Analysis of the natural micro-regions of Hungary from the aspect of their sensitivity to landscape degradation

Final report Project No. 108 755

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Project leader

1. Summary of results

A detailed description and analysis of the most significant landscape degradation processes acting in the natural micro-regions and landscape types of Hungary was carried out including sheet erosion, gully erosion, wind erosion, salinization and secondary salinization, physical degradation, soil sealing, desertification, flooding and mass movements. The aesthetical value of Hungarian landscapes was determined by GIS methods. In addition to the analysis of degradation processes sensitivity to landscape degradation was determined for the above processes, too. A maps series for the above processes was prepared as well. The impact of climate change will be very significant on the major part of landscape degradation processes. It will lead to the increase of the extension of the degraded areas and it will considerably affect landscape sensitivity.

Comparing the processes of landscape degradation in the world and in Hungary the main conclusion is that the landscapes of Hungary are relatively well maintained and they are part of the most valuable landscapes in Europe. This statement doesn't mean that landscape degradation processes should not be taken seriously. All degradation processes represent important environmental problems which have to be further investigated, analysed and on the basis of these the elaboration of a well-established policy making is necessary.

The results are important contributions to our knowledge on landscape degradation and sensitivity and on the landscapes of Hungary.

2. Usability, utilization, exploitation of results

The map series on landscape degradation and degradation sensitivity is very well applicable for planning purposes. The triggering factors of the processes are identified allowing for the establishment of a successful strategy to combat landscape degradation and to elaborate the guidelines of landscape conservation.

The GIS analysis of the landscape degradation maps will identify the relationships between present and future situations allowing to predict the development of degradation processes in the future.

Predicting future development of landscape degradation provides a good scientific basis for landscape protection and rehabilitation. This is absolutely necessary because the landscapes of Hungary are used very intensively and the exploitation of landscapes may become even more intensive in the future.

3. Deviations from the contract

Research staff

József Lóki and Gábor Négyesi joined the research team because of their significant activities in the field of wind erosion research. The publication list contains also authors who are not project participants but their contribution to the published results was remarkable. In these cases, however, there are also project participants among the authors playing a leading role in the preparation of the papers in question.

The publication list contains papers with important new results on the project topic. Some of these topics were not included in the original research plan (most of the papers will be published in September 2019 in the Hungarian Geographical Bulletin 68 (3).

Research plan

The research plan was modified in 2016 by the approval of the National Research, Development and Innovation Office, i.e. instead of the topic "degradation of waters" the topic of "flooding, drought and climate change" was taken up into the research programme.

The country-wide survey of land degradation processes couldn't be performed in the planned scale of 1:50 000 because of data availability. Gully erosion mapping was carried out in great detail (1:10 000 maps were digitized), but all other degradation processes were mapped in small scale (1: 500 000 – 1:1 000 000).

4. Detailed presentation of results

The most significant results of the projects are published in Kertész, Á. (ed.) 2019.: Landscape degradation in Hungary. Budapest. MTA RCAES Geographical Insitute. Theory-Methodology-Praxis 74. and in the Hungarian Geographical Bulletin, 68 (3). 2019. This issue contains exclusively papers on this NKFIH project. The 68 (3) issue of the HGB will be published in September 2019. The review and submission process is finished. The issue contains the following publications which are not indicated on the publication list of the website yet:

1. Kertész, Á. and Krecek, J. 2019. Landscape degradation in the world and in Hungary.
2. Józsa, E. Lóczy, D., Soldati, M., Dragut, L. Szabó, J. . 2019. Distribution of landslides reconstructed from inventory data and estimation of landslide hazard in Hungary
3. Négyesi, G., Lóki, J., Bertalan-Balázs, B., Pásztor, L. 2019.Wind erosion researches in Hungary – past, present and future possibilities.
4. Jakab, G., Bíró, T, Kovács, Z., Papp, Á., Ninsawat, C., Szalai, Z., Madarász, B., Szabó, Sz. 2019. Spatial analysis of changes and anomalies of intense rainfalls in Hungary.
5. Lontai-Szilágyi, Zs., Bertalan-Balázs, B., Zsíros, B., Vasvári, M., Kumar, S.S., Nilanchal, P. Martonné Erdős, K., Szabó, Sz. 2019. Landscape aesthetic value map and its validation with rural tourism data in Hungary and in the Danube Bend region
6. Szopos, N.M., Szabó, Sz., Bertalan-Balázs, B. László, E., Milosevic, D., Conoscenti, C., Lázár, I. 2019. Geospatial analysis of drought tendencies in the Carpathians as reflected in a 50-year time series

All other cited publications are on the list of publications on the project web site. If there is more than one publication of the same author(s) in the same year, they are indicated as e.g. 2019a, 2019b etc.

The execution of the project was performed according to the research plan. Landscape degradation processes were investigated by the analysis of various maps and remote sensing data including topographic, agro-topographic maps (1:100 000), air photos (Google-Earth) the CORINE Land Cover Database, etc. The sensitivity analysis was carried out by the identification of the driving forces for each process. In addition to sensitivity indices various GIS operations, map analysis etc. were also applied. The evaluation of the maps is performed for the whole country. The map of the micro-regions (micro-region boundary map) is overlayed on each landscape degradation map providing a good basis for the analysis of each micro-region. Landscape sensitivity analysis for the conditions of climate change was only performed in those cases where climate change could play a role and could be taken into account. This is described in the case of each process and a general discussion of the climate change issue is given under A)13. The last step was the sensitivity analysis for each landscape type.

A) Landscape degradation processes of Hungary

On the basis of the review of landscape degradation processes in the world the degradation processes endangering the landscapes of Hungary were identified and analysed in detail (see Kertész, Á. 2019., Kertész, Á. and Krecek, J. 2019).

It is emphasized that landscape degradation is strongly related to human impact including agricultural activities. In Hungary the role of agriculture is very important. In 2018 the percentage of arable land was 46,59 % (48.37 % in 2000) and that of agricultural land was 57.44 % (62.93 % in 2000). The decrease of agricultural land involves the need of a more intensive agriculture enhancing landscape degradation risk.

Landscape degradation maps with evaluation and description were prepared on the present state of each process and on sensitivity from the aspect of the process in question. It was not possible to produce two maps for every process. If this is the case there is an explanation in the report for that. Publications on sensitivity (see Kertész, Á. and Őrsi, A. 2014a, 2014b, Kertész, Á. et al 2014a, 2014b, Kertész et al. 2015a, 2015b, Kertész, Á. and Őrsi, A. 2016) report on the methods and results of sensitivity analysis in various landscape units.

The following landscape degradation processes were investigated:

1. *Sheet erosion*

Soil erosion is the most significant land degradation process in agricultural areas. The risk is very high in the mountain and hilly regions because a significant area of hillslopes is used for agriculture. Sheet erosion on arable land is especially hazardous on large arable fields created mainly in the 1960s, 1970s. The main triggering factors of water erosion are soil parent material (loose sediments), slope gradient, high intensity rainfalls and land use.

(a) The present state of the soil surface from the aspect of soil erosion changes continuously. Any map showing the present state would therefore be only a snapshot. That is why a remote sensing method was elaborated and tested for mapping the present condition of the surface. The method is based on the identification of the origin of the surface soil layer, i.e. whether it represents an originally deeper laying horizon (e.g. B horizon), or the parent material. A case study was carried out on a Cambisol formed on loess parent material. The soil and the parent rock have various reflectance spectra in the visible range, so this strip was used for the investigations. For map creation "training sites" were used in ArcMap environment. According to the obtained results, the method is highly effective and useful, however, other properties like moisture content and plant cover can limit automated application. In this case new training sites are needed. The method and the case study were presented at the 2016 EGU conference in Vienna (Jakab et al. 2016).

(b) Soil erosion sensitivity. Soil erosion maps compiled during the last 5-6 decades present actually soil erosion sensitivity. The given soil loss values indicate the degree of erosion so that in reality it is a degree on a scale between slight and strong erosion which is behind the values given as soil loss t ha^{-1}. All maps reflect a strong relationship between relief and soil loss. Strongly eroded areas are in the mountains and in the hilly countries. Slope gradient doesn’t play a decisive role as triggering factor of sheet erosion as the steep slopes are covered by forest. The main driving factors are soil parent material and land use. The high percentage of arable fields is an important risk factor. Fields are without vegetation cover for a long period after harvest and there is no protection against the eroding activity of rainfall as discussed above. Altogether four maps are included and analysed in the database (see Centeri et al. 2019).

The map of the current state of erosion would be similar to the map of erosion risk because the eroded areas where a considerable part of the soil profile is missing have a low resistance against erosion.

Soil erosion sensitivity was investigated also by the method of indices (Kertész et al. 2015c, 2015d). The map of the natural macro-region of the Transdanubian Hills was prepared by this method and the areas with different sensitivity values were identified (Figure 1). The method proved to be suitable to characterize soil erosion sensitivity.

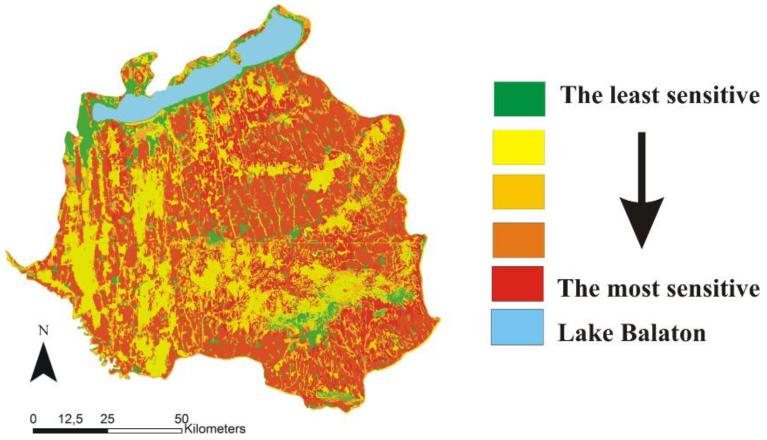

Figure 1 Soil erosion sensitivity map of the Transdanubian Hills (Kertész 2015b)

2. *Gully erosion*

(a) The gully distribution map (Figure 2, Jakab and Kertész 2019) was prepared by digitizing 1:10 000 topographic maps. Gully distribution values are very high in the forests of the mountains developed during a long period of time, whereas the rills and gullies on arable land were labelled by each cultivation operation. Ephemeral gullies are difficult to survey and the contradiction is that the sediment transported in the gullies plays the most important role in recent soil erosion on hillslopes. The high gully density values of the forested areas shown on the map reflect intensive soil erosion of former times not meaning a high erosion risk today. Gully erosion forms leading to serious damages on hillslopes cannot be included in the database and therefore cannot be presented on the map because of the reasons described above.

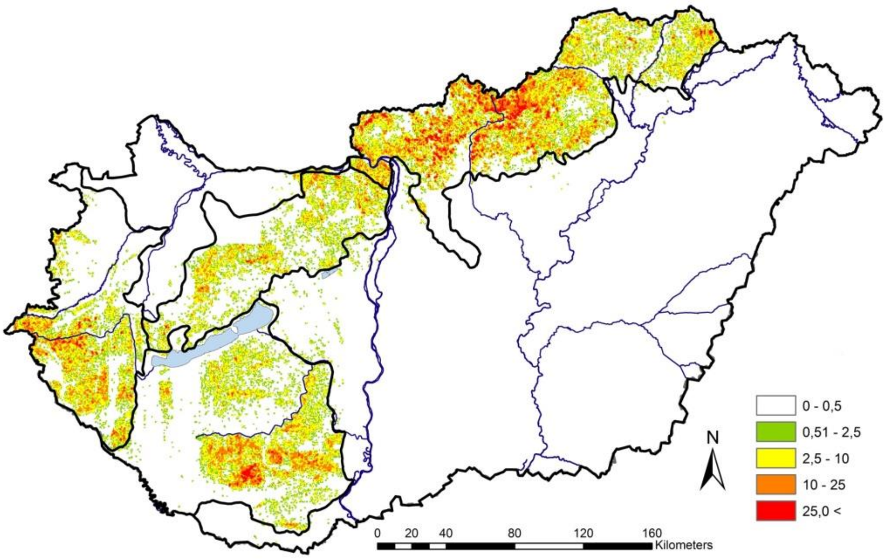

Figure 2 Gully distribution map of Hungary (km km^{-2}, Jakab, G. and Kertész, Á. 2019)

The analysis of the relationship between gully distribution and the driving factors show that the main driving factor of gully development is relief followed by soil parent material. The role of soil types and land use is less important because these variables are not independent form relief. Gully length is affected mainly by soil parent material. Longer gullies develop on loose, porous sediments than on compact rocks. Gully initiation and development are promoted also by subsurface erosion, i.e. by piping. Physical and chemical properties of loess and loess-like sediments offer favourable conditions for the development of pipes. Rainfall amount and intensity are important triggering factors of gully erosion. The role of land use, especially deforestation is very important as well.

(b) Gully erosion risk. The relationship between two most important factors of gully development (gradient and land use) in the most endangered areas was investigated from the aspect of gully erosion risk. Comparing slope gradient and gully density the conclusion is that gullies do not develop on the steepest slopes.

The mesoregions of Cserhát, Mátra, Börzsöny mountains, the North Hungarian basins, the Barany-Tolna hills, Zala hills and the Eastern Alpine Foreland are the most endangered regions. The most endangered micro-regions belong to the above mentioned macro regions.

Part of the gullies existed for a long time, their development is not related to present climatic, relief, land use and other environmental conditions. These gullies were formed on compact rocks, they are stable and will exist probably for a long time in the future, but without significant increase.

Another part of the gullies developed on porous rocks, mainly on loess and loess-like sediments. They may exist for several hundreds of years. However, their formation is relatively quick if momentary environmental conditions favour gully formation. From the aspect of risk they are much more important than those in the mountains. They represent a serious risk on cultivated areas, especially on arable land. The most fertile soils of Hungary were formed on loess and are cultivated intensively.

3. *Wind erosion*

(a) Wind erosion is different according to various climatic, geomorphic, soil and land use conditions. In the database there are two wind erosion maps (Négyesi, G and Lóki, J. 2019) presenting potential wind erosion susceptibility. According to this map 26.5 % of the country area is strongly or moderately affected by wind erosion. The critical velocity threshold value of erosive winds is 8.5 m s^{-1}. The map of potential wind erosion is presented in Figure 3.

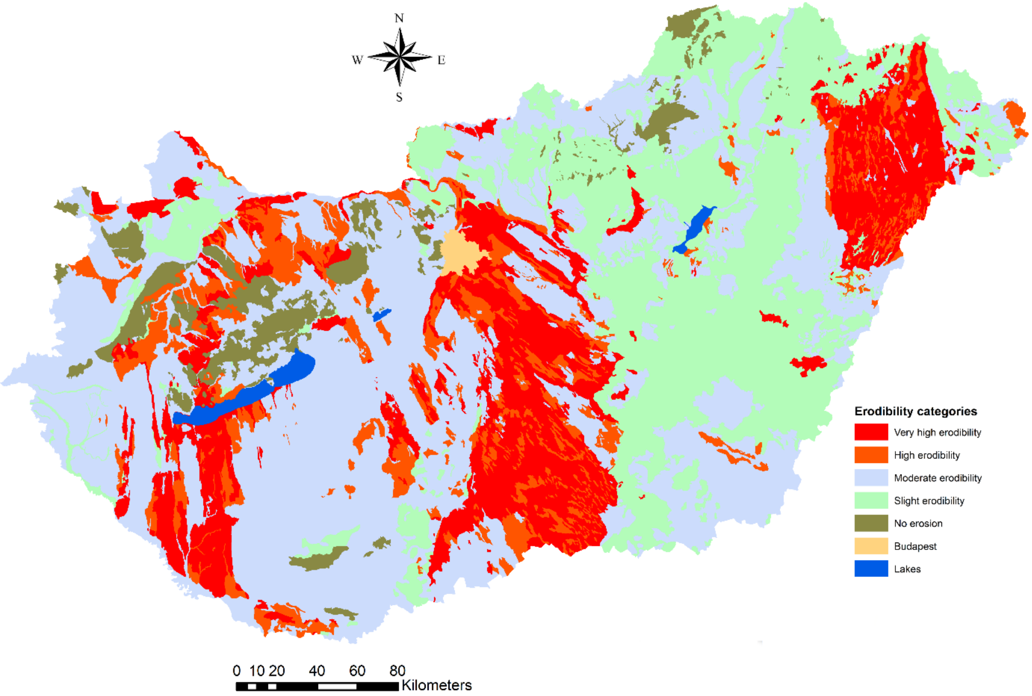

Figure 3 Map of potential wind erosion of Hungary (Kertész et al. 2019).

(b) Roughly 10% of the country is affected by high wind erosion risk. The reason for that are the vegetation cover and the incidence of erosive winds, i.e. wind with velocity exceeding the local critical threshold value. In most cases the critical velocity will not be exceeded during the year. Arable lands on lowlands with sandy soils are the most prone to wind erosion, because of the relatively small critical threshold velocity (6-7 m/s).

4. Water and wind erosion in a selected natural micro-region (Hajdúhát)

(a) Water erosion. The territorial differences are explained by the erodibility of soils changing form N to S. The areas less resistant to sheet erosion are E and SE of Hajdúnánás and to NW of Debrecen. Gully erosion is negligible despite of the presence of various loess and loess like sediments. There are practically no permanent gullies in the micro-region (Jakab, G. and Négyesi, G., 2019).

(b) The micro-region belongs to the areas of medium risk from the aspect of wind erosion. Wind erosion risk is higher in the northern and eastern border regions where wind-blown sand and loess sand cover the surface (Jakab, G. and Lóki, J., 2019). The distribution of various degrees of water and wind erosion are shown on maps, too (Jakab, G. and Lóki, J., 2019).

5. Salinization, secondary salinization

(a) Altogether 6 maps are in the database. Saline areas can be found in 67 natural micro-regions of the country (Madarász, B. 2019). The number of natural micro-regions with saline soils > 1 km^2 is 58. The largest saline areas are in the following micro-regions: Hortobágy (939 km^2), Tiszafüredi–Kunhegyesi plain (359 km^2), Csongrád plain (296 km^2), Szolnok–Túr plain (277 km^2), Bihar plain (273 km^2), a Dévaványa plain (268 km^2).

(b) The areas sensitive to secondary salinization (Figure 4) were determined from water depth data, critical water depth and the saline areas of the agro-topographical map Madarász, B. 2019). For future planning it is of crucial interest to reveal the sensitive areas on the level of micro-regions. Saline areas are present in 67 natural micro-regions of the country. The largest saline areas are in the following micro-regions: Hortobágy (939 km^2), Tiszafüredi–Kunhegyesi plain (359 km^2), Csongrád plain (296 km^2), Szolnok–Túr plain (277 km^2), Bihar plain (273 km^2), a Dévaványa plain (268 km^2).

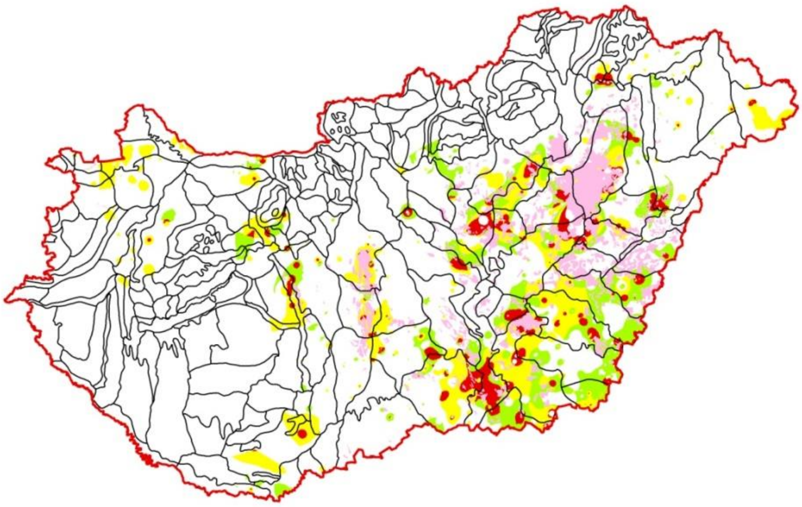

Figure 4 Extent of areas susceptible to secondary salinization as a function of potential rise of groundwater level Madarász, B. 2019, in : Kertész 2019)

On the basis of the results it can be asserted that one meter rise of groundwater level would only affect a smaller area (34 000 ha), but in the case of a 1.5 m rise the size of the areas affected by secondary salinization would be greater than 145 000 ha and a rise of 2 metres it would be 235 700 ha.

(c) It is difficult to forecast how the groundwater level in the critical micro-regions will change. This will be shown on the example of the 2010s. Drastic groundwater level subsidence happened at the beginning of the 2010s as a result of successive dry years. A rainy period followed the dry years triggering the rise of the groundwater level and the process of salinization took over again.

(d) It is difficult to forecast how the groundwater level in the critical micro-regions will change as a consequence of climate change because the changes of dry and wet year series lead to desalinization, or salinization. This happened in the 2010s.

6. *Physical degradation*

As the present state of degradation of the soil surface changes with time, maps of the present state and the state in the case of climate change were not prepared. The susceptibility map (Figure 5) was compiled by Madarász, B. (2019). The three categories of susceptibility are equally distributed (29-31-33%). It is quite probable that global climate change will not seriously effect physical soil degradation. However, if the extent of the areas covered with inland water will increase, it will influence the distribution and extent of the areas susceptible to physical degradation as well.

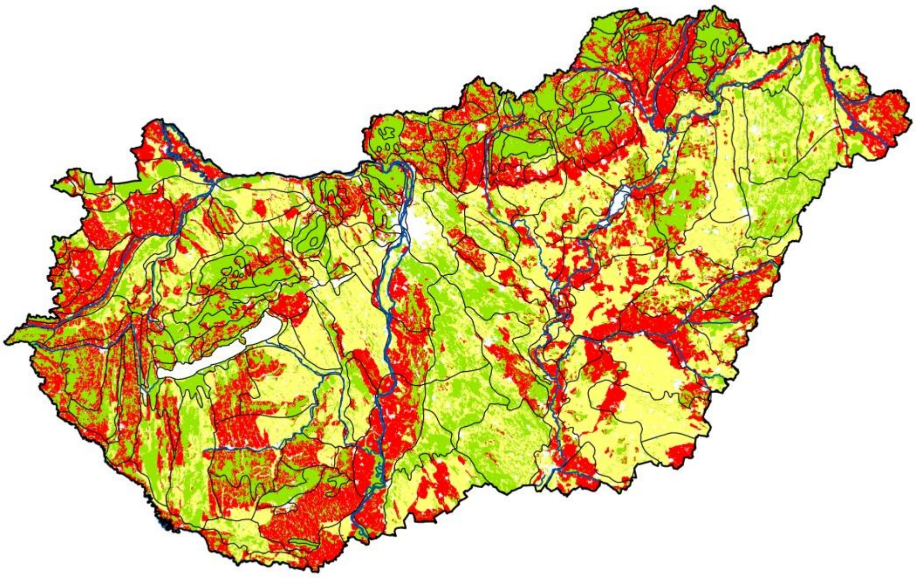

Figure 5 Areas susceptible to physical degradation (white = settlements, areas covered by water; red = highly susceptible; yellow = susceptible; green = less susceptible areas). Madarász, B. (2019)

7. *Mass movements*

(a) They represent a form of land degradation since threaten both human structures and agricultural areas and provide favourable conditions for further degradation in the form of soil erosion. A statistical summary of mass movement events was prepared in the updated national inventory. Based on this, three maps are included in the database: the locations of recent and subrecent mass movements, the number of mass movements in the micro-regions, the density of mass movements per km^2 in the micro-regions (Lóczy et al. 2019).

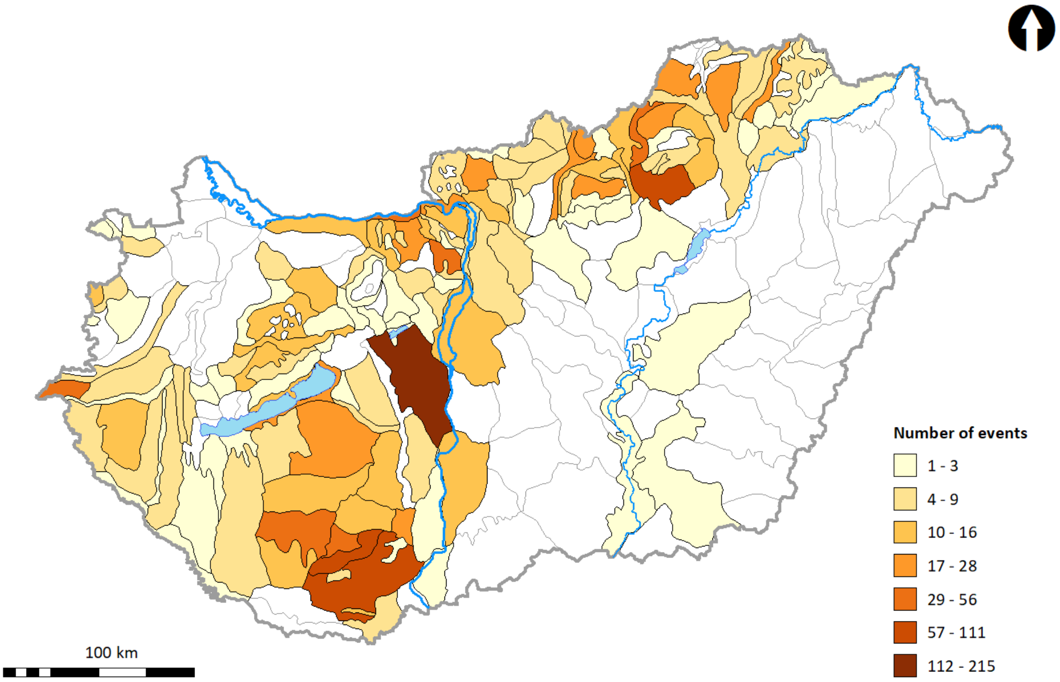

Figure 6 Number of mass movements by physical micro-regions (Lóczy et al. 2019).

(b) Landslide susceptibility can be estimated from the past occurrences of mass movements. Through the examples of representative case studies from the regions affected, the main types, mechanisms and causes of landslides are highlighted. Susceptibility of mass movements for the conditions of climate change it is assumed that the probability of the occurrence of mass movement events will grow because of the increase of extreme rainfall events.

8. *Soil sealing*

The percentage of sealed areas in Hungary in 2012 was 3.21 %, in 2009 only 3.17 pointing to an increase of almost 10 % in four years. The map of sealed areas (Figure 7) was compiled from COPENRNICUS data of 2015 (Kertész, Á. 2019). In 2015 the total sealed area covered already 3.975% of the country area. The area of sealed surfaces between 30-60 % is 2,1 % of the country area and 52.8 % of all sealed areas (Kertész, Á. 2019.).

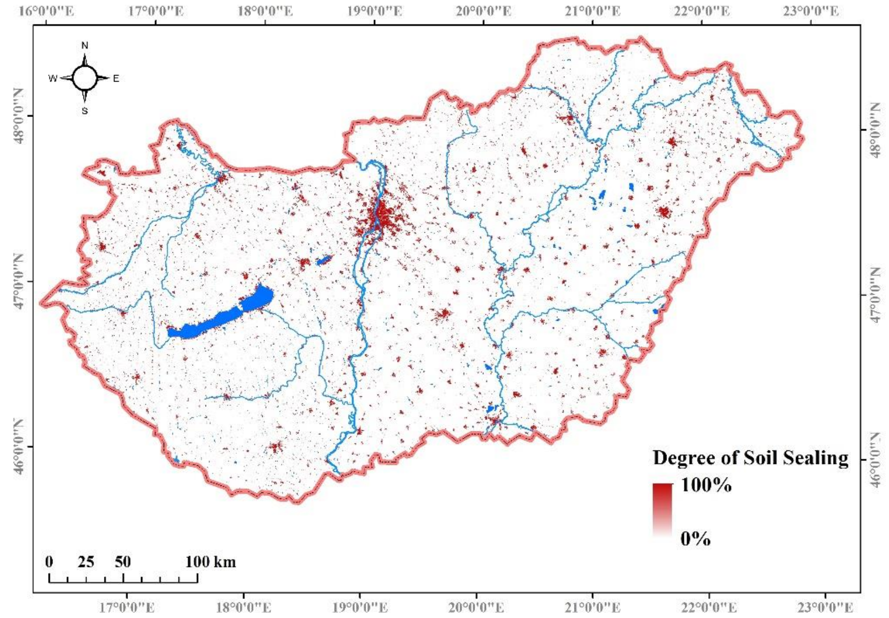

Figure 7 Soil sealing map of Hungary (Kertész, Á. 2019).

Soil sealing sensitivity was not investigated because it would not make sense.

9. *Desertification*

Desertification sensitivity was determined by applying the ESAI (Environmentally Sensitive Area, see Figure 8) index for an area of 10 000 km^2 in the Danube-Tisza Interfluve (Kertész, Á. and Őrsi, A. 2016, 2019).

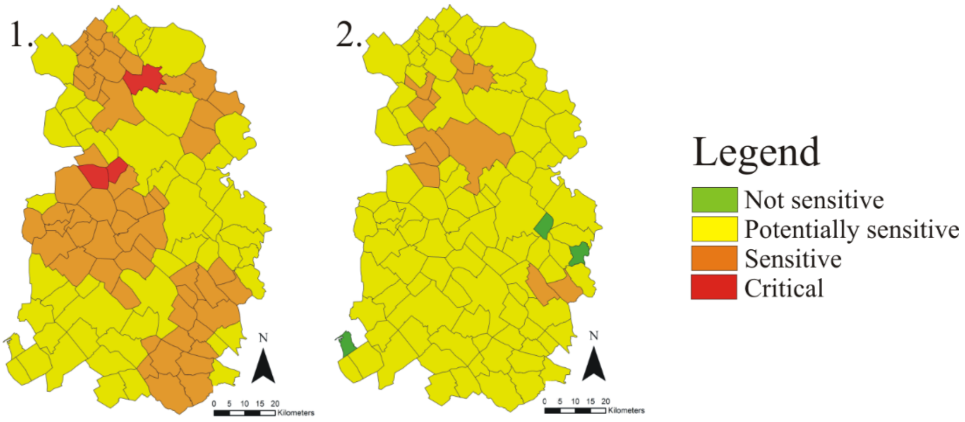

Figure 8 Desertification sensitivity indices in the Danube-Tisza Interfluve (1) due to natural factors and (2) taking land use intensity into account (Kertész, Á. and Őrsi, A. 2019).

According to climate change scenarios desertification risk will grow. Temperature increase and precipitation decrease accompanied with more frequent and longer periods of drought call for a policy making strategy to combat desertification (Kertész, Á. and Őrsi, A. 2019).

There is no map and description on the present state of desertification because there are no desertified areas in Hungary at the moment.

10. Floods

From the topic of the degradation of waters the degradation of waters the process of flooding was investigated. Two maps were prepared and included in the database: excess water hazard map and flesh flood hazard map (Figure 9, Lóczy, D. et al. 2019). The case study of flash flood hazard along the Drava rived is presented as a case study.

Recently a steady rise in flood levels has been observed along the major rivers as a result of interactions between human activities on the catchment (deforestation, housing and infrastructural development, restriction of floodplain widths) and the direct and indirect impacts of climate change (inclination to more intensive drought and unpredictability of rainfall, discontinuous vegetation cover).

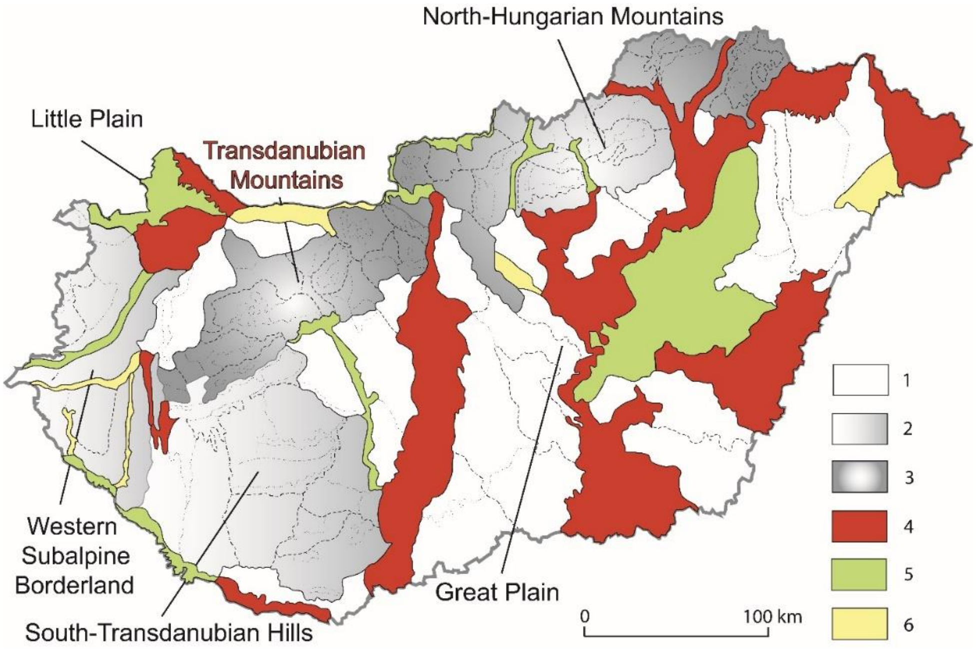

Figure 9 Assessment of riverine flood hazard by the microregions of Hungary (by Lóczy, D. in: Lóczy, D. et al. 2019, from data by VITUKI 1990-2015). Continuous lines indicate the borders of macroregions, dashed lines the borders of units lower in the hierarchy (meso- and microregions). 1 = lowland macroregions; 2 = hilly macroregions; 3 = mountainous macroregions; 4 = microregions with extensive active floodplain sections (inundated on more than eight occasions in the studied interval); 5 = microregions with floodplains affected by the locally defined design flood (floodplains inundated on four to seven occasions); 6 = other potentially affected microregions (floodplains inundated on less than four occasions)

There is no map on the present state of floods because the water level of the rivers changes in time including very high water levels.

11. Landscape aesthetics

The current state of the landscape aesthetical value of Hungary was determined by GIS methods (Pálinkás, M. et al 2019). Landscape elements increasing landscape beauty (relief, forest cover, lakes and rivers, protected areas and vineyards) and artificial landscape elements were evaluated. Six maps were stored in the database: the maps of relief and forests; protected areas; visibility buffers for lakes; landscape aesthetic value of natural landscape elements; artificial polygons and points, aesthetic evaluation of natural and artificial landscape elements (Figure 10).

The general conclusion is that the aesthetical value of Hungarian landscapes is high. The map helps to identify the Hungarian landscapes with outstanding beauty and rich biodiversity.

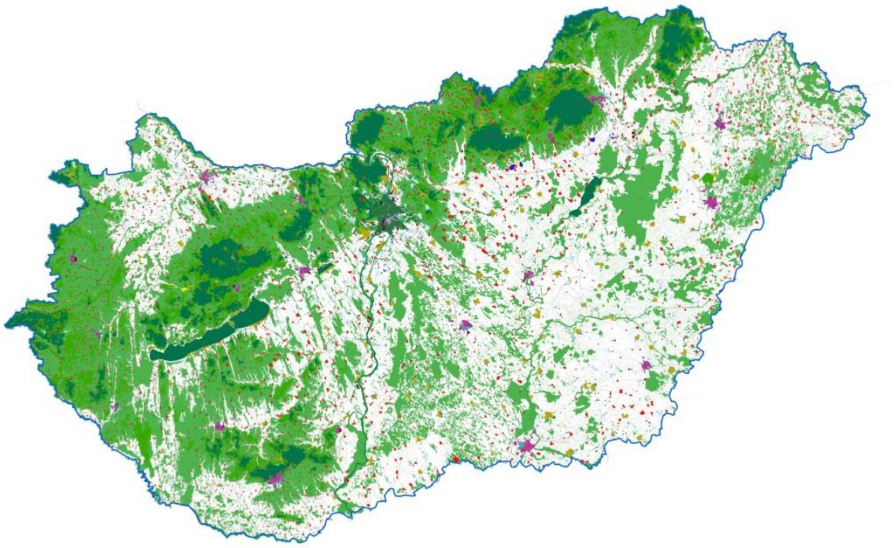

Figure 10 Aesthetic evaluation of natural (green tones) and artificial (other colours) landscape elements excluding agricultural areas (white, Pálinkás, M. et al 2019).

12. Landscape aesthetics based on human perception

A questionnaire survey and GIS approach were applied. Three value maps were prepared, one for land cover, one for topography and a map of landscape aesthetic value (Lontai et al. 2019). To validate the results of the maps, in the framework of the Cultural Ecosystem Services, the connection between landscape aesthetics and the offer of rural tourism was examined for the whole area of Hungary (Figure 11) and for the Danube Bend as priority tourism development area.

The conclusion is that there is a difference in the results of the objective and subjective assessment of landscape aesthetic value with the more important role of topography in the latter. It can also be concluded that both topography and land cover are decisive factors of landscape value. Only a partial territorial overlap was found between the recreational function and the landscape aesthetic value. Another conclusion is that the aesthetic value of the landscape and tourism are not independent of each other.

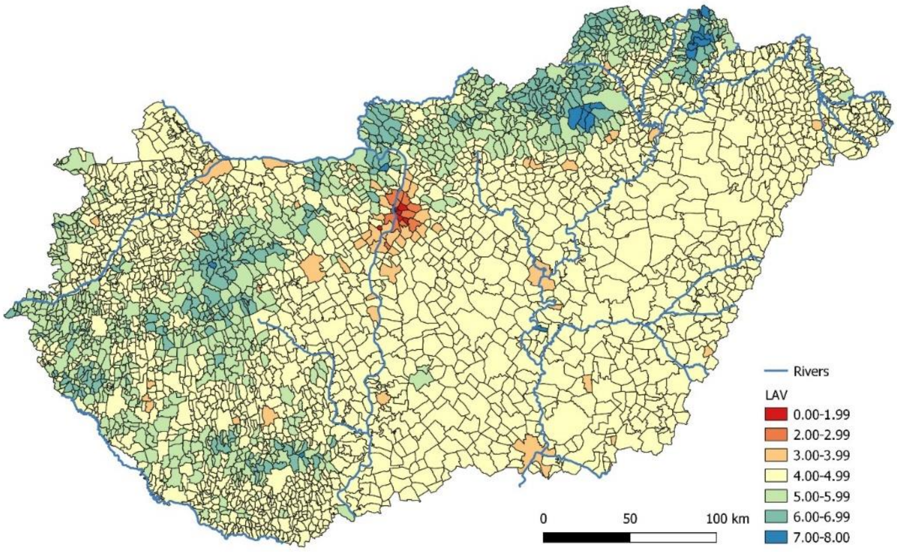

Figure 11 Landscape Aesthetic Value map of Hungary (Lontay-Szilágyi, Zs. et al. 2019)

13. Climate change

The effects of the projected climate change on eight land degradation processes (sheet erosion, gully erosion, wind erosion and wind erosion susceptibility, puffer capacity, groundwater level as a driving force of desertification, mass movements, physical degradation) were investigated by regression analysis. The following variables were selected form from the CARPATCLIM data set: annual global radiation, annual potential evapotranspiration, annual and seasonal precipitation and temperature values. Calculations were performed for the whole country and for six macro-regions. The projected changes are too large and therefore not realistic. Considering the role of the various variables the conclusion is that the climatic variables are less important than the environmental factors. This statement is not validated and it doesn't follow our hypothesis.

14. Degradation sensibility of landscape types

Landscape types were investigated from the aspect of the landscape degradation processes acting on them and summarized in a table. Soil sealing, wounds in the landscape may occur on any landscape type and the same is true for the decrease of the aesthetical value of the landscape so they were not included in the analysis. The most important processes endangering most of the landscape types are sheet erosion, gully erosion, wind erosion and mass movements. The process of desertification threatens every landscape type but its role is decisive on floodplain and alluvial fan landscape types. The degradation sensibility of landscape types will be presented at the 8. Hungarian Conference on Landscape Ecology in August 2019 and published in the conference proceedings volume.

B) Other scientific results

1. Landscape degradation and Ecosystem services.

Several publications discuss this important question (Kertész, Á. et al. 2015 a, 2015b, Kertész, Á. 2019a, 2019b). Land degradation reduces the quality of land in multiple ways. Improper land use leads to long-term losses of ecosystem function and productivity. Soil erosion and desertification processes decrease the rate and quality of ecosystem services. Land cover types of the Transdanubian Hills are presented on Figure 12. Table 1 shows the ecosystem services influenced negatively by soil erosion indicating the different land cover types which provide them.

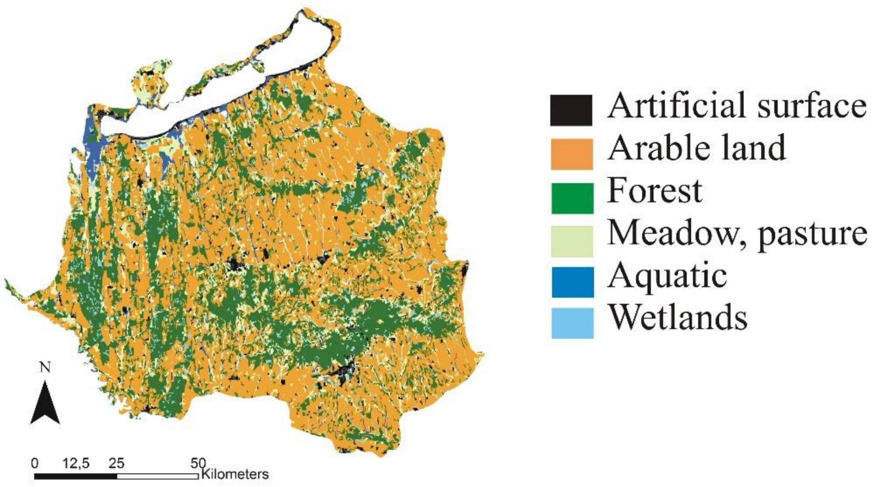

Figure 12 Land cover of the Transdanubian Hills (Kertész et al. 2015b).

Ecosystem service categories	Ecosystem services	Land cover types
Supporting	Soil formation	Ar, F, M
	Nutrient cycling	Ar, F, M, Aq, W
	Primary production (biomass)	Ar, F, M, Aq, W
Regulating	Water quality	F, M, Aq, W
	Erosion control	Ar, F, M, W
Provisioning	Production of food	Ar, F, M, Aq, W
	Fiber	Ar, F, M
	Fresh water	Aq, W
	Fuel (energy sources)	Ar, F
	Genetic resources	Ar, F, M, Aq, W
	Ornamental resources	F, M, Aq, W
Cultural	Recreation and ecotourism	Ar, F, M, Aq, W, S
	Aesthetic values	Ar, F, M, Aq, W, S

Table 1 Ecosystem services influenced by soil erosion, provided by various land cover types (Ar: Arable, F: Forest, M: Meadow, Aq: Aquatic, W: Wetland, S: Settlement).

2. *Spatial analysis of intense rainfalls in Hungary*

Extreme precipitation events can trigger flash flood, mass movement, fluvial flood and accelerated soil erosion. The changes and anomalies of intense rainfalls in Hungary were investigated by Jakab et al. (2019). Daily maximum mean precipitation amounts (MMPA) predicted by the Goda method for June and August as the most probable months of extremities were compared. The 50 years dataset was divided into two periods: 1960-1985 and 1986-2010. A general increase was found between the first and second half of the period in both investigated months. Spatial differences are as follows. Comparing the macro regions, lowlands had lower increase compared to the mountains. The highest increase was detected in the Transdanubian Hills. The most endangered location is the south of this micro-region where loose sediments and land use (high percentage of arable land) also point to the potential hazard.

3. *Drought tendencies in the Carpathians as reflected in a 50-year time series*

Drought is the main driving force of aridification processes in Hungary. Drought leads to water shortage and very high temperatures influencing agricultural production and water supply.

Statistical analysis on annual and seasonal level was carried out. The results show that monthly average temperature, maximum temperature and evapotranspiration had similar pattern and had positive trends in all seasons except autumn. Precipitation also had a positive trend, but it had negative values in winter. The geospatial analysis revealed that there is an increasing trend from west to east and from to north to west (Szopos, N.M. et al. 2019).

The most sensitive areas are Western Hungary and Eastern Croatia where all the involved climatic variables exceeded the threshold (Figure 13). Results can help in preparing the possible mitigation strategies to climate change and both landowners and planners can draw the conclusions.

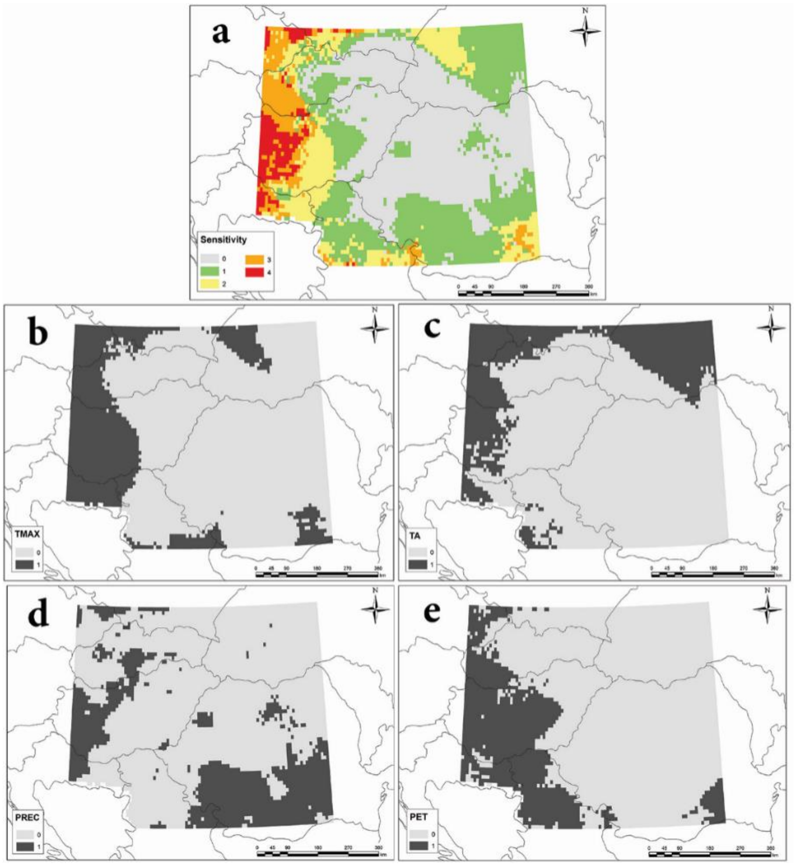

Figure 13 Sensitive areas based on the observed highest trends ($ß_1$-values) for the climatic variables using the threshold of upper quartiles (a: sum of climatic variables where all maps were added – the higher the value, the more climatic variable exceeded the threshold; b: TMAX; c: TA; d: PET; e: PREC, Szopos, N.M. et al. 2019).

4. MODIS NDVI and climatic variables: spatial and temporal trends of predicted changes

The CARPATCLIM (CC) database (1960–2010) and the MODIS NDVI images (2000–2016) were evaluated for the time period covered by both, i.e. between 2000–2010.

Regression analysis between the NDVI and CC variables and a time series analysis were carried out for the 1960–2008 and 2000–2008 periods. The results show that maximum temperature (TMAX), potential evapotranspiration and aridity all have a strong correlation with the NDVI. The short period trend of TMAX can be described with a functional connection with its long period trend. Consequently, TMAX is an appropriate tool as an explanatory variable for the spatial and temporal variance of NDVI.

The spatial pattern analysis revealed that with regression coefficients, macro regions reflected topography (plains, hills and mountains), while in the case of time series regression slopes, it justified a decreasing trend from the west (Transdanubia) to the east (Great Hungarian Plain). This is an important consideration for future agricultural and land use planning; i.e. that western areas have to allow for greater effects of climate change Szabó, Sz. et al. 2018).

5. *The relationship between landscape degradation and geodiversity was investigated and revealed*

Geodiversity is threatened by a series of anthropogenic activities and land degradation processes menacing not only biodiversity but also geodiversity.

Degradation processes affecting geodiversity were investigated in general and in a selected study site (Bükk Mountains). The effects of land degradation processes on landform development and on changes of geodiversity were analysed in the study area (Őrsi, A. 2014a, 2014b, 2014c).

As a result of landscape degradation parts of the landscape may change and natural processes may cease to operate. Processes like land levelling, soil erosion and removing water bodies and surfaces lead to geodiversity decrease.

It was also shown that land degradation, e.g. gully erosion can produce spectacular forms and therefore enrich geodiversity.