacity from the stage of initial field moisture can be calculated with the help of the following equation:

$$KT = 10 \times D \times (KP - M) \tag{4}$$

Similarly the amount of water (GT, mm), required for reaching the maximal rate of saturation from the stage of field capacity is calculated as follows:

$$GT = 10 \times D \times (P - KP) = 10 \times D \times GP \tag{5}$$

The determination of the significant time periods (T)

T_1 is received by solving the equation:

$$NR(t) = K1(t) \quad (6)$$

There is no rainfall excess between the time periods t = 0 and t = T_1; i. e. RE(t) = 0.

The rainfall excess between T_1 and T_2 is

$$RE(t) = NR(t)\text{-}K1(t) \quad (7)$$

T_2 is calculated as follows: the amount of water necessary for reaching the field capacity (equation (4)) is equalized with the function $K_1(t)$ integrated for the interval of (0, t). The unknown x (time in min) is then calculated by solving this new equation:

$$KT_1 = \int_0^x K_1(t)dt (= CK_1(x)) \quad (8)$$

The water absorption of the plough-pan starts at time T_2. If we suppose that this initially exceeds the rate of hydraulic conductivity in the topsoil we get to

$$K1(t) = K2(t\text{-}T2) \quad (9)$$

By solving this equation we receive the time period T_3 marking the initiation of backwater into the topsoil. In case equation (9) cannot be solved, or $T_3 < T_2$, then T_3 is taken to be equal with T_2. The development of rainfall excess happens in accordance with equation (7) during the period between T_2 and T_3.

This process will last as long as the period T_4, marking the limit of maximal water content (see equation (5)). T_4 is received by solving the following equation for x:

$$\int_{T_3}^{x} K_1(t)dt - \left[\int_{T_2}^{x} K_2(t - T_2)dt - \int_{T_2}^{T_3} K_1(t - T_2)dt \right] = GT_1 \quad (10)$$

The first term gives the total amount of water infiltrated into the soil from T_3, while the last two terms give the part that managed to infiltrate into the lower plough-pan. The pace of rainfall excess formation changes after T_4. It happens in accordance with the equation:

$$RE(t) = NR(t)\text{-}K2(t\text{-}T2) \quad (11)$$

There is a sudden change in the formation of rainfall excess at T_4, which is normally weakened under natural conditions. In order to make RE(t) continuous, the function was linearized between $0{,}95 \times T_4$ and $1{,}05 \times T_4$. The length of the interval defined by this linear equation can be modified later on depending on the outcome of control measurements.

The runoff submodel

When the net amount of rainfall exceeds infiltration, this results in the formation of rainfall excess on the surface (RE(t)). This excess rainfall starts moving down the slope in accordance with the law of gravity, influenced by such factors as the angle of the slope and surface roughness. The thickness of the water film is given by the equation h, derived from solving the following binary differential equation containing partial derivates and adopted from the EUROSEM model (MORGAN et al., 1993):

$$\frac{dh(x,k)}{dk} + \frac{5}{3} \cdot \frac{S^{0,5}}{MANN} \cdot h(x,k)^{\frac{2}{3}} \cdot \frac{dh(x,k)}{dx} = 1000 \cdot MRE(k) \qquad (12)$$

where:

x: is the distance measured from the upper end of the parcel (m)

k: is the time elapsed from the initiation of rainfall in sec (k = t×60)

h(x, k): is the thickness of the water film at a distance of *x* m from the upper end of the plot at time *k* (m)

MRE(k): is the amount of excess rainfall in relation to time given in sec (mm/min)

As the amounts under examination are independent of the width of the plot they are given for a unit size parcel (width = 1 m). The equation can be solved by a four-point implicit method utilizing the Newton-Raphson technique. The initial criterion is h(0, 0) = 0. By knowing the function h(x, k), the velocity of the downward moving water film can also be determined:

$$v(x,k) = \frac{S^{0,5}}{MANN} \cdot h^{\frac{2}{3}}(x,k) \qquad (13)$$

where v(x, k) marks velocity in m/s.

Furthermore, the discharge can also be calculated:

$$MQ(x,k) = \frac{S^{0,5}}{MANN} \cdot h^{\frac{5}{3}}(x,k) \qquad (14)$$

where MQ is the discharge rate in m^3/s for a unit size plot with a width of 1m (MORGAN, R. P. C. et al. 1993).

The following section describes the outputs that are important for the users of this submodel:

1. the intensity of runoff as a dynamic output (discharge):

$$\frac{Q(L,t)\cdot 1000}{L} \tag{15}$$

in mm/min or

$$Q(L,t)\cdot W \tag{16}$$

m^3/sec (for the whole plot),
where Q is the runoff from a unit size plot (width = 1 m) in relation to time given in minutes (m^3/s).

2. The total runoff in mm (17) or in m^3 (18), when the whole area is considered, as a static output:

$$\frac{1000}{L}\cdot\int_0^T Q(L,t)dt \tag{17}$$

$$W\cdot\int_0^T Q(L,t)dt \tag{18}$$

where T is the length of rainfall duration in minutes.

Summary of results and further possibilities

This article introduced a dynamic mathematical model bearing the following characteristics:

- suitable for the characterizing infiltration and runoff in ploughfields
- applicable for homogenous ploughfields at parcel scale
- applicable for a single event, i. e. capable of characterizing the effects of intensive downpour lasting only for minutes or seconds and longer mild showers as well
- the description of the temporal saturation of the cultivated layer and the backwater effect of the plough-pan gives the theoretical basis of the model

The model presented herein gives the basis for of a newer soil erosion model, with the following development stages:

- inclusion of rainfall events characterized by varying intensities
- determine the load concentration of the surface runoff by having the rate of soil erodability at hand
- and determine the rate of soil erosion with the help of the above.

The final step involves the calibration, testing and refinement of the model via the long-term comparison of theoretical and practical results gained from on location.

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THE INVESTIGATION OF REGIONAL VARIATIONS IN BIOMASS PRODUCTION FOR THE AREA OF THE DANUBE-TISZA INTERFLUVE USING SATELLITE IMAGE ANALYSIS

KOVÁCS, Ferenc

Abstract

Quantitative as well as qualitative alterations in the vegetation cover are good indicators of environmental changes. The present paper discusses the problem of the dynamics of vegetation changes in response to short-term climatic changes via the application of remote sensing methods. According to the spatial and temporal analyses of NOAA AVHRR satellite images for the determination of vegetation index (NDVI) for the area of the Danube-Tisza Interfluve, embedding a period of several decades, seasonal and trend-like dynamics seem to govern the alterations of the vegetation. The spatial analysis of the result gained may help us delineate the areas, which are potentially in danger of a presumed minor climate change.
Keywords: multispectral remote sensing, NOAA AVHRR, NDVI, vegetation dynamics, climate change

Introduction

The regional effects of a presumed climate change within the area of Hungary mainly affect the areas of the Great Hungarian Plains, especially the regions of the SE Great Hungarian Plains and the Danube-Tisza Interfluve. The identification of the effects of increasing temperatures, decreasing precipitation (MOLNÁR, 1996; SZÁSZ, 1997), and decreasing groundwater levels (LIEBE, 2000; RAKONCZAI-BÓDIS, 2001) on the environment at a regional scale, as well as the spatial and temporal delineation of endangered areas are highly important both theoretically and practically.

Several works draw our attention, besides the magnitude of potential dangers, to the necessity of increasing the spatial resolution of the environmental studies and the implementation of these at a regional scale, which would enable the accurate evaluation of the direct outcome of changes (KERTÉSZ et al, 2001). The vegetation cover may be a good indicator for such studies as climate can be regarded as one important factor playing a crucial role in the mobilization of biological energies and determining the actual rate of bioproduction. Changes in habitat conditions can be directly measured on the produced biomass. The analysis of the vegetation may solve the problem of evaluating the environmental effects of a possible climate change in Hungary, as the high scatter of meteorological data, thanks to the basin effect and the presence of overlapping climatic influences in the country, does not indicate a univocal change in all cases.

There are several papers available in the literature dealing with the application of remote sensing methods for the determination of biomass production among different climatic conditions both spatially and temporally (CSORNAI,2001; MASELLI et al, 1998) however, no such studies, embedding a longer period have been carried out in Hungary so far.

The available data series in our analysis, embedding a period of 9 years between 1992 and 2000, does not enable the determination of the relationship between identified vegetation alterations and the possible climate changes. *The aim of the author was to shed light on the effects of climatic differences on the environment within a given time period via the analysis of the vegetation.* The question is thus what changes there are in the vegetation and whether or not there is some sort of a trend in these changes. Can we identify important alterations besides the natural fluctuations? With our results at hand we can also justify the applicability of our method – besides the expansion of our work temporally – to study climate-change-induced alterations in surface processes and landforms.

Materials and methods applied

Data analyzed

Our analysis included the area of the Danube-Tisza Interfluve (**Fig. 1.**). According to geographic analyses the landscape ecological value of the region is expected to decrease in the future (MEZŐSI et al, 1996). The signs of soil moisture quality and differences are well-observable – though at different rate – on the composition of woodlands with deep-rooted arboreal and shallow-rooted non-arboreal plants. Furthermore, woodlands tend to preserve precipitation quite well, thus can be regarded as good indicators of long-term droughts or dry periods[1]. Non-arboreal plants in general react more acutely to short term droughts, since for them water supply comes mostly from precipitation. The primary goal was to observe natural water resources, thus large area irrigated agricultural regions do not fall into the area of analysis.

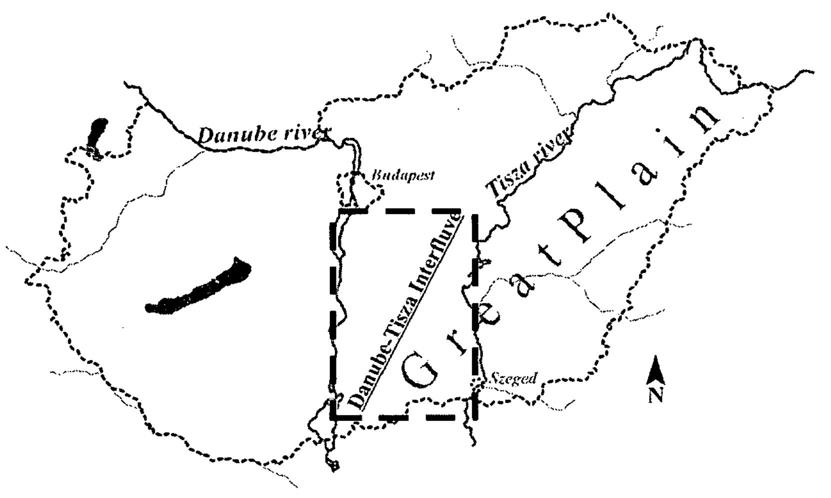

Figure 1. Location of study area (inside the frame)

[1] an important hardship in our work came from the introduction of montane spruces, hardly tolerating droughts, into the area under investigation (Mátyás 1998).

The areas with different surface vegetation were delineated from the digital landscape utilization map of CORINE Land Cover prepared at a scale of 1:100.000. The identification of vegetation cover and surficial forms was carried out on a LANDSAT TM image as well taken in April 1997.

The base of the analyses was given by multispectral satellite images. During the course of our work a monitoring type of analysis was carried out *on the landscape utilization classes of LANDSAT TM image bearing a better resolution with the help of NOAA AVHRR images, bearing a high temporal resolution.* The National Meteorological Survey (OMSZ) did the preparation of AVHRR images providing us with a series of monthly Maximum Value Composites (MVC) with a 1.1 km geometrical resolution for the period between 1994 and 2000, embedding a growth season lasting from April to September. Composites for the years of 1992, 1993 and 1995 are from the free database of the US Geological Survey (USGS) (EIDENSHINK–FAUNDEEN, 1996), which had been utilized following geometric correction. The ranges of wavelengths important for the spectral analysis did not change during the 9 years of the analysis[2].

In order to preserve the best regional resolution and eliminate cloud cover a minimum of 3 and a maximum of 11 MVCs were utilized from the images taken at different times. We have no usable data for several years due to the cloud cover (we have only four complete data series available out of the 9 years analyzed).

For the accurate determination of changes temperature and precipitation data collected by various meteorological stations, located in the area of the Danube-Tisza Interfluve, between 1930 and 2001 have also been utilized (Ásotthalom, Cegléd, Izsák, Kecskemét, Kiskunhalas, Kistelek, Szeged).

The applied methods

The heterogeneous landscape utilization pattern observable in the area of the Danube-Tisza Interfluve prevented a highly detailed determination of plant species or types covering the surface, thus fundamentally two major classes were determined and examined at length regarding the surficial vegetation cover. The class of *woodlands* is made up of the entities of deciduous, coniferous and mixed forests with a spatial value of 25 530 ha, 13 070 ha, and 39 680 ha respectively. These categories were first analyzed individually then the outcomes were synthetized yielding the final results. The gallery forests of Gemenc covering an area of 13 670 ha along the river Danube served as a reference in the comparison with the woodlands of the Danube-Tisza Interfluve.

The class of non-arboreal plants includes the entities of close-to-natural meadows, and pasturelands with a total value of extension of 9560 ha. From the 1,1 km cells of the AVHRR images only the so-called sample or representative pixels were taken into account during the analysis; i.e. those which overlap at least 70-80 % of the given landscape utilization type. Only polygons embedding 3 adjacent sample pixels were evaluated afterwards.

[2] Images between 1992-95. were taken by the satellites NOAA-11, that of 2001 by NOAA-16, and the rest by NOAA-14.

The most generally and frequently used method of predicting net biomass production via spectral analysis is the determination of the Normalized Vegetation Index (NDVI):

$$NDVI = (NIR - R) / (NIR + R)$$

where:

R: the red value of the pixel analyzed,

NIR: close to IR value of the pixel analyzed.

The NDVI values above +0.4 – +0.5 indicate full surficial vegetation cover. Precise surface identification of index values is possible only through on site survey of the sample areas (SZATMÁRI, 2004).

The analysis of NDVI values was carried out monthly and annually for the different individual surfaces. Via considering the distributions of precipitation, *so-called average profiles were constructed for the individual classes analyzed on the basis of the average values of the wetter periods -1996-1999.* The spatial and temporal analysis of alterations from these average profiles may be used for the determination of vegetation growth dynamics and supports delineation of areas threatened by permanent biomass-loss.

The meteorological data series collected in the area under investigation seem to correspond to the trends observable nationally indicating a general decrease in precipitation. They are below the normal value during the analyzed period showing a linearly decreasing trend.

Results

When evaluating the NDVI data the following factor had to be taken into account: *in the period of 1992-1994 the consequences of a period with precipitation decrease beginning in the 1980's, whereas in the second half of the 1990's a phase of higher precipitation (more than 500-600 mm/yr) can be observed.*

The fluctuations of the maximum, average and minimum values of the vegetation index tend to follow a similar path in case of the different vegetation covers, when the whole data series is regarded. A much more rapid spring growth of non-arboreal plants as well as the higher summer biomass production of the woodlands deriving from the foliage can clearly be distinguished in the graphs. Immediate and delayed response of the vegetation to the changes in precipitation can also be observed when viewing the relation between precipitation and NDVI values (**Fig. 2.**).

Concerning yearly NDVI values we can see evenly distributed conditions, so *in general we cannot declare a decreasing or increasing trend of biomass,* however this is not true when dealing with individual months.

When the alterations of the individual monthly values of a growth season are analyzed a *negative trend could have been observed in the average NDVI data series primarily in the months of April, July and September* (**Fig. 3/A-C**). This negative trend tends to be higher for the woodlands compared to the values of the more favorable months (May, June, August). The largest decreasing trend is two times of the value of the largest increasing trend.

Large-scale fluctuations in the NDVI are present in June, with an almost two-fold difference between the average values in the succeeding years. The larger fluctuations of May values tend to level off in the long term.

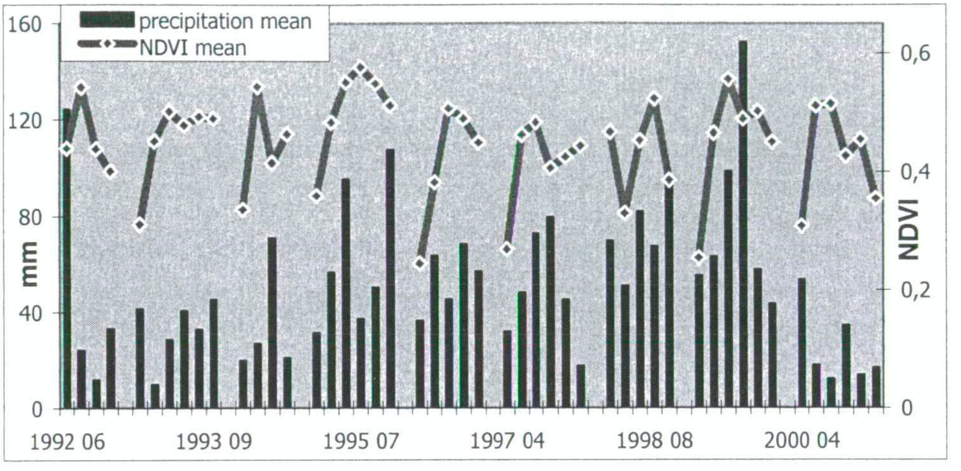

Figure 2. The average NDVI values of deciduous woodlands and average precipitation rates calculated from the measured data of 7 meteorological stations in the area of the Danube-Tisza Interfluve during the summer period

The index profiles clearly indicate the lower biomass values of the much more arid years of 1994 and 2000 as well as the beneficial effects of a more humid 1999 on the vegetation. The year of 1998 is a complex one from the point of NDVI analysis, when these values tend to indicate a more arid period for the months of June and September, and a more humid one for the months of May and August compared to the previous years.

The path as well as the relative position of the reference profile compared to one another meets the expectations concerning vegetation graphs related to different biomass amounts (**Fig. 4.**).

No larger differences than 0.1 can be observed in the deviations from the average. On the whole the positive deviations tend to be prevailing, though there are larger differences in the direction of negative deviations. *Unfavorable alterations are characteristic for the months of June, August and September*, especially in the years of 1994, 1998, and 2000. The smallest negative deviations are observed in the months of April and July.

Via averaging the differences of the years between 1992 and 2000 values between -0.1 and +0.15 were gained. It's important to not that these are average deviations for a period of nine years, thus the seemingly lower values have larger significance. *Fundamentally the amount of biomass produced is decreasing on one fourth of the area of the Danube Tisza Interfluve* (**Fig. 5.**).

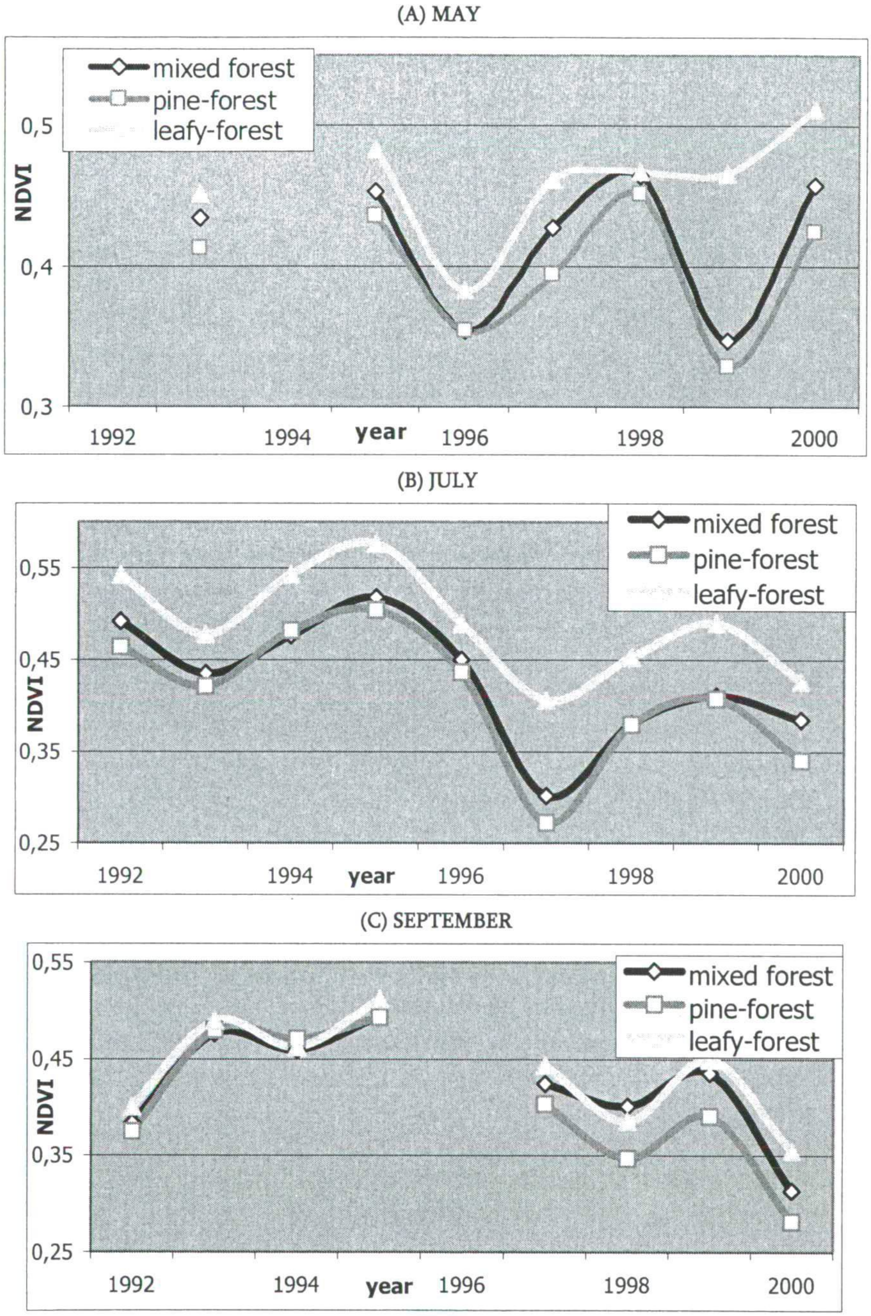

Figure 3. The monthly average NDVI values for the area of the Danube-Tisza Interfluve for deciduous and coniferous woodlands

The most sensitive regions, regarding alterations in the environment are located in the central and southern regions of the area of the Danube-Tisza Interfluve with patches of sensitive areas present in the northern edges as well. Especially it is the mixed forest areas that react the most badly to environmental changes in a given period.

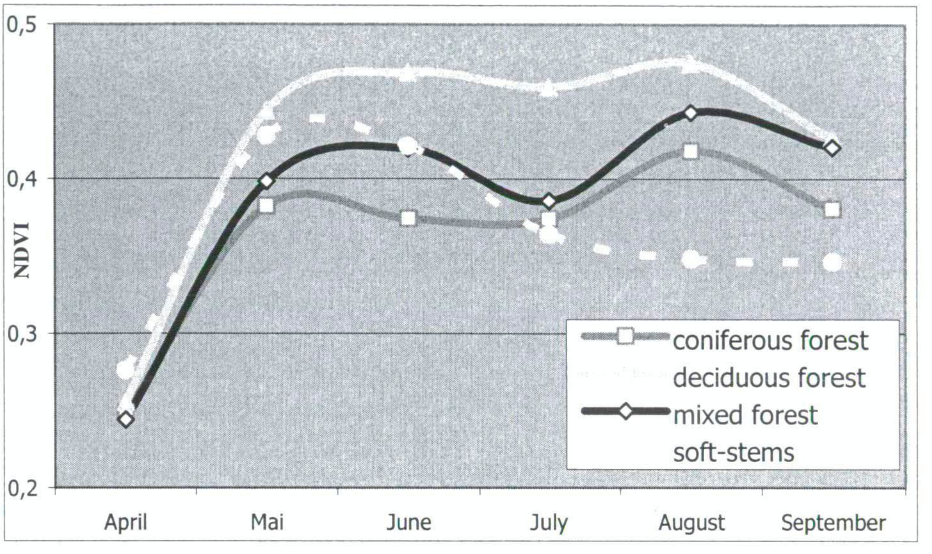

Figure 4. Average profiles for the humid periods

The most important remarks of the analysis

The dominant character of precipitation change is generally well-observable in the vegetation. When looking at the annual values we can observe balanced conditions in the area under investigation, thus no *general decreasing or increasing trends could have been found in this case.* Changes in the biomass are most prominent in the woodlands. One can expect a decreasing activity in the months of April, July and September during the growth season on the long run. According to the results of several approaches, *September can be regarded as a potentially imperiled month and one must account for a great fluctuation of the June values changing annually in the short run.*

No general trend could have been seen either after the analysis of deviations. The negative values of June and August, being favorable formerly, and the favorable values of July are quite remarkable. The prevailing positive deviations are counterbalanced by the large but less frequent negative deviations. *We must account for a decrease in the biomass in case of the woodlands of the central and south-eastern parts of the Danube-Tisza Interfluve.* There are significant differences in the NDVI values of the gallery forests along the river Danube, originally marked out for a reference area, which would require further investigations on the conditions of the vegetation.

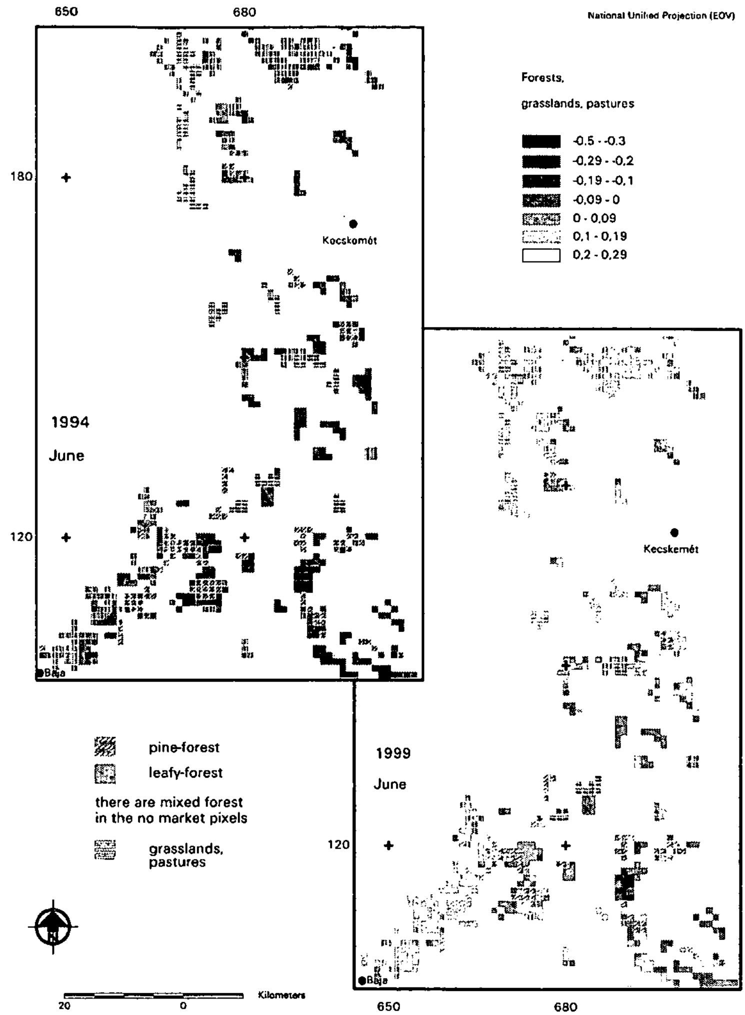

Figure 5. The regional distribution of NDVI differences for the area of the Danube-Tisza Interfluve

Summary

Multispectral vegetation analysis is considered to be the most frequently used and general tools of remote sensing. With the results reflecting geographical and environmental changes on a regional scale at hand we can say that this method, formerly applied to several other areas in different studies, is suitable for the investigation of highly heterogeneous areas regarding landuse at the given scale of the analysis. However, in order to gain objective results the steps of geoinformatical processing should be adhered to within the possibilities of the given heterogeneity and resolution.

The multiaspect analysis of NDVI data during the investigation of spatial and temporal vegetation changes enabled the determination of periodic, trend-like and other irregular fluctuations of the vegetation within the time span of nine years. Despite the short time involved, several alterations could have been identified reflecting natural and antrophogenic aridification. However, a further extension of our analysis in time as well as the comparison of our findings with other measured data on the surface is necessary for the refinement of our findings. The discovery of a strong link between the satellite images with different spatial resolution necessary for long-term multispectral analysis would open up newer possibilities for objective data evaluation. If we manage to find sufficient correlation between the vegetation index values calculated from the LANDSAT TM images and the NDVI values of the AVHRR images then the formerly mentioned method utilized in our analysis is applicable to data available down to the 1980's.

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EXPERIMENTAL APPLICATIONS OF PREDICTIVE MODELING IN ARCHEOLOGY

FEJES, Csaba

Abstract

As Boast put it righteously "there is no basic difference in the way of human thinking between primitive and civilized cultures" starting off from the first intentional deeds, through the man of the medieval times up to the modern man of today. Settlements are generally established in areas where the environment is capable to support human needs. Thus the environment is an important influencing factor on the presence and distribution of humans, and this special relationship must be also quantifiable, analyzable in a given way.

The major aim of the present study was to shed light onto various phenomena and their interrelations, the collective appearance or presence of which may refer to the existence of a prehistoric, mainly archean archeological site nearby with great certainty in an area with measurable physical properties or parameters. With the help of the exposed relationships a category map can be prepared for a less investigated area, which depicts the probability for the presence of a human settlement or archeological site. The gained results may be a good starting point for planning future excavations or any other kind of research.

Thanks to the large-scale variety of data and procedures applied in the model, the collective usage of different analytical and statistical methods and approaches had to be utilized in our work ranging from the fields of geostatistics (logarithmic regression analysis) through geoinformatics (digital elevation model) to remote sensing (Landsat TM indexes).

Keywords: predictive modeling, GIS, geography, archeology

Introduction

There has been a really spectacular increase in the demand of getting to know our past and cultural heritage especially for the last few years. On the other hand, the available financial resources for widening our information background on the subject have experienced a relative drop.

This is truly alarming, as the detailed survey and analysis of even a small area may require huge sums of money. Another major problem comes from the fact that only a small portion of the known, plus the not yet discovered but existing archeological sites have been documented by archeologists so far, yielding some sort of data loss complemented by a continuous perishment of artifacts causing a similar problem.

All these alarming phenomena called for the development of special methods and approaches, which may on the one hand reduce the amount of money necessary for detailed field surveys via increasing the number of known sites on the other hand.

One such efficient approaches might be the construction of predictive models.

The practice of predictive modeling is quite common from the middle part of the 1980s, initially used only in medicine and business planning. However, it has recently becoming more and more widespread in archeological research as well. These models allow for the spatial and temporal expansion of known patterns and interrelationships. Thus they might be extremely useful in archeology as well.

Archeological predictive modeling is based on the assumption that human settlements generally develop in areas offering ideal natural endowments to meet the demands of human cultural groups on the one hand. On the other hand, it also presumes that traces of the former environmental conditions can be relatively well assessed even today as well, even if it requires the application of indirect methods mostly. The major purpose of the constructed model was to reveal these traces and those differences between them, which might have had a decisive role regarding the development of a human settlement or archeological site. In other words, the major task of archeological predictive modeling is to offer a reliable identification method of those natural and social factors, which had fundamental influences on human activities and regard the settlement as a feedback given to these factors by human communities.

The clear distinction between settlements and other areas is fundamental, giving the basis of the algorithms used in the model for the statistical classification of the studied parts of a pilot area via the measurable parameters of the surrounding environment and noting the possibility for the presence or lack of settlement sites in the pilot area. Consequently, these models are capable to predict the probability of the presence of such settlement sites in a given pilot area via the quantitative analysis of the environmental parameters. One of the major strength of the method is the utilization of explicit data and variables enabling the adequate reproduction and verification of the received results.

One of the practical benefits of the model is its applicability to extensive, less investigated areas, where the majority of archeological sites or former human settlement sites are not yet. Knowing the predicted distribution probabilities is useful for several reasons. With the help of the results of the model, one can get a clear view of not only the probabilities for the presence of archeological sites in a pilot area, but can receive useful information on the parameters, which might have actually influenced the development of the settlement itself as well. Furthermore, these models might be useful in planning regional management and development measures via highlighting the areas worthy for protection. As from 2001 during the course of a general land resource assessment (filing a conception of urban development, local construction regulations) the preparation of a detailed survey regarding the presence and distribution of cultural heritage values is compulsory in Hungary. Models with such scope may be extremely useful in these applications as well, since as one chapter of the bill says "all areas where the potential presence of archeological sites can be justified or presumed should be considered as archeological areas worthy of protection, including all natural and artificial ditches and watercourses as well". This is exactly what we are doing with the help of our predictive models. Furthermore, the gained results may be also useful in other research applications as well.

The present study is a clear example of the first experimental application of the above mentioned modeling method to local Hungarian examples. The results are mainly applicable to prehistoric sites.

Material and methods

The pilot area

The area chosen for detailed analysis is located in Békés county, at the interface of the southern marginal areas of the basin of the Hármas-Körös and the Békés-Csongrád Lowland, covering an area of about 130 km2 north of the city of Békéscsaba. (**Fig. 1.**) The most important geomorphological forms are two Pleistocene abandoned riverbeds of the ancient river Maros, presently signified as Hajdú-(Kamut) valley, and Kondoros brook, located east of the former. These channels were active riverbeds even during the Oldest Pleistocene as well (from 2.5 MA to 650 ka) corresponding to the northernmost margin of river migration as well.

The channels were not active during the Holocene, receiving water supply only from the rainfall and groundwaters forming a continuous water surface in these inactive riverbeds. It must be noted that during times of high floods, when floodwaters also managed to reach these channels, they might have been turned into active watercourses, acting as drainage channels on the floodplain.

The geomorphology of the Pleistocene was fundamentally determined by the alluvial fan deposits of the river Maros, composed of coarse sands and gravels. This setting fundamentally determines the general morphology and view of the referred landscape even today as well.

The former loess steppes, constituting the original natural vegetation have been replaced by extensive arable lands. Traces of the original vegetation are observable in some protected areas only, like the Cumanian burial mounds. And their former extents are known only from written historical sources.

Data utilized

The following types of data groups have been used in our work:

- Topographic data
- Spectral data
- Soil data
- Attributes

As a first step a digital elevation model depicting the relief conditions of the area was prepared. For this stereographic maps with a scale of 1:10000, frequently used by archeologists were scanned and transformed into the national uniform projection system (EOV). Afterwards, contour lines and elevation points were digitized and the received layers were used for the construction of the DEM using the software pack Arc/Info 8.1.

The archeological sites identified by archeologists during the course of field surveys were depicted on the scanned maps, so they just had to be transformed into a digital vector or raster format from the corrected digital maps.

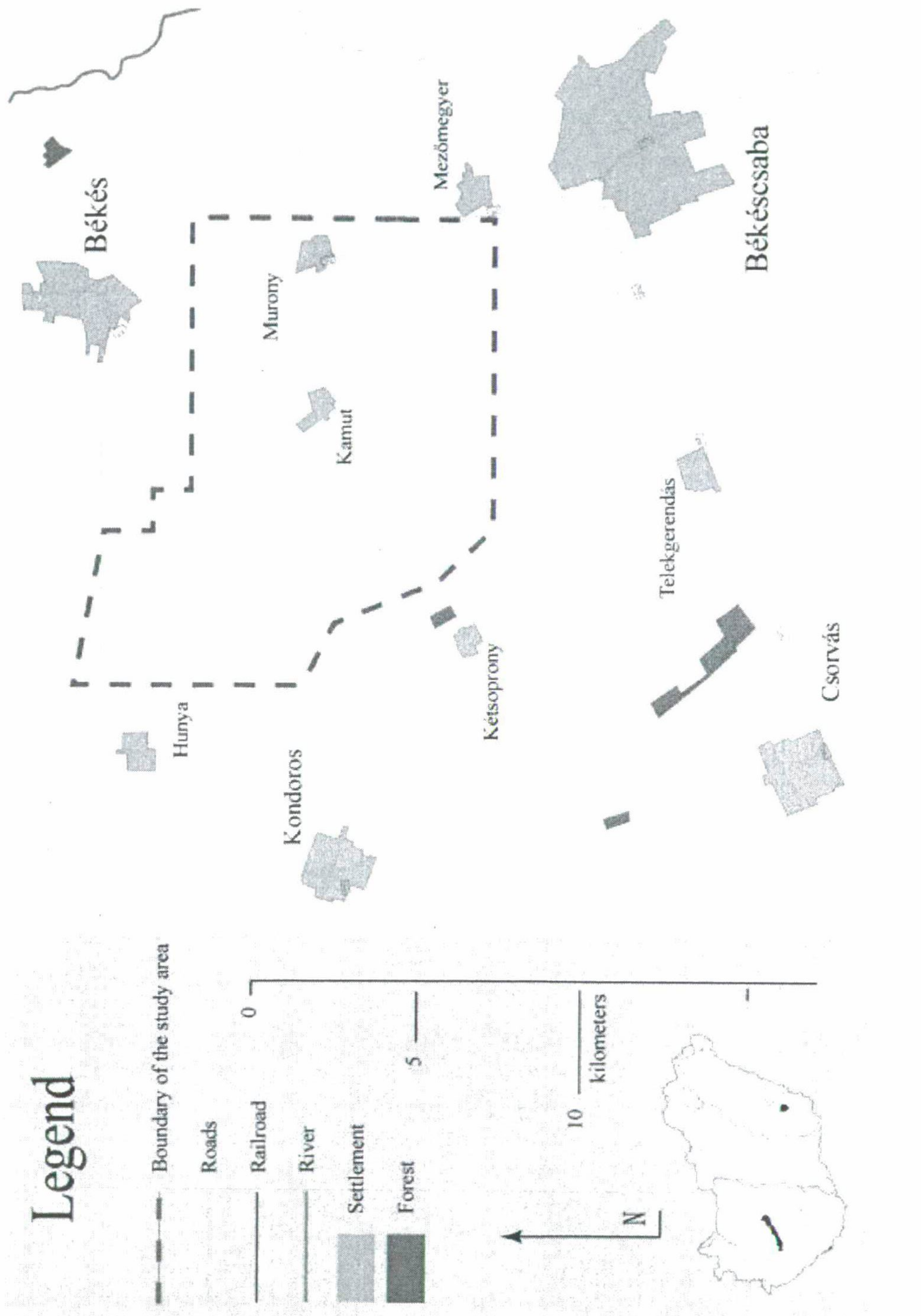

Figure 1. The location of the pilot area

The utilized spectral data, deriving from Landsat and TM satellite images correspond to such environmental parameters as soil temperature and humidity, as well as vegetation cover. These were received via the use of the ERDAS IMAGINE 8.4 software pack.

The low resolution (30 m) of the photos hampered the possibility of getting direct information on the location of the individual field objects. However, with the calculated indexes the individual areas could have been ordered regarding the probabilities for the presence of these objects.

The soil map layer was already in a digital format with a scale of 1:25000. The descriptive attributes of the model storing the name, age and code of the archeological sites derive from the archeological field reports and the volume entitled the Archeological Topography of Hungary.

Data processing was carried out in two steps. As a first step the raw data were transformed into a digital format, unless it was in that format, creating layers readable by the GIS software systems serving as starting layers for further analysis of the utilized environmental variables. These are the so-called primary layers.

The second step involved the construction of the so-called secondary layers, which contained only those variables deriving from the analysis of the primary layers, which directly participate in the modeling process.

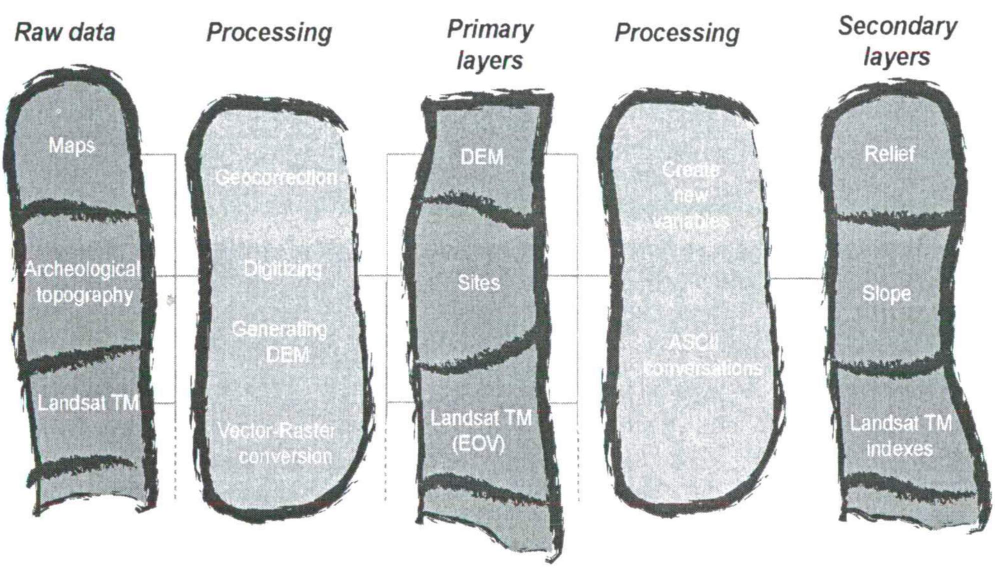

Figure 2.a The steps of predictive modeling (after Warren)

Raw data: maps, archeological topography, Landsat, TM photos; Primary Processing: transformation, digitizing, DEM construction, vector-raster conversion Primary layers: DEM, archeological sites, Landsat, TM (EOV) Secondary processing: new variables, ASCII conversion Secondary layers: relief, slope, Landsat, TM indexes

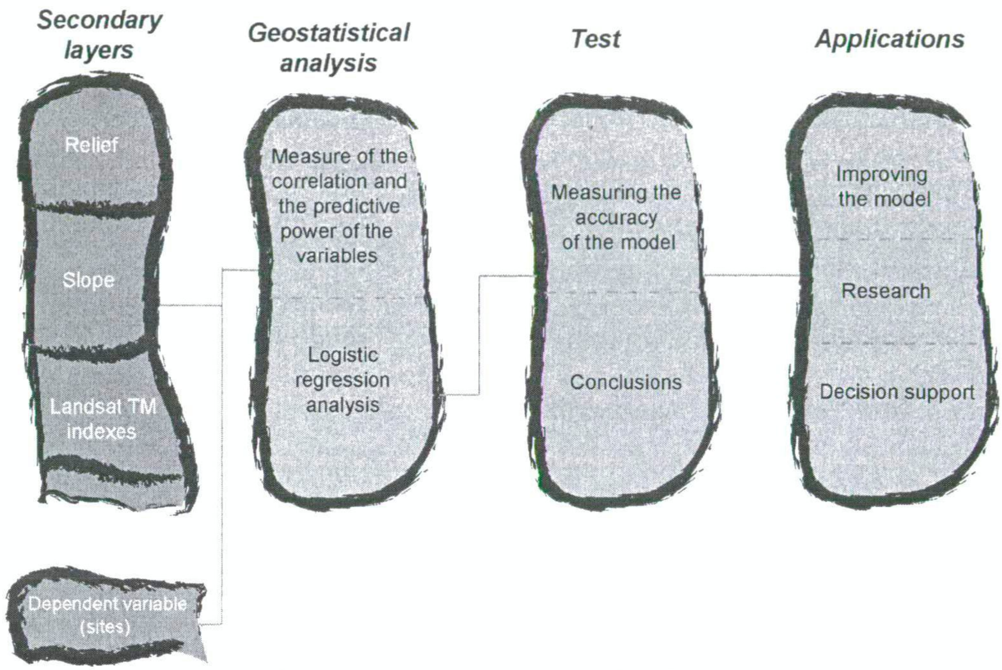

Figure 2.b The steps of predictive modeling (after Warren)

Secondary layers: relief, slope, Landsat, TM indexes, dependent variables (archeological sites) Geostatistical analysis: correlation and applicability, logistic regression analysis Testing: verification of predicted results, conclusions Usage: model improvements, research, support for decision making

Methods

The application of predictive modeling requires three major steps:

- Choosing dependent variables
- Choosing independent variables
- Assessing the relationship between these two variables

First let us have a look at what we can consider as dependent and independent variables.

Dependent variables were the raster layers containing information on the archeological sites, where the cells covering the sites were assigned a value of 1, while those cells not covering the sites received a value of 0. Cells located outside the pilot area had a value of NODATA.

The independent variables – in the factor of which we are examining the probabilities of the presence of sites- are the environmental parameters such as slope, exposure, relief, soil humidity, vegetation cover, genetic soil types, excess surface water inundation, and distance from watercourses.

Most likely, a lot of critics will let me know after the reading of this paper that there is not a single social or cultural component among these variables. And you know what they are absolutely right, at least, partly.

Since the cultural evolution of a human group is a very complex process, there is every reason to believe that nature and the parameters of the environment are important not only in the initial phase but during the whole process greatly influencing the shaping of thoughts and deeds. To put it in another way, in my opinion the characteristics of a culture as well as its demands are fundamentally determined by components of the environment giving the background of its birth as long as the culture is not modified by other external effects.

This must be applicable to hunting-fishing-gathering groups of humans as well as those dwelling on the steppes where the most common ornaments are all organic or naturalistic, referring to the former site and mode of the origin of that culture.

Of course, the non-natural parameters are also important. I just wanted to notify that their complete lack does not necessarily result in the total unreliability of our final results.

After the creation of the sufficient number of dependant and independent variables, their interrelationship should be assessed somehow in the next step of the analysis.

For this let us turn to the method of logistic regression analysis.

Logistic regression analysis

Several statistical methods have been utilized in the process of predictive modeling so far. However, the most popular and common of these is that of logistic regression analysis (ALLEN et al., 1990). This type of regression analysis developed from the method of linear regression. Regression analysis is the best tool for predicting the dependent variable values knowing those of the independent variables, in other words to reveal the relationship existing between two or more variables. In our case we were to shed light on the relationship between the archeological sites and the environmental parameters or components. In case of the logistic regression analysis the dependent variable is dichotomic – has dual value –, the best prediction is related to the probability of actual occurrence or happening, expressed as the logarithm of the quotient of the probability of occurrence and that of none occurrence (CSABA et al., 1997).

During this step our independent variables were introduced into an equation, which predicts the probability for the occurrence or non occurrence of an event in the studied area.

The equation of the process for several independent variables is:

$$p(B) = \frac{-1}{1 + Exp(\alpha + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_i x_i)}$$

where p(B) is the probability of occurrence; Exp is the exponential function, α is the section constant, representing the value of the dependent variable, when x = 0; βi is the component of independent variables; xi is the independent variable for the suitable βi coefficient. The procedure uses the so-called maximum-likelihood method for calculating the values of α and β.

This analysis was implemented in the software environment of Arc/Info 8.1 yielding a raster map, where the value of the cells represented the probabilities for the presence of archeological site in that cell unit with values between 0 and 1.

For verification purposes before the second run about 40% of the archeological sites was left out of the analysis using a random function. Thus by applying these removed sites onto the received maps the accuracy of the predictions could have been easily observed.

Results

In the final maps depicting the prehistoric archeological sites the points with the highest probability values were almost all restricted to the areas of the ancient riverbeds (**Figure 3.**). These points managed to perfectly delineate the Kondoros creek. The area of the Hajdú valley was less precisely contoured, but could have been clearly identified.

This must be attributed to the fact, that the area of the Kondoros creek is in a relatively lower position compared to that of the Hajdú valley thus must have enjoyed more waters as well.

The actual sites relatively well correspond to the predicted values. Furthermore, with the help of these values the location of the sites, left out of the analysis for verification purposes, could also have been relatively "precisely" identified.

The scattered peak probabilities along the Kondoros creek must correspond to the former embayments as well as the deepest parts of the ancient channels. As the area was generally poor in surficial watercourses during the Holocene, open water areas must have been restricted to the deepest parts of the former channels only. So it's quite apparent why many sites turned up in these areas.

Calculated probability values, contour line of the sites

The calculated probability values mostly draw out the outline of the former channels and the once existing morphological features of the area (the correlation coefficient between the probability values and the relief values is 0.8).

Consequently, the natural endowments must have played a crucial role in the settlement strategy and location of the ancient prehistoric human communities.

The model was run for three other cases too, when sites of three distinct historical periods present in large numbers in the pilot area were individually depicted (the age of the Sarmatians, Avars and the Arpadian period).

However, only the presence of sites connected to the channels could have been clearly justified with this method. It must be attributed to the fact, that these cultures were not as much dependent on the natural endowments of the area as the formerly examined prehistoric archaic groups.

To improve the reliability of predictions, in these cases the social parameters must also be given consideration in the models.

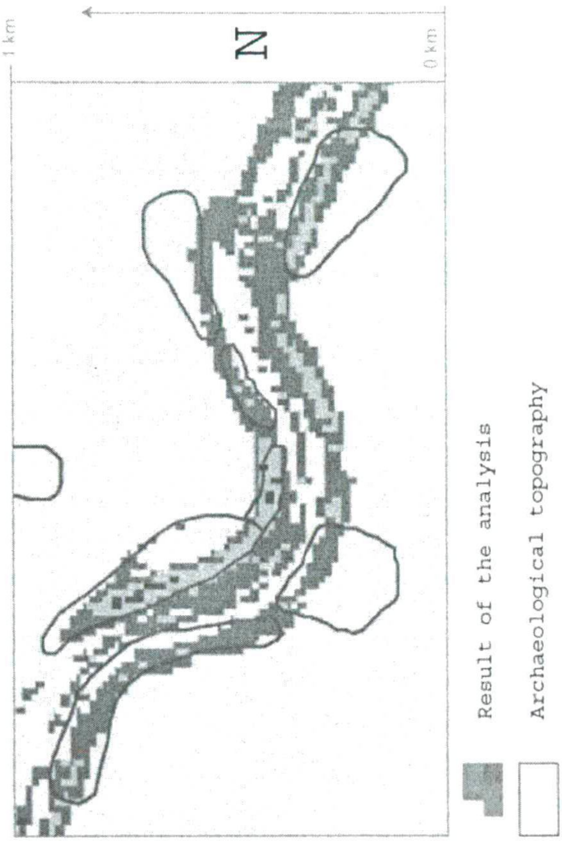

Figure 3. The final map with the location of the archeological sites depicted

Summary

On the whole the newly established predictive model was suitable for predicting the probability of the occurrence of archeological sites dated to the archaic prehistoric period. Thus the primary goal in the initial identification of these sites preceding archeological field surveys and understand the spatial characteristics of the identified settlement types was met for the period of the archaic cultures. However, in case of the younger cultural groups the results were not convincing and the model requires improvements.

There must be several reasons for this. It's possible that the quality of the raw data used for the calculation of the independent variables was not fully suitable for the task; like for example they derive from a Landsat image taken during a drought. Another possible source of error might result from the improper assignment of the sites during the field surveys, as in the practice of archeological topography even five pottery remains or fragments are considered to represent a site as well. Thus the exact delineation of such sites is utmost impossible via the application of the predictive method. Moreover, data on such sites are even harmful regarding the success of the outcome.

Despite all this, the utilized independent variables seemed to have yielded acceptable results in predicting the presence of archaic archeological sites. Since the actual physical parameters of the environment had the most decisive role in the settlement strategy during this time period.

In order to attain higher accuracy, the selection of the layers containing information on the natural environment should be carefully revised and tested. Furthermore, the introduction of the social and cultural parameters into the model may also enhance the reliability of the application rendering it suitable for use in the case of younger cultures as well in the future.

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WATER SUPPLY AND VEGETATION SYSTEM OF STREAM CIBULKA

HORVÁTH, Dénes – FARSANG, Andrea – BARTA, Károly – KITKA, Gergely

Introduction

The Stream Cibulka located in front of the Velencei Mountains (**Fig. 1.**) was probably not a „significant" water course either at the time of its first military depiction (in the second part of the 1700s). The spontaneous nature of the vegetation of the small water course surrounded by fields already at that time, distinguishes the stream from the surrounding areas. Thus, although the water course does not have any special natural qualities, it poses several interesting questions which can be considered to be "up-to-date".

Figure 1. River basin and the surroundings of the Stream Cibulka

The Stream Cibulka is a temporary water course. Its river bed is basically man-made in its overall length, it has a straight run-off and a regular cross-section (obtrapeziform) (**Fig. 2.**). The wetland, which undoubtedly used to surround the stream, has now almost completely disappeared. The same thing happened to the "services" provided by this wetland free of price. Recognizing this problem, there have been more and more efforts aiming at revitalisation-rehabilitation activities (NAGY, 2001; UDVARDI, 2001).

Approaching the subject from this perspective, we ask questions regarding particularly the environmental science, since our aim is to influence our own habitat and to establish more favourable conditions for ourselves.

Ecology has a different approach towards the same subject. Its main area of interest is the question, which species does this small regulated water course (water channel at the site, we would perhaps prefer using the expression water cannel instead), which has been surrounded by fields for centuries and which has a river basin that has been intensively cultivated until today, serve as a habitat. Furthermore, to what extent is the vegetation system in accord with the soil qualities, among them the parameter of water supply.

A potential question from the point of view of Geography (which induces a similar analysis) is the following: where and what sort of wetland does the relief of the river basin and its soil qualities predestinate?

Figure 2. Man-made bed fragments of the Stream Cibulka (taken in April).
Photo by Károly Barta

We have planned our analysis on the basis of the following approach:

1. Relying on the coenological samples and the relative ecological figures (relative groundwater and humidity index (WB)) we examine this kind of differentiation emerging in this vegetation.
2. We record some environment parameters that determine water supply.
3. We compare the results obtained.

To put it briefly, - out of the several questions arising in connection with the topic – we aim at answering the following: What kind of relation is there between some environmental parameters determining water supply and the differentiation in the vegetation?

The Stream Cibula was last regulated in 1982-83, when its overall length was regulated uniformly. The documentation called "Plan on the Recultivation of the Stream Cibulka" [„Cibulka-víz jókarbahelyezési terve"] gives an adequate picture of the work and the current state.

This documentation also contains the only evidence questioning the spontaneous character of the vegetation. It mentions a possible planting of *Baldingera arundinacea* on the lower section of the stream in order to secure the riverside of the newly made bed.

The relative ecological value figures (BORHIDI, 1993) include the likelihood rate of occurrence of the different plant species summed up in relation to the given parameters on the basis of the landscape approach. When we depart from the "prize-chosen" approach, it might result in the wrong interpretation. This also applies to the vegetation criteria that are in accordance with the habitat factors. In connection with the application of these indexes, conditions have a particularly important role (BARTHA, 2002).

Material and methods

We determined a 4.4 km long section of the Stream Cibulka from its spring to the highway M7 to be the examination site. The remaining section of the stream to the water course Vereb-Pázmándi (the estuary is on the territory of Kápolnásnyék) is 2 km long and flows mainly through an inhabited area (there are some places where the river bed is concrete-covered and enclosed), that is why this area we left out of the examination. On the stream segment examined sheep is grazed at irregular intervals; at some places the bed is deepened so that the sheep can drink.

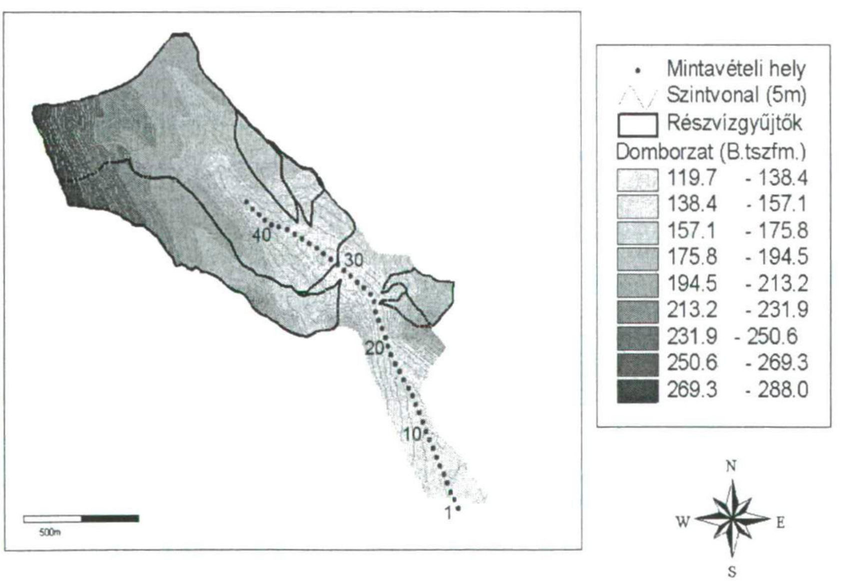


Figure 3. Sampling sites on the river basin and the bed-bottom belonging to the stream section examined

The sampling sites were determined at every 100 meter along the stream. The starting point was determined at random. The numbering of the 44 sampling sites (point 1) starts with the endpoint of the examined section opposite the spring. Thus the spring (the highest point of the man-made bed) is the sampling point 44 (**Fig. 3.**). The vegetation at the bottom of the obtrapeziform bed was characterized by taking coenological samples.

The middle point of the 0.6×1.5 metre sized squares followed each other in every 100 metre. The length side was parallel with the bank sole, the width side was adjusted to the squares located on the narrowest bed segment.

According to the data of the technical plans the width was 0.6 metre (ranging between 0.6 and 1.5 metres). The length of the squares of 5 metres resulted from the consideration of two factors.

Supposing a continuous change or transition in connection with the water supply along the stream, it was appropriate to determine the length of the square to be as short as possible. The other factor considered was to calculate the minimal dimension on the basis of the experience based on the classic coenological data. The coenological samples were collected in the last week of May 2004. We estimated a proportional coverage species by species and an overall coverage. The names of the species and the relative ecological figures (WB) correspond to the ones in the work by Borhidi (BORHIDI, 1993).

At every sampling point a hole was bored into the lower third of the bank slope with a hand drill until reaching the groundwater, then it was plugged with a long-shaped plastic bowl. From April (when the wells were deepened) until August the depth of the groundwater-plane was read at the beginning of each month (between the 6th and 10th). At places where we could not reach the bed bottom after boring 1.5 metres below the groundwater-plane, we stopped boring.

Measuring the height between the bed bottom and the well ledge the distance between the groundwater-plane and the bed bottom could be calculated from the data on the groundwater depth. When the groundwater-plane was measured monthly, it was also recorded whether the bed bottom was dry (bed has dried up) or wet (there was water in the bed).

The data obtained this way make it possible to make a distinction between the influent and effluent segments at every sampling time, so it can be stated that if the groundwater of the areas located on both sides of the bed supply (effluent) or rather drain (iffluent) the water out of the bed.

The soil samples were collected in June 2004. An undisturbed soil sample (0-5 cm) and a surface soil sample weighing approx. 1 kg (0-10 cm) were taken from the middle of the squares of the coenological samples at each sampling point. Following a general sample preparation, the Arany-type soil cohesion index and the vegetable matter content was determined (Tyurin method (BUZÁS, 1988)).

The digital relief model of the river basin and the borders of sub-basins were identified with the program EROSION 3D.

Results

Assessing the data of the groundwater wells

We have summarized the results in **Fig. 4.** The 0 point on the value axis and the horizontal line cutting this point stand for the bed bottom. The positive values (above the horizontal line) indicate that at those points it was the groundwater (spring) that supplied the stream with water.

In these cases some water can be found in the bed (which may also partially result from surface onflow). As for the negative values, the groundwater-plane did not come to the surface in the bed sections belonging to the given sampling point. In the present case the bed can both be dry and wet (should there be some surface onflows).

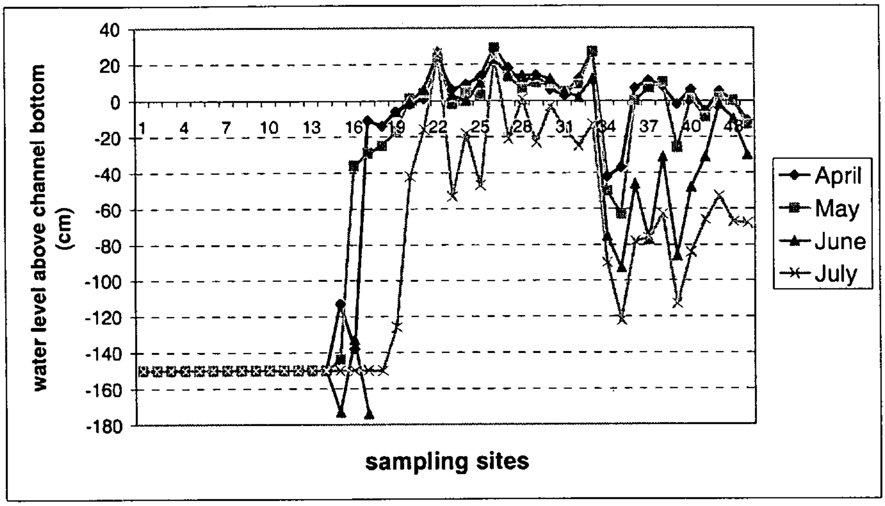


Figure 4. Location of the groundwater compared to the bed bottom

The first 14 sampling sites are uniform regarding the fact that the groundwater was found deeper than 1.5 metres at the time of all the four sample collections. Supposing that the groundwater-plane located deeper than 1.5 metres cannot be the water spring for herbs living in the bed, its depth was not relevant for the examination. The points on this segment of the stream are differentiated on the basis of the data obtained from the groundwater wells. At the remaining 30 points of the examined section in 94% of the cases the groundwater was found in a depth of max. 1.5 metres. In the following this segment is the focus of our examination. In general, it can be stated that the groundwater at all sampling sites decreased at the sampling collection times. The inaccuracy of the measurement was within 5 cm. The water level risings occurring occasionally were within the inaccuracy limits, thus it cannot be claimed whether the water level rising was real. From the point of view of the data obtained at four times and that of the aim of the examination, it is not significant. The pace of the decreasing varies at different sections of the stream. On the basis of this, the 1.2 km long segment located between the points 20 and 32 differs significantly.

A common feature of these points is that on the basis of the data obtained from the first three measurements (April, May, June) the groundwater did not exceed the decrease of 10 centimetres. Considering the data from July this segment is no longer uniform, as at some points the extent of the decrease of the groundwater exceeded even 40-50 centimetres (sampling sites 20, 23, 25); at other points the alteration was within the inaccuracy limits. Comparing the data indicating whether the bed is wet or dry (**Fig. 5.**) and the diagram it we can state that the stream had only four springs at the beginning of July.

There are six sampling sites where the bed contains water, however, there are only four of them where the groundwater comes to the surface (points 22, 26, 28, 30). At the point 30 the groundwater level is found to be 3 cm below the bed bottom, but at the same time, there was water in the bed. The alteration within the inaccuracy limits of 5 cm mainly resulting from the inequality of the bed bottom is of no importance for us; this point is also to be considered to be spring. The springs at the points 26, 28, and 30 cannot provide surface water at the sampling sites located 100 m further down along the stream. The spring at point 22 provides surface water along a section stretching at least 200 metres. Comparing the two figures it can also be stated that going downwards from point 19 to the end of the examined segment the water in the bed comes from the upper segment in each case, as there are no places where groundwater would come to the surface. Consequently, the 1.8 km long segment between the sampling point 1 and 19 can be considered uniformly influent during the examination period.

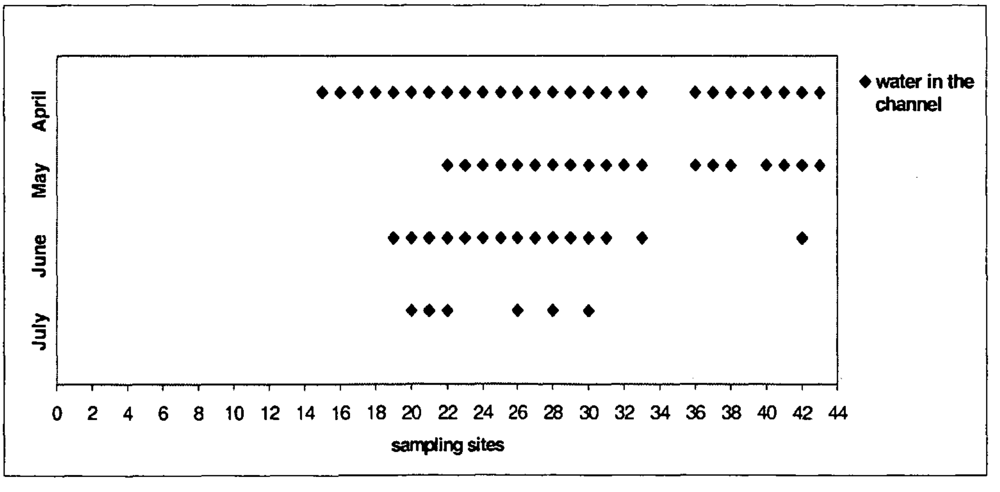


Figure 5. Surface water occurring in the stream bed at different times

The segment bordered by the sampling sites 33 and 44 is characterized by the fact that in comparison with the values from April and May, the decrease in June and July was more significant. On this segment there were only two places where there was water in the bed at the time of the recording in June, and the whole segment turned out to be completely dry at the time of the recording carried out in July.

Results of the pedological analysis

The lowest Arany-type cohesion index fell under the category sandy loam soil, while the highest index fell under the category heavy clay soil (STEFANOVITS, 1999). There is no unambiguous trend alongside the stream. The same may be said in connection with the results concerning the vegetable matter content, as well. The two parameters are in close relation with each other on the basis of the run of the curves. The proposed pedological examinations include determining the distribution of individual particles as well as the cubic mass of the undisturbed samples.

General characterization of the vegetation of the stream bed

The vegetation of the regulated bed cannot be satisfactorily described by listing the communities occurring. The fact that species having different coenological preferences and habitat needs occur "mixed", located near each other is probably the result of the small transversal dimension and of the few species available as well as of the man-made bed shape. Consequently, there are only few points where the characteristic physiognomic picture of some combinations can be observed. The types that still occur and can be unambiguously identified, outline a coenologically "idealized" picture. Based on the National Habitat Classification System (FEKETE ET AL., 1997; BÖLÖNI ET AL., 2003), which is rooted in coenology, after field studies made on several occasions the following picture can be outlined:

The vegetation on the segments where there is water in the bed during the summer for a long time (July-August) is *Glyceria, Sparganum and Schoenoplectus beds* (B2). The most typical species of this kind of vegetation are the following: *Glyceria plicata, Sium erectum, Catabrosa aquatica.* Typically, this zone is accompanied by a string of tall herb communities (*Water-fringing and fen tall herb communities* D5). Characteristic species: *Angelica sylvestris, Mentha longifolia, Epilobium hirsutum. Caricetum acutiformis-riparial* can be seen at some places (*Non-tussock beds for large sedges* B5). Typical species: *Carex acutiformis.* There are some places in the bed that are covered with sedge-marshes (*Eu- and mesotrophic reed and Typha beds* B1a). *Phragmites communis* és *Calystegia sepium* are the most common species.

These habitats often mix with each other, or with uncharacteristic treeless communities (*Uncharacteristic meadows and tall herb communities OB, Uncharacteristic wetlands OA*) forming a "network" difficult to be segmented.

Evaluation based on the coenological samples and the recordings concerning water supply

According to the mean WBs calculated from the group-proportion of the coenological examinations (**Fig. 6.**) it can be seen that there is a declining tendency from sampling point 22 to the lower end (point 1) of the segment analysed. Relying on the evidence represented by the graphs indicating the distance between the groundwater-plane and the surface (**Fig. 4.**) and showing the wet-dry points (**Fig. 5.**) it can be concluded that on this segment there are no such points where the groundwater directly supplies the stream with water except for point 22.

The water in the bed originates from the surface onflows. The declining tendency of the WB index can be explained with the fact that the surface water entering the bed leaks away, consequently, it keeps the lower section wet to a declining extent. **Figure 5.** serves also as a proof of this hypothesis. Below point 15 the bed was always found dry at the four samplings. The distribution of the WB2, WB3, WB4 categories (**Fig. 7.**) suggest a similar conclusion. Species connected to WB2 values occur only on the lowest segment of the stream (in small percentage). The percentage of the occurrence of the species connected to WB3, WB4 is increasing towards point 1, while the percentage of the occurrence of the species connected to WB7, WB8, WB9 shows a declining tendency.

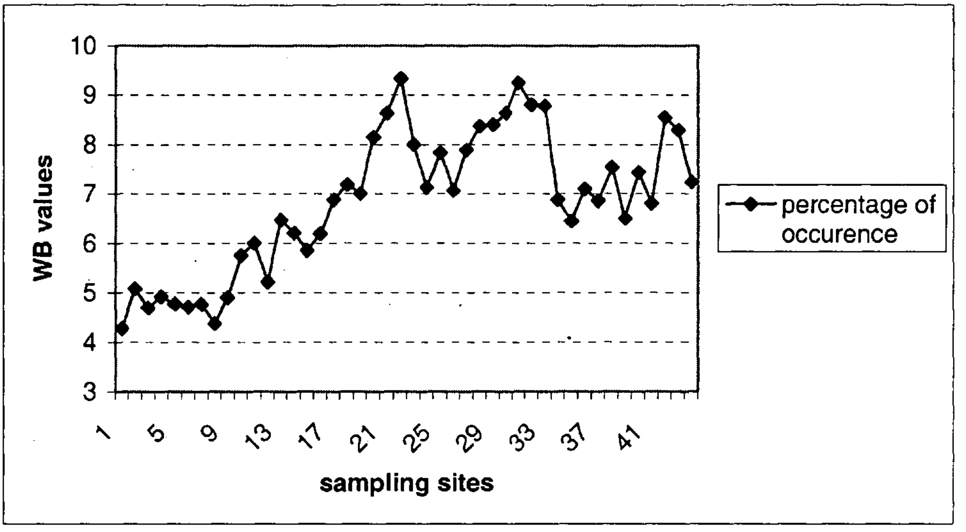
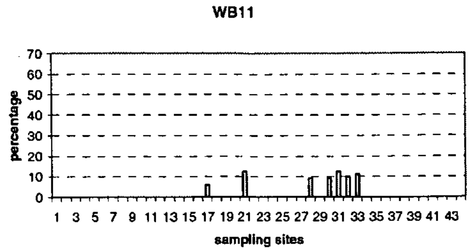
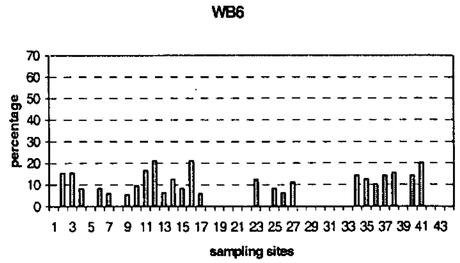


Figure 6. Mean WB calculated from the percentage of occurrence within the group of the coenological samples

The comparison of the segment between point 20 and 23, which was identified on the basis of the data measured directly concerning water supply, with the picture obtained basing on the vegetation is not as unambiguous as the above. Relying on the data recorded in July the low mean of point 26 (7.06) among the four points considered to be springs (22, 26, 28, 30) is especially conspicuous. According to the field minutes a 40 cm long segment of the bed is cut in a depth of approx. 30 cm. The coverage by plants is on this "current line" 0%. The vegetation examined does not characterize the bed bottom but the layers located higher, that is drier levels. Examining the distribution of the WB values based on sampling sites it is remarkable that there are only few places where the species WB2, WB3, WB4, WB5, WB6 occur, and if they occur at all, they cover only a small area, but the species of the category WB7 have a great percentage of occurrence (similar to the species WB8., WB9, WB10.).


WB11
percentage
sampling sites


WB6
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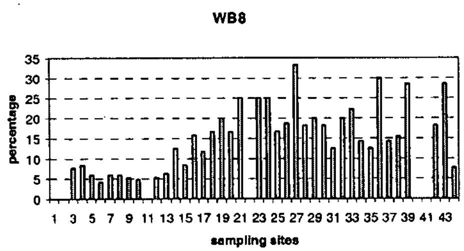
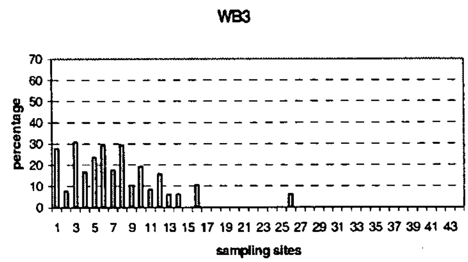
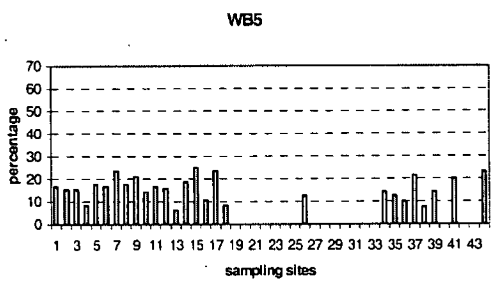
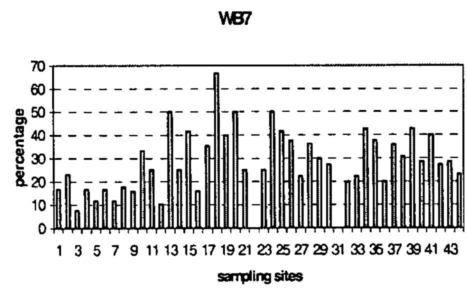
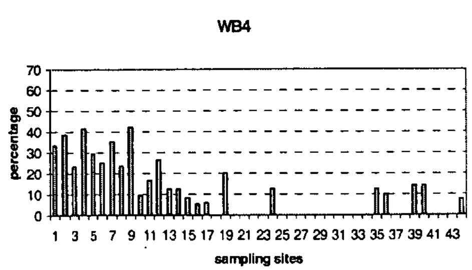
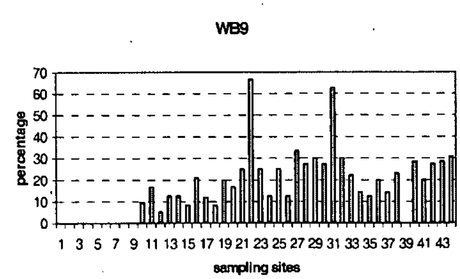

WB8
percentage
sampling sites

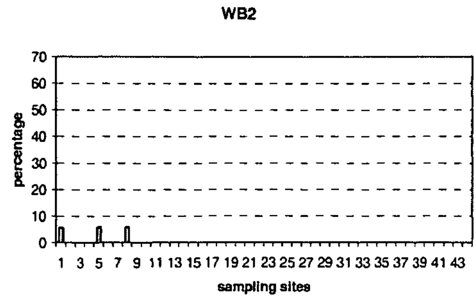

WB3
percentage
sampling sites


WB5
percentage
sampling sites


WB7
percentage
sampling sites


WB4
percentage
sampling sites


WB9
percentage
sampling sites



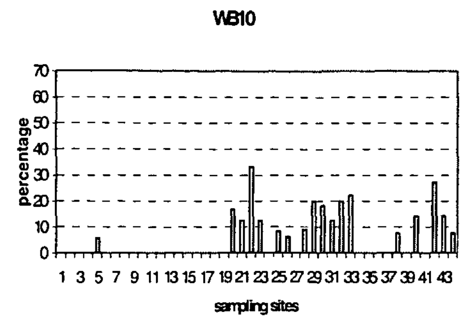


Figure 7. Proportional values calculated on the basis of the percentage of occurrence within the group per WB categories

The mean WB calculated on the segment between point 33 and 44, which was determined on the basis of the date measured concerning water supply, were recorded at the springs in June (points 42, 33). As opposed to the previous group, analysing the distribution it can be concluded that there is no such break to be seen previously as far as the presence and percentage of occurrence of the species of category WB6 and WB7 are concerned.

The depth of the groundwater-plane on the segment from point 19 to 44 (point 26 is left out as a distinct value) measured in June in centimetre is in correlation with means of the WB indexes (percentage of occurrence within the group). The correlation coefficient is 0.81. The relation between the two variables is significant (in addition to a significance of 99%).

Determination of sub-basins

The determined greater sub-basins (**Fig. 3.**) disembogue into the stream bed north of the sampling point 20. The sideward recharge probably decreases on the lower, narrower section of the basin because only a small-sized basin has remained. The data obtained from the groundwater wells have proved this hypothesis since at no sampling times on this section did the groundwater supply the stream with water.

Summary

In our work we aim at discovering the relation between the vegetation system and water supply of a temporary short water course surrounded by fields. We directly record some parameters that determine the water supply (the groundwater depth, soil qualities), while we approach the vegetation by recording coenological data. According to our current data we can conclude that the vegetation of the stream bed (which is difficult to study on the basis of the categories of the syntaxonomical system), it seems to be organized in relation to some measured parameters regarding the water supply.

There is a strong connection between the vegetation examined on the basis of the distance of the groundwater from the bed bottom and on the basis of the mean WB values (percentage of occurrence within the group) of the bed bottom.

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PHYSICAL GEOGRAPHIC CHARACTERISTICS AND GEO-HERITAGE OF FRUŠKA GORA MOUNTAIN (VOJVODINA, SERBIA)

MÉSZÁROS, Minucsér – MARKOVIĆ, Slobodan B. – MIJOVIĆ, Dušan – JOVANOVIĆ, Mlađen

Abstract

Geo-heritage represents a group of all geological, geomorphological, pedological and particular archeological features that are of great scientific and cultural importance (MIJOVIĆ et al., 1999)

The massif of Fruška Gora is the peculiar orographical form and the area of the biggest diversity of geological and pedological formations in Vojvodina. The big numbers of geological, geomorphological and pedological values satisfy to join this mountain in the list of geo-heritage. Greater parts of objects are *in situ*. The most important object of geo heritage, which are separated from their natural habitat, are located in Čerević Country museum and in the Institute for Protection of Nature of Serbia, Department of Novi Sad. Big concentration, diversity and scientific importance of it refer to us to make one step beyond and to proclaim this area for geo-park.

Introduction

Geo-heritage represents a group of all geological, geomorphological, pedological and particular archeological features that are of great scientific and cultural importance (MIJOVIĆ et al., 1999). During the last decades many national and international institutions and communities, whose main aims are making a list, study and management of geo-heritage sites, were formed in Europe. The National Committee for geo-heritage of Yugoslavia, whose projects draw more and more attention of experts as well as of wider public, was also formed. One of such projects, initiated five years ago, is the research of the geo-heritage of Fruška Gora as well. Within the planned activities by now preliminary list of geo-heritage sites has been made, a few suggestions about the protection of the most important geo-heritage sites have been made, and making plans for the promotion of geodiversity and its representatives of the unique mountain in Srem region is in preparation as well.

Fruška Gora is a low, isolated, island-mountain rising above the Vojvodinian plains in northern Serbia, with the highest peak at 539 m (Crveni Čot). Its lens shaped massif extends some 80 km in the direction W-E from the line Šarengrad-Šid from the west to the line Belegiš-Surduk-Stari Slankamen to the east (45° 0'N - 45° 15' N and 16° 37'E - 18° 01' E) (**Fig. 1.**).

With its position beside the river Danube, mineral reserves, unique flora and fauna it has a great economic, transportation and touristic significance. The mountain was declared a National park in 1960. including areas of various level of protection. The goal of protective measures is to ensure sustainable development in this micro region, giving the exploration of natural objects and phenomena a great importance for spatial planning.

Beside it's morphological excellence this mountain massif represents the area of the greatest diversity of geological and pedological formations in the Pannonian part of Serbia.

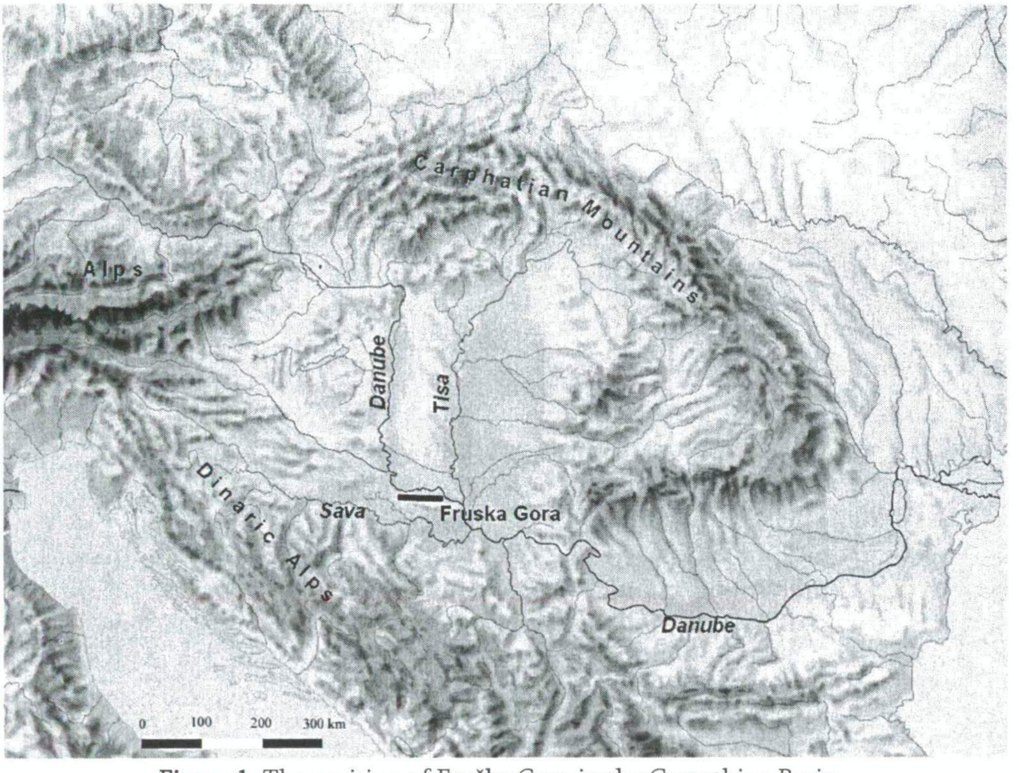

Figure 1. The position of Fruška Gora in the Carpathian Basin
(based on map by László Zentai)

The geological and geomorphological characteristics of Fruška Gora have been intensely studied from the second half of 19th century. Researchers had already noticed a great variety of geological formations of Fruška Gora (WOLF, 1861; KOCH 1871, 1876, 1896; LENZ, 1872; ROCHLITZER, 1877, after PETKOVIĆ et al., 1976.).The most prominent researchers of Fruska gora from this period were A. Koch, who published numerous works about the geologic composition of the mountain and was a devoted explorer of Fruska gora, establishing the foundation for modern studies with his book "A Fruska Gora geológiája" (Budapest, 1895), H. WOLF and O. LENZ whose findings contributed greatly to A. KOCH's works, M. KISPATIC with many valuable petrologic analyses.

The most important studies about geology, relief, hidrology, climate and pedology of Fruška Gora made by MILIĆ (1973), PETROVIĆ et al. (1973), MILOSAVLJEVIĆ et al. (1973), PETKOVIĆ et al. (1976), KNEŽEVIĆ (1995/97), MILJKOVIĆ (1973, 2001) and MARKOVIĆ et al. (2001).

All these works provided a detailed, but fragmented and unsystematic knowledge about the natural characteristics of Fruska gora. A comprehensive monograph about the physical geography of Fruska gora was published by Matica srpska from 1973. The monograph consists of 5 books dealing with geologic and tectonic structure, geomorphology, climate, waters and soils of Fruska gora, containing the summary of results of previous studies corrected or extended with the newest findings.

Geologic and tectonic characteristics

The geologic composition of Fruska gora is very complex. The soil and vegetation that cover almost the entire mountain greatly reduce the possibilities of direct observation. Some geologic features can be recognized in open profiles of quarries, uncovered loess profiles, clay mines, and valleys of water streams, especially if they contain fossils. Tectonic movements and metamorphism have changed the original position and constitution of rocks in many places, especially in central parts of the mountain, which makes reconstruction nearly impossible.

The base of the mountain consists of highly metamorphosed probably Paleozoic-aged rocks represented with green schists and phyllite, which reach the surface along the ridge. In the absence of paleontological find from the Paleozoic period, it is difficult to date these rocks in the core and ridge of the mountain.

Mesozoic sediments occupy smaller area, and are generally thinner. Mesozoic is represented with Triassic red and gray sandstones and mica schist, reddish lime stones, conglomerates and breccias, and cretaceous sandstones, conglomerates, lime stones, dolomites and flisch rich in some of the oldest fossils on the mountain.

Tertiary sediments cover large surfaces on the peripheral area of the mountain and are represented with marl, sandstones, and conglomerates.

Quaternary sediments are represented with thick loess cover, which can be found in the lower parts of the mountain and alluvial sediments, gravel and sand.

Magmatic rocks can be found around the tectonic faults, in forms of intrusions in Mesozoic and Cenozoic sediments, and both effusive forms - submarine/sublacustric and continental, and finally in form of tuff. These rocks date from Paleozoic, Triassic, Cretaceous and Tertiary period, and are represented with gabbros, diabase, trachytes which are being intensively mined in quarries for building material. One of the disputed environmental questions is related to a quarry near the Ledinacko Lake, which was formed during the process of exploitation. Further mining could damage the unique ecosystem around the lake and pollute its waters, and destroy its touristic potential.

Fruska gora is the easternmost representative from a range of low, isolated, hilly island-mountains (e.g. Papuk, Psunj) in Slavonia, Croatia, continuing southwards to the mountains of Sumadija in central Serbia (PETKOVIC, 1952).

Common to these various mountains are their E-W orientation, Paleozoic crystalline core with serpentine, magmatic intrusions along tectonic faults, their similar geologic composition consisting of Paleozoic, Triassic, Jurassic and upper Cretaceous layers covered with quaternary sediments. Questions were raised about the place and role of these mountains in the Alpine orogene.

According to one view, the Fruska gora and other mountains in this range belong to the Alpine system. More recent explorations of the Pannonian-basin support the view that the Fruska gora can be grouped in the Dinaric-Alpine system.

The formation of Fruska gora began in the upper cretaceous period, when a horst started to emerge from the surrounding terrain, which was subjected to tectonic sinking. The anticline core of the horst started to form between the Austrian and Savic phases in the Alpine orogene. From the early Miocene, a series of transgressions and regressions combined with epeirogenic movement and tectonic faulting exposed the mountain to erosion. Finally in the period of late Pleistocene and the beginning of Holocene loess and alluvial sediments were deposited and during this time an epeirogenic arch was formed, with its axis orthogonal to the sides of the anticline in the basis of the mountain.

Climate conditions

The climate of Fruska gora, as an isolated mountain significantly differs from its surroundings, and modifies the local meteorological conditions. Although the mountain is low, the wooded slopes and the E-W direction of the ridge influence the passing air masses greatly.

Table 1. Mean monthly and annual temperature for meteorological stations Petrovaradin and Iriski venac for the period 1968-1980
(source: Climatological Yearbooks for period 1968-1980)

Month / T(°C)	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Yr.
Petrovaradin	1.1	3.5	7.7	11.3	16	19.9	21.3	20.9	16.9	11.5	6.4	2.5	11.7
Iriski venac	-0.7	0.3	4	10.2	14.7	18.3	20.3	20.5	17	11.4	4.9	1.5	10.2

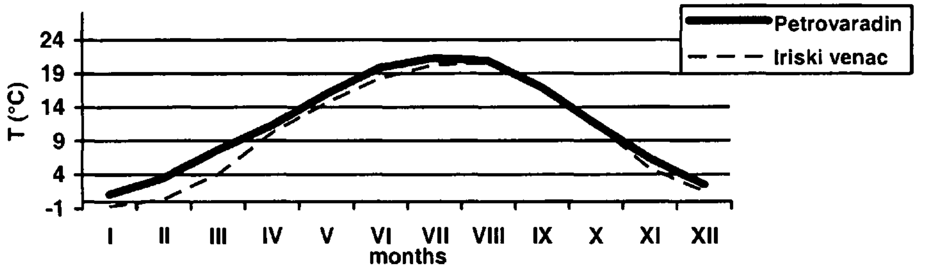

Figure 1. Mean monthly temperature for meteorological stations Petrovaradin and Iriski venac for the period 1968-1980 (source: Climatological Yearbooks for period 1968-1980)

Humid air masses coming from NW supply the northern part of the mountain with much higher annual precipitation compared to the surrounding lowlands. The strong SE winds called Kosava diverge on the eastern edge of the mountain, losing their intensity.

The temperatures fall according to increasing height. The following figures illustrate the climatic conditions by comparing lower parts of the mountain (Petrovaradin at 80 m) with higher parts (Iriski venac at 444 m)

Some of the typical problems arising from the climate influence on Fruska gora are soil erosion, landslides, and air pollution from the cement Factory in Beocin. The problem of air pollution from the cement factory is caused by the misplacement of heavy pollution emitting objects in the vicinity of nearby settlements. The planners did not consider the prevailing wind directions, which carries and deposits the fine dust from the factory on the settlements. This represents a great health hazard for the local population, and degrades the environment.

Table 2. Mean monthly and annual precipitation for meteorological stations Petrovaradin and Iriski venac for the period 1968-1980
(source: Climatological Yearbooks for period 1968-1980)

Month / mm	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Yr.
Petrovaradin	32	34	33	47	59	79	53	69	44	52	47	36	598
Iriski venac	64	69	52	64	89	91	65	48	45	48	74	79	788

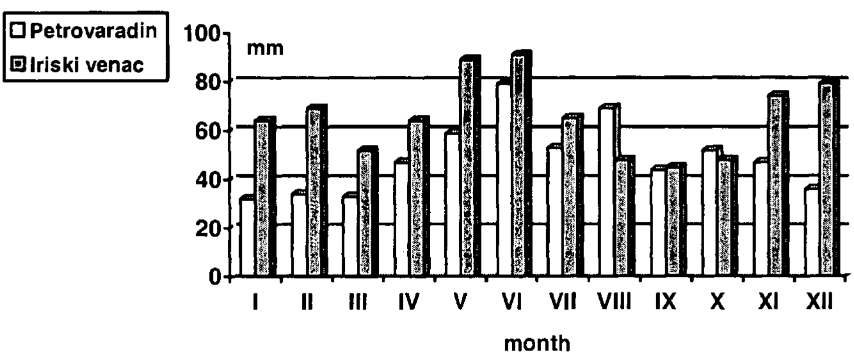

Figure 2. Mean monthly precipitation for meteorological stations Petrovaradin and Iriski venac for the period 1968-1980
(source: Climatological Yearbooks for period 1968-1980)

Hydrology

Fruska gora is a water rich mountain. Numerous drainage valleys dissect the surface from the vicinity of the ridge to the base of the mountain and a multitude of springs indicates an abundant groundwater. 28 streams can be found on the northern and 14 on the southern side of the mountain. On the steeper northern slopes the valleys are deeper, shorter and some streams reach the Danube, and other re-appear as concentrated or dispersed springs in places where the river uncovered the contact zone of collector and impermeable rocks.

On the southern slopes these valleys are longer and the water often disappears in the thick loess cover at the base of the mountain. Many of them end in a marshy terrain, which is submerged throughout the whole year. These small lakes and marshes are being fed from the uncovered shallow groundwater collectors.Some of these brooks were transformed to lakes by building dams (Lake Borkovac, Mutalj).

The springs in Fruska gora have three types of flow rate: constant springs flow all year, regardless of precipitation, and their flow rate depends from groundwater levels. The periodical springs flow only after long and heavy rainfalls or more often in the spring fed by the melting snow. The occasional springs flow from limestones after very heavy rain combined with melting snow, and depends from the internal water circulation in the collector environment.

Four levels of spring zones can be distinguished: the highest occurs near the ridge at the altitude of 420 m, and the lowest at 280 m. The general characteristic of these springs is their stable flow rate between 1-5 l/min. Also the temperatures are unchanging and are between 8-10 °C (5, 54)

There are 3 only springs in Fruska gora, which can be defined as thermal water (with water temperature higher than the mean annual air temperature). One thermo-mineral spring was accidentally opened near the Vrdnik coal mine, when a karst cavern was uncovered during prospective exploration. The karst groundwater forms in Mesozoic lime stones covered and enclosed in a barrier of tertiary sediments and infiltrates under great pressure in the surrounding terrain feeding the deeper horizons of groundwater. The Vrdnik thermo mineral spring has a temperature of 24 °C and a stable flow rate of 3-5 l/s (5, 24). The other two thermal springs are located near Stari slankamen (18,5 °C) and the monastery Staro Hopovo (18,5°C). The later flows from a contact zone of Paleozoic schist and magmatites, and has a high sulfur and iron content. (5, 25)

Geomorphology

Today's surface of Fruska gora is a result of a very complex interaction of endogenic and exogenous forces. The first striking feature of the mountain shape is the asymmetric N-S profile: the northern slope is much steeper and much more eroded. The Fruska gora massif forces the flow of Danube to turn from N-S direction to the east. The flow slowly undermines, erodes the northern parts of the mountain, causing landslides. The southern slope is more moderate, and disappears seamlessly in the Srem loess plateau.

The remains of the initial relief can be observed above 400 m. This terrain is surrounded nearly concentric surfaces. The first is situated between 420-440 m and represents a fluvial surface, because no littoral sediments were determined. The surface between 360-380 m is carved in crystalline schist, and its origin cannot be determined with certainty. The absence of littoral material suggests a fluvial genesis. The surfaces between 310-340 m, 240-270 m and 200-220 m have fluvial origin. The lower surfaces have been covered with loess during the Pleistocene. (2, 35-36) Numerous valleys dissect the surface of the mountain. The fact that none of the valleys reach the ridge and cross to the opposite slope suggests that these erosive forms are relatively young. B. BUKUROV (1952) determined three types of valleys. The valleys of brooks emerging near the ridge constitute the first type. They are deeply carved in the initial surface. The valleys of second type start from the middle surfaces ranging from 310 m, and are carved in younger sediments. Valleys formed in the loess cover at the base of the mountain belong to the third type.

The valleys on the steeper northern slope end often in alluvial deposits, in contrary to the southern side, where such forms are less prominent, but would be expected due to greater temperature amplitudes on the southern exposition and the process of stone crumbling. This shows that the climate has only limited influence on the forming of accumulative forms, and that the steepness of relief played a primary role in forming the recent accumulative forms.

Large areas are covered with aeolic sediment – loess, accumulated periodically during the glacial phases in the Pleistocene. The warmer interglacials have left a mark in form of fossil soils in loess. However, the increased erosion, re-accumulation and tectonic movements complicate the reconstruction of this process.

Landslides represent the greatest problems in construction, transport that arise from recent geomorphologic processes, and require close monitoring.

The Important Localities of the Geo-heritage of Fruška Gora

The geo-heritage sites of Fruška Gora are selected on the following criteria:

Scientific importance, educational significance, degree of preservation, aesthetic attraction, and approachability for visitors (MIJOVIĆ-MILJANOVIĆ, 1999) The following facts are given for every selected locality: the ordinal number, name/toponym, a short description and the value level. Their position is shown in **Fig. 3.** with the appropriate numbers from the table.

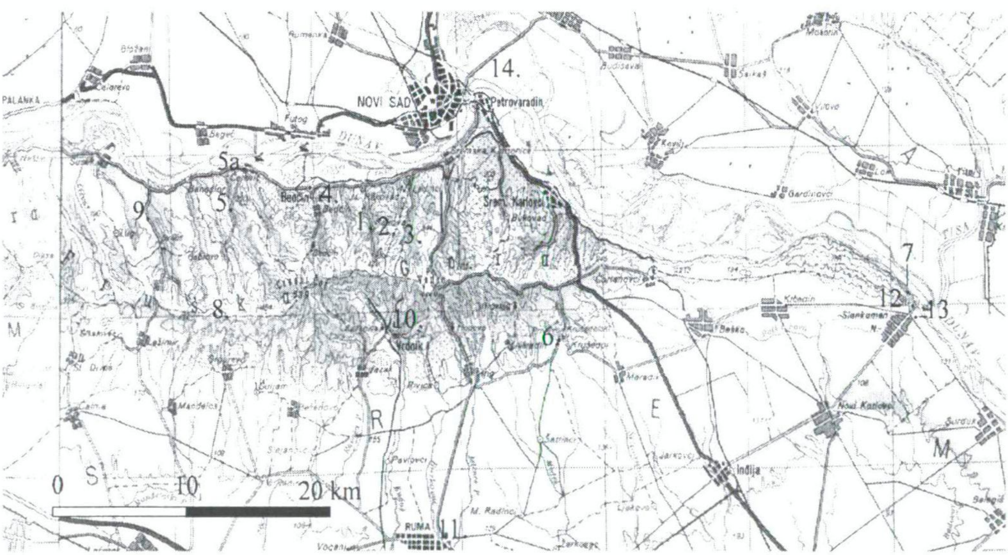

Figure 3. Geo-heritage sites on Fruška Gora

All the listed geo-heritage sites of Fruška Gora are *in situ*, and under a different degree and regime of protection (some sites are not protected at all), level of management and facilities of aesthetic qualities and distance from the existing traffic lines.

All these things indicate that it is necessary to put the selected geo-heritage sites under the appropriate degree of protection, management and to label them with informative boards, and to connect them separately with the unique geo-path for tourist visits.

The appropriate propagandistic material should be made, therefore the public would be informed about their importance.

The special part of the geo-heritage of Fruška Gora includes two important collections of material evidence, fossils, rare rocks and minerals collected on the sites of the geo-heritages of Fruška Gora.

Collected from the natural ambient, one part of these scientific proofs is in the geosite section in the custody of the Institute for Protection of Nature of Serbia, Department of Novi Sad, and the other part is in the collection of Cretaceous fossils in the Country Museum of Čerević. These collections serve for scientific researches and indeed they contribute to promotion of the selected geo-heritage sites.

Precious documentation-profiles, maps, drawings of the geological labyrinth Vrdnik, as well as numerous objects that keep the memory of long miner tradition are in rooms of RMU "Vrdnik" in Vrdnik.

The most important features of the geo-heritage sites of Fruška Gora are their scientific and educational importance. These sites, formed during different geological periods, ranging from the Paleozoic to Quaternary (PETKOVIĆ et al., 1976) represent the history of the creation of Pannonian (Carpathian) basin.

It should be pointed out also that their significance, in the system of all the geo-sites of Pannonian geotectonic unit, moves from local Grgurevačka cave, speleologic site of average dimensions (PETROVIĆ, 1968) to European – locality Čot near Stari Slankamen which represents one of the most important Middle

Pleistocene loess-paleosol site on our continent (BRONGER, 1976, 2003; MARKOVIĆ-KUKLA, 1999; MARKOVIĆ et al., 1998, 1999).

The given preliminary list of the geo-heritage sites of Fruška Gora is not concluded and future geo-scientist researches will mark new localities such as the IGM "Ruma" eastern open clay-pit, where 8 skeletons of Middle Pleistocene bears of *Ursus deningeri* were discovered in 2000 (MARKOVIĆ et al., 2001, in press).

Great scientific and educational importance, solid aesthetic quality and a good position from the existing net of traffic lines suggest the important tourist potential of the geo-heritage of Fruška Gora.

When the positions of the shown geo-heritage sites are analyzed, it can be noticed that they are near other natural and anthropogenic tourist sites of Fruška Gora, i.e. on the tourist paths that had already been established.

Table 3. The preliminary list of the geo-heritage sites of Fruška Gora mountain

E: European; **B**: Balcanic; **N**: National; **L**: Local

N°	The geo-heritage site	The description of locality	The value level
1.	The locality of volcanic tufa, Galerija near Rakovac	8 m thick layer of tufa interstratificated into Miocene-Tortonic sediments. The monument of Nature from 1982.	N
2.	The stone-pit of trachyte Kišnjeva Glava	Trachyte dyke injected into Cretaceous sandstone and flysch. The height of steep slopes up to 80 m.	L
3.	The stone-pit of trachyte, Srebro near Ledinci	Deserted stone-pit where the lake of great aesthetic qualities was formed. Steep slopes high up to 110 m.	L
4.	The paleontological site of Miocene marine fossils, Filijala near Beočin	Upper-Miocene-Pannonian sediments that consist of rich marine fauna. Classified in the sites for establishing the age of sediments in the Tethys area.	B
5.	The paleontological site of Cretaceous marine fossils in Čerević	The most complete succession of Upper-Cretaceous sediments. Fossil remains of orbitalinids, corals, worms, brachiopods and gastropods.	N
5a.	The collection of Cretaceous marine fossils in Čerević	The collection represents the richest Maastrichtian fauna in former Yugoslavia (127 species).	N
6.	The paleontological site miopliocenic fossils, Grgeteg	The sediments of Sarmat, Pannon and Upper Pont with rich marine fauna of mollusks. More than 40 species have been fortified, and twelve of then are in our country for the first time.	B
7.	The structural paleontological site of Neogene fossil marine snails near Stari Slankamen	The Pannonian sediments are placed discordantly and transgresively across the Badenian lime stones. The numerous shells of fossils marine snails.	N
8.	Grgurevačka cave	A unique gomorphological object in Vojvodina province.	L
9.	A gorge-like part of Almaš brook valley	Composite valley formed in the lower course of brook (of around 100 m) sediments.	N
10.	Vrdnik basin	The geologic treasury that consist of 26 vertical miners pit deep up to 280 m and with cores from drilled wells.	N
11.	Loess exposure of brick factory in Ruma	Around 20 m thick loess exposure with detailed evidence of paleogeographic events during the last 350.000 years. Huge Pleistocene mammals – *Mammuthus primigenius* and *Ursus deningeri*, are found in quarry of local brick factory.	B
12.	The exposure in loess valley situated between Stari Slankamen and Novi Slankamen	The only protected loess exposure in Serbia	N
13.	Loess exposure Čot in Stari Slankamen	40 m thick exposure with 10 paleosols layers where precious paleoclimatic and paleoecological evidence of Middle and Upper Pleistocene are preserved.	E
14.	The geological collection of the Institute for Protection of Nature of Serbia, Department of Novi Sad	The richest natural collections in Vojvodina province are: the collection of cores from deep drilled wells for petroleum investigations, the collection of paleofauna from the area of Fruska Gora (localities: Grgeteg, Čerevićki potok, Bukovac...), the collection of paleoflora from the localities Vrdnik and Janda, the collection of fossil remains of Pleistocene vertebrate, mineralogical and petrological collection from numerous localities in Fruška Gora and Vršačke mountains	N

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20 METER RESOLUTION DEM OF LAKE BALATON AND ITS SURROUNDINGS – CREATION, IMPROVEMENT, APPLICATIONS

BARTON, Gábor

Introduction

There are several ways for the researcher to obtain a Digital Elevation Model (DEM) of their area of interest. One is to purchase a database from a mapping and surveying authority. This is simple to carry out, because after specifying the area the authority can easily select it from its own national database and have it sent to the researcher. There are two drawbacks to this method however: price and precision. In terms of price there is great variability, nevertheless the fees are usually quite substantial. Precision depend on the level of detail the researcher requires for their studies, so they represent another problematic question. Authorities usually derive fine-resolution data from their existing coarser databases by direct interpolation, which means that no additional information is present in the newly created DEM, only the number of cells is increased.

In order to avoid these obstacles one often has to create their own DEM. This is cheaper (financially speaking) and much more accurate than the previous methods, though it requires a lot more effort. The present article demonstrates the creation and possible uses of a DEM representing most the Lake Balaton basin. The model includes about 95 % of the surrounding areas with elevation lower than 125 maB (metres above Baltic). The result iss a database that can be used in many fields of study, including geomorphology, archeogeology, illustration materials (**Figure 1.**) and so on. The second part of this article discusses some possible applications of the model.

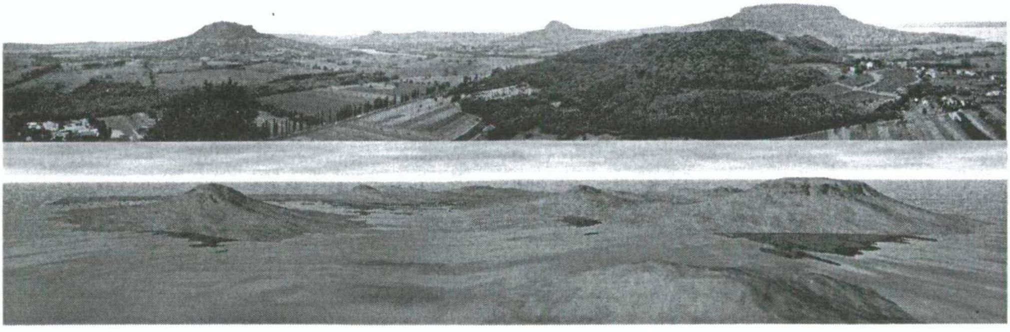

Figure 1. Above: panoramic photograph from Szigliget Castle
Below: the same area on the DEM with a hypothetical water level
(see Possible Applications)

Methods

The model was created through manual digitising of contour lines and spot heights. These data originated from the National Topographic Map Series (1971), partly because the whole national grid is available in the library of the Department of Physical Geography and Geoinformatics at the University of Szeged. **Figure 2.** shows the map sheets and what they became after about 2.5 years of digitising. This time may seem very long, but it includes earlier attempts to digitise portions of the area (Kis-Balaton and the Keszthely-mountains), which took much longer than expected. The actual digitising of the almost 30,000 km's of contour lines was done with assistance from several other GIS students at the Department. Thus the interpolation process could be tested and experimented using partial datasets evolving gradually. This opportunity proved to be very useful, because appending the sheets and checking for errors also took a long time. During this process many conditions were discovered which could cause some problems in the interpolation, these will be detailed later.

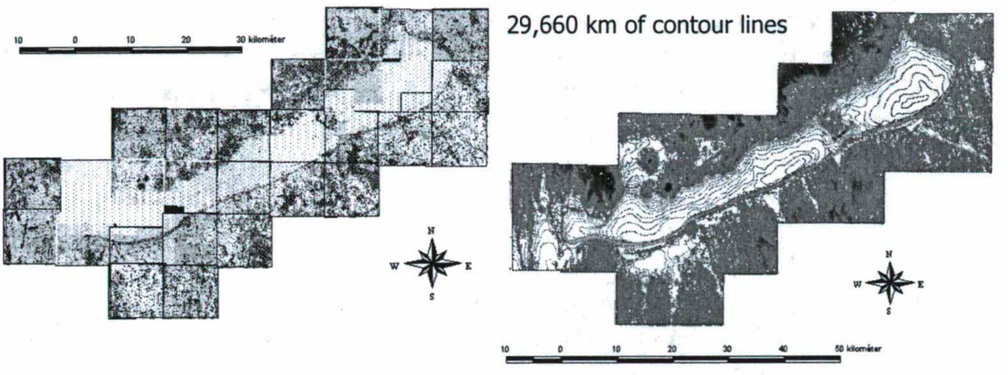

Figure 2. The used map sheets and the resulting contour lines (ESRI ArcView)

The sheets' scale is 1:25,000, they cover an area of 9.5×9.5 km with about 300 metres of overlap on the edges. The whole area contains almost 30,000 km-s of contour lines and more than 3,500 spot height data sources. The manual digitising of these data required about 1000 working hours, most of which was done using ESRI ArcView GIS 3.2. Geometric transformation was completed before digitising using Erdas Imagine 8.4. In order to be able to show perspective images with realistic texture an additional geocorrection was needed. This post-correction was done using 9-metre-resolution SPOT images found at the NGA GeoEngine website. These are available in WGS-84 co-ordinate system and GeoTIFF format, so they could easily be used in the process.

Creating the DEM

The DEM was created using the TopoGrid module of ESRI Arc/INFO. The original plans aimed a more detailed, 10-meter-resolution model, but due to the inadequate quality of source data only the 20-meter model was precise enough.

There were some minor corrections made afterwards, mostly because of the local morphological characteristics. The most apparent error was that the interpolator calculated a "trench" of app. 0.7-0.9 metres depth along the shorelines.

This happened because the lake-basin has slopes of about 0.5-1 %, while the closer surrounding terrain contains relatively steeper slopes (2-5 %) and the program often misinterpreted these data. To correct this error the model had to be interpolated in two parts: one was the lakebed bordered by the 1971 shoreline, and the other was the "rest", the surrounding hills and plains.

These two models were than combined into a database that aptly represents the artificial shores built along most of the lake. All the improvements up till this point have contributed greatly to the precision of the model, making it much more accurate than other DEM-s also created using digitised contours. Naturally, it cannot reach the level of perfection achieved by direct laser or radar measurements, but if there is no way to utilise such methods the advancements proved to be very usable and efficient.

The following section provides some hints about making the model more realistic, closer to the detail level expected from a terrain model. These "tricks" evolved through weeks of experimenting and produced quite spectacular results.

The resulting terrain models proved to be a viable substitute instead of laser and photogrammetry based technologies used in terrain modelling, which require sophisticated hardware and software elements.

Cliffs, Loess Walls

Due to the nature of the interpolation method the model in itself could not have abrupt changes in elevation such as quarries, cliff walls, etc. Instead it replaced these with long, gentle slopes, often more than 60-70 metres in length. The cliffs in real life produce elevation changes of about 20-40 metres in less than 5-8 metres distance, so the results from interpolation were far from the real features.

The cross-sections in **Figure 3**. show this problem. The continuous line shows the interpolated slope using the contour lines and spot heights. The dashed line represents what the model should look like: a step-like formation between the two areas of different elevation.

It is true that there are not many such formations along the lake, but these few (near Balatonföldvár, Balatonszárszó, along the south-eastern corner and in Fonyód) are quite impressive. This resulted in lengthy experimenting in order to achieve the cliffs' correct appearance in the model (**Figure** 3.).

The solution closest to reality came from the combination of two surfaces. One contains the low, the other the higher areas.

These two surfaces were merged along the digitised cliff line, which meant that the unwanted parts from the high area were replaced with the important regions of the low surface. The results of this method can be observed in **Figure 4.**

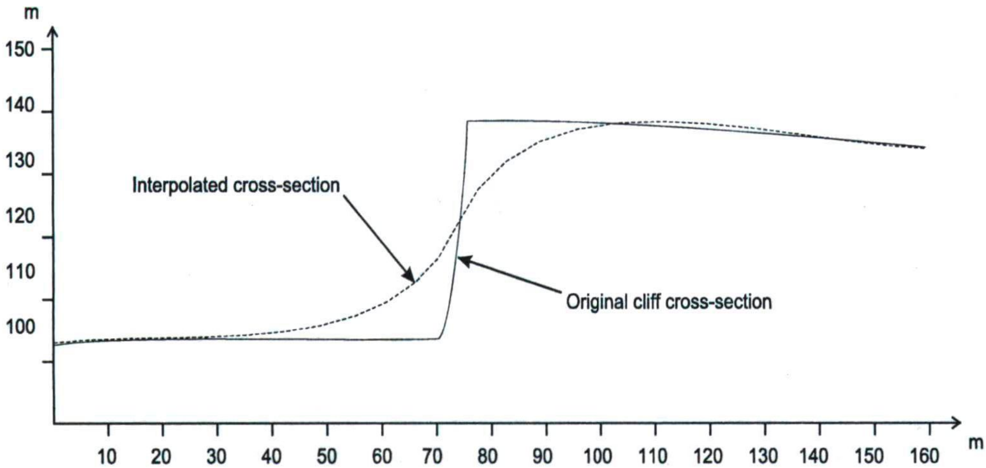

Figure 3. The problem with interpolation of cliffs and walls

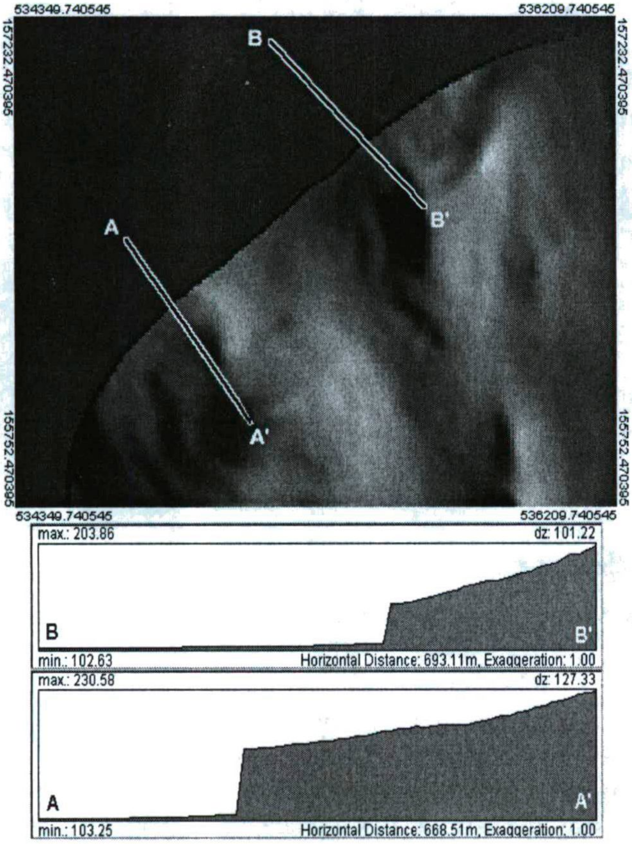

Figure 4. Modelling cliffs example (Fonyód)
Left: the DEM resulting from the combination of low and high surfaces; right: cross-sections of the cliff. (DiGeM 2.0)

Railway Lines Along Cliff Faces

The Budapest-Nagykanizsa and Budapest-Tapolca railway lines arrive to the lake's eastern shores approximately 40-50 metres above the shore level (140-155 maB), and gradually descend to about 108-110 maB along the shore over distances of several kilometres. This means a very gentle, long slope which is horizontal in the direction perpendicular to the rails on the edge of the cliff wall. The modelling of this structure involved almost every terrain-modelling technique: conventional raster interpolation, TIN surfaces with their raster conversion and raster arithmetics (performing mathematical and logical functions on surfaces). The resultant models contained every important feature (though some were a little exaggerated) with about 85-90 % precision.

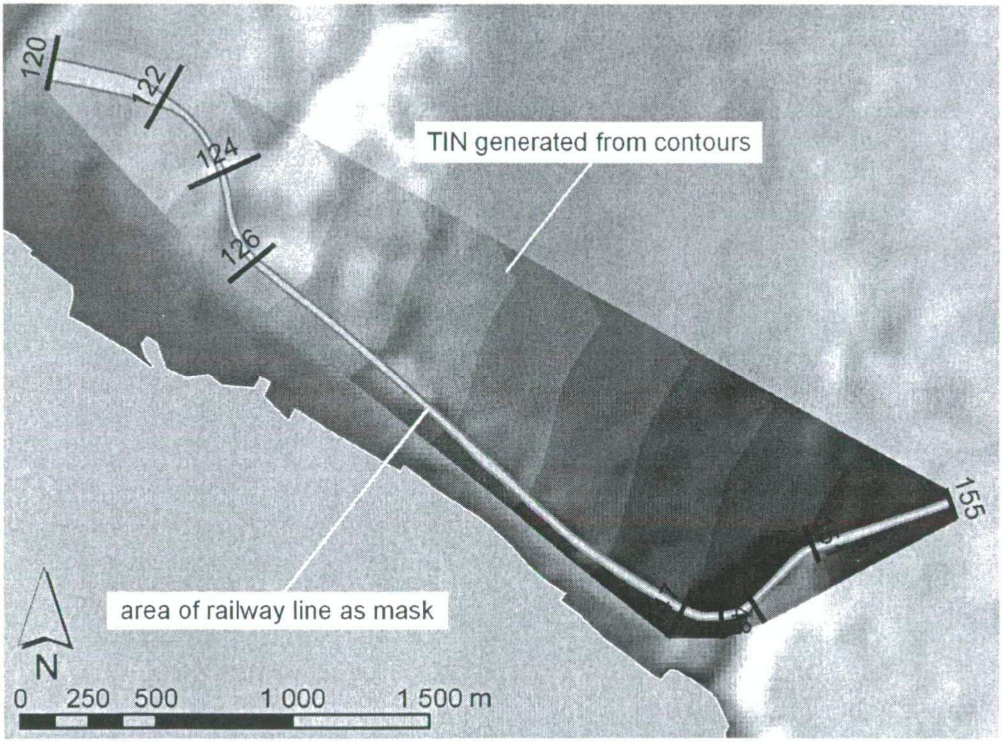

Figure 5. Steps of creating the railway line along the cliff at Balatonakarattya (ESRI ArcMap)

Figure 5. demonstrates the use of these techniques through the example of the Balatonakarattya-Balatonfűzfő railway line. First the slope of the rails had to be represented using contour lines so that they could define a 0.5-1 % slope. These contours were used to create a TIN (Triangulated Irregular Network: a surface modelling method which represents the relief with irregular triangles connecting points of known elevation.) surface which connects the lines with irregular triangles, forming a surface.

This method also solved the problem of straight slopes, because the artificial "terrace" of the railroad had to be as smooth as possible, and the TIN model could achieve this easily by placing flat triangles among contour lines. This TIN model then had to be converted into a raster dataset for further processing. The next step was to extract the width of the railway from this surface and to merge it into the original surface with the cliff already built in. The resulting cross-sections can be seen in the right side of **Figure 6.**

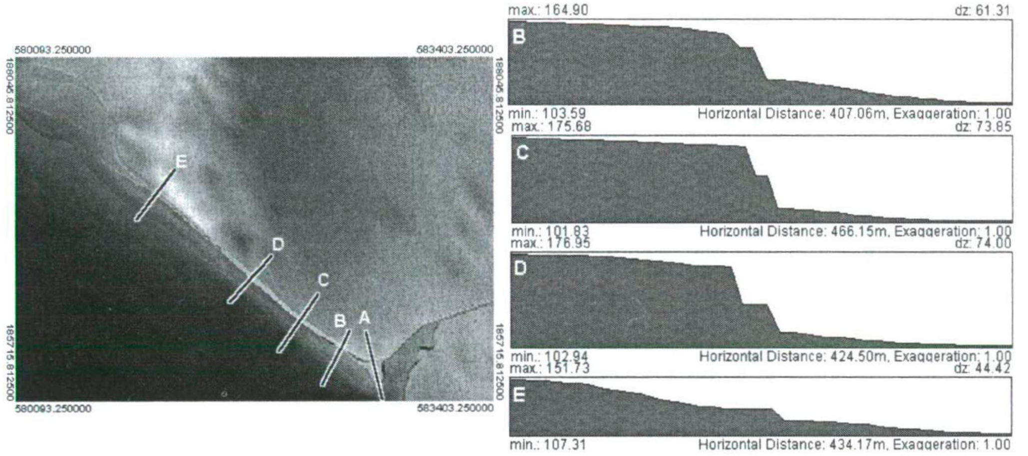

Figure 6. Railway line along the cliff wall; right: cross sections at the marked locations (DiGeM 2.0)

Quarries, Mines

The northern surroundings of Lake Balaton offer many opportunities for mining minerals or other resources. The two most important products were basalt and limestone.

Most of the limestone comes / came from the Keszthely mountains, while basalt originated in the volcanic "witness-hills" of the Tapolca basin and its neighbourhood.

Mining was almost completely terminated in the region, only a few quarries do still operate, most of them in the Keszthely mountains, (Cserszegtomaj, Gyenesdiás) producing limestone.

Some of the quarries and mines are large enough to appear in a 20-metre-resolution DEM, so in order to maintain precision, they should be included in it. The largest quarry-yard (with an area of approximately 75,000 m^2) is located in the E side of Badacsony, above the village. The basalt quarry was closed down in the late sixties, so many of today's holiday-makers can still remember the explosions.

As it is with the cliffs and walls, interpolation is unable to handle this kind of formation as well. The most satisfying method turned out to be a relatively simple one. The floor of these quarries is mostly flat and level, thus it can be represented with a polygon. This polygon would carry the elevation value of the floor-level and would be merged into the original terrain. Higher precision can be achieved if we use comparison operators, so that only such parts of the polygon would be inserted into the original model, that are lower in elevation than the terrain would have been without the quarry yard.

It is also possible to recreate multiple quarry levels by creating separate polygons for each elevation level. This method gives us the cross-section shown in **Figure 7.**

Possible Applications Of The Model

Evolution History

Lake Balaton has been studied intensely ever since the late 18th century. The most thorough and comprehensive research project began in 1920, when Lajos Lóczy initiated a program in order to increase our knowledge about the largest freshwater lake of Central Europe. The result: a 32 volume book series containing about 7000 pages and several map supplements. Most of this extensive work proved to be invaluable and valid even today. The findings in geology, hydrology and morphology gave much information about the origins and the formation of the lake, even if new theories emerge with time.

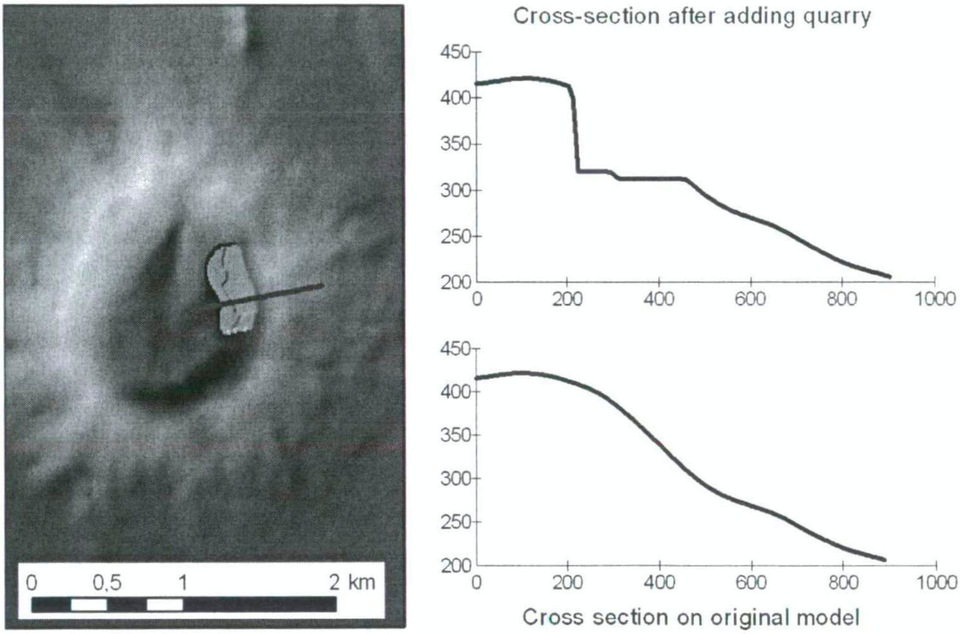

Figure 7. Cross-sections of the eastern side of Badacsony (see map on the left) without and with the quarry in the model (DiGeM 2.0)

A lake's life is best represented through the abrasion levels it leaves behind after the water level changes. These levels appear as step-like features in the landscape, with a narrow, relatively steep slope surrounded by gentler sides. The size of these levels can hint at how long the lake had that water level. Strong, well-visible levels indicate long times while shorter periods may not even show up as levels. Once these features are found scientists can obtain lots of information about the climate, vegetation etc. of the time when that water-level was existent. It is quite difficult to find these formations however, especially in densely populated areas. Lake Balaton has been a concentration point for many centuries and cultures. Generations lived one after the other significantly changing natural environment. This meant that many natural features were erased or modified, so that today only very few can be seen. The DEM proved to be a great help in identifying these formations being otherwise invisible or at least hard to notice.

Béla Bulla has discovered two abrasion levels of the lake in 1962. One of them (proved through measurements) is at 116 maB. The second one has not been proved yet, but many clues indicate its existence at 130 maB.

The present study aims to (among other goals) evaluate the potential of a manually created DEM in finding abrasion levels around Lake Balaton. At first we did not think that the model's resolution (20 m) would provide information about abrasion levels, but it turned out that we could pinpoint several potential sites. When we overlaid present day topography on the DEM and its derivations many more locations became apparent. The shape of settlements concurs significantly with our calculations concerning water cover of both recorded and theoretical abrasion levels.

The following example demonstrates the method through a very apparent location. The village Kéthely (6 km south from the lake) lies on the E side of a low hill-ridge.

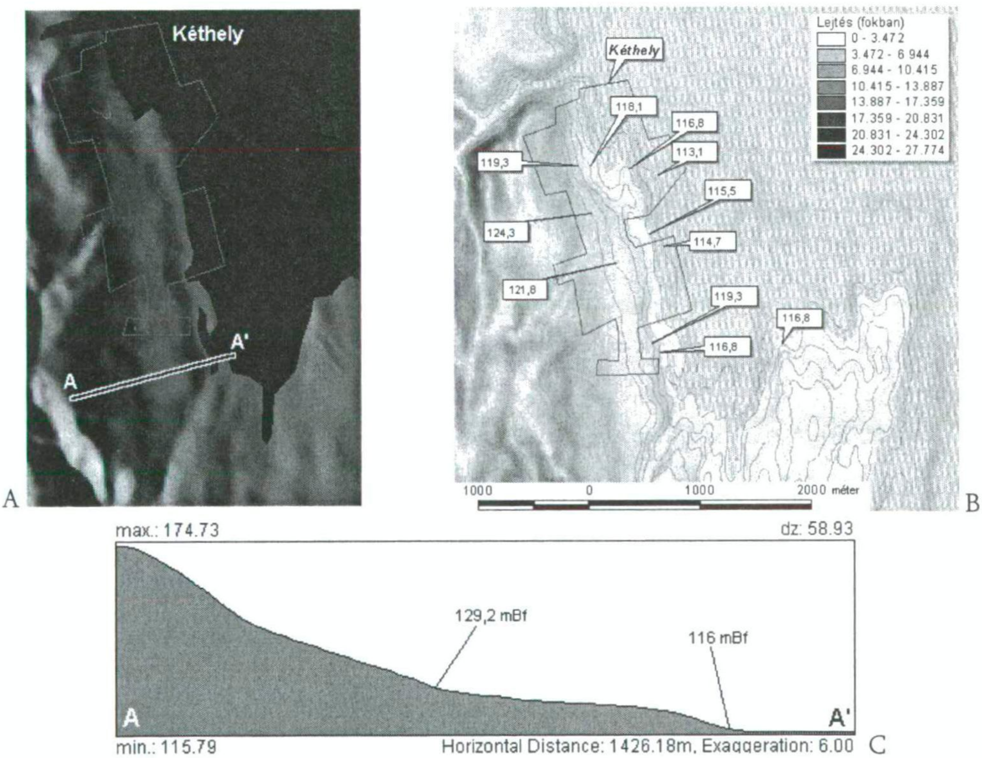

Figure 8/A Shaded relief with elevation as colour (blue: water at 116 maB); B Cross-section at marked location with suspected level heights (DiGeM 2.0); C Slope map with contour lines and calculated lake area

Near the southern edge of the settlement there is a structure that appears to be an abrasion level. **Figure 8/A** shows a shaded relief map of the area, with illumination coming from the southwest at a low angle.Contrast has been increased just to amplify the shades. It is clearly visible, that there is a relatively significant difference in slope values just at approximately 116 and 129 maB. If we compare this image to the profile taken along the specified line, it becomes evident, that at one time in the past waves broke here.

The above is just one very noticeable example taken from some 18-20 more sites identified in the DEM. Some are just as clear as the previous one, others are less obvious. Sometimes it takes other map coverages to point out the abrasion levels, but these 18-20 locations are all along the 115.4 – 116.7 m height. The following maps (**Figures 9., 10.**) show some more examples, when present day topography indicates possible water levels in the past. The maps contain the calculated extent of the lake for the abrasion level at 130 maB with blue dot pattern.

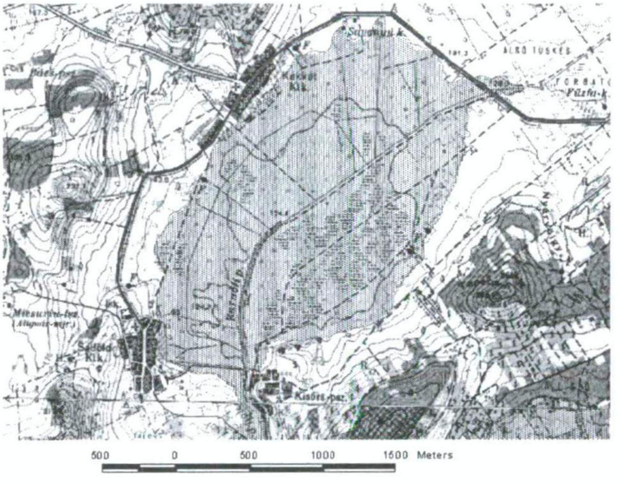

Figure 9. Káli basin – observe the road (red) at the edge of the calculated extent

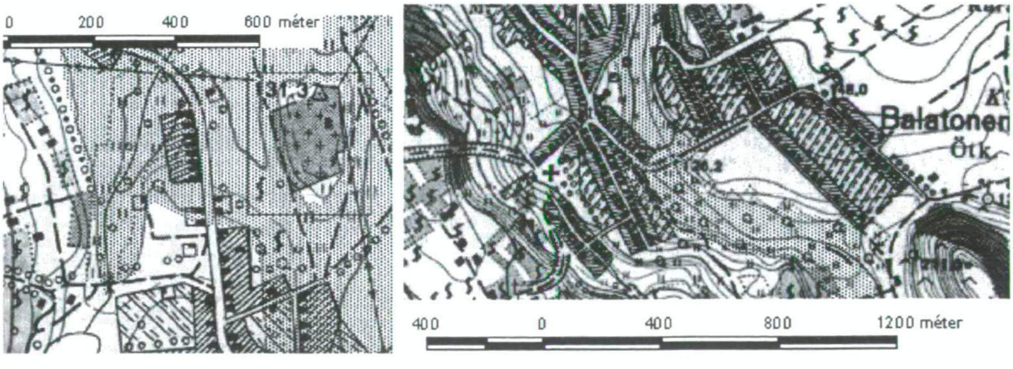

Figure 10. Left: cemetery of Látrány on the top of a 131-metre-high hill
Right: Balatonendréd divided by a small valley just under 130 maB

Tourism

Most of the northern neighbourhood of Lake Balaton is part of the Balaton Highlands National Park. There are many look-out towers in the hills from where the viewer can enjoy some breathtaking landscapes. The region does not provide the "amazingly overwhelming power of nature" kind of beauty but something more serene, relaxing and closer to our own size and scale.

Planning of look-out towers could use the elevation model very efficiently, since many software offer tools for visibility and line of sight analyses (**Figure 11.**). It is true that the model does not contain artificial features such as railway lines or dams, but the results of such examinations can pinpoint some candidate locations. These locations can be analysed more thoroughly afterwards and possibly prove to be excellent sites for the tower. The model also provides a great tool for the planning of scenic routes, from where the traveller can enjoy really nice vistas.

Visibility parameters also affect the placement and operation of cellular telephone antennas, thus their planning process can also utilise the DEM and the appropriate GIS techniques.

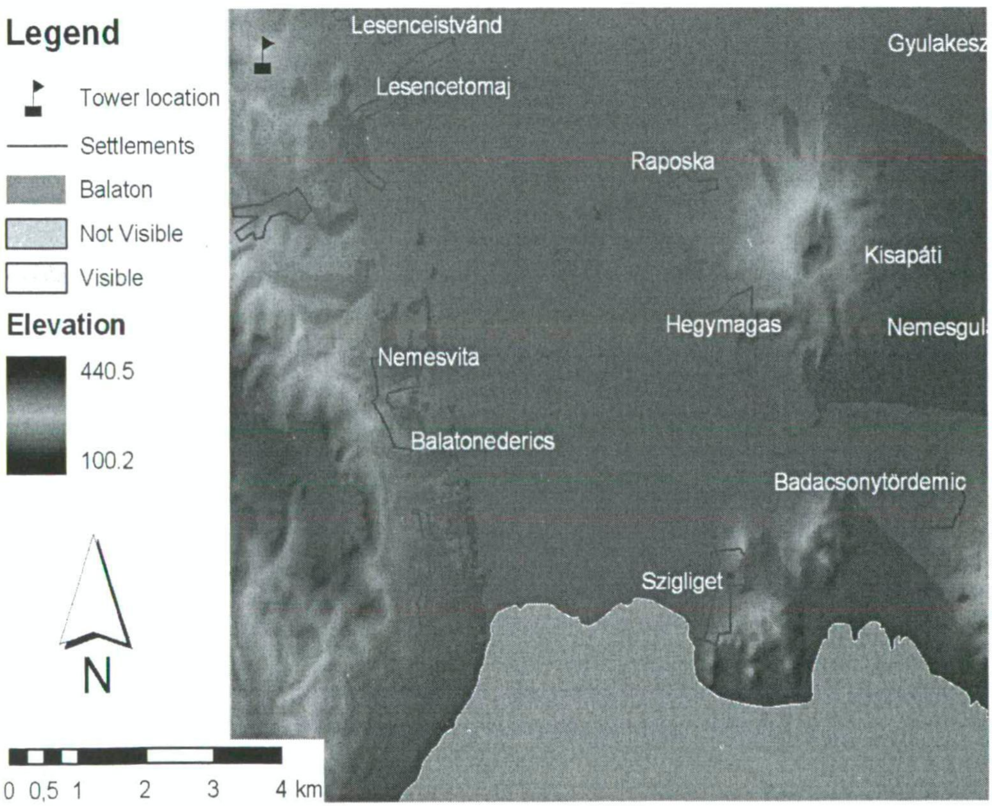

Figure 11. Example for visibility analysis: test site for lookout tower (ESRI ArcMap)

Illustration, Education, Advertisement

Today's computer technology offers excellent tools for the creation of virtual landscapes, terrains and to create the illusion in the viewer of being inside that virtual reality. Using this 3D technology the educator can provide students with exceptionally visual and attractive illustrations. This method can be used in many fields of study, for example geography, geology, history, morphology.

Apart from strict scientific usage there are also the more widely usable presentation applications. Even today's more sophisticated GIS programs (ESRI ArcGIS, Erdas Imagine) provide quite easy-to-use opportunities to create animations, so-called flyovers using the DEM data as a base surface. Of course many types of information can be draped over the surface, aerial photographs, orthographic imagery is used most frequently. These photos are usually large in size and require lots of computation to produce the 3D images. Another possibility is to use satellite images, but these are only usable for animations that "do not go too close to the surface". **Figure 12.** shows an example of the second method: 9-meter-resolution SPOT image draped over Taploca-basin.

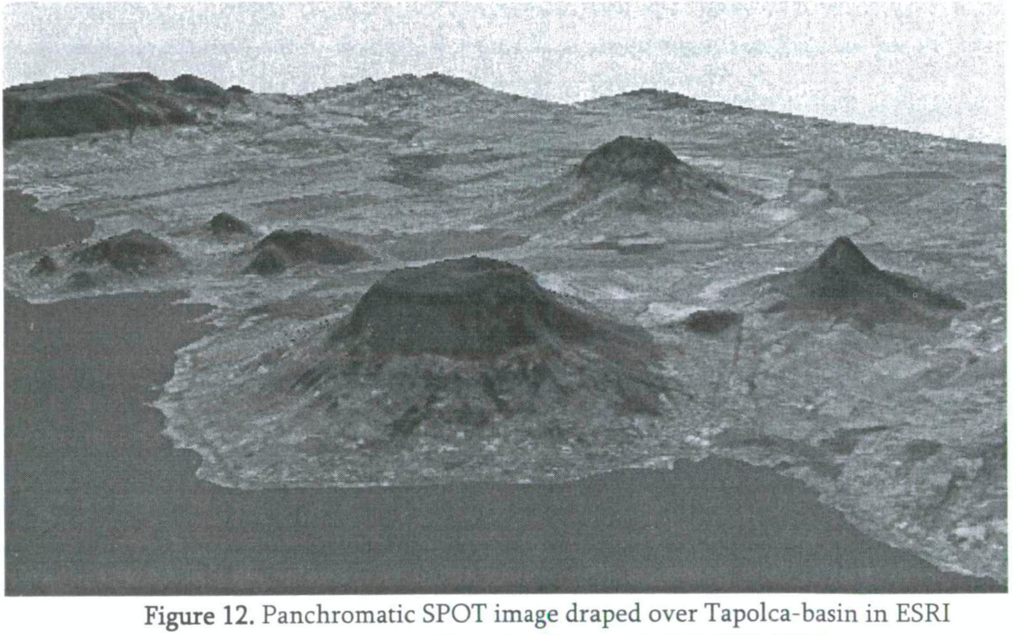

Figure 12. Panchromatic SPOT image draped over Tapolca-basin in ESRI ArcScene (Image from NIMA GeoEngine, SPOT 1992-1995)

It is of course also possible to drape any kind of data over the relief. The images can be enhanced by adding artificial objects (e. g. houses, dams, etc.) and even generalised forests or other natural features. These can be very useful in modelling a planned construction or to solve various problems (floods, wind energy assessment, etc.). In order to achieve this there are some other datasets needed, most often digitised by hand from topographic maps, aerial photographs or according to proposed plans.

An enhanced version of animations is when the viewer is able to see the terrain in 3D anaglyph mode, using red and blue or red and green glasses or, using more sophisticated equipment, true stereo visualisations. This is probably the most efficient way of displaying any surface model, because the viewer is completely deceived, embraced by the illusion of seeing the real terrain from an aeroplane.

Results, Conclusions

The current paper discussed the creation, refinement and possible applications of a Digital Elevation Model about the Lake Balaton area. The procedure of DEM generation revealed several problematic questions, which were solved by extensive experimenting. During refinement we were able to develop techniques to bring the model closer to real landscape features (cliffs, quarries, etc.) Thus the model became a very accurate representation of the research area.

In the second part we explored some application opportunities, including scientific research, illustration purposes, multimedia applications and the mapping of historic lake-levels. The examples show, that the model at its current resolution is capable of satisfying the requirements set by these functions. The most impressive results came from the modelling of historic changes and abrasion levels. This may prove to be of great assistance for geomorphologists looking for abrasion remnants signalling past extents of Lake Balaton.

More information and images available on the web at the following address:
http://www.geo.u-szeged.hu/~papesz/dem

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BULLA, Béla – MENDÖL, Tibor (1962) Magyarország földrajza, Budapest
ESRI ArcGIS Online documentation system, 2001
SPOT images from NIMA GeoEngine (http://www.nga.mil/portal/site/nga01/)

Used Software

ESRI ArcView GIS 3.2 (3D Analyst, Spatial Analyst)
ESRI ArcGIS Desktop 8.2
ESRI ArcInfo Workstation 8.2
DiGEM 2.0
Corel Bryce 5.0 Demo Version

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ASSESSMENT OF ENVIRONMENTAL LOAD ON URBAN AREA IN THE CASE OF KOLOZSVÁR (CLUJ) VIA ANALYSIS OF SPATIAL DISTRIBUTION OF LICHENS AND ARBOREAL VEGETATION ALONG THE ROADS

GÉCZI, Róbert – BÓDIS, Katalin

Introduction

The most important tasks of urban ecology are to reveal the environmental problems and confrontations within urbanized area via the evaluation of various ecological parameters in the city, the development of an environmental cadastre and the decision making support for ecology-based urban development (MUCSI, 1996). The so-called environmental bioindicators have crucial importance in estimation of anthropogenic effects in urban settings (JÓRI et al., 2002). NYLANDER (1866) discovered in the middle of the 19th century that lichens are highly sensitive to the air quality and in this way they are excellent bioindicators of air pollution.

Lichens as bioindicators

Lichens usually dwell on trees, rocks, soils, as well as plant and animal remains, but they also appear on anthropogenic materials (tiles, bricks, concrete, cement) as well. Their extraordinary sensitivity to the air quality can be explained by their unique structure: the creature itself is made up of several algae cells embedded into a thick network of fungi fibers, covered by a dense layer of hygroscopic hyphae on the outside. This hyphae layer soaks up water like a sponge, including moisture in the air along with its dissolved content transporting it freely into the inner parts of the thallus. The moisture accumulating among the fibers ensures the aquatic conditions required by the algae cells. Thus the dissolved acidic ions present in them are especially harmful to these. The leaves of higher order plants are protected by a thick epidermis, preventing them from such damages in fairly polluted air while lichens have no similar protective layer. Furthermore they are also unable to filter out these harmful substances from the thallus. Due to their slow growth rate, the positive effects of air quality improvements are detectable on them only with a 4-6 year delay. However, they very rapidly react to worsening conditions causing sometimes the complete decease of certain species even within a span of a few months, due to their high sensitivity.

Polluted air acts as a stress factor in the habitat, tolerated by different lichens to differing degrees. Based on the mithridatism of individual species and measured air pollution values the species collected in the vicinity of air quality monitoring stations can be ranked on a sensitivity scale. (HAWKSWORTH et al., 1970).

The top of such scale systems are occupied by extensive, bush-like lichens, which are generally missing from the urban areas, being especially sensitive to dry, dusty, and polluted air conditions prevailing in the cities.

Some leaf-shaped lichens turn up in the cities. However, it's only some epiphytic lichens that can tolerate highly polluted air to a certain extent. After this level of air pollution the so-called lichen desert phase appears, characterized by the general lack of lichens on tree trunks, yet these life forms are still preserved on the roofs and limestone surfaces. The general aridity of urban air is another negative factor for lichens besides air pollution. Among humid conditions, certain taxa are more tolerant to poor air quality than in drier conditions. The city can be divided into normal, conflict as well as desert zones on the basis of the distribution of lichens (SERNANDER, 1926). The desert zone more or less coincides with the center of the city, lichens being most sensitive to sulphur- and nitrogen dioxides, as well as a load from heavy metals. This zone is encircled by the next confrontation zone, where the degradation of lichen communities via the decay of the thalluses lead to a decrease in the diversity of lichen species as well as the changes in the general composition. Only the so-called toxic tolerant taxa are capable to survive here (*Buellia punctata, Lecanora conizaeoides, Physcia aipolia, Physconia grisea.* This confrontation zone can be further subdivided into an inner and outer part (VARESCHI, 1936). The outer part forms the undisturbed normal zone, where the size, shape and color of lichen communities are not altered.

Based on their style of living lichens can be classified into the following groups: tree dwellers (epiphites), wall dwellers (epilithic), soil dwellers (epigeionic) (WITTIG, 1991). Epilithic species are usually strongly attached to the substrate and sometimes can dissolve and absorb the carbonates present in them, enabling the neutralization of acids in the "inner solution" of the lichens reducing its harmful effects. However, the seemingly similar tiles, mortars and cement surfaces are characterized by highly differing buffer capacities. Thus the lichens populating them not necessarily reflect the actual conditions of air quality in all cases.

In case of the epiphytes, the buffer capacities are less influenced by the substrate they dwell on. Consequently, these species were taken into account for the preparation of a lichen-based air quality map in our work.

The general climatic and geographical characteristics of the study area

Kolozsvár is a medium-sized city with 340,000 inhabitants located in the terraced valley of the river Kis-Szamos at the interface of three medium landscape units, the Mid-Transylvanian Mountains (Erdélyi-szigethegység), the Mezőség and the ridge of the Szamos River (Szamos-hátság), about 300 and 500 m ASL. The city itself occupies several geomorphological horizons (floodplain, terraces, nearby hills). According to TREWARTHA's classification system, the climate is temperate continental with long summers. According to a 40-year meteorological record taken between 1957 and 1997, the major climatic parameters of the city can be given as follows: mean annual temperature 8.4 °C;

the maximum potential intensity of heat island calculated from the comparison of minimal temperature values is 8.1°C (UNGER, 1996); the maximum calculated value of the heat island, by taking into account the physical properties of artificial materials and the extent of communal areas is 7°C (GÉCZI et al., 1998); the mean January and July temperatures are -4.6 and 19.3 °C; the rate of annual mean precipitation is 619 mm; the annual duration of sunshine is 1978 hours; the mean annual relative humidity is 74%; the prevailing winds are westerly with almost 90% frequencies, blowing parallel with the course of the river Szamos (this is often complemented by the valley winds of the Gyalu Mts.). The unique road network of the city composed of streets running in an east-west direction can be attributed to these latter two factors. The high frequency of atmospheric inversion is also worth noting (sometimes reaching the annual value of even 100 days, the majority being restricted to the period between October and February). Potential pollution sources are located in the eastern parts of the city in the form of industrial centers. However, pollution from transportation must not be neglected either.

Materials and methods

As a first step of data collection the study area has been covered by a reference grid with 200 m resolution. The so-called wandering method was applied for data gathering (SZABADOS, 1997). Samples were collected from 5-6 different types of trees per cell yielding a total of 20-25 different arboreal species, then the digitized information provided input variables to Arc/Info 7.0.3 GIS (Geographical Information System) software. Mapping the observed information in digital form and using GIS tools in further analyses the spatial distribution of individual lichen taxa could have been qualitatively and quantitatively assessed and compared. The results were displayed on thematic maps. The systematic comparison of these thematic maps finally led to the construction of the lichen-based air quality map of the area containing the three mentioned zones or regions of normal, conflict and desert zones.

Results

26 lichen taxa are present in the city of Kolozsvár. Most of these are restricted to the area of the city's botanical garden (22), the Házsongárd cemetery (13), and the marginal parts of the woodlands surrounding the city (10-11). In the the green areas and ecological corridors of the city harbor about 3-5 different lichen species are living. In the area of Sétatér (a square), only two taxa (*Xanthoria candelaria* and *Physconia grisea*) are present due to the nearby streets and boulevards, characterized by a very heavy traffic. Along the highway to Torda, enjoying heavy traffic as well, again two species could have been identified on the bark of a *Robinia pseudoacacia* (*Xanthoria parictina, Physcia ascendens*). The highly toxic-resistant *Buellia punctata* also turns up in the central parts. The presence of these numerous lichen taxa in the central downtown areas must be attributed to the relative proximity of extensive green belts (**Map 1.**).

The most extensive urban forms of lichens are those tolerating slightly polluted air conditions as well such as *Xanthoria parietina* and *Physcia ascendens.*

In contrast to the Central European cities, the most resistant forms are present to a lesser degree in the flora (*Buellia punctata, Lecanora conizaenides*).

The species *Parmelia furfuracea, Parmelia exasperata, Caloplaca sp., Ramalina farinacea*, preferring clean air are also present in low numbers, appearing usually outside the communal areas. According to POP (1996), the distribution of lichens in Kolozsvár is just the opposite of the system of SERNANDER (1926). Namely, the number of species decreases as we move away from the center. However, the referred author based his statement regarding the city of Kolozsvár on a total misconception.

Partly, because he considered the area of the botanical garden located in a terrace about 60-75 m ASL, it is a part of the city center. On the other hand, he also failed to recognize the importance of the high frequency of climatic inversions and that of the summer valley breezes in his concept. The high heavy metal and sulphur-dioxide concentrations must be the main reason of the development of desert zone in the city of Kolozsvár, the latter having concentrations around 0.0125 mg/m^3 as well. Based on other opinions the reason is the decreasing humidity for the decay of urban lichens and the development of desert zones (RYDZAK, 1968).

However, this assumption can also be refuted on the basis of the following evidences: on the one hand, deserted areas, regarding the appearance of lichens, more frequently appear in those places of the city, which are characterized by more humid conditions. On the other hand, they are not exclusively restricted to the central areas of the city but also turn up in the vicinity of isolated pollutant sources as well (industrial objects, thermal power plants).

The relative poverty of the lichen communities in the industrial areas compared to the communal areas, as well as the complete lack of the mountainy *Usnea* taxa in the city due to acid rains seem to corroborate the assumption according to which the presence of lichen desert zones are not a factor of air humidity primarily, but rather that of air quality.

The study of tree-lined roads

The general conditions of trees located along roads and highways can also reflect the general ecological conditions of a city, similarly to lichens. The characteristics of age and species distribution of these trees may also be used as bioindicators in urban ecological studies (WITTIG, 1991). Urban tree stands either represent the original woodland communities of the area or those of managed woodlands. The new environment poses them new factors to cope with, and the less resistant forms quickly decay in an urban environment. They are also subjected to frequent mechanic injuries in this new urban environment.

The survey of the city management office of Kolozsvár talks about the presence of 81 290 trees in the city in 1989, while this value was only 75 747 in 1995 (FEKETE, 1995). Today approximately 58,000 trees can be found along roads and highways in the city. The dominant species of these is silver lime (*Tilia tomentosa*) with 13599 specimen, making up about 23.3% of planted trees.

The stands of locust-tree (*Robinia pseudo-acacia*) with 11,141 specimens come second. While lime species in total (*Tilia tomentosa, T. cordata* and *T. plathyphyllos*) make up almost one third of the total stands. (**Table 1.**).

If we consider the distribution patterns of *Tilia sp.* and *Robinia pseudoacacia* within the city, the following conclusions can be drawn: the suburban and central areas are primarily dominated by limes. While the ancient suburbs, marginal areas and industrial areas of the city are prevailed by the stands of locust-tree.

A similar pattern can be observed for elm (*Ulmus campestris*), white mulberry (*Morus alba*) and walnut (*Juglans regia*). These latter species are common to the rural quarters of the city and the dirt roads leaving the city. Conversely, the central roads enjoying much traffic are generally populated by stands of elm. The species *Aesculus hippocastanum, Catalpa bignoides,* and *Acer platanoides* are present in relatively equal proportions in the area of the city.

Table 1. The species composition of tree-lined roads in Kolozsvár

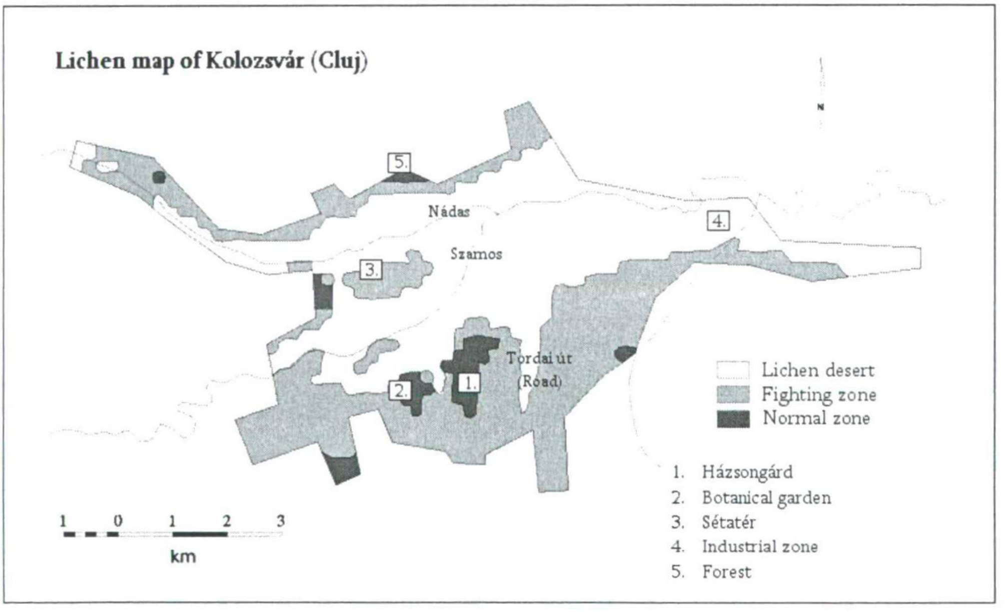
Species	Percent (%)	Absolute value (pc)
Tilia tomentosa	23.3	13599
Robinia pseudoacacia	19.1	11141
Ulmus campestris	8.6	5013
Aesculus hippocastanum	7.1	4139
Morus alba	6.5	3789
Juglans regia	4.9	2876
Acer platanoides	4.4	2565
Tilia cordata	3.2	1867
Tilia plathyphyllus	1.7	991
Other species	21.2	12359
Total	100	58339

Approximately one fifth of the newly planted trees perish within the span of a couple of weeks (FEKETE, 1995). The volume of the canopy of an adult tree growing among natural conditions usually exceeds 2500 cubic meters, while that of a young tree is only around 20-25 cubic meters (GORDON, 1990). Thus only 125 young trees can make up for the loss of an old tree. During the past 4-5 years several old trees fell victim of the ongoing road and other construction works as well as that of general city management. However, the plantation of new tree-lines along the roads lags behind. The problem is further intensified by the use of not quite successful stands in one place as well as the complete disregard of spatial and volumetric proportions. The conditions after modernization works implemented in 1995 in the central areas stand as clear examples of what have been said before: the stands of *Tilia tomentosa* originally occupying four lanes were logged down and after the completion of road widening they were substituted by stands of *Picea pungens*, which species is not quite ideal for this purpose being less tolerant to air pollution on the one hand.

On the other hand, the low and wide canopies of the planted stands prevent the easy free flow of the traffic on the road as well. Furthermore, the stands of *Betula verrucosa* mixed with the pines was also not an ideal choice for an urban setting, turning yellow even as early as June. Rather the introduction of xerophyte and thermophyte elements should be advocated in the city centers and industrial quarters. In our case only the species *Robinia pseudoacacia*, *Tilia sp.* and *Celtis occidentalis* belong to these groups. All this seems to imply, that the canalization of the Szamos and its tributaries as well as its diversion into an artificial concrete riverbed initiated a process of gradual increase in aridity.

The hygrophilous floodplain taxa were greatly reduced (*Salix, Alnus, Populus*) in numbers, appearing in artificially humid and abandoned areas alone today.

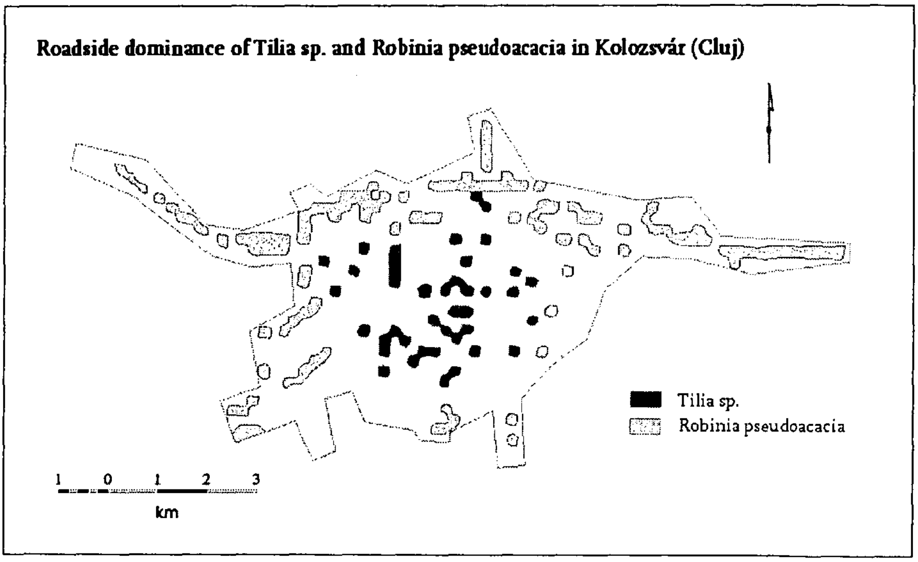
According to the information of the tree cadastre for the city, the majority of the downtown trees are damaged and decaying, or has already perished. The young stands tend to be more sensitive to these factors. The survey was implemented in June, so that the degree of damages could be relatively accurately assessed on the basis of the observed characteristics of newly shooting leaves. Since these are not yellow in healthy trees during this time of the year.



Map 1. The lichen distribution map of Kolozsvár

One fifth of the trees have a decaying canopy, showing clear signs of necrosis. However, in places harboring smaller, bigger relatively uniform green area, in our case for example a minor park, very few trees were damaged. In these cases trees located at the marginal parts of these green spots are the most prone to the harms of pollution.

According to the results of a study implemented in a square characterized by very high traffic in one of the city's natural terraces, trees located at crossroads are the most prone to the harmful effects of pollution. Thus even the smallest green spots have some sort of a moderating effect on pollution even in road crossings with the heaviest traffic and the most polluted air. Thus they may serve as a starting point for establishing better ecological conditions within the city. These points are to the possible dangers of establishing communal areas in the places of these minor biotopes on the one hand. On the other hand, it also clearly exemplifies the way the negative environmental effects can be moderated via rational intervention. The increase in the environmental load of trees located along the roads is a clear factor of traffic intensity. There has been an almost fourfold increase in the intensity of the traffic and the quantity of the participating motor vehicles in Kolozsvár since 1982, with 290 cars per 10,000 people in 1982 increasing to 340 in 1980 and 1341 today. A similar increase is observable in the traffic intensity measured as the number of vehicles participating the traffic of a downtown street in an hour-from 130 to 690.



Map 2. The map depicting the species composition of tree-lined roads

Summary

With support of the prepared lichen map the major polluted areas, signified as desert zones, could have been easily delineated in the city of Kolozsvár. These desert areas are restricted to the low-lying terraces, the downtown area on the floodplain of the Szamos, the Nádas valley and the eastern industrial areas. Based on our study it became apparent that the desert zones appear in the lower-lying geomorphological units of the city (floodplain and three lowermost terraces) characterized by the lack of general air currents and the prevalence of inversions with an average annual frequency of 70-80 days.

The other major desert zone is located in the eastern part of the city, where most of the polluting industrial objects are present, and the purifying effect of the valley breeze on the air is relatively negligible.

Similar conclusions can be drawn from the results of cadastral studies done on the city's trees: the increased decay of trees implies a larger environmental load on the low-lying areas and the increasing in the elevation accompanies by general decrease in the air pollution.

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