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# THE RELATIONSHIP BETWEEN THE ECOLOGICAL NETWORK AND THE WATER SYSTEM IN THE CARPATHIAN BASIN - FINDING A WAY FOR SUSTAINABLE LAND USE

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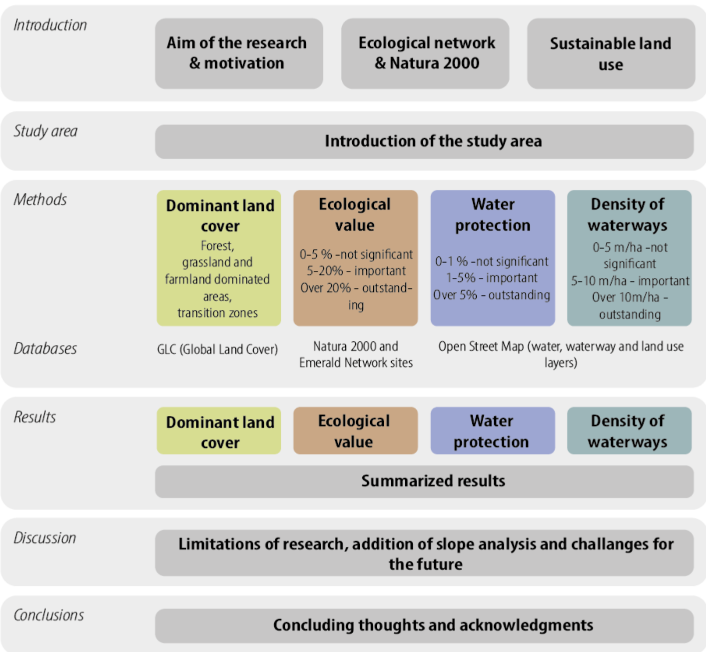
**Abstract**

In our research we dealt with the relationship between the water system (including both the groundwater bodies and the surface waters), the ecological network and land use. Our primary goal was to compare the agricultural suitability to conservation areas, which can provide a framework for sustainable land use in a national-international scale. Our research took place in the Carpathian basin, so that we could observe broader, more comprehensive correlations between the researched aspects at the water catchment area.
We explored the landscape and environmental features of the Carpathian Basin and then analyzed them with the help of GIS methods. We analyzed three different feature categories: the first aspect was water presence and protection, the second was the current land cover, and the third was the Natura 2000 network as a habitat-system and biodiversity protection element. Data collection was obstructed by the fact that the catchment-based study area belongs to 9 countries, only a part of which are EU member states, so we could not rely on EU databases (e.g. CORINE land cover). Based on the available data, we performed GIS analyses, which revealed the common values and dilemmas of the three different aspects.
Based on our results, it was possible to define the areas that adapt to the landscape function but are primarily suitable for cultivation (either arable land, grassland or forestry), the habitats that are sensitive from a natural point of view, and the transitional areas located between them. Our results suggest that the management between these two fields are not cooperating currently. Agricultural land could play a significant role in the joint development in the future, since these areas struggle with both floods and droughts and also with maintaining biodiversity.

**Keywords:** sustainable land use, ecological network, water management, land cover, GIS

**Graphical abstract**



## INTRODUCTION

The goal of our research was to assess the common challenges and possibilities of the Ecological Network and the water cycle. We aimed to identify the similar conflicts and strengths to suggest the joint development of the two systems which could be a way for us to reach sustainable land use. Observations were also made about how the land cover and the geographical structure is connected to the evaluated systems.

The concept of the Ecological Network (EN) is widely used as a conservation tool to protect valuable habitats and species (Jongman et. al. 2011, Jongman et. al. 2004, Opdam et. al. 2006, Graves et. al. 2007). The EN is a coherent system, containing natural and semi-natural habitats, and it is designed and maintained to sustain ecological functions (Bennett & Wit 2001, Meier 2005, Konkolyné 2003). The EN is more than a system of protected habitats, the connections between protected zones, provided by links and corridors is a key for a functional network (De Montis et. al. 2014, van der Sluis & Chardon 2001). Which means that it is present and has an effect beyond the borders of legally protected areas (like for example National Parks and Nature Reserves).

The role of the EN continuously changed during the years, since the first concept was formed in the 1980's, in Latvia and Estonia (Jongman & Veen 2007). Originally its main function was to provide balance between the intensive, the extensive agricultural farming, and the protected natural habitats. The shift towards nature protection happened in 1990 when the Netherlands adopted the concept of the EN, combined it with the metapopulation and island biogeographical theories and this way the EN became a flagship tool for the conservation of biodiversity. The new concept gained popularity and an EN was planned or legislated in almost all European countries in the 2000's (Bennet & Mulongoy 2006).

The EN is an effective tool for biodiversity conservation, since it provides a framework for species dispersal and migration, decreases the landscape fragmentation, increases connectivity by providing links and corridors (Jongman & Veen 2007, Jongman et. al. 2011, van der Sluis & Chardon 2001, De Montis et. al. 2014, Feng et. al. 2021). The EN also promotes the rehabilitation of degraded habitats (Jongman et. al. 2011, Mander et. al. 2003), and provides protection against pollution, disturbance and damaging with the inclusion of buffer zones (Godfrey 2015, Kuglerová 2014). The EN helps to maintain natural processes, like the circulation of matter and energy (Fath et. al. 2007, Mander et. al. 2003). It also provides socio-economic benefits since these areas have a high recreational value and they help to mitigate the effects of climate change (Linenhan et. al. 1995, Mander et. al. 2003).

The Natura 2000 areas form a Europe-wide ecological network (Mander et. al. 2003), though its functionality as an EN is questionable (because in some EU states, like Hungary, the network aspect wasn't considered when determining these areas) (Kertész 2011, and the coherence of the network could still be improved (European Comission 2012). However, it is an effective tool for habitat protection at a continent level. The two types of Natura 2000 areas, the Special Protection Areas (SPA) and the Special Areas of Conservation (SAC), were founded in the Birds Directive (1979) and the Habitat Directive (1992), protect the threatened and migratory bird species and the valuable habitats in Europe (Jongman et. al. 2011, CEEWeb 2019).

Natura 2000 areas usually include the legislated protected areas (like National Parks and Nature Reserves), and also contain other valuable habitats, that might not prove to be large or vulnerable enough for national protection but still are an important part of the EN. In the countries where there is a legislated National Ecological Network NECONET, it usually has an even larger extent and is more detailed (especially regarding the links and buffers), than the Natura 2000 system. Unfortunately, due to the different methodologies in the designation of NECONETs they cannot be compared in a nation-wide analysis.

The Bird and Habitat Directives aim to preserve biodiversity and valuable natural habitats, while the Water Framework Directives goal is to protect surface waters and groundwaters, while also aims to reach "good ecological status" for our waters (CEEWeb 2019). These policies together can help the joint concept of the ecological network and water-system. Cooperative and integrated water-management is needed between countries (Danube River Protection Covention 1994), which could also include the ecological perspective. The "Framework on the Protection and Sustainable Development of the Carpathians" states that integrated planning and management of water resources should be implemented.

In the summer 2022, Hungary faced an extreme drought, especially in the Great Hungarian Plain. Many local farmers experienced great financial loss, and the lack of water combined with the effects of intensive agricultural methods (like the damages in the structure of the soil) frightened some land owners. According to professional opinion, a change in land use and water-management, focusing on water retention, is needed to increase the resilience of the agricultural areas (Timár et. al. 2024).

In our study we aimed to create a general framework in the Carpathian basin, that combines the concept and benefits of the EN with the demands for change in the water-management methods creating a discussion about the possibilities and techniques of sustainable land use. Along with revealing the connections between the water system and the ecologically important areas, the purpose of the research was also to identify the areas with different characteristics based on the land use, presence of water and biodiversity.

## STUDY AREA

Though we first chose the catchment area of the river Tisza in Hungary as our research, later we decided to identify some key factors in a larger scale. The Carpathian basin is a strongly distinct and unitary geographical region in Europe, defined by the Carpathian Mountains, the Alps and the Dinaric Alps, it almost entirely belongs to the Danube's catchment area. The extent of the geographical region is ca. 330 000 $km^2$ (Gábris 2000).

In our research we assessed an area based on the catchments of the tributary rivers of the Danube. We used the data from the International Commission for the Protection of the Danube River (ICPDR) and determined a 290 196 $km^2$ area that is close to the geographical region but aligns more with the flow of the surface waters. The area contains the entire catchments of the Bodrog, Drava, Körös, Ipoly, Laborec, Latorica, Mures, Poprad, Ruba, Somes, Tamis, Tisza, Uzh and Vah rivers, and partially the Olt and Mura rivers.

The assessed area extends through 9 national borders: Slovakia, Poland, Austria, Slovenia, Croatia, Hungary, Serbia, Romania and Ukraine, from which Hungary is the only country that is affected with its whole territory (Fig. 1).

The waterways are arising from the springs in the mountains. The topography of the area causes the water flow to the lower areas which makes the rivers to converge together in the Danube. The most significant rivers alongside the Danube are the Tisza, the Mures, The Sava and the Drava (Karátson 2010). Usually, the basin experiences significant flooding two times a year in these rivers: one the early spring which is caused by the melting snow in the mountains, and one in early summer which is the result of heavy rainfalls typically occurring in June (Gábris 2000).

The largest water surfaces are the Lake Balaton, the Lake Velence and the Lake Neusiedl. All three still waters are quite shallow (between 1-5 meters) which causes them to warm up in the summer and to entirely freeze in winter. The Carpathian basin is also rich in underground waterbodies (Gábris 2000).

Regarding the climatic aspects, the Carpathian basin lies in a transitional zone between oceanic, continental and mediterranean climate. The effect of the topography and the surrounding mountains causes changeable weather in the basin, while extremes are also quite common. The variability in temperature and the amount of rainwater is also dependent on the topographical aspects and the elevation (Gábris 2000). Climate-change will strongly affect the area, significant temperature increase is expected, probably exceeding the global warming rate (Bartholy et. al. 2009). Precipitation in summer is projected to decrease by 20%, while in winter it will increase with 5-20 % by the end of the century (Werners et. al. 2016). Climate change will heavily impact our water-management, especially the rivers and their water yield (Kovács 2009).

The natural vegetation mostly disappeared from the basin, only the mountains are covered in largely extending forests, while the middle areas are mainly used as agricultural land and valuable habitats can be found in smaller patches.

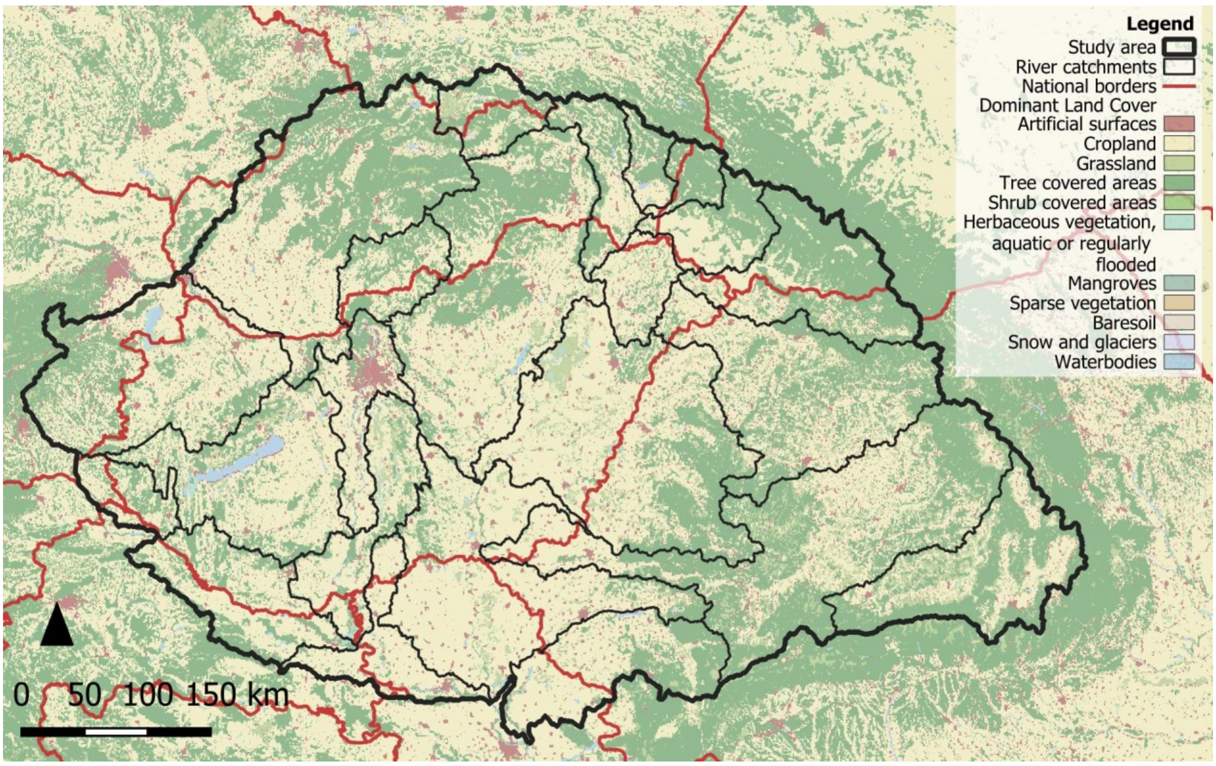



*Fig.1* Study area – land cover of the Carpathian basin and the river catchments (GLC – Global Landcover 2019)

## METHODS

To analyze our robust study area, a grid system was used. We chose the hexagon shape, because it visualizes the connections and contiguity better than rectangular grids (Burdziej 2019). The study area was divided into 5x5 km sized hexagons (2165 hectares each) which resulted in 13 404 hexagons altogether.

Evaluation of the hexagons was conducted by four aspects: we examined land cover, ecological value, areas of water protection and waterway-density. The value of each hexagon was calculated using GIS tools.

For dominant land cover it was determined if the hexagon is mainly covered by grassland, crops or forest. We used a globally available, raster-based data source with 1 $km^2$ resolution and firstly transformed them into a vector layer containing 1 $km^2$ sized polygons. The intersection tool was used to calculate the ratio of each land cover type in the units. The resulting polygons were merged according to the grids ID field to get the final result for each three discussed land cover class. Using these values, we determined the dominant land cover in each hexagon.

When calculating the ecological value, the vector layers containing the Natura 2000 and the Emerald Network sites were used. The area of these sites in each hexagon was measured and evaluated accordingly.

Water protection value was determined by the ratio of water-related habitats in each of the units. The method was similar as before: the water surfaces, rivers and wetlands were contracted from the available database and summarized in each of the hexagons, then categorized the units based on the presence of these habitats. We wanted to include not only the actual water bodies but the wetlands as well, because their preservation is strongly linked to the cycle of water. The groundwater bodies were also included in this map, to show where are the most important aquifers located, where water protection is also a key factor.

Small waterways (streams and canals) are an excellent tool for water retention (Kutnyánszky & Szilvácsku 2023). We wanted to include their potential into the evaluation for determining the water retention capacity. Also, waterways have an important role in the EN as they mainly function as a landscape-level ecological corridor or as a link between core area habitats. They provide connectivity for water-related species (like amphibians and fish species) or the surrounding vegetation zones are key habitats in the matrix of intensively farmed land (Rinaldo et. al. 2018, Nucci et. al. 2022). Which makes the high density of waterways beneficial in the ecological and climactic point of view. For the categorization the length of these landscape elements was calculated in each hexagon and we based the evaluation based on these values.

A value was given a category based on different thresholds: not significant, important and outstanding (Table 1). The margins were determined using the natural breaks of the dataset, but in some cases 6 breaking points were identified and then merged into 3 categories, resulting in lowered thresholds for some of the important classes. A hexagon was ecologically not significant if less than 5% of the hexagon was part of the Natura 2000 network, it was considered important if this value was between 5-20% and outstanding over 20%. Similarly, a hexagon was not valuable from a water protection perspective if it contained water-related habitat less than 1%, was considered valuable between 1-5% and important over 5%. 5% with a 2165-hectare hexagon means over a 100-hectare large water-related habitat in the grid. Analyzing the of presence waterways, we measured the length of streams and canals in each hexagon. With the density of 0-2 m/ha a unit was not significant, between 2 and 7 m/ha it was important (which means between 10 000–25 000 meters of waterway in a grid cell) and over 10 m/ha the hexagon was considered outstanding.

The land cover layer was evaluated differently. We did not use the same categories but tried to aim to identify the dominant land cover of each grid. We wanted to define the mainly forest covered areas, mainly grasslands and agricultural lands, but also determined transition zones between them, where both of these categories are significant. The goal of this evaluation was to identify an optimal use of land that is based on actual, stable use. The purpose of separating transition zones was to determine the areas where encouraging land use change can be feasible at a greater scale. We determined the final category based on the ratio of each land cover type, which is shown in Table 2. In any other situation the hexagon was categorized by comparing the values manually. Grasslands were weighted compared to forests and agricultural land due to their importance in habitat preservation and also the CAP objectives.

Our theory was that the ecological role and the water system is connected through the land cover to achieve sustainable land use. To investigate this conjecture, the ecologically important and outstanding areas were compared with the dominant land use and also the water-related results. For our final results we identified the areas is with both ecological and water-related importance and compared them with the actual use of the land. This way, the three main aspects: the ecological importance, the presence of water and the stabile land use can be compared to suggest a sustainable land use.

*Table 1.* Classifications of ecological value, water protection potential and density of waterways

| Categorization of analyzed aspects | Ecological value | Water protection potential | Density of waterways |
|---|---|---|---|
| Not significant | 0-5% | 0-1% | 0-5 m/ha |
| Important | 5-20% | 1-5% | 5-10 m/ha |
| Ooststanding | 20-100% | 5-100% | Over 10 m/ha |

*Table 2.* Methodology for determining the dominant land cover class

| Land cover classes | Forest | Transition zone: forest-grassland | Grassland | Transition zone: crop field -grassland | Crop field | Transition zone: forest-crop field |
|---|---|---|---|---|---|---|
| Ratio of forest | 50-100% | 25-50% | 0-50% | 0-25% | 0-50% | 25-50% |
| Ratio of grassland | 0-10% | 0-10% | 25-100% | 10-25% | 0-10% | 0-10% |
| Ratio of cropfield | 0-50% | 0-25% | 0-50% | 25-50% | 50-100% | 25-50% |

*Databases*

The goal of identifying a larger scale framework made the data collection challenging. As only 7 of the 9 affected countries are members of the EU (Hungary, Slovakia, Poland, Austria, Slovenia, Croatia, Romania), we could not use the databases available for only EU countries (like the CORINE land cover).

For the land cover the Global Land Cover (GLC 2019) data (available from Copernicus Service) was used which is a raster database with the resolution of 1 $km^2$. It not only provides information about the dominant land cover but it also identifies the ratio of the other land use categories as well. Altogether the database distinguishes 11 land use types. For our calculations we used the layers that show the ratio of the forests, grasslands and crop fields instead of the dominant land cover, which gave us a more accurate result.

Not all of the countries have legislated ecological networks, and the existing ones also widely differ thanks to different planning methods and tools. To eliminate this difference in the countries, we aimed to use the Natura 2000 network for ecological values which provided a more integrated though less precise result. Since Ukraine and Serbia are not part of the EU, they have not designated the Natura 2000 network, but they are part of the Emerald Network system (Roekaerts & Opermanis 2018). Though the Natura 2000 and Emerald Network sites are not designated with the same methodology, they both provide information about the values of the habitats and aim to form a cross-national ecological network. The study area contains 1544 Natura 2000 sites and 49 Emerald Network sites.

To identify the water surfaces, wetlands and watercourses the available database of Open Street Map was used (downloaded from Geofabrik site). The OSM data was downloaded, and the required layers were merged for the 9 countries. We used the land use, waterway and water layers of the database to identify the habitats that are strongly depending on the presence of water.

Unfortunately, we could not acquire data about groundwater bodies for 9 different countries. We only included the groundwater bodies with transnational importance (from ICPDR), but in the evaluation, it did not get a significant role since this layer is not detailed enough for the methodology used.

For all the data management, calculations and visualization of maps we used the QGIS 3.32.2 Lima software.

## RESULTS

After categorizing the hexagons according to each of the aspects we could process the results for the dominant land cover, the ecological value, the water protection areas and evaluate the density of the waterways.

*Dominant land cover*

When observing the dominant land use – with the three main categories and the three transition zones we could state that the mountain area of the Carpathian basin is forest dominant, while the lower areas are mainly used as farmlands (Fig 2). Almost half of the units (48%) were categorized as dominant by agricultural land, 29% forest-dominant and only 10% was mainly covered by grasslands. The transition zones lie between the corresponding dominant categories, but their proportion is significantly lower compared to the dominant classes.

We could clearly observe the presence of forests in the basin as well, like in the Transdanubian Mountains and the North Hungarian Mountains, in the feet of the Alps and also along the Danube River. The plains are clearly marked by the dominant farmlands, like the Great and the Little Hungarian Plain and also the Transylvanian Plateau in Romania.

The dominance of grasslands was present both in the mountain region and on the lowlands as well. There are larger grass-dominant areas in the eastern region of the study area for example in the Apuseni Mountains and the Southern Carpathians. The extent of grasslands in the northern part of the Carpathian Mountains is less than in the eastern areas. We found the continuous meadows of Hortobágy and the grassland along the Danube outstanding in the lower areas of the basin.

There were three main areas where these three categories and their transition zones could not be interpreted: the Lake Balaton, the Lake Neusiedl and the Agglomeration zone of Budapest, where none of these three categories were dominant. These areas are mainly undisturbed water surfaces and large extent of urban fabric, where the use of land could not be classified according to our methods.

According to these observations we could state that the dominant land cover is strongly affected by the elevation, slope and the geographical characteristics of the basin. The presence of water is also a key factor, especially if it comes to the higher ratio of grasslands.

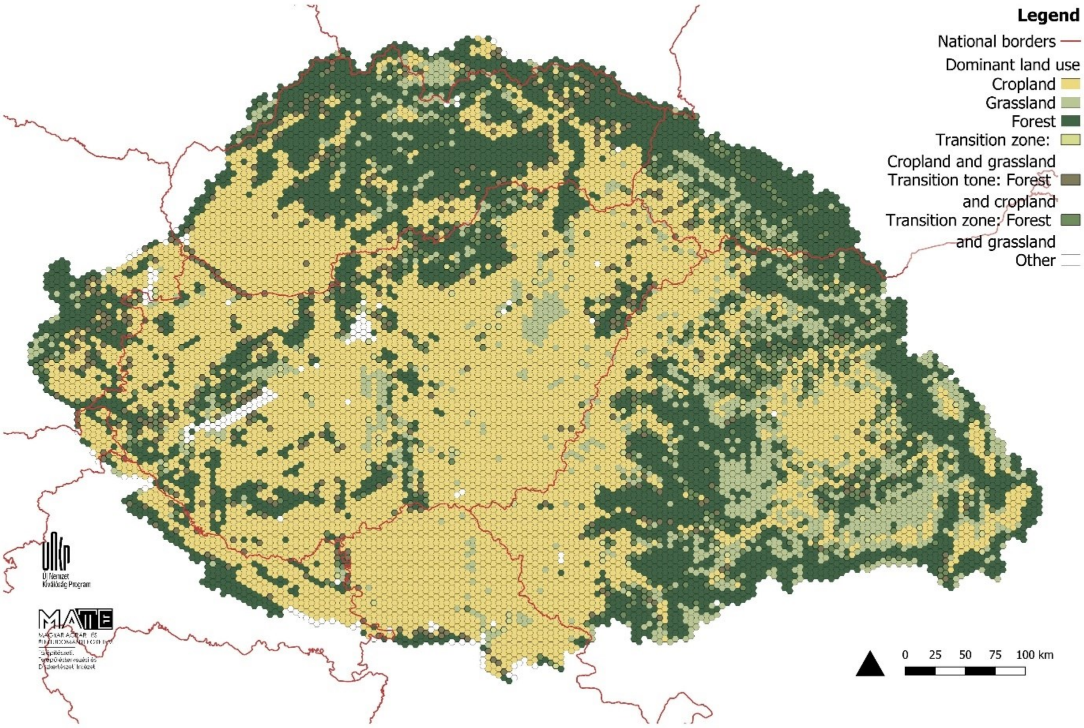



*Fig.2* Dominant Land cover in the Carpathian Basin

These results are an approximate interpretation of land cover – and also stabile land use. These conclusions can be integrated in a larger scale, and could function as a framework for land use, but when it comes to regional planning and sustainable land use in national or county level, a more detailed evaluation is necessary.

*Ecological value*

As shown on Figure 3, the Natura 2000 and the Emerald Network areas are present in the whole basin. Nearly 15% of our units fall into the ecologically important areas while 26.5% is categorized ecologically outstanding, which means that ca. 30% of the basin is part of a protected network, adjacent, or strongly connected to an ecologically valuable area.

For most parts of the study area these ecologically valuable areas are scattered all around the Carpathian basin, forming a network where the links are more or less present between the denser core areas (like for the Hortobágy National Park or the Târnava river). The ridges of the Carpathian Mountains are also ecologically valuable areas according to the high presence of Natura 2000 and Emerald Network sites. The mountains form a semi-circular chain of protected areas around the basin – similarly to the geographical structure.

Though the network is present almost everywhere in the study area, we could identify some “hollow” areas, where there were no significant ecologically valuable areas – at least as part of the two analyzed networks. These areas were the Plain of Bácska (mainly in the Serbian part of the basin) and the surrounding the Transylvanian Plateau.

*Water protection areas*

The areas that are important from a water protection perspective were identified by the presence of water surfaces and water-related habitats (Fig. 4). We found that the important and outstanding areas mostly accumulate in the lower part of the basin, following the natural elevation and geographical morphology of the region. 8.5 % of the analyzed hexagons were outstanding, and almost 16% of the units were classified as important from a water protection aspect. Almost half of the important and outstanding units are found in Hungary, and 25% of the outstanding areas are located in Serbia, which in proportion is far higher than in other countries.

The prominent water protection areas can be found along the main rivers: the Danube and the Tisza, and around the large lakes of the basin. The addition of wetlands resulted in the highlight of the Hortobágy National Park and also the habitats along the Tisza in the Plain of Bácska.

While the plain areas of the basin are richer in water surfaces, in the northern and eastern highlands only a few rivers propose a value, like the Leitha in Slovakia and Mures in Romania.

When evaluating the aspect of aquafers, we found that the largest groundwater body lies underneath the Plain of Bácska, extending from Southern Hungary through Serbia and into West-Romania. Some smaller water bodies are present in the northern region, on the border of Hungary and Slovakia and the border of Hungary and Austria. According to the ICPDR, that most of the groundwater bodies’ chemical and quantitative status is good, only the Hungarian and Romanian parts of the southern groundwaters reached poor status in their evaluation.

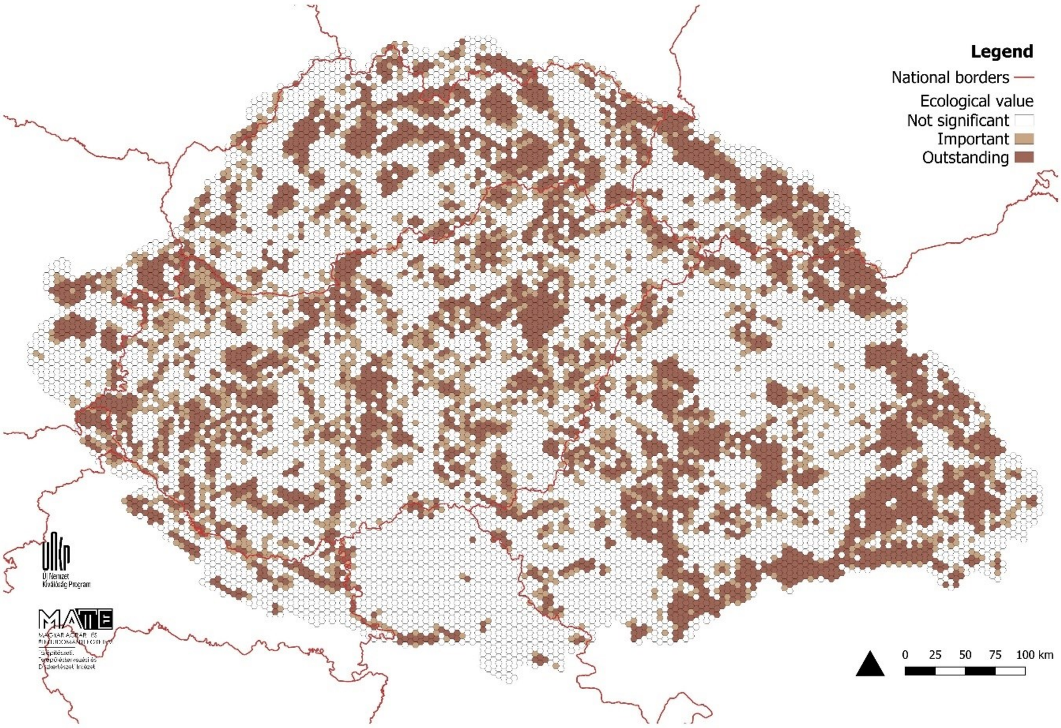



*Fig.3* Ecological value in the study area

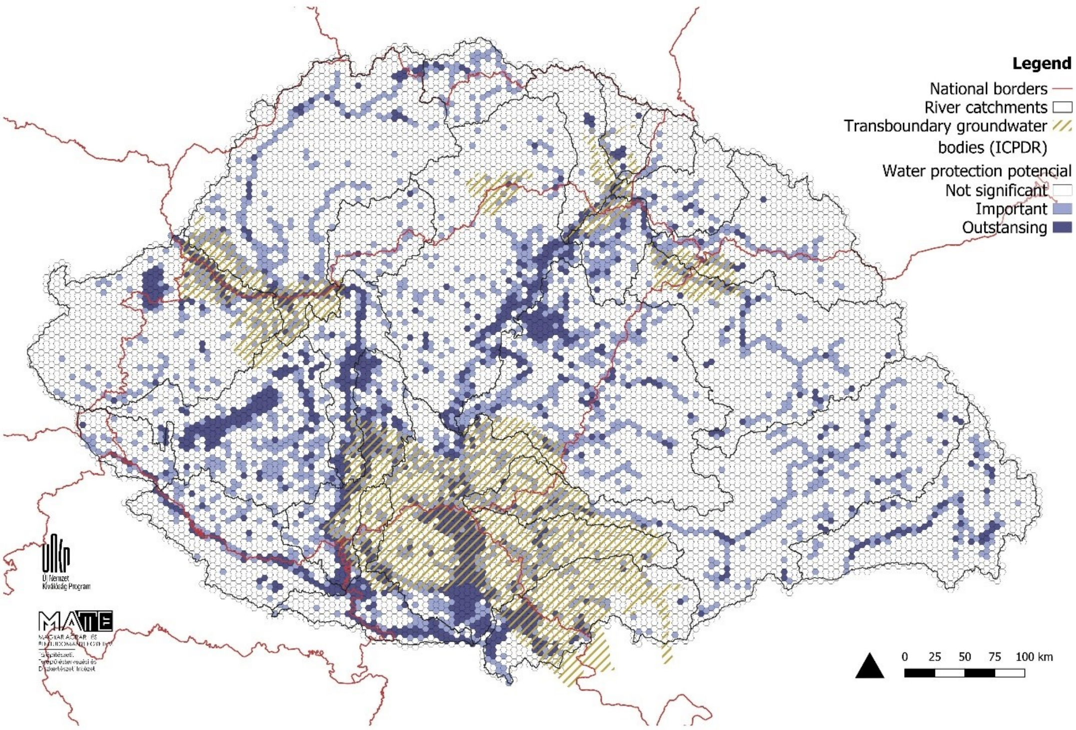



*Fig.4* Evaluation of water protection areas in the Carpathian basin

*Waterway density*

When classifying out units, we divided the hexagons according to the natural breaks in the data set. This time the key factor was not an area/area ratio but the summarized length of the waterways in a unit (meter/ha). This caused the dataset to have a higher deviation then the data before, which made the classification process different. The northern Carpathians had an outstandingly high density compared to the other parts of the basin, making them appear less significant than the highlands, though waterways were represented there as well (Fig. 5). According to this classification, Slovakia and Austria are the richest in streams with over 10 meters of waterways per hectares in their territory. Some other dense patches could be found in the Carpathians is Ukraine and Romania, and also north from the Lake Balaton, in the Bakony mountain.

To evaluate the waterways from a different perspective, focusing more on the water retention capacity, we decided to re-run the analysis, but this time only with the canals, not including the natural streams. The density of mountain springs made the dataset distorted and did not show the disposition of canals in the lowlands – where water retention is a more realistic goal, and also needed for agricultural lands.

We executed the same steps as before, only including the length of the canals (provided from the OSM database). We lowered the thresholds of each class (over 2 m/ha density the unit was considered important, and over 7 m/ha outstanding, compared to the 5-10 thresholds before) and displayed our results (Fig. 6). We found that the densest areas are connected to the Danube and Tisza rivers and spread out in the Transtisza region, where irrigation is (and was) used supporting the farming. Important and outstanding units follow the Danube in all of its length in the basin, excluding only the Agglomeration of Budapest. From this water-retention perspective the Plains of Bácska, where the two rivers mentioned join, proved again to be outstanding.

We found that this additional analysis was needed to see a more nuanced result, and to determine the water retention capacity of the units, while including the natural streams showed the ecological point of view of the waterways – they showed where the areas are richest in ecological links and ecotones.

*Summarized results*

After evaluating each map, we analyzed the overlaps between the important and outstanding areas from an ecological point of view and the other three aspects. These synthetized results expressed the complexity and contradictions of the nature protection and the water system, and also raised dilemmas regarding the joint planning for the future.

We found that most of the ecologically outstanding areas (49%) are located in a forest dominated hexagon, but the ratio of grasslands was also significant with 16%. Only 24% of the ecologically outstanding areas were farmland dominated. On the other hand, when observing the second category, the ecologically important areas (where the ratio of valuable habitat is between 5-20%), we saw a different distribution. The forest dominated areas only covered 25% of units, while agricultural land was represented the highest, with 54%, which is a higher proportion compared even to the whole study area (48%).

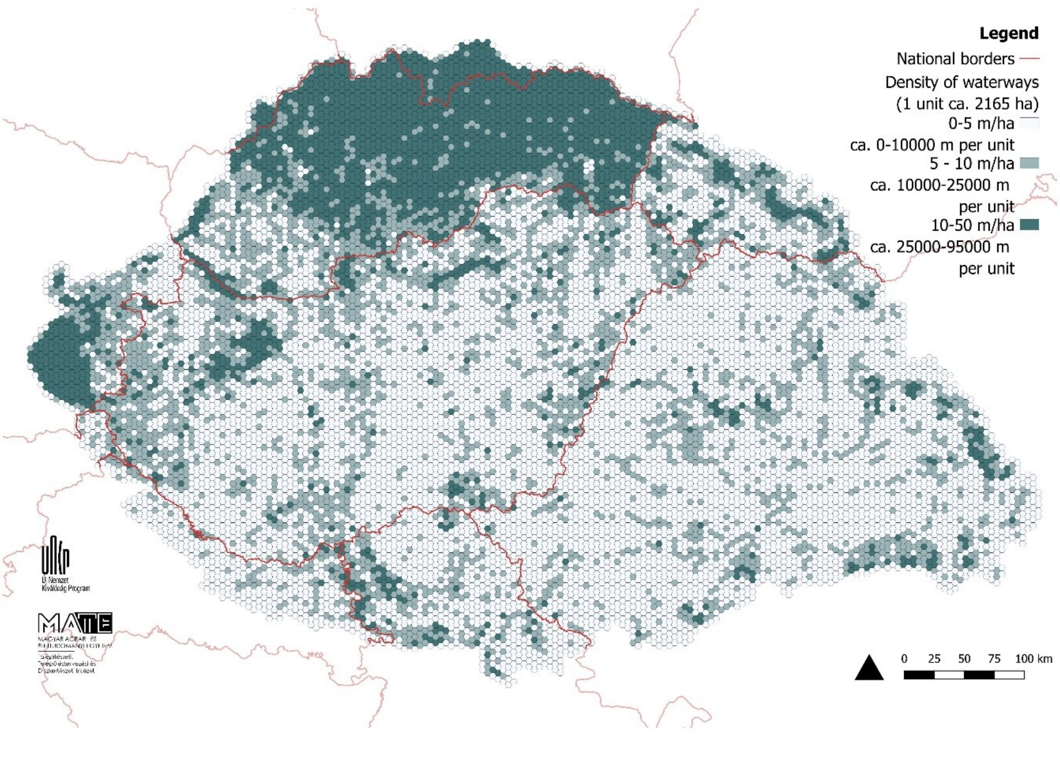



*Fig.5* Waterway density in the Carpathian Basin

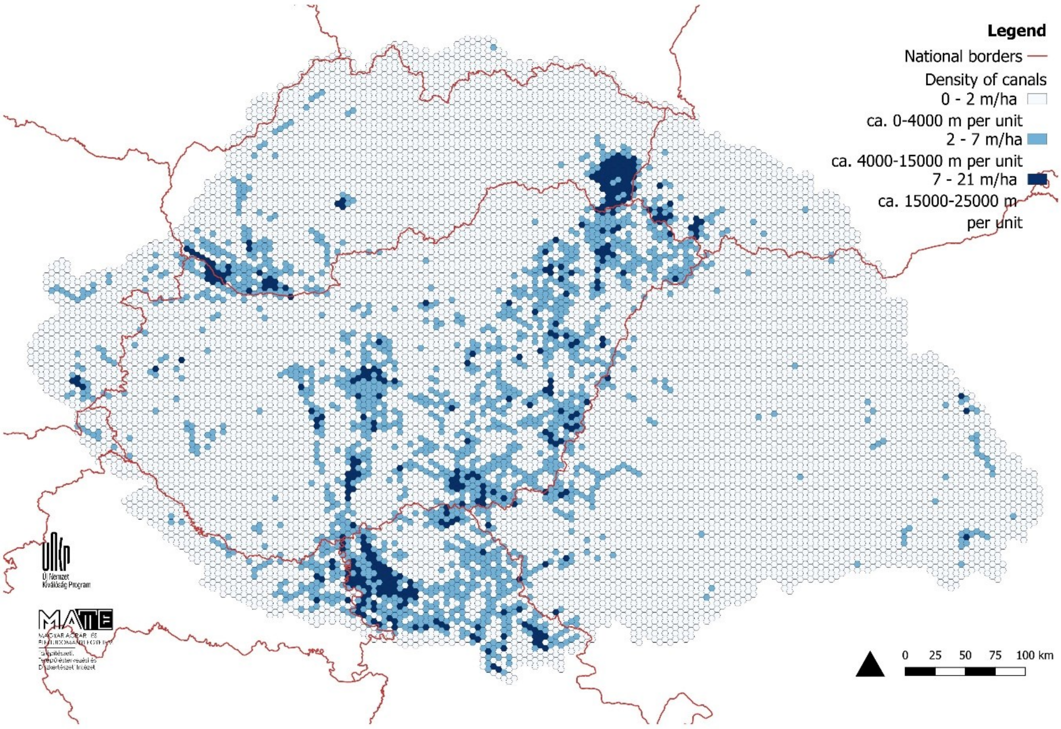



*Fig.6* Density of canals showing water retention capacity in the plains

This means that most natural habitats are surrounded by (mostly intensively) farmed land, that could affect their state and natural processes. Looking at the spatial distribution we found that most ecologically important crop fields were located in the Great Hungarian Plain. Ecologically important forests could be present in all areas of the study. The extensive grassland patches, mentioned before, also proved to be ecologically valuable habitats.

The results show, that when comparing the ecologically valuable units with the presence of water there is little connection. Only 12% of the ecologically important and outstanding areas was outstanding from a water-protection aspect and 16% was considered important. These areas are mostly located in the plains and not in the highlands. If we reverse the evaluation, we found that 26% of the important and outstanding water-protection units were also ecologically outstanding, and 21% was classified as important, which makes ca. half of the water-related habitats protected by or be near to Natura 2000 or Emerald Network sites.

Most of the overlapping areas were present in the lowlands, while in the mountains there were significantly less protected water elements. We could observe protected water-related habitats along the most important waters in the basin, like the Lake Balaton and Neusiedl, the Danube and Tisza rivers and also the wetlands in Hortobágy. This correlates with the fact that most of the protected areas in highlands are forests, and large water surfaces are not presented there. Although there were some outstanding rivers in the mountains, their surroundings are not part of the Natura 2000 or Emerald Network system in a large extent which made them not to appear in the evaluation.

When we compared the overlaps between the waterway-dense areas with the ecological values we could conclude that the areas that are outstanding from both aspects are present in the northern part of the region, mostly in Slovakia, but we could observe some patches along the mountains in Austria and Ukraine as well. These were the areas that were the richest in streams, so naturally the results were correlating with that. There were no other significant hotspots, the displayed units were scattered around the basin. Though this outcome was expected, only a small part of the units with dense waterways proved to be part of the European EN system. Quantified, 30% of dense areas were also ecologically valuable and 16% was considered important. Reversing the evaluation, we could state that 20% of ecologically valuable areas had extensive stream network (over 5 /ha), and 28% had moderate density (between 2-5 m/ha).

The supplemented water-retention focused evaluation, where we have taken only the canals and calculated their density showed similar results. Only 13% of ecologically valuable areas (important and outstanding combined) was located in a moderately dense or dense unit. While 21% of outstandingly waterway-dense and 16% of important areas was ecologically valuable. Which suggest, that about the third of the EN areas have an extensive waterway-network, while only a small portion of waterways have natural protection. The areas that are important and outstanding from both aspects are dispersed in the basin, mostly defined by where the canals-system is extensive. We could observe significant patches in the border of Hungary and Ukraine, along the Tisza River, in

Hortobágy, and along the Danube in the plain regions. This correlated with the fact that some important ecological areas are dominated by farmland and they usually have a dense canal-system for irrigation.

To summarize, we found that when designating the Natura 2000 and Emerald networks, the protection of water was not the priority. The important and outstanding areas are randomly overlapping, which suggests that the field of nature protection and water management are not cooperating together currently. However, along the main rivers there is a correlation with the two aspects, but this probably can be traced back to a fact, that these water-affected areas (like wetlands, riparian forests, saline lakes and marshes) are also important natural habitats. Most common areas were found in the lower elevation areas of the region, which is caused by the basins geographical structure that makes the water flow to the middle and southern areas of the area, mainly to Hungary and Serbia, where water-related valuable habitats can form.

## DISCUSSION

The connections and common possibilities of the ecological network and the water system is a new concept. It is well established, that wetlands and water surfaces are key areas of the ecological network since these are usually valuable natural habitats. Rivers are transnational scaled ecological corridors, where the surrounding habitats can function as core areas in a regional scale, while channels and streams provide links in a local-scaled network (Rinaldo et. al. 2018, Nucci et al. 2022, Jongman et. al. 2012, de Boer & Bressers 2012). Therefore, the importance of the presence of water from an ecological point of view is unquestionable. But revealing the reverse connections is a new idea which we aim to study more detailed the future.

### *Database limitations*

Though we aimed to use the most suitable databases for our research, we found that collecting data for 9 different countries is a challenge, and we had to compromise with the detail of the data for it to be uniform and comparable. We used the GLC (Global Land Cover) from Copernicus for the dominant land cover evaluation, which proved to be a useful database due to the complementing layers featuring the proportion in a unit for each category. We used these layers instead of the dominant land cover for out analyses to get a more accurate result. Although the resolution of this raster layer is 1 km2, it proved to be accurate enough for the scale of our research. When transforming the raster into vector no information was lost.

Regarding the metric of ecological importance, the use of Natura 2000 and Emerald Network sites has its limitations. We had to sacrifice the network function of the EN to get a uniform and detailed information about the valuable habitats. Since the examined networks do not include links and corridors, but only are designated based on the presence of species and habitats important from a conservation view. Though the mentioned networks do not distinguish links and corridors, some protected sites (especially the ones along rivers) are functioning as links in a larger scale. From this lens, the Natura 2000 and the Emerald Network cannot be considered as a classic EN, but this system of protection is the closest existing to the idea of an EN in a cross-national scale.

With the use of Open Street Map, we could identify the water surfaces and waterways very accurately in a detailed form, that proved to be suitable for our analyses. The addition of wetlands and the differentiation between canals and streams was key in identifying habitats and potential water-retention capacities. The GLC 2019 also differentiates water surfaces and wetlands, but the OSM database proved to be more detailed and specific regarding these habitats.

### *Limitation of methods*

We found that the use of hexagons as an evaluation unit was an effective way to investigate our research question. The used thresholds reflected the diversity of the database showcasing the important and outstanding areas of the basin. Our result-layers were processed and we found that everything correlated with the natural attributes of our region, and we got a result that reflected the expectations for each of the aspects. Only the density of waterways was surprising in the northern region, which led us to accomplish a refined evaluation using only the canals, to showcase the water-retention possibilities.

The positive influence of the density waterways could be argued, both from an ecological and from a water-retaining perspective. Since these channels are both used for irrigation and for draining inland-water, they are a tool for a non-sustainable water management currently. We argue though, that these elements, when used and maintained correctly, could be a tool for keeping the water near the fields, not draining them.

Regarding the waterways ecological value: for some species these streams and canals function as a barrier in the land, they are an obstacle instead of a linkage between habitats. This can depend on their artificial state and their location, but it also depends on the species. For most species used to monitor ecological connectivity (like large mammals, birds and butterflies), these elements are not an obstacle in the landscape. The trees, shrubs and grass bands, that follow the streams are valuable ecotones, even with a small width, and their ecological benefits outweigh the disadvantages.

### *Addition of slope analysis*

To support our observation – that the elevation and topography is a key factor defining both the water system and land use – we carried out a slope analyses, using the SRTM Digital Elevation Model, and identified the areas endangered by erosion (over 12% slope). Using similar steps as for the evaluation before, we summarized the percentage of these areas in a hexagon and classified each unit into three categories. Between 0-5% it was considered erosion-free, between 5-50% it was mostly endangered and over 50% it was classified as endangered.

Observing our initial results, we found that most forest-dominated areas and grasslands are on a steep surface, and only a small ratio of farmlands are dominant on an erosion-endangered topography (for example the Transylvanian Plateau and Eastern-Austria). Comparing erosion with the presence of waters we found that the less steep the surface, the more water-surface, and related habitats, can form. The density of streams is also mush higher in a sloped area, while canals are more commonly found in the plains. There was no connection between ecological value and the topography.

*Relationship in the lens of landcover/land use*

We discussed the connection of the land cover and EN, and stated that the ecologically outstanding units are mostly covered with forests, while the important areas are dominated by farmlands. Looking at the results of the evaluation of the land cover and water-related habitats we can state that the important wetlands and water surfaces are almost entirely located in an agricultural land, a smaller portion of them is grassland dominated, and forest are represented in the lowest rate. Intensive farming threatens the state of waters with chemical pollution caused by the artificial fertilizers and insecticides. The lack of vegetation on the banks makes the waters even more vulnerable to pollution, because the natural biofilter functions are not filtrate the draining chemicals out.

If we compare that both the ecologically important areas and water-related habitats are located in the neighborhood of intensive agricultural lands, it is easy to see that change is needed in the farming methods of these areas. Extensive agricultural methods, restoration of ecotones and landscape elements is needed to keep the state of our waters and to protect our biodiversity. Diverse land use and extensive farming methods combined with the use of the irrigation channels as water retention tools also benefits the agriculture decreases the risk of drought and increases resilience of the natural system.

These solutions are challenged not only by the current agricultural and economic environment but also by some water management professionals, politics and also the farmers themselves (Timár et. al. 2024). Though these difficulties might not come to a short-term solution, demands for water retention are increasing – especially taking the experience of the extreme drought of 2022 into account.

*Extension of research*

Though the methodology proved to be useful to identifying the relations between the waters and the EN, it should be improved in the future. As a next step we aim to solve the limitations caused by the international aspect our study area and use a smaller scaled region to continue our research. We plan to work in a new study area, in the catchment of the Tisza River, in Hungary. According to our current results, this area can serve a more nuanced yet useful interpretation from our perspective. Using an area entirely belonging to one country, we have access to far more detailed, up-to-date databases (especially regarding the aquifers, flood-periods and the quality of waters), which help us to form a more complex and accurate methodology based on our current analysis.

This study was the first step in finding the common challenges and possibilities of the two researched systems. In our future research we hope that the driving forces and factors of these two networks can be identified which would significantly improve the effectiveness of determining the impacts of future interventions.

## CONCLUSIONS

In our research we used the Carpathian basin, as a compact geographical and hydrographical region. We used open databases, both in vector and in raster format, and used GIS tools to evaluate the relation between the water system and the designated EN. We examined four aspects: the ecological value based on the presence of the Natura 2000 and Emerald Network sites, the vulnerable water-influenced habitats, the density of waterways (both natural and man-made) and also dominant land cover which we speculated could be the common ground for the two analyzed networks.

Our analysis found that the water system and the designated European ecological network are more related in the basins lower areas, where the water naturally flows forming valuable habitats. The results also suggest, that when determining the Natura 2000 and the Emerald Network there was no intent to include the water-system (especially the waterways) into the legislations methodology in our site.

According to our observations we found some outstanding areas – both for the EN and the water-system, like the Hortobágy National Park, and the chain-like habitats along the Danube. We identified a deficiency in the Emerald Network: there were no significant protected areas in the Plains of Bácska, though this region proved to be outstandingly valuable from a water perspective.

During the evaluation process we found that not only the land cover, but the topography also plays a significant role in both systems. To support our results, we carried out a slope analysis, which strengthened our observations about the large-scale connection between the topography, the water and the use of land.

We state that our evaluation can establish the key areas for sustainable land use, where sample-projects can be implemented. Our results are an approximate interpretation of the water system, the EN and the land cover, serving as a framework in the international scale of the Carpathian basin. We aim to improve our methods, to get more accurate results, that can be used by spatial planning and agriculture in the future.

The water and the ecological network are two systems in the landscape that are driven by different factors, but can support each other hence the overlap in the actual land use. Therefore, when planning and intervening in these systems, both networks should be taken into account. Agriculture dominated areas could play a significant role in the joint development in the future, since these areas have an ecological potential according to our analyses, and these farmlands have struggled with uneven water supply and drought recently.

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