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THE LOCATION AND EXTENT OF SYSTEMATIC DRAINAGE IN RELATION TO LAND USE IN THE PAST AND AT PRESENT AND IN RELATION TO SOIL VULNERABILITY TO ACCELERATER INFILTRATION IN THE PROTECTED LANDSCAPE AREA ŽELEZNÉ HORY

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Abstract

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This study searched for associations between the extent of hydromelioration systems and the land use (in the past and at present), degree of nature conservation, and infiltration of water through soil profile in the Protected Landscape Area (PLA) Železné hory. According to the available evidence, 34.6% of arable land and 32.1% of permanent grasslands in this area are drained by the drainage systems. Analysis of the original design documentations of drainage structures indicate, that the extent of drained areas can actually be even higher. The hydromelioration systems were built namely in the second half of the 20th century. The drainage also affected alluvial meadows, wetlands, and ecologically valuable stations. After establishment of PLA Železné hory in 1991, the protected area was divided into four zones according to their significance and protection regime. This study has revealed the presence of areas drained by systematic drainage systems (101 ha of grasslands) even in the zones of highest landscape protection degree (1st and 2nd protection zones). The inadequately executed drainage systems should be eliminated and the character of the land should be brought closer to its natural conditions. On the model part of the PLA we also performed a study of historical changes in the landscape in three time horizons (1839, 1950, 2014) to show differences in land use before building of drainage, at the time of building, and at present.

Keywords: drainage area, land use, protected landscape area, accelerated infiltration, design documentation

INTRODUCTION

The Protected Land Area (PLA) Železné hory was established in 1991 (Czech Republic, degree No. 156/1991). The landscape dominant is the Železné hory Ridge. The highest locality is the Vestec Hill (668 m.a.s.l.). The landscape of Železné hory is characterized by harmonious picturesque diversity, with alternating forests, meadows, agricultural land and small habitations with conserved historical situation (Nature Conservation Agency of the Czech Republic, 2010). Hydromeliorations cover a wide spectrum of activities aimed at more intensive and efficient use of land for agricultural production.

In the Czech Republic (CR), the agricultural land drainage has been implemented not only in lowlands in the vicinity of the lower reaches of watercourses but, in a large extent, in the central and upper reaches of watercourses in water spring areas. Drainage using systematic drainage systems was at its prime in the 1970's and 1980's. Its general implementation in Europe is hardly comparable (Tlapáková *et al*., 2013).

According to Agricultural Water Management Administration (ZVHS) digital database more than 1,078,000 ha have been drained in the Czech Republic (Kulhavý *et al*., 2007).

As noticed by Tlapáková *et al*. (2013), the extent of drained areas in the ZVHS database is far from final. To search for and document the existing hydromelioration measures, it is necessary to make maximum possible use of supporting data including original design documentation.

The main source of information on the established drainage systems were archives of the former Agricultural Water Management Administration (ZVHS). In general, these archives contain the preserved design documentation of the system in all its phases. At the time of its origin, the design documentation was executed in several copies (specimens). These copies were provided to both ZVHS and the subject managing the drained land. At that time, such system of registering and archiving the design documentation was standard and adequate.

The objective of specific wildlife and landscape preservation is long-term protection and amelioration of the environment, its fauna and flora. One of the problems it faces is the presence of a large extent of hydromelioration systems (systematic drainage by pipe drains), introduced namely during the collectivization of agriculture in the second half of the 20th century. Systematic drainage with field spacing and depth has greatly disturbed and impaired the landscape character. This way of drainage enabled conversion of land that had been so far covered by grass into arable land, thus allowing changes in the land use and land cover – permanent grasslands were transformed into agricultural arable land. As a consequence of the altered water regime in arable land, wetlands had gradually dried up and large blocks of arable land were formed, abolishing the existing road system and bringing significant impacts and changes into the landscape organization, which in turn led to the altered character of landscape in entire regions.

The drainage in the submontane region of Železné hory, along with subsequent intensive agricultural activity, resulted in significant destabilization of agroecosystems and the surrounding wildlife stations. The processes of land improvement and drainage led to reduction of biotopes, and consequently of plant and animal species, changes in the species distribution of meadow and forest covers, lowered landscape retention capacity, land desiccation, elimination of line greenery, field paths, excessive fertilization and use of pesticides. These effects, which today are intensified by local defects or total malfunction of the drainage (due to the changes in agriculture, land use, neglected maintenance, aging of construction elements, etc.), led to both quantitative and qualitative changes in the water regime of entire river catchments (Kulhavý *et al*., 2013).

Agricultural land drainage has an impact on the environment and hence on the landscape through changes made in space and time. Such changes were characterised by Spaling et. Smit (1995). These authors used the conceptual model of the agricultural land drainage effects on the environment to show that drainage changes the water regime. It also contributes to changes in the spatial distribution of pollutants and increases their concentrations in relation to the source, to their transfer from agroecosystems to aquatic ecosystems, and contributes to changes in the landscape structure (spatial fragmentation).

Focusing on landscape changes in the West South Central USA, where wetlands have been drained on a massive scale by straightening river courses, the authors draw attention to degraded bank ecosystems and their transformation into an unstable and „simplified" aquatic environment (Huang *et al*., 2009). Jelínek (1999) notes that hydromelioration measures were basically limited to drainage and watercourse training from the 1950's. Langhammer and Vilímek (2008) classify the extent of systematic drainage as one of the key indicators (besides long-term changes in the use and changes of the landscape cover, shortened river networks and river training).

It is therefore reasonable to expect that the landuse within the most vulnerable enclaves due to infiltration – critical source areas of the catchments – will significantly influence the hydrology and hydrochemistry dynamics of tile drainage systems built on the territory of the Czech Crystalline Complex (Novák *et al*., 2012). The EU's Water Framework Directive commits European Union member states to achieve at least good surface water status by 2015. Water quality in the rivers is influenced by the development of the whole catchment (Matysik, Absalon, 2012). The quality of surface and groundwater is significantly influenced by pollution from point sources (settlements, waste-water treatment plants, fish ponds and industrial or agricultural works) and also by non-point pollution sources from prevailingly agricultural activities, causing elevated leaching of nutrients into waters and increased erosion (MacLeod *et al*., 2007). Investigation of non-point pollution sources was therefore focused on the drainage systems that could significantly contribute to the nutrient load of surface waters. The presence of drainage systems modifies the natural pathways of water circulation and runoff – depending on soil characteristics and morphological conditions of a locality, weather course and parameters of the drainage

system, the drainage usually shortens water cycle and retention time in the soilrock environment (Doležal *et al*., 2000). The pollution of water bodies is significantly enhanced by vertical leaching of compounds from the soil profile. A major role in this process is played by the presence of soil vulnerable to accelerated infiltration, and namely by the presence of hydromelioration drainage systems. These localities are particularly threatened by the risk of increased leaching of compounds present in industrial fertilizers applied to the agricultural land, resulting in prospective degradation of both surface and ground water (Schottler *et al*., 2014).

MATERIAL AND METHODS

The Železné hory PLA is situated in the central part of the Czech Republic (Fig. 2). The territory was selected because of long-term research activities in this area carried out by Research Institute for Soil and Water Conservation.

The landscape in this area is characterized by a large diversity. The surface of the PLA is 285.5 km^2. The entire territory is divided into four protection zones; each zone is regulated by a clearly defined method of wildlife and landscape protection and established limits of land use, or where needed, limits of agricultural activities.

This study is focused on the evaluation of landscape development related to hydromelioration systems and specific management of a particularly protected area.

The following analyses were performed in the study:

- Analysis of land use and protection of the PLA zones.
- Analysis of soils vulnerable to infiltration in the PLA.
- Analysis of drained surfaces (hydromelioration systems) in a selected PLA locality.
- Analysis of historical changes in land use in a selected PLA locality.

All necessary analyses (overlays, statistics, calculations) and map outputs were performed using the ArcGIS tools.

For detailed analyses of the historical changes in land use, we selected part of the catchment of the Chrudimka River of 28.4 km^2 surface situated in seven cadastral areas. To record the evolution and historical changes in the selected area we chose three time horizons characterizing the development in the years 1839, 1950, 2014. The selection of time horizons was based on essential changes occurring in the landscape in the 19th, and especially in the 20th century, with particular focus on the land management, and wildlife and landscape management changes. The historical situation was analysed based on Imperial map prints of the stable cadastre originating from the years 1824–1843 and systematically mapping the entire historical landscape of the Czech Republic. The second time horizon of the middle of 20th century (1950) represents the beginning of major changes in the landscape and its structural organization. As a material, we used historical black-and-white aerial images. The third time horizon corresponds to the current state and to analyse it we used the LPIS (Land Parcel Information System) data, Fundamental Base of Geographic Data of the Czech Republic, current colour orthophoto. On these raster data, vector map layers of the land use corresponding to the selected time horizons were digitized.

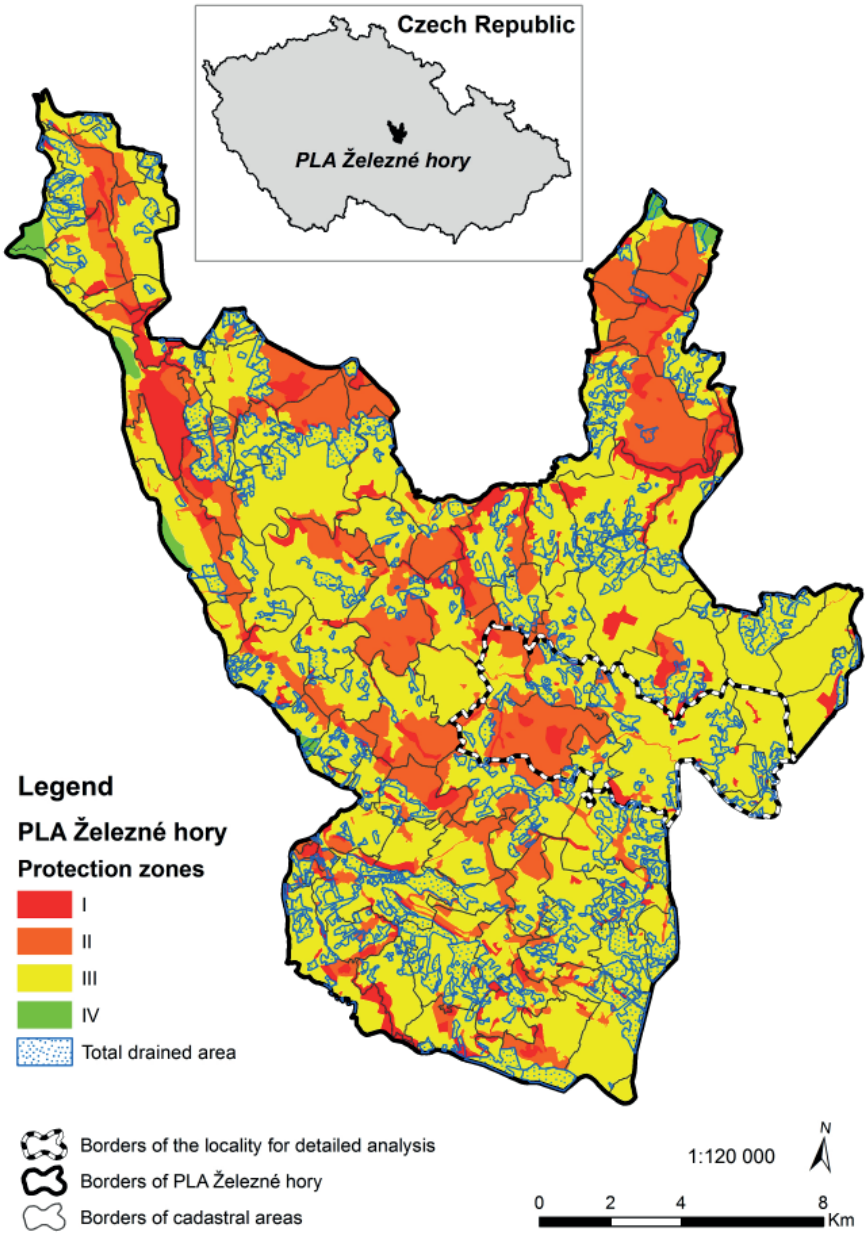
To analyse the role of the drainage systems we used two basic data sources. The main source of information on the established drainage systems were archives of the former Agricultural Water Management Administration (ZVHS). The second, and in principle the only digitized source processed for the entire Czech Republic, is the polygon layer of drainage with the most significant attributes (the district number of the system and its year of origin). This digital layer is generalized and incomplete. Data layer was processed by digitalization of maps at a scale of 1:10 000. In these maps were hand-drawn outlines of drained areas.

Analysis of the hydromelioration systems was done in several steps:

- Provision of entry data – design documentation and digital vector layer of hydromelioration systems.
- Transformation of the design documentation to the digital form (scanning).
- Georeferencing – transformation of the scanned documentation to the system of coordinates.
- Overlay analysis, zonal statistic in the ArcGIS environment.

To localize and analyse infiltration vulnerable soils we used the "Methodology for Preparation of a Synthetic Map of Ground Water Vulnerability" (Novák, Slavík, 2012).

1: *Historical photo of construction of a hydromelioration system – example of grooving*
source: Author's archive



2: *Survey map of the PLA Železné hory including protection zones, drained areas and the selected model territory for detailed analysis of the historical evolution of land use and extent of drained areas according to original design documentation*
source: Authors

3: *Examples of maps of a part of the model territory in the studied time horizons (from the left the years 1839, 1950 and 2014)*
source: Authors

The results of partial analyses were transformed into map outputs representing the graphical representation of the data on development, changes and status of the monitored area in selected parameters. The results correspond to the zone distribution in the PLA Železné hory, defining the zone limits and management specificities.

RESULTS

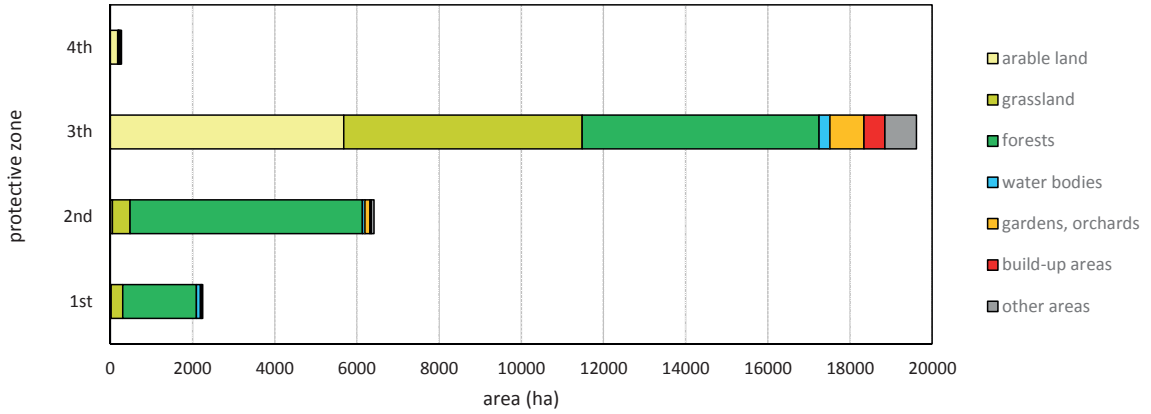
Analysis of Land Use and Protection Zones in the Territory of PLA Železné hory

According to the degree of regulation and wild-life and landscape protection, the PLA Železné hory has been divided into four protection zones: the 1st protection zone (the strictest protection regime) covers 7.9% of the territory, the 2nd protection zone occupies 22.5% of the territory, the 3rd protection zone 68.7% of the territory, and the 4th protection zone 0.9% of the territory. The PLA Železné hory is characterized by large forest surfaces (46.3% of the territory). The proportion of arable land is below the average for the Czech Republic (20.7% of the territory). Grasslands and meadows cover 22.9% of the area. In the 1st and 2nd protection PLA zones, forest communities and grasslands prevail. Here, the arable land takes only a minimum space. In the 3rd protection zone of the PLA, the distribution of forest communities, arable land and grasslands is practically identical.

Analysis of the Areas Drained by Drainage Systems in the Territory of PLA Železné hory

Systematic drainage is located on more than 15% of the total territory. According to the valid digital data layer used in the Czech Republic, 34.6% of arable land and 32.1% grasslands are drained by the drainage systems. With regard to the status of particularly protected territory, oversized and inadequately executed drainage (interception of spring outflows in localities with higher altitude, drainage of marshlands and wet meadows) should be eliminated and the character of the land should be brought closer to its natural conditions.

In the 1st protection zone of PLA Železné hory, 33.8 ha of grasslands and 4 ha of arable land are drained by drainage systems. Drainage is operating in 66.8 ha of grasslands and 10.9 ha of arable land in the 2nd protection zone and in 1996.7 ha of grasslands and 1997.9 ha of arable land in the 3rd zone. However, the drainage can also be found in forests, occupying 12.8 ha in the 1st protection zone, 11.6 ha in the 2nd protection zone, and 110.1 ha of forests in the 3rd protection zone.



4: *Land use in individual protection zones of the PLA Železné hory*
source: Authors

I: *Analysis of drained areas in relation to the land use and protection degree (zone distribution)*

Land Use	Drained in the protection zone – surface [ha]				Total [ha]
	1st zone	2nd zone	3rd zone	4th zone	
Arable land	4.0	10.9	1997.9	36.2	2048.9
Grasslands, meadows	33.8	66.8	1996.7	0.1	2097.4
Forests	12.8	11.6	110.1	0.0	134.4
Water bodies	1.3	0.3	5.4	0.0	7.0
Gardens, orchards	0.2	1.5	25.2	0.7	27.6
Build-up areas	0.1	0.2	19.8	3.9	24.0
Other area	1.8	4.8	113.3	3.2	123.1
Total [ha]	53.9	96.1	4268.4	44.0	4462.5

source: Authors

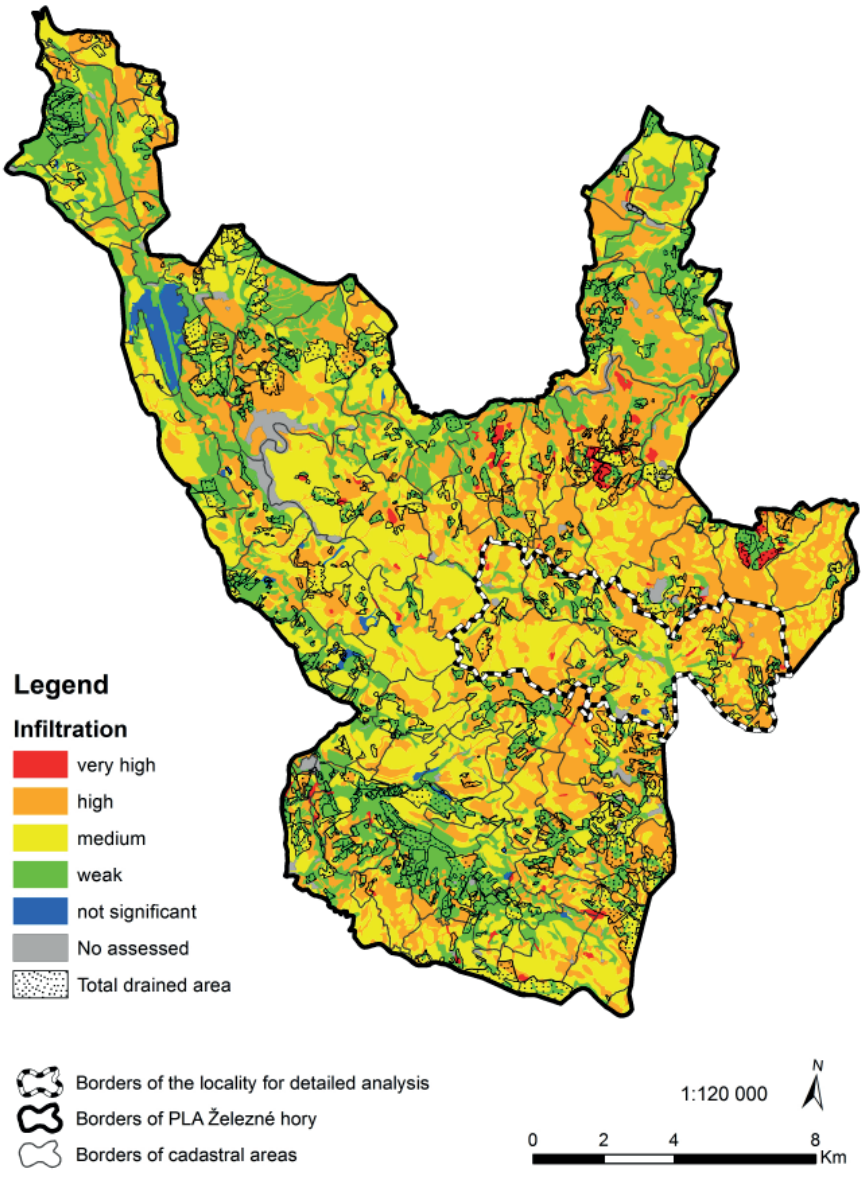
Analysis of Infiltration Vulnerable Soils in the Territory of PLA Železné hory

As a part of our study, we identified soils vulnerable to infiltration (Novák, Slavík, 2012). These soils are at high risk of accelerated infiltration of water and other compounds by the soil profile. The types of soil that are not capable of long-term water retention are mostly shallow, sandy, and skeletal soils. In such localities, there is a high risk of leaching of compounds from the soil profile, such as mineral fertilizers, pesticides, etc. In the studied area, these soils (at high or very high risk of accelerated infiltration) are localized in 35% of the territory. They are not suitable for use as arable land and should be transformed into the category of permanent grass covers (Fučík *et al*, 2008; Fučík *et al*., 2010; Kvítek *et al*., 2009).

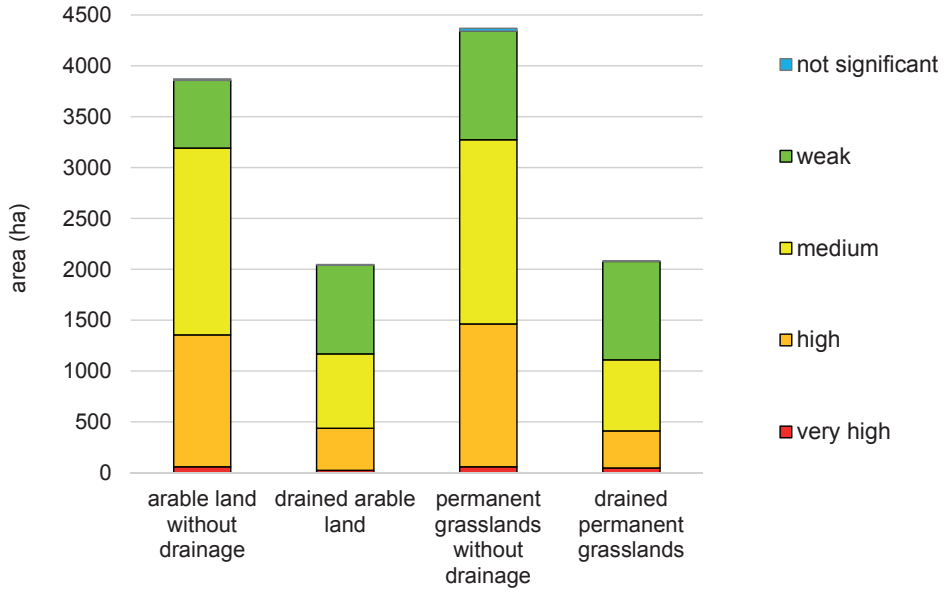
Surfaces of arable land drained by systematic drainage (34.6% of the total arable land surface in the locality of interest) are often threatened by accelerated infiltration, greatly influencing the entire water retention system in the landscape. More than 437 ha of drained arable land (7% of the total arable land area) have also been classified into the category at high or very high risk of accelerated infiltration.

A similar situation holds for grasslands – with 32.1% of the total surface of permanent grass covers drained in the model territory. Of these, 411 ha (6.3% of the total surface of permanent grass covers) has been classified into the category of high or very high risk of accelerated infiltration.

These localities require increased attention and adequately selected management measures and



5: *Classification of soils in the territory of PLA Železné hory according to their infiltration rate*
source: Authors



6: *Classification of agricultural land (arable land and permanent grasslands) in PLA Železné hory according to the degree of soil vulnerability to accelerated infiltration and presence of drainage*
source: Authors

regime, particularly in the zones with highest protection.

Analysis of the Drained Surface According to the ZVHS Database and to the Original Design Documentation

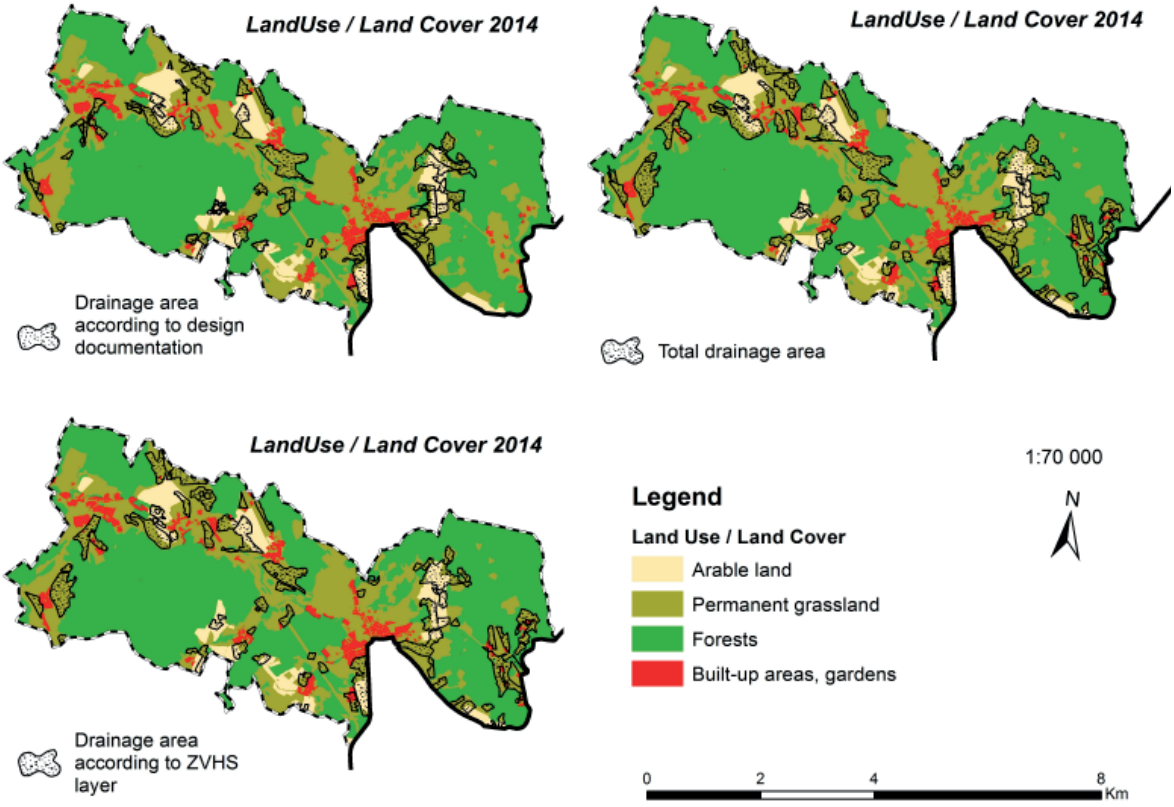
We obtained the original design documentation of hydromelioration systems for the model territory and we compared it with the currently used data layer in the Czech Republic processed by ZVHS. According to the ZVHS layer, the selected model territory contains 341 ha of drained surfaces. By intersecting these two layers we found that an additional 77.5 ha of drained surfaces had been recorded in the design documentation (and are missing in the ZVHS layer). This fact clearly shows differences in both data layers. The officially used data layer processed by ZVHS therefore cannot be considered as the best accessible basis for spatial determination of the extent of hydromelioration systems. The best approach therefore seems to be combining this data layer with actual design documentation and confronting them (Fig. 7 – total drainage area).

Analysis of Historical Changes in Land Use in a Selected Part of the PLA Železné hory

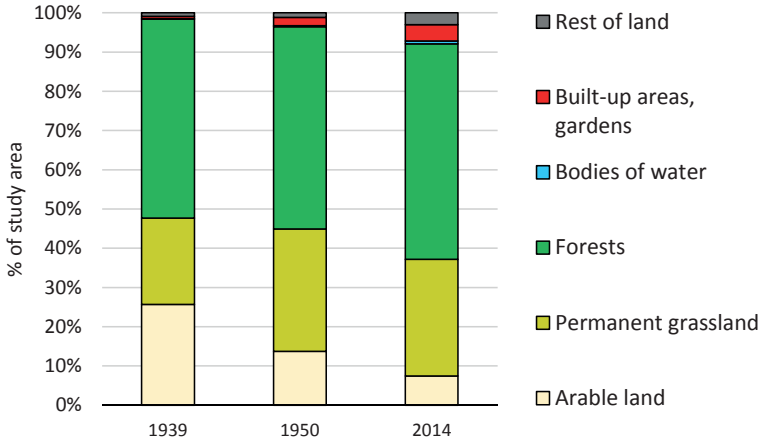
In time, the land use undergoes changes. These changes concern the management, regime of wildlife and landscape protection, changes in funding, etc. Localities drained by the drainage systems were not always used as they are today. Most drainage systems were introduced into the territory of Železné hory after 1950. Since then, the manner of land use has undergone extensive changes. The analyses performed at the model territory (selected part of Železné hory) show a visible trend in arable land reduction. This land is gradually replaced by permanent grasslands, forests and residential areas. Today, the areas of arable land drained in the past are often covered with grass, forests, or used in another way. That is why we also recorded the presence of drainage in water bodies (earlier, these localities were used as agricultural land). At the time of extensive drainage introduction, the main objective was to make accessible, manageable and effective a maximum extent of agricultural land. After the establishment of PLA Železné hory in 1991, the priorities in the region have been re-evaluated. Accent is laid on restoration of natural stations and ecosystem components. For both intensive and extensive agricultural land use the presence of drainage systems has been found counterproductive. The drainage disrupts the entire water regime in the landscape, reduces water retention, leads to desiccation of river floodplains, etc.

DISCUSSION

In the past, the region of Železné hory was disturbed by land consolidation, ploughing of meadows and pastures, and adaptation of the water regime. In the catchment of the Chrudimka River (crossing the studied area), up to 42% of agricultural land had been drained by drainage systems in the years 1960–1986. Concerning wildlife and landscape preservation, the most valuable natural wetlands were suppressed and the natural watercourses straightened. Among the first steps of revitalization of the Železné hory landscape, the Programme of Care of PLA Železné hory envisages the measures of the following type:



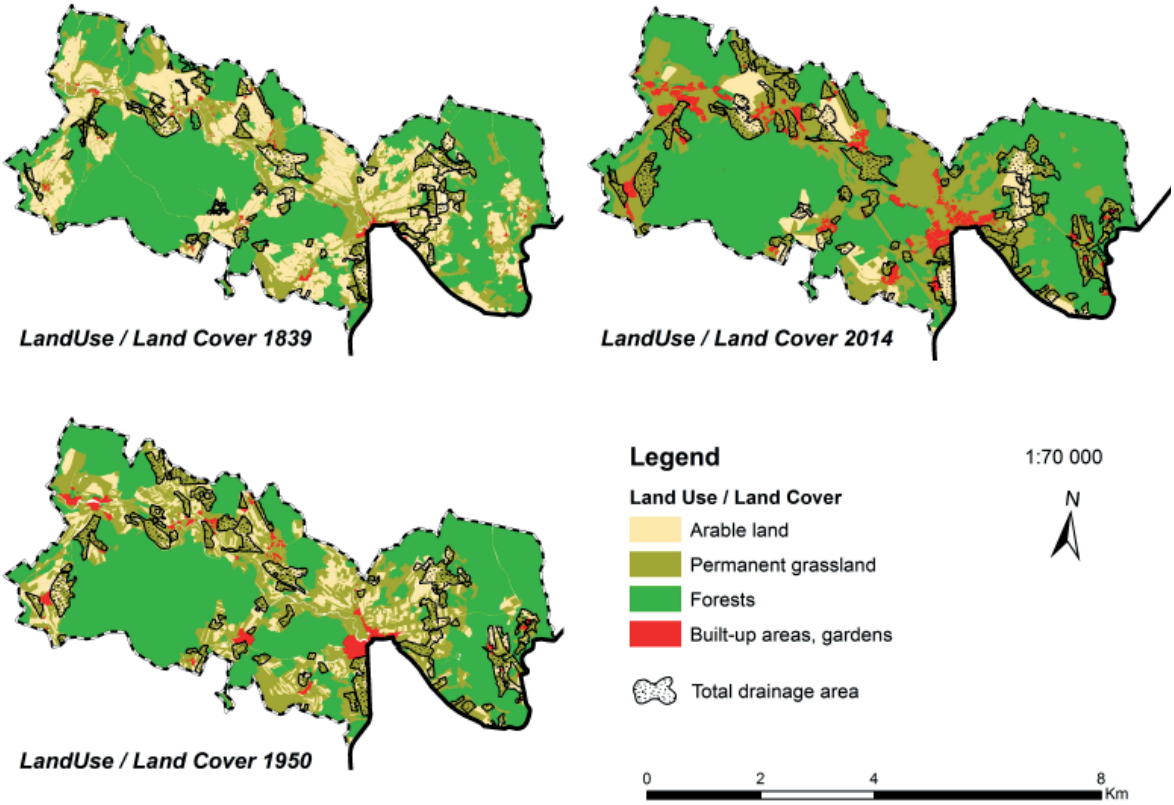
7: *Extent of drained surfaces in a part of PLA Železné hory (model territory) according to the ZVHS data layer, original design documentation and combination of the two layers – total drainage area*
source: Authors



8: *Land use in a part of PLA Železné hory (model territory) in the years 1839, 1950 and 2011*
source: Authors

"initiate and support removal of hydromelioration systems both in the PLA and in the surrounding landscape and their replacement with anti-erosive and retention measures". Further, to "preserve a favourable water regime in waterlogged and wetland stations", and "in the localities drained in the past, enforce restoration of the natural water regime" (Nature Conservation Agency of the Czech Republic, PLA Administration Železné Hory, 2010).

According to the Programme of Care of PLA, in the 1st and 2nd PLA zones the agricultural land should be used as extensively managed permanent grassland. Our study has shown that the 1st and 2nd zones still contain at least 64 ha of arable land, of which ca 15 ha is drained by the drainage systems. In this land, the drainage should be eliminated and the culture changed to permanent grassland. Further, 715 ha of the 1st and 2nd protection zones are covered by permanent grasslands, of which 101



9: *Changes in land use in a part of PLA Železné hory (model territory) in the years 1839, 1950 and 2011*
source: Authors

ha (14%) have been drained. These localities should be conveniently regulated by the recommended measures of the Programme of Care of PLA Železné hory ("in the localities drained in the past, enforce restoration of the natural water regime"). The elimination of inadequately drained surfaces should carefully observe the historical map documentation (see Analysis of historical changes in the selected model territory), allowing good identification of land use in these localities prior to the introduction of hydromelioration systems and return of the locality to the original character and function by revitalization.

The potentially best option for retaining water in the area is transforming arable land with high and very high infiltration rate to permanent grassland. This concerns 1357 ha of arable land in the area of the PLA Železné hory. Of these, more than 437 ha are drained by drainage systems especially in the 3rd protection zone (this type of land is practically absent in the 1st, 2nd, and 4th protection zones). Grassing of this land would significantly contribute to augmentation of water retention in the soil and prevention of accelerated subsurface water runoff.

In our study, we also performed detailed analysis of the land use in a part of the PLA Železné hory (model territory). The landscape underwent pronounced changes in the land use. The trend shows reduction of arable land in favour of permanent grassland. The parcels drained in the last century were often used very differently in the past. Despite extensive grassing, hydromelioration systems still remain functional under the soil cover.

Our analyses of the surface of drained areas in the PLA Železné hory was based on the data layer of hydromelioration systems produced by ZVHS that is officially used in the Czech Republic. About this data layer, we know that is very generalized, inaccurate and does not contain all of drained areas. The basis for the preparation of this map layer were hand-drawn polygons of drained areas on a map with a scale of 1:10 000. Based on field survey and previous research activities, we know that the actual extent of the drainage in the landscape corresponds mainly original project documentation. Large number of these project documentation was lost. For a part of the area (model territory) in the PLA Železné hory we obtained original design documentation of hydromelioration systems and compared it with the existing ZVHS data layer. We found significant differences in acreages and we identified drained areas that have not been recorded in the ZVHS data layer. We may therefore question our actual knowledge on the surface extent of the drained areas in the Czech Republic.

CONCLUSION

The purpose of this work is to identify the area of the systematic drainage in the Protected Landscape Area Železné hory. The extent of drainage area is compared to the land use. Over time, there are significant changes in land use. These changes in land use over time were analysed through a retrospective evaluation of land use on the part of the PLA Železné hory. The analysis confirmed the trend of decreasing arable land, increasing trend in the area of permanent grassland. During the construction of drainage (the second half of the 20th century), parcels were often used as arable land. Today are these parcels mostly used as meadows. Their hydrological regime is strongly influenced. The extent of these drainage areas was compared with the degree of nature and landscape protection (protection zonech of PLA Železné hory). The result is the indentification and localization of drained areas that are currently in zones of highest degree of nature conservation. These drainage areas (101 ha) should be revitalized throught appropriate measures.

Hydrological regime of the PLA Železné hory is also strongly influenced by the characteristics of soil. Soils with shallow soil profile, sandy, skeletal (rapid infiltration), used as arable land should be permanently convert into grassland (to increase water retention in the area). If these areas are also drained (437 ha), the need for grassing of these locations is even higher.

The study confirmed the fact that the actual extent of drained areas is not exactly known. The best way to identify all areas is drained through the original design documentation, which are deposited in the archives.

The result of the analysis is knowledge that in areas with a higher degree of nature conservation (in this case the PLA Železné Mountain), it is necessary to know the risk factors that affect the hydrological regime. In this case, the extent of drainage, pedological characteristics, and regime of conservation. In areas with a high degree of nature conservation is necessary to support the revitalization of the hydrological regime of these areas.

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