The Cultural Ecosystem Services and Land Use Characteristics of Mining Ponds in Hungary

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Abstract

Our previous research on mining ponds has focused on their spatial extent and pattern as well their role within nature conservation. We analyzed their distribution of size, time of formation and role in the greenway network. It was found that over the past half century, thousands of mining ponds have been created in Hungary as a result of raw material extraction. The landscape and nature conservation importance of the water surfaces created by mining activities is considerable after abandonment. This is evidenced by the fact, that according to our former research results, about 28.8% of the mining ponds in Hungary are regulated by some kind of nature conservation designation (Módosné et. al., 2019, Varga et. al., 2022)

There have already been several landscape studies and analyses on the reuse and 'welfare' role of mining ponds at local and regional level (e.g. diploma theses and dissertations at the Faculty of Landscape Architecture and Urban Planning of the Szent István University), but no national overview has been produced to date. Therefore, this publication deals with the analysis of the landscape characteristics and cultural ecosystem services of water surfaces, mining ponds and their riparian zones created by mining on a national scale.

Mining ponds have a significant recreational potential due to their natural values and/or favorable landscape conditions. The after-use of water-filled mine pits can be very diverse: fishing and nature conservation/habitat functions are common, but they can also be used as public parks with recreational and sporting usage (bathing, beaches, water sports, etc.) or even for industrial after-use (e.g. settling ponds). In many places, the reuse causes the encroachment of lakeshores, creating many land-use conflicts. The after-use of mining ponds and the way in which they are rehabilitated after the end of mining activity have a fundamental impact on their ecological and natural value and landscape characteristics (National Landscape Strategy 2017-2026). The topicality of the subject is among other things, the European Green Deal, and the newly introduced Nature Restoration Act. The Green Deal (European Commission 2019) aims for the EU to achieve climate neutrality by 2050, tightening mining regulations and promoting sustainable practices. As part of this, the Nature Restoration Law (European Commission 2022) mandates the restoration of ecosystems, including the rehabilitation of mining lakes, making their restoration a key priority.

The aim of this research is to prepare a nationwide geoinformatics analysis and situation analysis on the characteristics of mining ponds created by mining activity from 1975-2025, and how their cultural ecosystem service role can be interpreted in Hungary. Landuse characteristics of the riparian zone of the mining ponds will be analyzed within the 30-50 and 300 m buffer zones around the ponds using spatial information methods. For landuse analysis we use our formerly created database of mining ponds and the Hungarian National High Resolution Layer base map. We

analyze whether the ‘welfare’ role and landuse characteristics of mining ponds differ by the extraction of different types of raw materials, and whether the size, distance from settlements and agglomeration location of the ponds influence the way they are exploited. Our research results will be supported by more detailed sample area analyses. Data will be provided on the characteristics of the mining ponds that serve as ecotourism sites, and on the location of nature trails, birdwatching sites, or lookouts in the vicinity of mining ponds. The article also presents international and Hungarian best practices on the landscape use characteristics of mining ponds and systems. The results show that, with proper reuse and landscape rehabilitation, mining ponds can become valuable landscape and green infrastructure enriching elements.

Introduction

The mining ponds resulting from mining activity play an important role in the ecological network of their landscape context, as their biologically active surface contributes to the improvement of microclimatic conditions, and in the case of abandoned mining ponds, to the increase of biodiversity, and the formation of new habitats. In our previous research we found that about 28.8% of the mining ponds in Hungary are affected by some kind of nature and landscape conservation designation. Mining activity has significant environmental impacts, including changes in land use and degradation of ecosystems. One of the aims of the European Green Deal is to minimize these impacts and promote the rehabilitation of mining ponds and other mining sites. On the other hand, the rehabilitation and restoration of mining ponds provides an opportunity to use them for recreational and tourism purposes. The goal of the Green Deal (European Commission 2019) is for the EU to become climate-neutral by 2050, which includes stricter regulations on mining activities and the implementation of more sustainable practices. Additionally, it emphasizes increasing and protecting green spaces to enhance biodiversity, preserve natural habitats, and reduce environmental impact. The Nature Restoration Law (European Commission 2022), established as part of the Green Deal, sets specific obligations for the restoration of degraded ecosystems, including the rehabilitation of areas affected by mining activities.

Background and Literature Review

The impacts of mining activities on landscape and nature are the subject of a number of Hungarian and international studies. In the following, we briefly highlight those that focus on the impacts of mines on ecosystems and those that are related to aquatic ecosystems. Bishop, J. and L. M. Smith (2022) explore the impacts of surface mining on North American waters. The research details how the formation of mining ponds affects water quality and ecosystems, and suggests remediation measures.

Jonhnson, R., and P.A. Lee. (2021) based on their study research in the Animas River (Colorado) watershed to assess the long-term effects of mining on wetlands. The research describes how mining has transformed them and the associated impacts on water quality and ecosystems.

Ngug, M., and Y. Zhang. (2020) provide an analysis of the environmental impacts of mining activities in Kenya, including mine drainage. The study finds that mining has caused significant land use changes that have affected local ecosystems and aquifers.

Psotová, Hedvika (2020) examines the integration of the mining ponds environment and its landscape use potential. It deals with the ecological role and landscape use potential of mining ponds.

The authors of this article have previously studied the role of mining ponds in the green space system and landscape character, their conservation role and landscape significance (Varga et al. 2022, Módosné et al. 2019, Módosné et al 2022).

Method and Data

As a first step in our research, we produced an up-to-date mining pond database built from several input sources. We used the official mine inventory of the SZTFH for the current mine sites (SZTFH 2024) and the MBFSZ database of abandoned mine sites (MBFSZ 2019). The Open Street Map (OSM 2024) vector dataset for standing water is the primary database of mining ponds with open water surfaces. These were searched for overlaps with the area of abandoned and functioning mines, then, supplemented based on the results of our previous research, and finally revised to reflect their current state using space imagery (Google 2024) (Figure 1).

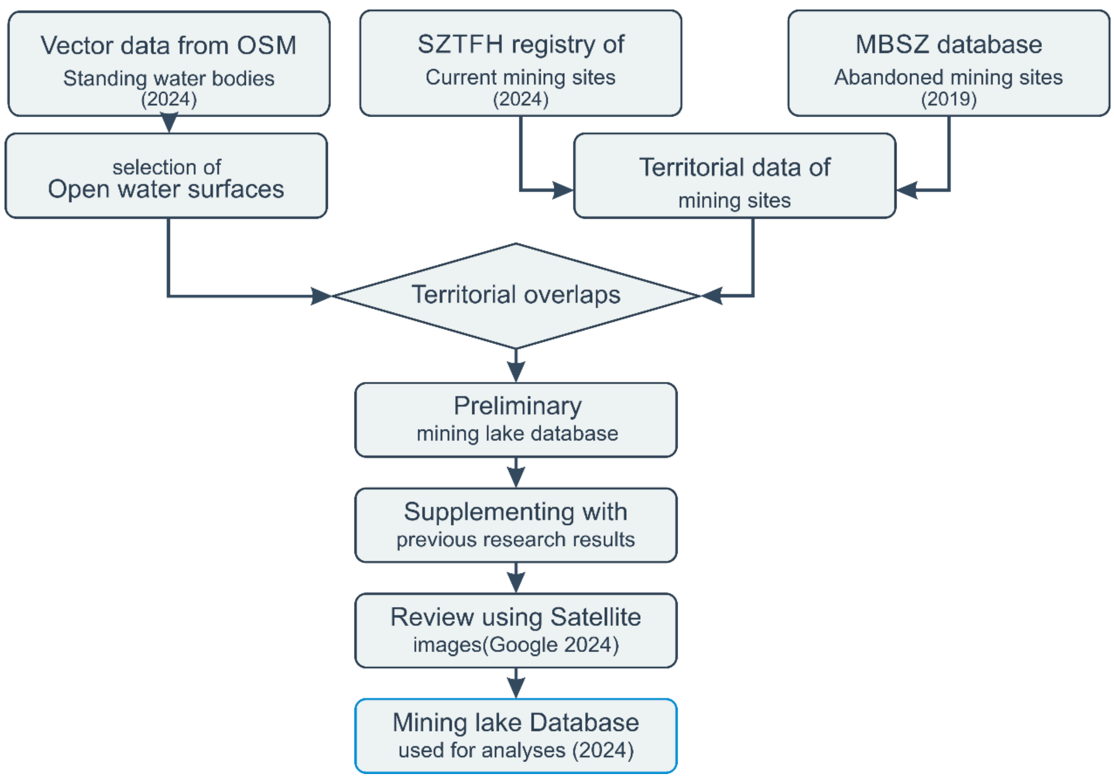

Figure 1. Workflow for managing and analyzing data related to mining ponds and water bodies

The database of mining ponds needs to be continuously updated, because on the one hand they are dynamically increasing in number and changing in size as new extraction sites are opened, and on the other hand there are examples of their being filled in during rehabilitation (e.g. Salföldi mine, Dunaharaszti gravel mine (Innoteka 2025).

Our survey currently includes 1369 mining ponds, of which 635 are in currently operating and 734 are abandoned mining ponds.

To understand the utilization around mining lakes, we used the so-called National High Resolution Layer (hereinafter NHRL layer), which illustrates land cover categories with an accuracy of 10x10 meters (Eurodata Cube 2021) (the MMU value is unknown). We analyzed land uses on two levels: within a narrow 30-meter buffer zone and a wider 300-meter buffer zone around the mining ponds identifying the characteristic land use categories. The first step of the analysis was to simplify the detailed category system of the NHRL map by merging similar types of categories from a land use perspective. This resulted in the following land cover categories:

- **built-up area**, which refers to areas occupied by buildings;
- **artificial surfaces**, which include areas occupied by other infrastructure, including surfaces altered by mining activities that do not fall into other categories;
- **road network and railway**, which are part of the gray infrastructure;
- **forested area**, which refers to areas covered by trees and contributes to increasing ecological value, formed by merging the deciduous, evergreen, and heterogeneous wooded shrub NHRL categories;
- **grassland**, which refers to areas covered by herbaceous plants, mainly grasses, and also represents ecological value, formed by merging the grassland and saline grassland NHRL categories;
- **shrub**, which refers to areas covered by shrubs and low vegetation;
- **arable land**, which includes agricultural lands under cultivation, formed by merging the cereals, row crops, and rapeseed categories in the NHRL;
- **water surface**, which refers to areas occupied by lakes and other water bodies (open water surfaces);
- **reed bed**, which provides riparian habitats and is therefore treated as a separate category;
- **"small" garden**, which is generally used for recreation or backyard cultivation;
- **orchard and vineyard**, which are cultivation areas and partly serve recreational purposes;
- **wetland** and **wet grassland**, which are marshy or boggy areas closely associated with the mining ponds.

The analysis was carried out using geospatial methods - using ArcGis 10.4 software - to compile the mining ponds database and the merged NHRL categories, and then to perform sampling in 30 and 300 m buffer zones around the mining ponds. The results were evaluated in graphical form.

Results

The data within the 30 m buffer are representative of direct bank use and surface cover. These areas are generally subject to more intensive human activities such as development, agriculture or recreational use. Coastal zone cover is an important factor in understanding the ecological condition and use of the area.

Values within the 300 m buffer zone are more indicative of the occupying land uses, reflecting the location of the mine workings in the wider landscape. We are looking for correlations between how abandonment induces land cover changes, are there significant differences?

Tables 1 and 2 present the percentage distribution of land use in the 30-meter and 300-meter surroundings of active and abandoned mining lakes, as well as the aggregated data.

Table 1. Land use in the 300-meter buffer zone around functioning and abandoned mining ponds (The colored bands illustrate the distribution of land use types.)

300-meter buffer zone around mining ponds						
	FUNCTIONING MINING PONDS		ABANDONED MINING PONDS		TOTAL	
Land use	Area (hectares)	Distribution (%)	Area (hectares)	Distribution (%)	Area (hectares)	Distribution (%)
Built-up area	172,66	0,83%	580,86	2,43%	753,52	1,69%
Artificial surface	2338,4	11,31%	1416,89	5,93%	3755,29	8,42%
Road network	316,66	1,53%	664,27	2,78%	980,93	2,20%
Railway	71,09	0,34%	103,12	0,43%	174,21	0,39%
Bare soil	1,79	0,01%	1,36	0,01%	3,15	0,01%
Arable land	8377,53	40,51%	7755,37	32,44%	16132,9	36,18%
Grassland	2084,82	10,08%	2331,69	9,75%	4416,51	9,90%
Orchard, vineyard	186,45	0,90%	337,32	1,41%	523,77	1,17%
Small garden	836,51	4,04%	2174,79	9,10%	3011,3	6,75%
Shrub	1687,05	8,16%	2324,08	9,72%	4011,13	9,00%
Forested area	2417,15	11,69%	3290,09	13,76%	5707,24	12,80%
Wet grassland	383,43	1,85%	555,1	2,32%	938,53	2,10%
Wetland	370,99	1,79%	549,85	2,30%	920,84	2,07%
Reed bed	410,81	1,99%	806,54	3,37%	1217,35	2,73%
Water surface	1026,89	4,97%	1018,65	4,26%	2045,54	4,59%
	20682,23	100,00%	23909,98	100,00%	44592,21	100,00%

Table 2. Land use in the 30-meter buffer zone around functioning and abandoned mining ponds (The colored bands illustrate the distribution of land use types.)

30-meter buffer zone around mining ponds						
	FUNCTIONING MINING PONDS		ABANDONED MINING PONDS		TOTAL	
Land use	Area (hectares)	Distribution (%)	Area (hectares)	Distribution (%)	Area (hectares)	Distribution (%)
Built-up area	3,13	0,16%	22,48	1,09%	25,61	0,64%
Artificial surface	630,51	32,64%	253,81	12,33%	884,32	22,17%
Road network	11,79	0,61%	32,69	1,59%	44,48	1,11%
Railway	1,88	0,10%	2,48	0,12%	4,36	0,11%
Bare soil	0,75	0,04%	0,01	0,00%	0,76	0,02%
Arable land	229,09	11,86%	168,26	8,18%	397,35	9,96%
Grassland	309,54	16,02%	315,37	15,33%	624,91	15,66%
Orchard, vineyard	12	0,62%	25,21	1,23%	37,21	0,93%
Small garden	36,04	1,87%	139,82	6,79%	175,86	4,41%
Shrub	166,52	8,62%	272,16	13,23%	438,68	11,00%
Forested area	270,22	13,99%	450,61	21,90%	720,83	18,07%
Wet grassland	11,74	0,61%	24,52	1,19%	36,26	0,91%
Wetland	32,57	1,69%	72,36	3,52%	104,93	2,63%
Reed bed	56,55	2,93%	164,29	7,98%	220,84	5,54%
Water surface	159,47	8,25%	113,71	5,53%	273,18	6,85%
	1931,8	100,00%	2057,78	100,00%	3989,58	100,00%

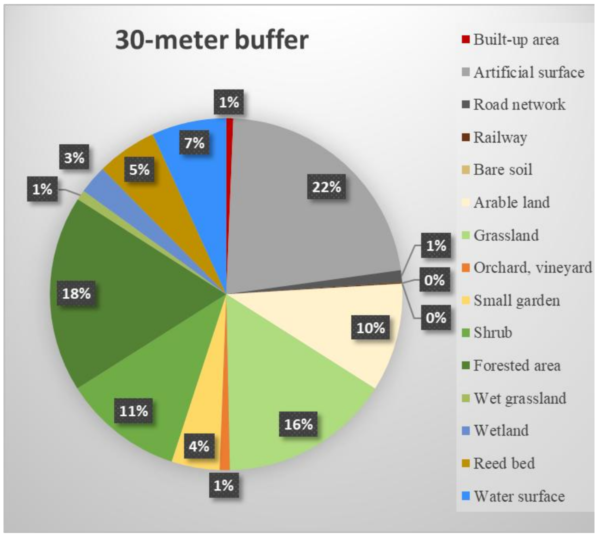

Figure 2. Land use distribution in the 30-meter shoreline zone of mining ponds for functioning mines

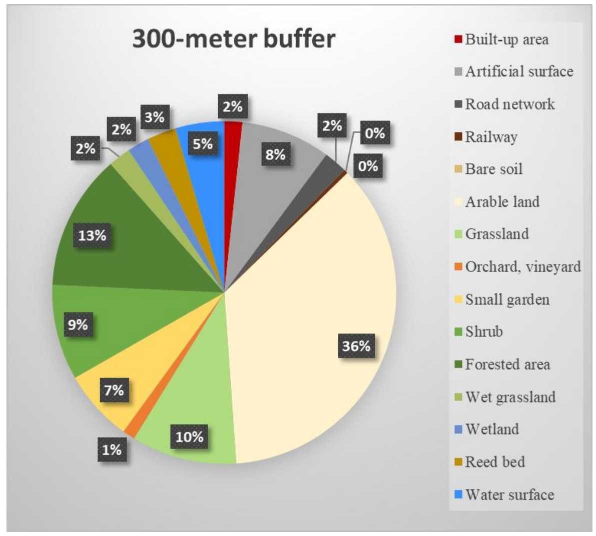

Figure 3. Land use distribution in the 300-meter shoreline zone of mining ponds for abandoned mines

The land use characteristics in the 30-meter buffer zone (Figure 2)

The shoreline of mining ponds is predominantly covered by **arable land**, which poses a potential source of water pollution from an environmental perspective. The proportion of **artificial surfaces** in functioning mining ponds (32.64%) significantly exceeds that of abandoned ones (12.33%). This data highlights the impact of mining activities on areas distant from extraction sites and indicates the initiation of natural regeneration and the results of intentional landscape rehabilitation following the cessation of operations. The percentage of **forested areas** in abandoned mining ponds (21.90%) is significantly higher than in functioning ponds (13.99%), suggesting natural regeneration and an increase in ecological value after mining has ceased. The proportion of **grasslands** remains relatively stable, with 16.02% in functioning ponds compared to 15.33% in abandoned ones. The increase in **shrubland areas** (8.62% in functioning vs. 13.23% in abandoned) following abandonment is likely an important indicator of natural regeneration. Conversely, the proportion of **water surface** is lower in functioning mining ponds (8.25%) compared to abandoned ones (5.53%). However, the proportion of **reed areas** has significantly increased in abandoned mining ponds (7.98%), indicating an increase in ecological value and habitat diversity. Lastly, the proportion of **built-up areas** (0.16% in operational vs. 1.09% in abandoned) suggests that mining ponds may become attractive for residential or recreational developments after abandonment.

The land use characteristics in the 300-meter buffer zone (Figure 2)

We analyzed the land use characteristics of the wider landscape band covering the mining ponds. The proportion of **artificial surfaces** is still dominant: in the case of functioning mining ponds (32.80%) and around abandoned ones (13.43%), indicating that mining activity is having an impact in the wider environment. The proportion of **forested area** in abandoned mining ponds (21.90%) is higher than in functioning mining ponds (13.99%), which indicating that natural succession is starting in these areas. The proportion of **grassland** and **scrub** and shrubland is similar within both categories. The proportion of **water surfaces** decreases for functioning mining ponds (8.25%) compared to abandoned ones (5.53%).

Analyses by type of raw material extracted

We have analyzed the 30 m coastal zone of the mining ponds according to the type of raw material extracted to determine whether there are typical land uses. The extracted raw materials were analyzed in five groups: clay, sand, gravel, peat and others. (Figure 4., 5)

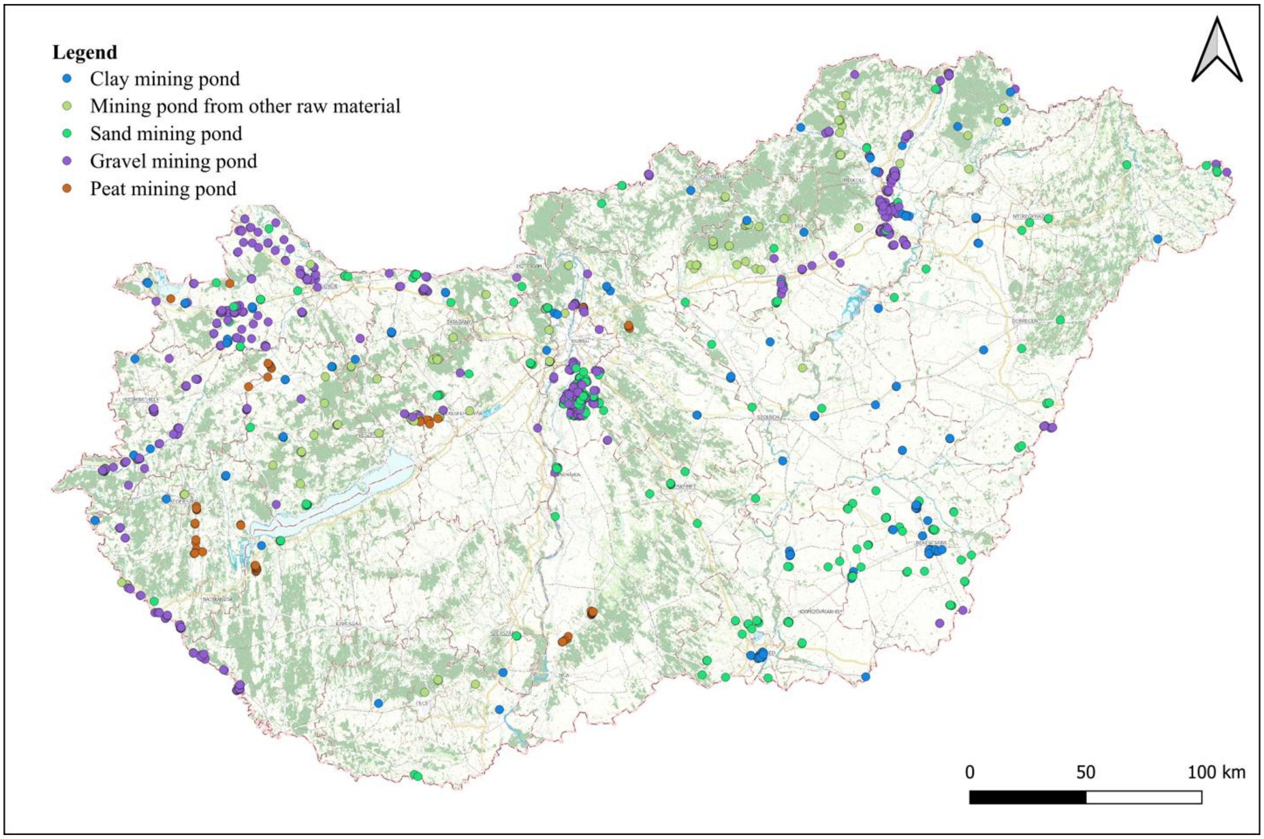

Figure 4. Distribution of mining ponds in Hungary by extracted raw materials

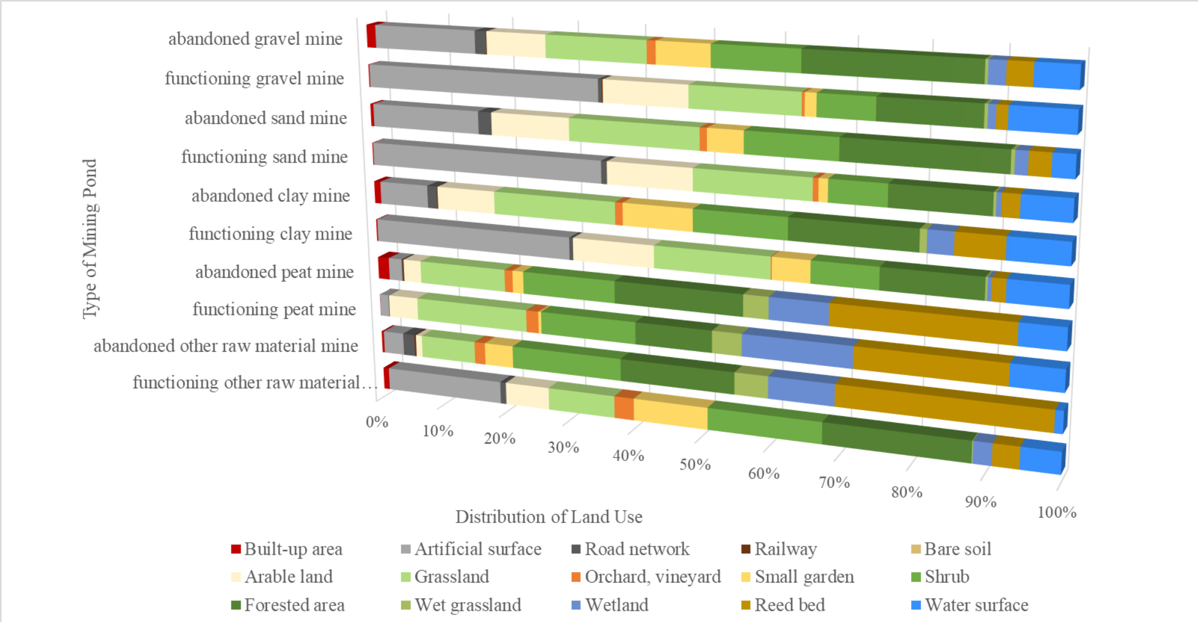

Figure 5. Land use ratio in the 30-meter shoreline zone of mining ponds by type of extracted raw materials, for functioning and abandoned mines

There are significant differences in the landscape use of the coastal zone of the mining ponds, both by the type of raw material mined and by the operational status. Abandoned mining ponds tend to have a higher proportion of semi-natural areas (57-86%), while the 30 m shoreline of functioning gravel, sand and clay mines is characterised by a significant **artificial surface** (30-36%). A raw material-specific characteristic is that the bordering zone of peat mines has a particularly high proportion of semi-natural areas (73-74%) and a significant **reed cover** (21-25%), while **agricultural use** is most significant in the bordering zone of clay mines (17-20%). **Forest cover** increases after abandonment mainly in the case of gravel mines (functioning 14%, abandoned 24%). The proportion of artificial surfaces is highest for working quarries of construction materials (gravel, sand, clay), so the magnitude of the intervention is most significant. The data suggest the following regeneration trends: after abandonment, (partly through processes of ecological succession) the proportion of semi-natural areas increases and the proportion of artificial surfaces decreases. In general, agricultural areas are not affected by this change.

Environmental aspects

The interactions between mining ponds and farmland have a significant impact on groundwater levels, water quality and ecosystems. Excess evaporation from mining ponds lowers groundwater levels, which in the long term affects agricultural production. Riparian vegetation and wooded areas contribute to maintaining biodiversity, while grassland and reed bed habitats play an important role in maintaining ecosystem stability and improving water quality. However, the growth of built-up areas may pose potential environmental risks.

Cultural Ecosystem Services of Mining Ponds

Recreational Potential Based on Land Use Patterns: The presence of high forest cover (21.90% in abandoned mining lakes) and near-natural areas is favorable for recreational use. The grasslands developed in the riparian zone (15-16%) are suitable for the establishment of resting places and viewpoints. The reed areas (7.98% in abandoned mining lakes) provide opportunities for creating birdwatching sites.

Accessibility and Infrastructure: The presence of the road network (around 1.5-2%) ensures accessibility. The high proportion of small gardens (especially in clay pits, 5-10%) indicates recreational potential. The increase in built-up areas after abandonment (from 0.16% to 1.09%) signals the development of recreational infrastructure.

Educational and Tourism Value: Diverse habitats (forests, reeds, wetlands) offer environmental education opportunities. Protected conservation areas (28.8%) are particularly suitable for ecotourism developments.

Landscape Aesthetic Value: The presence of water surfaces enhances the aesthetic value of the landscape. The diverse vegetation cover resulting from natural succession improves the scenic appearance. In rehabilitated areas, intentional landscape architectural interventions enhance aesthetic value.

Cultural Identity and Sense of Place: Mining ponds are part of the industrial heritage. Recreational use strengthens local communities' attachment to the area. The repurposing of these sites serves as an exemplary model for sustainable land use.

Discussion and Conclusion

The 30-meter coastal zone of the mining ponds plays a key role in maintaining water ecosystems and managing environmental impacts. An appropriate legal framework and the application of sustainable land use practices are essential for the protection of the mining pond environment (for example in maintaining a vegetated buffer zone).

The ecosystem services of mining ponds can also be considered significant. The presence of high forest cover and near-natural areas around abandoned mining ponds enhances their recreational potential, providing suitable locations for resting places, viewpoints, and birdwatching sites. Additionally, the road network and the prevalence of "small" gardens indicate good accessibility and recreational opportunities, while protected conservation areas support ecotourism development. Overall, these sites not only contribute to aesthetic and educational values but also strengthen local cultural identity and community attachment.

The high proportion of arable land also indicates that gravel and sand quarry ponds are typically located at the expense of arable land. According to European Commission guidelines, good quality soils should not be a victim of economic growth (URL1), and therefore restoring the original land use during landscape rehabilitation should be important from an environmental and landscape potential/ecosystem service perspective.

References

Bishop, J., and L. M. Smith**.** 2022. "Assessing Impacts of Surface Mining on Aquatic Resources in North America." *Journal of Environmental Management* 300: 113-125. https://doi.org/10.1016/j.jenvman.2021.113125.

Eurodata Cube. NHRL. 2021 Accessed January 10, 2025. https://collections.eurodatacube.com/nhrl.

European Commission. "Proposal for a Nature Restoration Law." Last modified June 22, 2022. Accessed December 20, 2024. https://ec.europa.eu/environment/nature/nature-restoration-law_en.

Google. 2024. "Map Data." https://www.google.com/maps.

https://www.parlament.hu/documents/10181/63291245/Infojegyzet_2022_25_foldellatottsag.pdf/d3dd51b7-c827-b5b5-d3bf-52e244a358b4?t=1667555915818.

Innoteka. "Bányató Visszatöltéssel a Fenntarthatóságért és Szokatlan Madárvédelem." Accessed January 14, 2025. https://www.innoteka.hu/cikk/banyato_visszatoltessel_a_fenntarthatosagert_es_szokatlan_madarvedelem.2423.html.

Lechner Knowledge Center. *NHRL Database*. Accessed December 1, 2024. http://www.lechnerkozpont.hu/nhrl.

MBFSZ. 2019. *"Geographic Database of Abandoned Mines."* Hungarian Mining and Geological Survey.

Módosné Bugyi, Ildikó, Hubayné Horváth, Nóra, and Varga, Dalma E. 2019. "The Role of Mining Ponds in the Hungarian Greenway Network." In *Proceedings of the Fábos Conference on Landscape and Greenway Planning*, 6: 1-15. Massachusetts. http://dx.doi.org/10.7275/f4h4-e594.

Módosné Bugyi, Ildikó, Varga, Dalma, and Hubayné Horváth, Nóra. 2022. "The Landscape and Ecological Significance of Mining Ponds." *In Proceedings of the 10th Landscape Ecology Conference*.

National Landscape Strategy (2017-2026). Budapest: Kormányzati Tájékoztatási Központ.

OSM. 2024. *"OpenStreetMap Geographic Data*." https://www.openstreetmap.org/.

Psotová, Hedvika. "Landscape Character and Integration of Mining Lakes into the Landscape - Opportunities and Risks." Otrokovice: Arvita P spol. s r.o., 2020. https://doi.org/10.11118/978-80-7509-904-4-0140.

SZTFH. 2024. Supervised Activities Regulatory Authority, "*Latest Inventory of Mining Areas."* https://mbfsz.gov.hu/banyaszati-teruletek-legfrissebb-nyilvantartasa.

Varga, Dalma, Módosné Bugyi, Ildikó, and Hubayné Horváth, Nóra. 2022. "The Role of Mining Ponds in the Landscape Character." In *Proceedings of the 7th Fábos Conference on Landscape and Greenway Planning*.