MORPHOMETRIC ANALYSIS OF AGRICULTURAL LANDFORMS IN LOWLAND PLOUGHED-FIELDS USING HIGH RESOLUTION DIGITAL ELEVATION MODELS

Balázs BENYHE & Tímea KISS

University of Szeged, Department of Physical Geography and Geoinformatics (6722, Szeged, Egyetem u. 2-6, Hungary), e-mail: blarance@gmail.com, kisstimi@geo.u-szeged.hu

Abstract: Geomorphological processes and micro-relief landforms within the Hungarian flat lowlands are rarely studied in detail. This study aims to identify the morphometric characteristics of agricultural landforms developed by ploughing and ridges along drainage and irrigation canals (canal-ridges) based on a digital elevation model. The study found that the average height and width of canal-ridges is 0.44 m and 17 m approximately, and in several cases they block routes of runoff. Considerably larger ridges were formed along the main canals with a height of 0.8-1.4 m and a width of 25-50 m. In addition, many of the canal-sections lie on elevated surfaces and therefore they do not perform their drainage function. Symmetry analysis highlighted that most of the canals has ridges with different sizes, therefore orientation of canal sections to slope direction can be a major runoff modifying factor. Micro-landforms developed by ploughing are considerably lower (0.05-0.2 m) than canal-ridges but still have water retention function especially on the flattest plots.

1. INTRODUCTION

Human induced alteration of the natural environment began simultaneously with the ancient agricultural activities. The geomorphic responses to the thousands of years old agricultural activities can be found in many region of the world (Henck et al., 2010; Dreibrodt et al., 2010). Despite the fact that agriculture has a very long history, its obvious marks on the landscape can be studied just at some specific location. The effects of agriculture on surface development are the most evident in hilly areas, where human induced erosional processes are intensified by high relief (Marsh, 1867; Sherlock, 1922). Recent agro-geomorphologic studies often aim to examine surface degradation (Ambers et al., 2006; Stolz & Grunert, 2006; Reiß et al., 2009; Dreibrodt et al., 2010) or direct landforms such as agricultural terraces and their effects on slopes (Lesschen et al., 2009; Henck et al., 2010). In Hungarian geomorphological studies, surface erosion and accumulation processes are often analysed in connection with agricultural activity especially in hilly regions (Pinczés, 1980; Kerényi,

1994; Gábris et al., 2003; Szilassi et al., 2006). However processes on flat lowlands are rarely studied in detail (Lóki, 2006). An exception is aeolian activity, since on lowland agricultural parcels it can be considered as one of the most studied geomorphologic process in Hungary (Borsy, 1972, Szatmári, 1996, 2005; Lóki & Szabó, 1997).

Natural and anthropogenic micro-forms on lowlands can be connected to several environmental problems. For example, micro-forms have considerable effect on desiccation of the surface, therefore they influence the drought vulnerability or such chemical processes in the soils like salinisation (Blaskó et al., 2011). In addition, due to the existing hydro-meteorological and geological conditions of Hungary the development of inland excess-water is common (Kuti et al., 2006), especially in those areas where the opportunity is provided by micro-topography (Lászlóffy, 1982, Rakonczai et al., 2001, 2003). The development of excess-water could be analysed from the point of view of runoff (Pásztor et al., 2006) and its barriers (Patchett & Wilhelm 1999). Such barriers are the depressions collecting and holding the excess water and the linear micro-forms impeding runoff. Such

micro-forms are the ridges and furrows that have been developed by parallel ploughing (Coones & Patten, 1986), or the ridges along the drainage and irrigation canals (canal-ridges).

The analyses of these micro-forms cannot be performed using topographic maps due to their small scale. The most accurate available digital elevation model (DEM) that covers the entire area of Hungary has a 5 m horizontal resolution and 0.7 m average vertical accuracy, which is not appropriate for studying lowland micro-forms (Szatmári et al., 2011). Detailed maps and digital elevation models can be obtained just by field surveys (Kiss & Benyhe, 2009), stereo photogrammetry or LIDAR data.

The aims of this study are (1) to identify the morphometric characteristics of agricultural landforms on lowland ploughed fields, (2) to reveal the processes, which cause the alteration of the natural surface, (3) to analyse the runoff modified by the agricultural micro-landforms, and (4) to spatially analyse and locate the depressions where due to the insufficient runoff excess-water can develop. The research is based on data acquired during a LIDAR survey in November 2009, displaying the agricultural plots northeast of Szeged (Szatmári et al., 2011). The derived DEM has a horizontal resolution of 1 m, and a vertical accuracy of ±4.6 cm respectively, thus it is appropriate for micro-relief studies.

2. STUDY AREA

The study area is located within the Hungarian part of the Lower Tisza Region, northeast of the town of Szeged. The area was formed by fluvial processes, as it is reflected by the abandoned meanders, natural levees, point-bar systems, scour channels and swales of the Maros and Tisza Rivers (Mezősi, 1983). Before the flood protection works carried out the 19th century the lower parts of the area (below 83 m asl) belonged to the active floodplain of the rivers (Dövényi, 2010). Thus old meanders and scour channels had played an important role in the drainage of the floods. Later on these landforms were used as part of the artificially created canal network to drain or to retain surface waters. The altitude differences of the area are quite low, as its average is 0.5-1 m/km^2 (Dövényi, 2010). The area is considered as moderately and strongly threatened by excess waters that can be explained by (1) the increased groundwater level during floods, (2) the geomorphology of the area and (3) the slow infiltration capacity of the clayey alluvial soils (Pálfai, 2000, Pálfai et al., 2004).

The most common soil types of the area are the combination of fluvisols and meadow soils with clayey or silty texture (Keveiné Bárány, 1988).

These soil types promote the appearance of rainfall-induced excess water through compression of the soils especially by heavy agricultural machines. The soil compression due to agricultural machinery affects almost the entire area of investigation, since about 90% of the area is cultivated as plough field (Deák, 2005). As a result of the flood protection works the groundwater level decreased by ca. 3 m (Rónai, 1956). Over 2000-2007 period the average groundwater level was located 4 m below the surface, regardless the proximity of the Tisza and Maros Rivers. Since soil properties are almost the same in the entire area, the scattered disposition of the excess water puddles can be explained mainly by the micro-forms of the area.

To evaluate the micro-landforms of the area three study areas characterised by different geomorphologic features were chosen (Fig. 1). The northern study area (No. 1) covers 10 km^2 and it is divided by a 300 m wide and 1.5 m deep paleo-meander of the Tisza (Gyúló-ér). Its point-bar system is located west of the paleo-meander, whilst the eastern point-bars belong to another meander. The width of the point-bars varies between 50-150 m, while their height is 0.4-0.6 m. A main artificial drainage canal was shaped in the former river bed and the density of canals in northern part is 3.13 km/km^2.

The central study area (No.2) covers 9.6 km^2 and it is located north of an artificial cut-off of the Tisza. The main form of the study area is a tributary channel connecting to the cut-off and has a well-developed (2-3 m high) point-bar system. On the western part of the study area a paleomeander fragment can be found with some low-lying point-bars. In this area the density of artificial drainage canals is 1.73 km/km^2 and the greatest artificial channel of the area divides the study area.

The southern study area (No.3) is 4.8 km^2 and it is the result of the common fluvial activity of both the Maros and the Tisza Rivers. The extended floodplain bottom is completely braided by aggraded old meanders and scour channels, bordered by low natural levees. The southern part of the study area lies on a 1-1.5 m high elevated recent levee of the Maros River. The network of agricultural roads has been artificially elevated and running north to south and east to west divide the area into rectangular shaped plots. The drainage channels usually run parallel along the two sides of the roads, and their density is about 2.92 km/km^2.

The runoff modified by agricultural micro-landforms has been studied on smaller representative test sites, which were affected by excess-water. These have been chosen based on a Rapideye multispectral satellite image from March 2011.
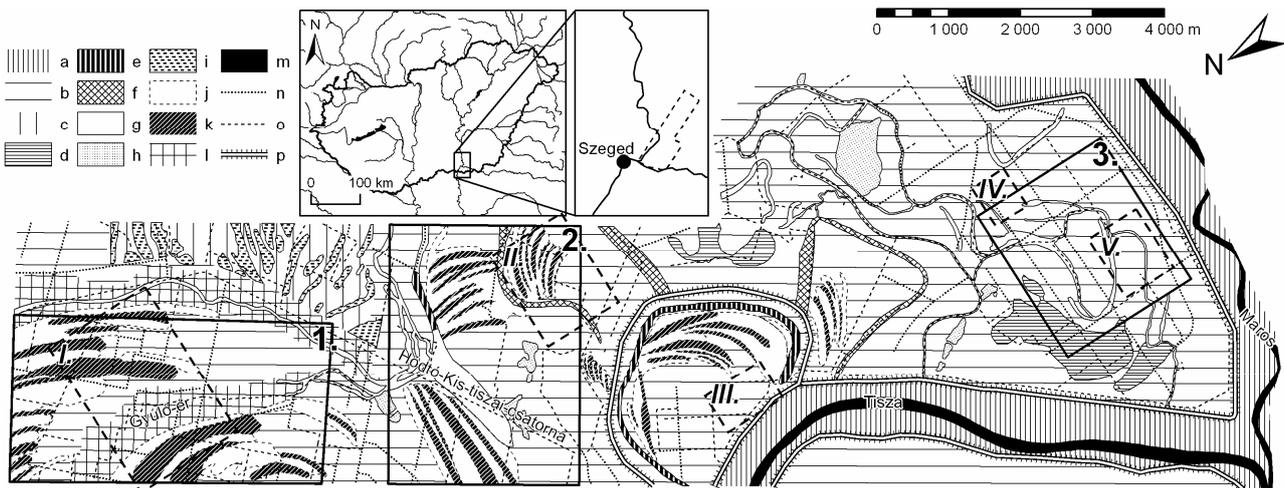
Figure 1. Geomorphologic map and location of the study areas (1-3) and test sites (I-V).
Natural landforms – a: recent floodplain, b: flood protected former floodplain, c: high floodplain, d: floodplain bottom, e: oxbow lake, f: oxbow filled with sediment, g: scour channel, h: Pleistocene loess surface, i: sand dune, j: point-bar, k: swale, l: old meander with unknown age, m: river, Artificial micro-landforms – n: single canal, o: twin canal, p: artificial levee.

The territory of the test sites varies between 0.32-3.79 km² depending on the open area of the excess-water surfaces and the landforms connected to their emergence.

3. METHODS

3.1. Determination of natural runoff routes

A LIDAR DEM is available to runoff modelling after an adjustment, as its fine resolution and accuracy result in numerous amounts of sinks, making flow direction or flow accumulation calculation difficult. Therefore, during the runoff calculations a modified version of the original DEM was used, which does not contain the micro-landforms and depressions without drainage. The modified DEM has been created by re-aligning contour lines and it was free of ridges, furrows, canal-ridges and drainage canals. Natural depressions without drainage were filled (Tarboton, 1991) and spatially located.

3.2. Calculation of morphometric parameters of the canal-ridges

Calculations were made on canal sections of the three study areas under ArcGIS 9.3 software. Long profile interpolation tools can display the cross sections. Since the height and width of canal-ridges vary along the canals, these data has been obtained as average values along the whole sections of drainage canals. Height of canal-ridges was determined as the difference between the topmost points of the ridges and the base-level of the 15-50 m buffer polygons on

the corresponding side of the canal. Width of canal-ridges was determined at the altitude of the base-level. Altitude difference of the base-level zones was measured as profile-relief, and was compared with the height-relief ratio of canal-ridges (Fig. 2).
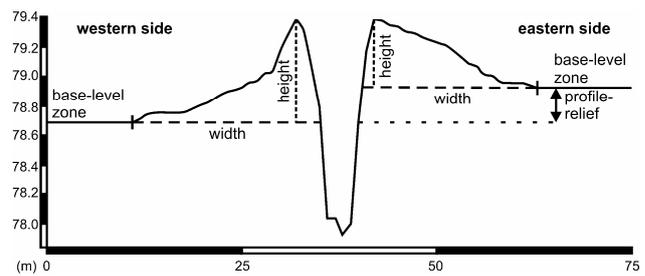

Figure 2. Determination of morphometric parameters of canal-ridges along cross sections perpendicular to the artificial channel

The average height and width of the canal-ridges were calculated from the average values of buffer polygons (2-20-25-50 m) created parallel to the canals. The largest canal of the area required wider zones and here the buffer distance was set to 150 m. The width of the associated buffer zones was determined in a previous study by Kiss & Benyhe (2009). Height and width values of artificial fillings were determined as well in the southern study area.

Zones were erased around the junction of canals, since cross depressions would have made false results. Twin canals along the agricultural roads in the southern study area were taken into account as single canals during the length calculations. Morphometric parameters have been measured on 68 canal sections with a total length of 38.4 km in all study areas. During the statistical analysis the two sides of canals

73

were typified based on both their exposition and their relative height difference. The average morphometric values were weighted with the length of the corresponding canal-section during the computations.

3.3. Classification of canal-ridges by symmetry

The canal-ridges on the two sides of the canals have been distinguished based on their symmetry. Ridges were considered as symmetric if (1) the difference between their highest point was ≤0.1 m, (2) the difference of their relative height calculated from the base-level zone was ≤0.1 m, (3) the height difference between their base-level zones was ≤0.1 m, and finally (4) if the difference between the width of ridges was ≤2 m. These threshold values have been determined by the breakpoints in the distribution histograms of the morphometric values. If a canal-ridge pair did not fulfil one of the criteria above, it was classified as semi-symmetric. Canal-ridges without pair or with two or more missing criteria have been classified as asymmetric. Canals without ridges, ridges along twin canals and artificially elevated roads have not been classified by symmetry.

3.4. Calculation of morphometric parameters of ploughed-ridges

Ridge and furrow patterns on agricultural lands have been developed as the result of ploughing in the same direction year by year. Height and width parameters of the ridges and furrows have been measured on designated plots more or less free from natural elevation differences. The calculations were performed on 9 plots in the northern study area (No.1.), 7 plots in the central study area (No.2.) and 9 plots in the southern study area (No.3.). Plots were divided into 300 zones similar to the buffer zones used to measure the canal-ridges. Each zone was 1 m wide and 100 m long, thus the territory of each plot was 3 ha. Several plots were tilled from different directions, thus in 10 cases a primary and a secondary pattern could be identified in the plot. Therefore, calculations were performed on two intersecting plot polygons more or less perpendicular to each other. Using zonal statistic analysis, the average elevation (m asl.) of each zone was calculated. Long profiles were made along the plots perpendicular to tillage direction, displaying the ridges and furrows of the area. Ridge heights were calculated by subtracting the elevation of the ridge's peak and the mean value of the lowest points of the two adjacent furrows (Fig. 3). The width of ridges was defined as the horizontal distance between the lowest points of two adjacent furrows. Minor altitude changes, less than 5 cm along the sides of a ridge have not been considered.
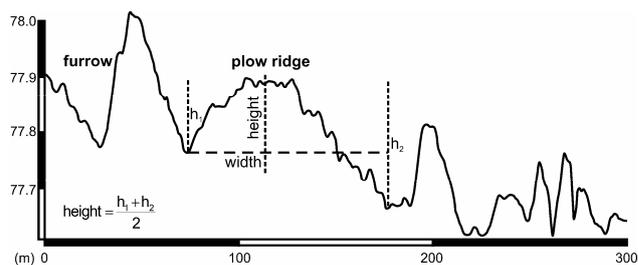

Figure 3. Determination of the plough-ridges parameters along long-profiles

To evaluate the runoff modifying effect of the plough-ridges, the direction and exposition of the natural and the ploughed surface were compared.

4. RESULTS

4.1. Natural runoff routes

Before the 19th century the runoff routes were not influenced by human impact, therefore they depended on the natural slope. In the northern study area the surface runoff was drained into swales and scour channels, then into the one of the two paleo-meanders. The natural drainage of the central study area is determined by the meandering tributary channel draining waters to north. The primary route of runoff in the southern study area is uncertain since slope direction of the scour channels could not been accurately determined from the DEM. The network of the scour channels probably enabled runoff from almost the entire study area. Natural depressions with poorly defined outlet or natural sinks were mostly located in the swales of the northern and central area. The altitude difference along the swales was 3-10 cm/km in the northern area, and slightly larger (15-20 cm/km) on the central area, suggesting that these areas had small runoff coefficient. In the southern area, it is likely that the depressions along scour channels and the backswamp of the northwest corner were not drained.

During the planning of artificial canalisation the natural runoff routes were not considered. Several sections of the artificial canals cross higher surfaces instead of natural channels. Therefore, the natural runoff is sometimes perpendicular or opposite to the direction of artificial canals.

4.2. Morphometric parameters of canal-ridges

The morphometric parameters of twin canal-ridges were calculated for 51 canal-sections (Fig. 4).

Figure 4. Morphometric parameters of canal-ridges and the location of studied plots.
a: height of canal-ridge (m), b: height of artificial filling (m), c: average height of plough-ridges in the plot (m), d: main slope direction, e: twin canal-ridges, f: single canal-ridge, g: twin canals with artificial filling, h: section without canal-ridge

Ridges have not developed along 8 canal-sections and 5 canal-sections had single canal-ridge. The average height and width of canal-ridges in the northern area is 0.3 m and 13 m respectively. The tallest canal-ridge of that area is 0.91 m high and its width is 16 m along a 339 m long canal-section. There was a significant difference in height-relief ratios between the two opposing sides of the canals. The height-relief ratio on the western side of the canal-sections is 4.63, while it is 15.38 on the eastern side. Under these circumstances, the ridges along the eastern side of canals have a significant role in blocking natural runoff. The ridges along the Hódtó-Kis-tiszai-csatorna in the central area are the largest canal-ridges within the entire study area. The average height and width values on the west side of the canal were 0.96 m and 23 m, while the ridges on the east side have an average height of 1.18 m and width of 52 m, respectively. The highest canal-ridge is 1.43 m high, 55 m wide and it runs along a 430 m long section. The widest ridge is 60 m wide, its height is 1.41 m and its length is 426 m. The height-relief ratio of canal-ridges in the central area was 6.04 on the west side and 8.67 on the east side of the canals. This means that canal-ridges are approximately 9 times higher than the altitude difference of the natural relief measured along cross sections. In the southern area relatively small canal-ridges were identified showing an average height of 0.33 m and width of 14m. However, the artificial filling of roads is considerably larger, since the height is 0.56 m and width is 16.3 m.

The highest man-made filling in the study area lies along 381 m and has a height of 1.32 m and a width of 18 m. The widest micro-landform of 34 m is also an artificial filling with its height of 0.8 m and running along a 173 m long section. The height-relief ratio on the southern area was 7.6, and thus ridges and artificial fillings are about 8 times higher than the natural relative relief of the area.

4.3. Symmetry conditions of the canal-ridges

Within the entire study area only 4 pairs of canal-ridges were determined as symmetric and 8

75

ridge-pair were semi-symmetric, while all other canal-sections were asymmetric (44 sections) or did not have canal-ridges at all (8 sections). In the northern area the largest number of symmetric and semi-symmetric ridge-pairs appears. Relationship between symmetry and size of ridges cannot be determined. The ridges of the highest symmetric ridge-pair have a height of 0.74 m and their width is 9 and 11 m. Ridges along semi-symmetric sections are relatively smaller. The canal-ridges of the highest semi-symmetric ridge-pair have a height of 0.44 and 0.47 m and a width of 15 and 25 m. In the cases of semi-symmetric sections (apart from one situation when the difference of base-level did not meet the criteria) the difference of the width values exceeded the limit value of 2.0 m. Six asymmetric canal-sections were identified along the Hódtó-Kis-tiszai-csatorna within the central area. The ridges of the highest asymmetric ridge-pair along the main canal are 1.12 and 1.23 m high and their width varies between 20 and 55 m. Symmetry conditions of several asymmetric canal-ridges in the southern area could have not been evaluated, since usually one side of the sections was an artificial filling instead of a real canal-ridge. Therefore, these data were not selected into the statistical analysis.

4.4. Morphometric parameters of plough ridges

The height of ploughed-ridges is lower than of the canal-ridges but their width value and their number is considerably higher. A total of 82-86 ploughed-ridges were identified in the entire study areas (8-10 per plot). Height and width values were more or less the same on the different study areas. The average height of plough-ridges is about 0.09 m and their average width is 27 m. The largest plough-ridge is 0.26 m high and 44 m wide. In some cases (10 parcels) the ploughing made in different directions resulted in a furrow-pattern under oblique angle. The average height of these oblique plough-ridges was just 0.03-0.05 m. The angles formed by ploughed-ridges and main slope directions are considerably larger in the northern area where the runoff modifying role can be even more significant in those plots. Most of plough-ridges in the central and southern areas are more or less parallel to the main slope direction, but nearly transverse ridges were identified as well. The average height-relief ratio over the entire study area is 2.51.

5. DISCUSSION

Agricultural activities have an effect on surface runoff, as they smoothen and degrade the natural landforms and create micro-landforms simultaneously. These new micro-landforms can greatly decrease runoff potential, especially in lowland areas.

Runoff modifying effects of micro-relief could be proven by several examples. Excess water patches were located in areas under various geomorphologic settings. For example, in test site I. within the northern area, the surface runoff could not flow into the scour channels due to the existence of ploughed-ridges, and rectangular excess water patches could be formed behind the canal-ridges. In this test site the importance of artificial micro-landforms could be well demonstrated in a natural paleo-channel, which represents the main stem of the drainage system. However, canal-ridges form a barrier interrupting the runoff into the channel, resulting in elongated parallel excess water patches along the furrows. These effects can be identified in test site III as well. In some cases, e.g. test site II and V, construction of roads, smoothening the natural relief and re-depositing of the material of point bars led to the development of micro-landforms blocking the routes of runoff. In the test site IV, located within the southern area, a dirt road with an artificial filling of 0.3-0.4 m height lies in the centre of the area, dissecting a west-east oriented scour channel and blocking the runoff. It must be noted that in this case, the origin and purpose of the road was not connected to agricultural activity, since the access road was built to improve the accessibility of a gas extraction utility.

6. CONCLUSION

In this study morphometric parameters and runoff modifying effects of landforms induced by agricultural activities or related surface alteration works have been measured in three study areas. Several agricultural micro-landforms have been identified in the entire area with considerable size that can influence the formation of excess water.

Canal-ridges along irrigation and drainage canals are 0.4 m high and 17 m wide in average, but canal-ridges higher than 1 m were also found. Ploughed-ridges are relatively lower averaging about 0.09 m high, but considerably wider, 27 m in average.

Everywhere has been shown that canals do not perform their function, since canal-ridges have been developed along drainage canals. These are made of the deposited scoured material of the canals, and these ridges create a barrier on the natural route of runoff in the plots.

The badly planned spatial pattern of canals harms their usefulness, since many of the canal-

sections lie on elevated surfaces, therefore they do not perform their drainage function. Thus, runoff may occur not in the canals but different flowing paths appear towards lower areas.

In the flat plots, runoff towards drainage canals can be blocked by plough-ridges induced by tillage. Intersecting ridges in plots created by changing ploughing direction are common. Furrows parallel to the slope direction favour the runoff of rainfall-induced water, but cross ploughed-ridges are blocking the runoff routes.

Twin canals along agricultural roads are often filled up almost completely. This results in the formation of excess water patches along one side of roads depending on slope direction. Despite that, the Local Water Management Associations are obligated by law to keep the canals in good conditions and to drain the excess water (Babos & Mayer, 1939), the draining capability of the canals deteriorates and their water conductivity decreased by 50-90 % (Goda, 1997).

ACKNOWLEDGEMENT

REFERENCES

Ambers, R.K.R., Druckenbrod, D.L. & Ambers, C.P., 2006, *Geomorphic response to historical agriculture at Monument Hill in the Blue Ridge Foothills of Central Virginia*. Catena 65, 49-60.

Babos, Z. & Mayer, L. 1939. *Flood protection and inland water management in Hungary. Part II.* Vízügyi közlemények, 1-2., 3-65. (In Hungarian).

Blaskó, L., Czimbalmos, R., Őri, N. & Lengyel, H. 2011. *Relief dependent C-factor in sodic soils*. In: Az elmélet és a gyakorlat találkozása a térinformatikában II., 35-42. (In Hungarian)

Borsy, Z. 1972. *Aeolian erosion on Hungarian blown sand areas*. Földr. Közl., 156-160. (In Hungarian)

Coones, P. & Patten, J.H.C. 1986. *The Penguin guide to the landscape of England and Wales*. Penguin Books, Harmondsworth, 348.

Deák, J.Á. 2005. *Landscape ecologycal researches in the western Marosszög (Hungary)*. Acta Climatologyca et chorologica, 33-46.

Dövényi, Z. 2010. *Regions of Hungary*. MTA FKI, Budapest, 187-195. (In Hungarian)

Dreibrodt, S., Lubos, C., Terhorst, B., Damm, B. & Bork, H.R. 2010. *Historical soil erosion by water in Germany: Scales and archives, chronology, research perspectives*. Quat. International 222, 80-95.

Gábris, G., Kertész, Á. & Zámbó, L. 2003. *Land use change and gully formation over the last 200 years in a hilly catchment*. Catena 50, 151–164.

Goda, P. 1997. *A fenntartható fejlődés és a vízgazdálkodás kapcsolatai a Körös-vidéken*. Alföldi Tanulmányok, Békéscsaba, 17-33.

Henck, A., Taylor, J., Lu, H., Li, Y., Yang, Q., Grub, B., Breslow, S.J., Robbins, A., Elliott, A., Hinckley, T., Combs, J., Urgenson, L., Widder, S., Hu, X., Ma, Z., Yuan, Y., Jian, D., Liao, X. & Tang, Y. 2010. *Anthropogenic hillslope terraces and swidden agriculture in Jiuzhaigou National Park, northern Sichuan*. China, Quaternary Research 73, 201-207.

Kerényi, A., 1994. *Loess erosion on the Tokaj Big-Hill.* Quaternary International 24, 47-52.

Keveiné Bárány, I., 1988. *Soil studies around Szeged*. Alföldi Tanulmányok, 25-33. (In Hungarian).

Kiss, T. & Benyhe, B., 2009. *Connection between geomorphology and excess water: case study near Mindszent*. Hidrol. Közlöny, 89/3, 14-18. (In Hungarian).

Kuti, L., Kerék, B. & Vatai, J. 2006. *Problem and prognosis of excess water inundation based on agrogeological factors*. Carpathian Journal of Earth and Environmental Sciences, 1, 5-18.

Lászlóffy, W., 1982. *Flood protection, river regulation and water management along the Tisza.* Akadémiai Kiadó, Budapest, 609. (In Hungarian)

Lesschen, J.P., Schoorl, J.M. & Cammeraat, L.H. 2009. *Modelling runoff and erosion for a semi-arid catchment using a multi-scale approach based on hydrological connectivity*. Geomorphology 109, 174–183.

Lóki, J. & Szabó, J. 1997. *Deflation sensitivity of lowland soils*. Kompolt, Regionális Agrárkutatási és vidékfejlesztési workshop, 73-83. (In Hungarian).

Lóki, J., 2006. *Geomorphology of ploughing and gradening*. In: Szabó, J. – Dávid, L.: Antropogén geomorfológia. Kossuth Kiadó, Debrecen, 64-77. (In Hungarian)

Marsh, G.P., 1867. *Man and nature – or physical geography modified by human action*. C. Scribner & co., New York,. 128-329., 451-516.

Mezősi, G., 1983. *Geomorphological description of Szeged*. Alföldi Tanulmányok, 59-74. (In Hungarian)

Pálfai, I., 2000. *Flood and drought risk on the Hungarian Great Plain*. In: Pálfai, I. (edt): A víz szerepe és jelentősége az Alföldön. Békéscsaba, 85-95. (In Hungarian)

Pálfai, I., Bozán, C., Herceg, Á., Kozák, P., Körösparti, J., Kuti, L., & Pásztor, L., 2004. *Complex excess water risk index and its application in Csongrád county*. II. Magyar Földrajzi Konferencia, CD kiadvány, 1-6. (In Hungarian)

Pásztor, L., Pálfai, I., Bozán, C., Kőrösparti, J., Szabó, J., Bakacsi, Z. & Kuti, L., 2006. *Spatial stochastic modelling of inland inundation hazard*. 9th AGILE Conference on Geographic Information Science, Visegrád, Hungary, 139-143.

Patchett, J.M. & Wilhelm, S.G. 1999. *The ecology and culture of water*. In: Great Cities Institute/Illinois-Indiana, Sea Grant College Program; Urban Water Resources Conference Proceedings, 80-105.

Pinczés, Z. 1980. *Effect of land use types and cultivation methods on soil erosion.* Közlemények a debreceni KLTE Földrajzi Intézetéből, 357-379. (In Hungarian)

Rakonczai, J., Mucsi, L., Szatmári, J., Kovács, F. & Csató, S., 2001. *Spatial distribution of excess water*. Magyar Földrajzi Konferencia Cd kiadványa, 1-14. (In Hungarian)

Rakonczai, J., Csató, S., Mucsi, L., Kovács, F. & Szatmári, J. 2003. *Evaluation of the excess water distribution in 1999. and 2000.* Vízügyi Közlemények, 317-336. (In Hungarian).

Reiß, S., Dreibrodt, S., Lubos, C.C.M & Bork, H.R. 2009**.** *Land use history and historical soil erosion at Albersdorf (northern Germany): Ceased agricultural land use after the pre-historical period.* Catena 77, 107-118.

Rónai, A. 1956. *Ground water of the Carpathian Basin.* MÁFI Évkönyv 46. 116-131.

Sherlock, R.L., 1922. *Man as a geological agent, an account of his action on inanimate nature*. H. F. & G. Witherby, London, 372.

Stolz, C. & Grunert, J. 2006. *Holocene colluvia, medieval gully formation and historical land use, A case study from the Taunus Mountains/southern Rhenish Slate Massif.* Zeitschrift für Geomorph. Suppl. 142, 175–194.

Szatmári, J. 1996. *Anthopogenic alteration of the national environment and its effect on deflation.* In: Geográfus Doktoranduszok Országos Konferenciája, Pécs, 53-63. (In Hungarian)

Szatmári, J. 2005. *The evaluation of wind erosion hazard for the area of the Danube-Tisza Interfluve using the Revised Wind Erosion Equation*. Acta Geographica Szegediensis Tomus XXXVIII., 84-93.

Szatmári, J., Szijj, N., Mucsi, L., Tobak, Z., van Leeuwen, B., Lévai, C. & Dolleschall, J. 2011. *Spatial data collection serving the mapping and modelling of excess waters.* In: Az elmélet és a gyakorlat találkozása a térinformatikában II., 27-34. (In Hungarian)

Szilassi, P., Jordan, G., Rompaey, A. & Csillag, G. 2006. *Impacts of historical land use changes on erosion and agricultural soil properties in the Kali Basin at Lake Balaton, Hungary*. Catena 68, 96-108.

Tarboton, D.G., Bras, R.L. & Rodriguez-Itrube, I. 1991. *On the extraction of channel networks from digital elevation data*. Hydrological processes, 5, 81-100.