

Propositions of PhD theses

**INVESTIGATION OF ANTHROPOGENIC GEOMORPHOLOGICAL PROCESSES
IN CONNECTION WITH THE TRADITIONAL LAND USE IN THE AREA OF
TOKAJ-HEGYALJA**

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1 Introduction

The increasing environmental load was an inevitable consequence of the development of human civilization. The growing needs of people required more and more resources, which lead to the increase of the degree of the environmental impact. Today we can claim that humans became a major surface-forming factor, and it may be more effective than natural processes in areas which have been in intensive use for a long time (Gouide, 1995). As a result of the above, it is more and more common that society has to face the consequences of the undesirable effects caused by itself.

Land use, including agriculture and its various cultivation methods, caused significant changes in the past and continues to shape our environment today. In terms of agriculture, the activity with one of the largest surface-forming potential is vine cultivation, because on the steep slopes of vine parcels covered with long and scarce flora a heavy summer rainstorm, or in winter, the rapidly melting snow could lead to the erosion of soil. Vine production dates back to more thousands of years in Hungary and it is part of the cultural heritage of the country (Nyizsalovszki és Fórián, 2007).

Tokaj-Hegyalja wine region was declared a UNESCO World Heritage Site in 2002 in the cultural landscape category, as a result of the interaction between nature and society lasting for thousands of years (Frisnyák és Gál 2012). In terms of this heritage category, the values which should be protected are the combination of natural and anthropogenic elements. The land development and its dynamic have been formed due structural and functional connection over the years, which resulted in the unique character of this landscape (Antrop, 2000). The natural environment and the anthropogenic effects are major forces which shape the features of cultural landscapes, which are mirrored in the traditional values of rural regions as well (Antrop, 2004, 2005). However, during the last century, the extent and the rate of changes occurred due to anthropogenic effects fundamentally threatens the existence and preservation of traditional landscapes (Kozak, 2008) and their traditional cultivation methods which have been used for centuries (Antrop, 1997; Austad, 2000; Sallay et al. 2012). However, it is not known exactly how large area has been affected and what types of processes are resulted by the impact.

In this regard, I find it important to identify and quantify the extent of anthropogenic effects on the surface forms and surface development in the Tokaj-Hegyalja wine region which has a history of viticulture dating back to thousands of years.

2 Aims

The aim of my dissertation is to identify the geomorphological processes in connection with the land use regarding the traditional land use of Tokaj-Hegyalja wine region, and the geographical characteristics and temporal changes of the anthropogenic forms. In my work, I attempt to answer the following questions.

- How the area of cultivated vine parcels was changed and what was the mean rate of cultivation and abandonment during the last 230 years?
- Do the topographical characteristics of vine areas itself play a major role in certain periods regarding the abandonments, and could we identify patterns considering the most important relief properties of vine production?
- What is the extent of the terraces with retaining walls? When were they abandoned, and which natural geographical factors were most important regarding the abandonment of vine areas?
- Which are the most important geomorphological properties of terraced slopes and dryly built stone walls and what is the condition of the former vine terraces as cultural-historical values which are part of the world heritage?
- What kind of similarities and differences could we find between the soil properties of terraced and non-terraced abandoned vine areas?
- To what extent the lithological properties affect the construction of stone walls and their method of construction?
- What is the extent of gullies and loess roads? What are the geomorphological properties of these and what is the estimated amount of the eroded material?
- Which are the most vulnerable areas and settlements with regards to gullies?
- What is the extent of the area affected by surface mining, and how the size of stone mines changed following the 1940s and what was the amount of material which has been transported over the years?
- At the end of my dissertation, I attempted to identify the extent of anthropological impact on the sample area based on the ratio of the materials which has been transported during natural processes and anthropological activities.

3 Material and method

In my research, I used historical and contemporary maps and aerial photographs in order to investigate the changes occurred in surface coverage during the past centuries. For the separation of vine areas, I used visual sorting method, while for the investigation of these in terms of slope category, slope exposition and altitude I used a surface model generated from contour lines. Beside the topographical characteristics, I described the changes occurred in the abandonment of vine parcels between 1784 and 2010 in six subsequent time intervals (1784-1858; 1858-1884; 1884-1940; 1940-1969; 1969-1989 and 1989-2010).

The mapping of terraces with retaining walls was mainly based on aerial photographs, which I further refined during fieldwork. During the field measurements, I recorded the accurate EOV coordinates of terraces in every case, I measured the total length, height and width of retaining walls and the length of sections which were partly or completely destroyed, and counted the number of building block per 1m². Using a sextant, I measured the steepness of the terrace surface, the steepness of the original slope (the slope radius determined by the upper edges of two subsequent retaining walls) and the gradient of the retaining wall. I categorized the retaining walls by their construction methods, that is, whether they are dry, mortar or concrete walls. The classified the flora of the terraces into herbaceous plants, shrubs and woody plants.

In four settlements of Tokaj-Hegyalja – Mád, Tarcál, Tállya, Tokaj – I explored 29 soil sections (in 10 and 19 non-terraced and terraced areas, respectively) in abandoned vine areas with different age, down to a mean depth of 1-1.5m. With the laboratory analysis of soil samples I identified the characteristic morphological, lithological and soil features of vine regions. The sections have been dug up close to the bases of the retaining walls in order to examine to differences in terms of the construction of the walls. During the laboratory analysis of soil samples I investigated the granulometric composition, pH, carbonated lime content, and organic carbonic content in the case of soil sections, and I measured the total copper and phosphorus content of topsoil in the cases of 17 soil sections. The interpreted the results using Mann-Whiney U non-parametric statistical test and Spearman's rank correlation.

For the identification of the excavation forms (gullies, loess roads and stone mines) and its characteristics and material loss I used a surface model generated from LiDAR data and contour line coverages. In order to reconstruct the vine parcel abandonments and to create the erosion sensitivity maps I used logistic regression in a GIS environment considering the topographical factors.

4 Research Results

Thesis no. 1

During the investigated periods, the dynamic of changes occurred in vine regions (abandonments and new plantation) showed significant differences, which – beyond the environmental factors – was affected by the societal, economic and historical factors of the given period.

In this phase of my research, I attempted to reconstruct the vineyard abandonment of the investigated time periods considering the topographical properties. By using models based on logistic regression I was able to identify the abandoned areas with a probability rate between 64.6% and 67.6% in each time intervals, based on which it can be concluded that with regards to the abandonments, the societal, economic, organizational and cultural aspects should also be considered during the evaluation of certain tendencies beyond the environmental/topographical factors.

The dynamics of the vineyards abandonments, the new plantations and the unchanged areas during the investigated periods are different from each other. While between 1784 and 1884 an area of 7000 ha remained unchanged (Table 1), between 1969 and 1989 only 2911.6 ha was unaffected. The largest areas were abandoned between 1884 and 1940 (4045.4 ha). This occurred partly due to the phylloxera epidemic which destroyed a significant part of the vines. The rate of abandonment was the highest between 1989 and 2010 (159.4 ha per year⁻¹) when over the course of 21 years 3348.3 ha was abandoned which can be explained by the political and economic changes of regime. Among the new plantation periods, the 1969-1989 interval should be noted when the mechanization of agriculture prospered.

Table 1.: The changes of vineyards and rate of changes between 1784 and 2010

The investigated time intervals (year)	Vineyards the size of which remained unchanged during the period (ha)	The abandoned vineyard areas (ha)	The mean rate of abandonment per year (ha year ⁻¹)	The new plantation of vineyards during the given period (ha)	The mean rate of new plantation of vineyards per year (ha year ⁻¹)
1784-1858	6976.0	3609.7	48.8	2946.8	39.8
1858-1884	6946.2	2976.6	114.5	1731.3	66.6
1884-1940	4632.0	4045.4	72.2	1538.4	27.5
1940-1969	3283.3	2887.1	99.6	2395.0	82.6
1969-1989	2911.6	2766.7	138.3	4472.6	223.6
1989-2010	4035.9	3348.3	159.4	1163.3	55.4

In the investigation of the changes occurred approximately during the past 230 years the continuous decrease of the extent of vines cultivated in slopes steeper than 12% should be noted. The most intensive change was observed in landscapes with a gradient of less than 5%, where between 1969 and 1989 the share of vine parcels increased from 20.6% to 46%, which reached 47.6% in 2010. The majority of vine regions was cultivated at an altitude of 150.1-200m, above that threshold a gradual decrease could be observed in terms of vineyard areas. From the year 1969 onward, continuous extension could observe in the region at an altitude of 100.1-150.

Thesis no. 2

The terraces with retaining walls were mapped in an area of 660 ha, then I identified the most important topographical and geomorphological properties of these areas.

The vineyard terraces with stone walls can be found in 20 from 27 settlements (Figure 1), and they cover an area of 660 ha in total. The area of terraces is distributed unevenly between the 20 settlements, since 51% of the area of these can be found in the administrative boundaries of only four settlements (Abaújszántó, Tarcal, Tállya, Erdőbénye).

51.1% and 32.9% of the terraced slopes can be found in slopes with a steepness of 17.1-25% and 12.1-17%, respectively. Regarding their distribution according to slope exposition the southern slopes are predominant, but the ratio of terraces is also considerably high in the case of western and eastern slopes. 84.6% of the terraces with retaining walls can be found at the altitude of 150-300m.

During the geomorphological investigation of terraced areas I determined the mean length of the stone walls, which varied between 20m and 30m in 11 settlements, between 30m and 40m in 5 settlements, and it exceeded 40m in 4 settlements. The total length of stone walls 253329.9m, of which Tarcal (64548.9 m) and Abaújszántó (40184.5 m) together make up 41%. The mean height of the stone walls was the highest in the case of Mezőzombor (1.8 ± 0.6 m), and the lowest in the case of Szerencs (0.7 ± 0.3 m). The width of stone walls varied between 0.4m and 0.6m, higher numbers could only be measured in the case of Tarcal (1.1 ± 0.5 m), Abaújszántó (0.9 ± 0.3 m) and Szegi (0.9 ± 0.3 m). The mean number of building blocks per 1m^2 was 27, while the inclination of stone walls was under $15.7\pm 6.9^\circ$ in the case of 17 from 20 settlements. The mean width of terrace surfaces did not exceed 15m with the exception of Bodrogkisfalud ($21.5\pm 9.1\text{m}$) which demonstrates the small parcel nature of the terraced vine production. The slope-decreasing feature of the terraces is not a novel concept, since this is

one of the primary reasons why the terraces have been built. The degree of decrease in inclination was the lowest in Tarczal ($9.2\pm 6^\circ$), and the highest in Legyesbénye ($20.5\pm 7.2^\circ$).

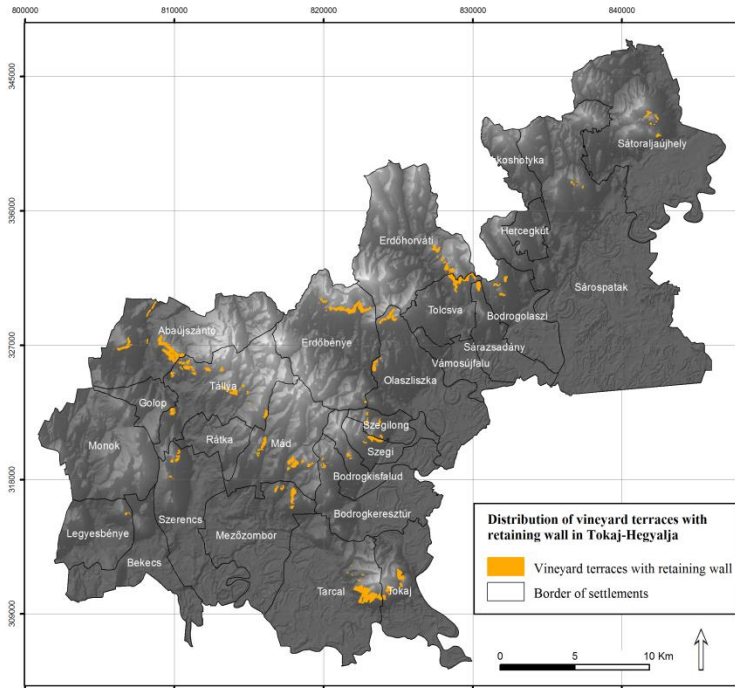


Figure 1.: Spatial distribution of vineyard terraces in Tokaj-Hegyalja

Thesis no. 3

The construction methods of retaining walls were classified into four categories based on their lithological bases, and after the evaluation of their current state I concluded that on average 50% of them was partly or completely destroyed.

The construction of retaining walls can be classified by their lithological base. The first group contains the terraces where the retaining walls were built on the original surface and the bedrock is loess or transported loess. Since in the case of this type, the soil contains only a small amount coarse fraction, the stones should have been transported to the location from elsewhere. This required a significant additional effort from the builders, thus it was not a frequently used method. The second group contains the terraces

where the retaining walls were built on the surface in slope debris containing coarse skeletal fraction. In this case the slope debris providing the basis of the retaining wall contains a mix of colluvial, transported loess and weathered volcanic rocks. The third category includes the cases where the retaining walls were built in solid fibrous rock. Typically, we can find such terraces where the bedrock appears on the surface, or it is located close to the surface. The last category includes the terraces where the bases of the retaining walls have been recessed under the ground level. In this case the builders dig a shallow track perpendicular to the slope surface, into which they rolled the excavated stones. The types are frequently combined even within a short section, which can be explained by the varied microrelief.

In the case of the abandoned vine terraces the cease of cultivation caused a serious problem, since in the lack of continuous maintenance, the structure of walls weakens during the heavy rains and eventually the wall falls down. In Tokaj-Hegyalja the mean length of retaining walls which entirely and partly fell down are $39.8 \pm 12.7 \text{m}/100\text{m}$ and $9.4 \pm 4.7 \text{m}/100\text{m}$, respectively, which means that approximately half of the retaining walls are damaged or completely destroyed.

The terraced areas are irreplaceable parts of the World Heritage Site, therefore their preservation is of outmost importance. This, however, requires a collaboration in which the parties can reach a consensus from every standpoint.

Thesis no. 4

During the soil investigation of abandoned vineyards, I have found significant differences between the certain soil properties of terraced and non-terraced.

During the investigation of granulometric composition, from the soil samples I identified the ratio of coarse fraction, the sand, the silt and the clay fractions, based on which I have found a significant ($p < 0.01$) difference between the terraced and the non-terraced soils using the Mann-Whitney U test. The coarse fraction, the sand and the clay fractions were higher in the case of terraced soils, while the silt fraction was higher in non-terraced soils.

The pH of the soils was determined using both water and potassium-chloride method, based on the result of which it can be concluded that significant differences ($p = 0.01$) can be observed between the pH value of terraced and non-terraced soil profiles. The non-terraced soil are slightly alkaline ($\text{pH}_{\text{H}_2\text{O}} = 8.0$; $\text{pH}_{\text{KCl}} = 7.6$), while the terraced soils are neutral or in some cases slightly acidic ($\text{pH}_{\text{H}_2\text{O}} = 7.5$; $\text{pH}_{\text{KCl}} = 7.0$).

During the investigation of the organic carbon content, the amount of carbon measured at the depth of the entire profile significantly different ($p=0.043$) in the case of the terraced (median: $12.2 \text{ g}\cdot\text{kg}^{-1}$) and the non-terraced soils (median: $6.9 \text{ g}\cdot\text{kg}^{-1}$), however, if I compared only the topsoil, I did not find such differences between the profiles. Among the non-terraced soils, I measured the highest organic carbon content in the case of profile no. 2 abandoned 145 ± 13 ago ($54.5 \text{ g}\cdot\text{kg}^{-1}$), while in the case of terraced abandoned vineyards I found the highest value in section no. 14 abandoned 62 ± 15 years ago ($84.1 \text{ g}\cdot\text{kg}^{-1}$). This indicates that the abandoned vineyards function as carbon storages after their abandonment.

During the investigation of the calcium carbonate content I did not find significant differences between the terraced and non-terraced soils, however, I observed significant differences between the terraced soils regarding their CaCO_3 content. In the case of certain profiles (e.g. Mád 5.6, east) I measured very low, while other times exceptionally high values. The highest CaCO_3 content was measured in the no. 3 (38.3%), no. 4 (39.6%), no. 14 (31.6%) and no. 18 (46%) soil profiles collected from the Nagy-hegy in Tokaj.

By using Spearman's rank correlation, I identified the relationship between certain investigated soil properties. The silt fractions showed a significantly positive ($p < 0.01$) relationship, while the coarse fraction, the sand fraction and the clay fraction showed a significantly negative relationship with the pH of the soils. The above correlations and the aforementioned differences between the granulometric composition of terraced and non-terraced soils (determined with Mann-Whitney U test) were related to the lithology of the sample area and indirectly to the terrace construction. The terraces with retaining walls have been predominantly constructed in places where stones suitable for building were excavated from the topsoil or its close vicinity. Most of the sampling and the exploration of sections has been performed in the Nagy-hegy in Tokaj, where the bedrock is acidic dacite. However, the non-terraced soils have been sampled mostly in loess bedrocks, where the ratio of silt fraction was higher and they contain coarse skeletal fraction in only a slight amount. The positive correlation between pH and the silt fraction can be explained by the slightly alkaline pH of loess.

Thesis no. 5

I concluded that 70% of the gullies and loess roads has been formed on porous and loose bedrock (rhyolite tuff and loess), and established that gullies can be classified among two land use categories: the former vineyard areas and the woody, shrubby and grassy areas located above these. Then by using the erosion sensitivity map I identified the areas and settlements which are most vulnerable with regards to gullies.

The localization and investigation of gullies and loess roads has been carried out using a surface model generated from LiDAR data. In the sample area I mapped 614 gullies and loess roads which covered an area of 625 ha.

Approximately 70% of the area of gullies is related to porous and loose bedrock: welded rhyolite tuff (95.6 ha), rhyolite tuff (90.5 ha), rhyolite tuff (60.6 ha), fallen rhyolite tuff (54.6 ha), transported rhyolite tuff (47.6 ha), rhyolite ignited pumice (7.9 ha). The mean width of gullies varied between 17.4 ± 9.2 m (holy-stone perlite) and 31 ± 10.3 m (pseudotrachite). The gullies were the deepest on the pseudotrachite (7.8 ± 3.3 m) and the welded rhyolite tuff (6.7 ± 3.7 m) bedrocks on average, while they were characteristically shallowest on rhyolite tuff (4 ± 2.1 m). Considering the mean gradients of the gullies, it can be concluded that the highest values were observed on the diatomite ($385.8\pm 118.6\text{m}\cdot\text{km}^{-1}$), pyroxene-dacite ($353.0\pm 267.0\text{m}\cdot\text{km}^{-1}$), the grey fluid rhyolite ($348.9\pm 284.6\text{m}\cdot\text{km}^{-1}$) and the holy-stone perlite ($324.2\pm 188.0\text{m}\cdot\text{km}^{-1}$) bedrocks.

The appearance of gullies is related to two land use categories: The vineyards cultivated between 1784 and 2010, and forests and mountain pastures located higher than the above areas. In the vineyards I observed 8m longer and 3.5 km narrower gullies on average. Their mean depth, however was nearly identical. Slope exposition distribution of gullies formed in the area former vineyards generally matched the ratio which has been observed in the vineyards, therefore they can be found predominantly on the southern slopes.

In order to create the linear erosion sensitivity map I used logistic regression. By using certain environmental variables I investigated the properties of existing gullies, then based on the above, I identified the areas with similar values and are probably vulnerable regarding the gully formation. Based on the Wald-test it can be concluded that altitude plays a key role in the formation of gullies, but the slope steepness and cross-sectional curve are also important variables. In the case of curvature, the negative values of β coefficients indicate that the gullies are related typically to concave slopes. The accuracy of the model was evaluated with a ROC curve which showed excellent results on all three of the study and test areas.

Considering the probability of gully distribution, I identified four categories: Fewer than 25%, between 25% and 50%, between 50% and 75%, and above 75%. The areas with a probability value of higher than 75% covered an area of 35.2 km² in total (Figure 2). Among the settlements, the most affected ones are Sárospatak (498.2 ha), Erdőbénye (463.7 ha), Erdőhorváti (461.4 ha) and Sátoraljaújhely (421.6 ha). Furthermore, the settlements where the ratio of erosion sensitive areas is relatively high compared to the total area of settlements should be noted. Examples of the above are Makkoshotyka (9.4%), Tokaj (7.9%) and Szegilong (7.6%).

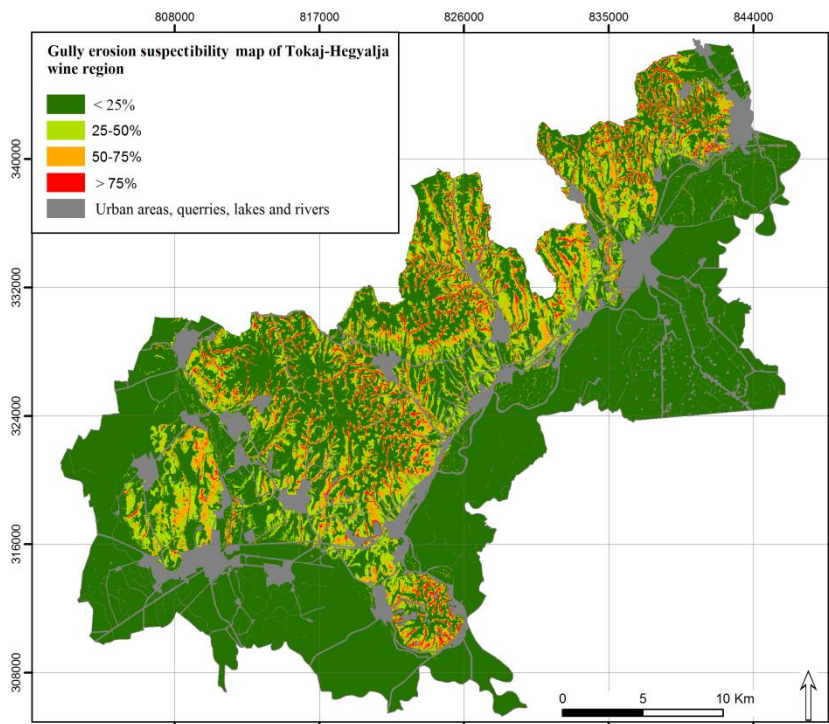


Figure 2.: Gully erosion susceptibility map of Tokaj-Hegyalja wine region

Thesis no. 6

I concluded that the total area of stone mines is 366 ha in the sample area, then I investigated the locations of these mines, the changes occurred regarding the mine areas between 1940 and 2014 and the driving forces behind the changes, and the qualitative and quantitative distribution of the excavated materials.

Based on the maps, I identified the areas of the major surface mines (which can be seen on the maps) which covered 366 ha in total. The total area of mine cavities was 289 ha. After the investigation of temporal changes, I concluded that the extent of stone mines has increased more than 3.5 times since the 1940s. The most important change occurred between 1969 and 1989 when over the course of 20 years the total area of mines was doubled since following the Second World War mining has become an industry with a symbolic significance. After 1989, however, the rate of increase significantly slowed down due to the undesirable effects of the changes of regime. Today, the surface mining activity has been stopped in 48.6% of mines.

The largest stone mines have been created with the purpose of rhyolite tuff, pyroxene-andesite and pyroxene-dacite mining. The demand for pyroxene-andesite and pyroxene-dacite increased significantly following the 1970s. More than 16 billion (36.3%), close to 15 billion (32.5%) and more than 8 billion (18.2%) m³ tons were excavated from pyroxene-andesite, pyroxene-dacite and rhyolite tuff, respectively, which made up 87% of the total excavated amount of material.

At the settlement level, Tállya (14.5 billion m³) and Tarcal (10.4 billion m³) should be noted. More than half of the materials (53%) transported from the Hegyalja mines was related to the above two settlements.

Thesis no. 7

I concluded that 80% of the sample area is affected by the anthropogenic effects, which I classified into six categories by the ratio of anthropogenic and natural material transportation.

In order to identify the anthropogenic effects in geomorphological processes, I used a dimension-free ratio ($R_{ag} = V_a/V_n$). This ratio indicates the extent of the anthropogenic geomorphological modifications (R_{ag}) in accordance with the amount of material transported as a result of anthropogenic activities (V_a) and the natural processes (V_n) (Novák et al., 2013).

In natural or semi-natural areas the ratio is $R_{ag}=0$. In this case the given area has been covered with forests and the anthropogenic impact is limited. These areas were classified among the "olygohemeromorph" category, which covers an area of 14500 ha in the sample area.

By the extent of the anthropogenic impact, I identified six categories:

- Mesoheomeromorph: $R_{ag} < 10$. This category includes the erosion processes in connection with grazing and deforestation.

- β -euhemeromorph: $10 < R_{ag} < 20$. This category includes the terraced areas which were created with the purpose of protection against erosion, and their construction lead to significant surface alteration and material transport.
- α - euhemeromorph: $10 < R_{ag} < 100$. Into this category, I classified the agricultural areas which have been cultivated for a long time. In Tokaj-Hegyalja, the majority of slopes were cultivated in connection with viticulture which caused significant erosion processes in the cultivated areas.
- β -polyhemermorph: $100 < R_{ag} < 1000$. This category includes the accelerated or reactivated gullies and loess roads which were formed due agriculture or inappropriate draining methods.
- α -polyhemermorph: $1000 < R_{ag} < 10000$. This category includes the surface mines which lead to one of the most extensive surface modification per area.
- metahemeromorph. This category includes the covered built-up areas. These surfaces were not only altered by the society but they are still continuously controlled as of today. Regarding this category, I did not calculate the ratio of R_{ag} .

The investigation of lakes and rivers were not part of my research.

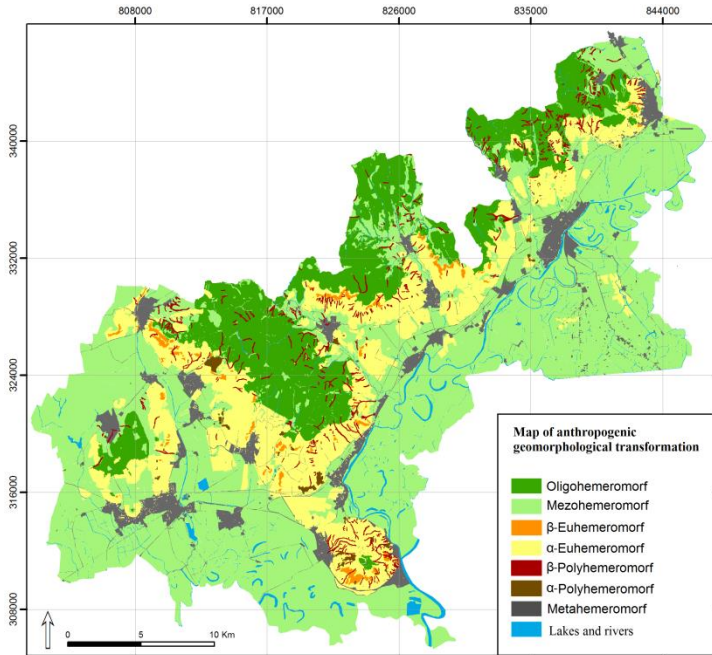


Figure 3.: Map demonstrating the extent of anthropogenic effects in Tokaj-Hegyalja

The aim of my work was to identify certain processes in connection with the traditional land use of Tokaj-Hegyalja, and to describe the spatial characteristics and the temporal changes of the anthropogenic structures. In my dissertation I presented the nearly 230-year-long period of viticulture, the changes and the intensity of abandoned and new planted areas during the given time periods, the spatial identification of the anthropogenic structures which were constructed intentionally (vine terraces, stone mines) and indirectly (gullies, loess roads) and I attempted to estimate the amount of transported materials during these events. Furthermore, I also described the most important soil properties of the areas following their abandonment.

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List of publications related to the dissertation

Hungarian book chapters (1)

1. Novák, T., **Incze, J.**: Kőrákások, kőgátak, támfalak, obalák: a szőlőtermesztés pusztuló emlékei a tokaji Nagy-hegyen.
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Hungarian scientific articles in Hungarian journals (1)

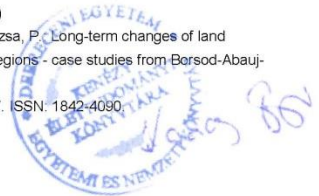
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3. Novák, T., **Incze, J.**: A tokaji Nagy-hegy felhagyott szőlőteraszainak támfalai = Retaining walls of abandoned vineyard terraces on Tokaj Nagy Hill.
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Total IF of journals (all publications): 7,954

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The Candidate's publication data submitted to the IDEa Tudóstér have been validated by DEENK on the basis of Web of Science, Scopus and Journal Citation Report (Impact Factor) databases.

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