CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

FACULTY OF ENVIRONMENTAL SCIENCES

DEPARTMENT OF LANDSCAPE AND URBAN PLANNING

Monitoring changes in landscape development with a focus on wetlands.

DIPLOMA THESIS

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CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Environmental Sciences

DIPLOMA THESIS ASSIGNMENT

Nshimirimana Delphine Huriro

Landscape Engineering
Landscape Planning

Thesis title

Monitoring changes in landscape development with focus on wetlands.

Objectives of thesis

Information on wetlands dynamics at landscape level is necessary to understand factors influencing wetland loss and can serve as basis for wetland restoration.

The main goal of this research is to assess long term change of wetlands biotopes at landscape level in four cadastral districts of the city of Prague namely Běchovice, Dubeč, Uhříněves and Dolní Počernice. This goal will be achieved through the following specific objectives:

- To assess the spatial -temporal changes of wetlands in each cadastral district expressed as the size of extinct, continuous, and recent wetlands.
- To evaluate wetlands change trajectories by identifying and quantifying LULC (Land Use Land Cover) categories that replaced extinct wetlands and those at the expense of which recent wetlands occur.

Methodology

Imperial mandatory imprints of the Stable Cadastre will be prepared in Adobe photoshop 2021 and then be processed in ArcMap 10.8.1 to produce historical LULC maps.

The current LULC maps will be produced from contemporary orthophoto of the Czech Republic supplemented by different sources that delimitate wetlands, forests types, built up areas and arable land.

Historical and current Wetlands maps will then be processed in GIS environment to assess spatial-temporal changes of wetlands expressed as the size of extinct, continuous, and recent wetlands.

Extinct and recent wetlands will be intersected in ArcMap10.8.1 with current and historical LULC maps respectively to identify and quantify LULC categories that replaced extinct wetlands and those replaced by recent wetlands.

Resulting tables from GIS will be processed in Microsoft excel to produce tables and figures for better results presentation.

The proposed extent of the thesis
min. 40 str.

Keywords
LULC change, wetlands, spatial-temporal, trajectories, GIS

Recommended information sources

Davidson, N., Fluet-Chouinard, E., & Finlayson, M. (2018). Global extent and distribution of wetlands: Trends and issues. Marine and Freshwater Research, 69. https://doi.org/10.1071/MF17019.

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Author’s declaration

I, Nshimirimana Delphine Huriro, hereby declare that I have independently elaborated this diploma thesis with the topic of: “Monitoring changes in landscape development with focus on wetlands '' and that I have cited all the information sources that I used in the thesis and that they are also listed at the end of the thesis in in the list of used information sources.

I am aware that my diploma/final thesis is subject to Act No. 121/2000 Coll., on copyright, on rights related to copyright and on amendment of some acts, as amended by later regulations, particularly the provisions of Section 35(3) of the act on the use of the thesis.

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With my own signature, I also declare that the electronic version is identical to the printed version and the data stated in the thesis has been processed in relation to the GDPR.

Prague, 31.03.2021

Nshimirimana Delphine Huriro

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I am forever grateful to my family especially my husband and daughter and friends for their support and encouragement.

Abstrakt

Význam mokřadů v krajině je nevyvratitelný. Patří mezi nejproduktivnější ekosystémy, na nichž závisí přežití člověka a dalších bezpočtu druhů. I přes svůj význam alarmujícím způsobem klesají. Zemědělství a urbanizace jsou hlavními činiteli úbytku mokřadů.

Cílem tohoto výzkumu bylo posoudit dopad rozvoje krajiny na biotopy mokřadů ve čtyřech katastrálních územích hl. M. Prahy prostřednictvím posouzení časoprostorové změny vyjádřené jako velikost vyhynulých, souvislých a posledních mokřadů a identifikováním a kvantifikací kategorií LULC, které vyhynulé mokřady a ty, které byly nahrazeny nedávnými mokřady.

K rekonstrukci historického LULC byly použity imperiální povinné otisky stabilního katastru. Ke konstrukci současného LULC pomocí nástrojů GIS bylo použito současné ortofotografie České republiky doplněné o databáze orné půdy, lesů a mokřadů.

Výsledky ukázaly, že mokřady poklesly z 305,32 ha (9,34% z celkové studované plochy, tj. 3268 ha) v roce 1841 na 146,90 (4,50%) v roce 2020. Celkem 227,80 ha mokřadů vyhynulo a zemědělství, nelesní lesní vegetace a zastavěné oblasti jsou hlavními faktory ztráty mokřadů. Na druhé straně 69,36 ha pokrývají nedávné mokřady, které nahradily hlavně zemědělství, lesy a trvalé travní porosty. Souvislé mokřady pokrývají celkovou plochu 77,51 ha.

Předpokládá se, že tento výzkum přispěje k existujícím studiím o historickém vývoji mokřadů na krajinné úrovni v České republice a jeho nálezy by mohly být použity jako základ pro obnovu mokřadů ve studovaném území a budoucí výzkum.

Klíčová slova: změna LULC, mokřady, prostoročasové, trajektorie, GIS

Abstract

The importance of wetlands in landscape is irrefutable. They are among the most productive ecosystems upon which human and other countless species depend on for survival. Despite their significance, they are declining at alarming rate, agriculture and urbanization are the leading drivers of wetland loss.

This research aimed to assess the impact of landscape development on wetlands biotopes in four cadastral districts of the city of Prague by assessing spatial-temporal change expressed as the size of extinct, continuous, and recent wetlands and by identifying and quantifying LULC categories that replaced extinct wetlands and those at the expense of which recent wetlands occur.

Imperials mandatory imprints of the stable cadastre were used to reconstruct historical LULC. Contemporary orthophoto of the Czech Republic supplemented by arable land, forests and wetlands databases were used to construct current LULC using GIS tools.

The results showed that wetlands decreased from 305.32ha (9.34%of the total studied area i.e. 3268 ha) in 1841 to 146.90(4.50%) in 2020.In total, 227.80 ha of wetlands are extinct, agriculture, non-forest woody vegetation and built-up areas are the leading factors behind wetland loss. On other hand, 69.36ha are covered by recent wetlands which replaced mainly agriculture, forests, and permanent grassland. Continuous wetlands cover a total area of 77.51 ha.

This research is expected to contribute to existing studies on historical development of wetlands at landscape level in Czech Republic and its findings could be used as basis for wetlands restoration in the studied area and future research.

Keywords: LULC change, wetlands, spatial-temporal, trajectories, GIS

Contents

1. Introduction

Earth, our home planet currently faces numerous challenges such as loss of biodiversity and threatened ecosystems. Land use change is the leading factor behind decline of species diversity, population loss or at worst extinction. Thus, land use monitoring has become an important tool in assessing pressures on ecosystems and biodiversity. (OECD ,2018).

Kumar & Kanaujia (2014) state that ecosystems services provided by wetlands are diverse and range from nutrients recycling, water purification, flood protection, erosion control, food and drinking water provision to serving as wildlife habitat and recreation to society. Despite their undisputable importance, they are declining at alarming rate as result of anthropogenic activities.

Therefore, an understanding of wetlands origin and dynamics is crucial to a better management, conservation, and restoration (Meyer et al., 2015).

In today's Czech Republic, wetlands are mostly extinct or represent only bits of their original size in a sea of large fields, commercial monocultural forests and built-up areas i.e. buildings and roads (AOPK ČR, n.d.).

This research will contribute to existing scientific knowledge about long term LULC change at landscape level in Czech Republic and its impact on wetlands.

Furthermore, it could provide a scientific basis for future related studies, wetlands conservation and restoration projects.

2. Thesis main goal and specific objectives

Despite wetlands being among the most productive ecosystems, they are declining at an alarming rate because of anthropogenic activities (Kumar & Kanaujia, 2014).

Skaloš et al. (2017) suggested that research into historical development of wetlands should be continued, and that the method used in their study can be applied to the analysis of the wetland dynamics in other landscape types in the Czech Republic.

Therefore, the main goal of this study was to contribute to existing research on historical development of wetlands at landscape level in four cadastral districts located in Eastern part of Prague city.

2.1 Specific objectives

The main goal of this thesis was achieved through the following specific objectives:

- To assess spatial -temporal changes of wetlands in each cadastral district expressed as the size of extinct, continuous, and recent wetlands.
- To evaluate wetland trajectories by identifying and quantifying LULC categories that replaced extinct wetlands and those at expense of which recent wetlands occur.

2.2 Research Questions

To achieve the research goal, the following questions were asked:

- What are the spatial-temporal changes of wetlands in each cadastral district expressed as the size of extinct, continuous, and recent wetlands?
- What LULC categories replaced extinct wetlands and those replaced by recent wetlands?

2.3 Research hypotheses

- The landscape development in the study area negatively affected wetlands.
- Agriculture and urbanization are the main drivers of wetland loss.

3. Literary research

3.1 Background information on wetlands

Under the text of Ramsar Convention on wetlands (Article 1.1), wetlands are defined as: "areas of marsh, fen, peatland, or water whether natural or artificial, permanent, or temporary, with water that is static or flowing, fresh, brackish, or salt, including areas of marine water the depth of which at low tide does not exceed six metres " (RAMSAR,2013).

Wetlands are often said to be among the most productive ecosystems because of invaluable services they provide. They play an important role in hydrology by serving as water reservoirs, filtrating water, and thus improving its quality and controlling floods, they also provide food and construction materials. Many animal and plant species depend on them for survival either for food, as habitat or both. Furthermore, they are economically and socially valuable because of tourism and recreation opportunities they provide to humans (Dabboor & Brisco, 2018).

Over the past decades, wetlands ecosystems have undergone important changes mainly because of global climate change and land use conversion that led to their degradation, reduction in areas or extinction. Since the 1900s, the loss of wetlands has been estimated to more than 50%. Thus, their continuous monitoring is crucial for better urban and regional planning as well as sustainable management (Kaplan et al., 2019).

3.2 Wetland classification/types

Considerable efforts have been put into establishing national/regional wetland classification systems. In fact, some countries like U.S.A, Canada have established their own national wetland classification system but developing a global system has been very problematic especially because the definition of wetland is itself very controversial among several authors (Scott & Jones, 1995).

To this date, Ramsar convention on wetlands has 171 contracting parties which recognize the value of having one international treaty dedicated to a single ecosystem (RAMSAR, n.d.). Therefore, it is recommended that its definition and classification system should be used for international purposes. The Ramsar Convention has adopted a wetland classification system that contains three main categories further divided into 43 wetlands types as shown by figure 1:

Marine/Coastal	Inland Wetlands	Man-made wetlands
A. Permanent shallow marine waters less than six metres deep at low tide; includes sea bays and straits.	L. Permanent inland deltas.	1.Aquaculture (e.g. fish/shrimp) ponds.
B. Marine subtidal aquatic beds; includes kelp beds, sea-grass beds, tropical marine meadows.	M. Permanent rivers/streams/creeks; includes waterfalls.	2. Ponds; includes farm ponds, stock ponds, small tanks; (generally below 8 ha).
C. Coral reefs.	N. Seasonal/intermittent/irregular rivers/streams/creeks.	3. Irrigated land; includes irrigation channels and rice fields.
D. Rocky marine shores; includes rocky offshore islands, sea cliffs.	O. Permanent freshwater lakes (over 8 ha); includes large oxbow lakes.	4. Seasonally flooded agricultural land.
E. Sand, shingle or pebble shores; includes sand bars, spits and sandy islets; includes dune systems.	P. Seasonal/intermittent freshwater lakes (over 8 ha); includes floodplain lakes.	5. Salt exploitation sites; salt pans, salines, etc.
F. Estuarine waters; permanent water of estuaries and estuarine systems of deltas.	Q. Permanent saline/brackish/alkaline lakes.	6. Water storage areas; reservoirs/barrages/dams/impoundments; (generally over 8 ha).
G. Intertidal mud, sand or salt flats.	R. Seasonal/intermittent saline/brackish/alkaline lakes and flats.	7. Excavations; gravel/brick/clay pits; borrow pits, mining pools.
H. Intertidal marshes; includes salt marshes, salt meadows, saltings, raised salt marshes; includes tidal brackish and freshwater marshes.	Sp. Permanent saline/brackish/alkaline marshes/pools.	8. Wastewater treatment areas; sewage farms, settling ponds, oxidation basins, etc.
I. Intertidal forested wetlands; includes mangrove swamps, nipah swamps and tidal freshwater swamp forests.	Ss. Seasonal/intermittent saline/brackish/alkaline marshes/ pools.	9. Canals and drainage channels, ditches.
J. Coastal brackish/saline lagoons; brackish to saline lagoons with at least one relatively narrow connection to the sea.	Tp. Permanent freshwater marshes/pools; ponds (below 8 ha), marshes and swamps on inorganic soils; with emergent vegetation water-logged for at least most of the growing season.	Zk(c) Karst and other subterranean hydrological systems, human-made
K. Coastal freshwater lagoons; includes freshwater delta lagoons.	Ts. Seasonal/intermittent freshwater marshes/pools on inorganic soil; includes sloughs, potholes, seasonally flooded meadows, sedge marshes.	
Zk(a) Karst and other subterranean hydrological systems, marine/coastal	U. Non-forested peatlands; includes shrub or open bogs, swamps, fens.	
	Va. Alpine wetlands; includes alpine meadows, temporary waters from snowmelt.	
	Vt. Tundra wetlands; includes tundra pools, temporary waters from snowmelt.	
	W. Shrub-dominated wetlands; Shrub swamps, shrub-dominated freshwater marsh, shrub carr, alder thicket; on inorganic soils.	
	Xf. Freshwater, tree-dominated wetlands; includes freshwater swamp forest, seasonally flooded forest, wooded swamps; on inorganic soils.	
	Xp. Forested peatlands; peatswamp forest.	
	Y. Freshwater springs; oases.	
	Zg. Geothermal wetlands.	
	Zk. Subterranean karst and cave hydrological systems.	
	Zk(b) Karst and other subterranean hydrological systems, inland	

Figure 1:Ramsar wetland classification System (Modified from Finlayson, 2018).

3.3 Significance of Wetlands

The role of wetland ecosystems in landscape is vital and it is argued that countless species of fauna and flora depend on them for their survival (RAMSAR, n.d.).

The following figure summarizes services provided by wetlands.

Services	Comments and Examples
Provisioning	
Food	production of fish, wild game, fruits, and grains
Fresh water[a]	storage and retention of water for domestic, industrial, and agricultural use
Fiber and fuel	production of logs, fuelwood, peat, fodder
Biochemical	extraction of medicines and other materials from biota
Genetic materials	genes for resistance to plant pathogens, ornamental species, and so on
Regulating	
Climate regulation	source of and sink for greenhouse gases; influence local and regional temperature, precipitation, and other climatic processes
Water regulation (hydrological flows)	groundwater recharge/discharge
Water purification and waste treatment	retention, recovery, and removal of excess nutrients and other pollutants
Erosion regulation	retention of soils and sediments
Natural hazard regulation	flood control, storm protection
Pollination	habitat for pollinators
Cultural	
Spiritual and inspirational	source of inspiration; many religions attach spiritual and religious values to aspects of wetland ecosystems
Recreational	opportunities for recreational activities
Aesthetic	many people find beauty or aesthetic value in aspects of wetland ecosystems
Educational	opportunities for formal and informal education and training
Supporting	
Soil formation	sediment retention and accumulation of organic matter
Nutrient cycling	storage, recycling, processing, and acquisition of nutrients

[a] While fresh water was treated as a provisioning service within the MA, it is also regarded as a regulating service by various sectors.

Figure 2: Ecosystems services provided by or delivered from Wetlands (Adopted from Millennium Ecosystem Assessment ,2005).

- **Food**: Wetlands play an important role in food web providing food upon which countless species depend on. An example is rice crop which is agronomically produced in man-made wetlands. "Rice is the staple diet of nearly 3 billion people. Forty two percent (59 million ha) of rice area in developing countries is rainfed wetland paddy, producing 24 per cent of total rice output of these countries " (FAO, 2000).
- **Habitat**: An estimated 40% of the world’s species use wetlands as habitat and three-quarters of the breeding bird species in North America use wetlands at some point during their life cycle (Mitsch & Gosselink., 2001). Specifically, macrophytes provide more surface area attachment for periphyton, a major component in the diet of macroinvertebrate primary consumers (Batzer & Wissinger, 1996). In addition, macrophyte community

provide shelter for vulnerable prey species like macroinvertebrates protecting them against vertebrate predation (Gosselain et al., 2005).

- **Flood alleviation**: Wetlands act as sponges that soak up water during storms and release it slowly during dry periods (Bullock & Acreman, 2003). In their study titled "Impact of Size and Location of Wetlands on Watershed-Scale Flood Control ", Tang et al. (2020) concluded that within the effort to regulate watershed-scale floods, wetlands size and location influence the downstream flooding i.e., the more upstream they are located, the smaller the floods (flooded area, flood depth and duration) will be downstream.
- **Wastewater treatment**: Emergent macrophytes in free water surface constructed wetlands (FWS CWs) are vital as they reduce wind speed, hence enhancing sedimentation and preventing re-suspension. They facilitate nutrients uptake by bacteria and periphyton and supply carbon for denitrification in carbon limited system during biomass decomposition (Vymazal ,2013).
- **Climate change mitigation**: The role of wetlands extends to climate mitigation. Were et al. (2019), in their review of enhancement measures for climate change mitigation, concluded that wetlands are undeniably crucial because of their capacity to sequestrate carbon.

3.4 Wetlands in global context

Wetlands occur throughout the planet. "An estimated 5 to 8 percent of the land surface is covered by wetlands. About 95 percent of wetlands are freshwater and only 5 percent are saltwater. The Pantanal in Brazil, Paraguay, and Bolivia, covering about 88,803 square miles (230,000 square kilometres), is often considered the largest wetland in the world " (Anderson, 2019).

RAMSAR (2018) reports that accuracy of global wetland area data is increasing, global inland and coastal wetlands cover over 12.1 million km^2 with 54% permanently inundated and 46% seasonally inundated. However, natural wetlands are in long-term decline around the world, between 1970 and 2015, inland and marine/coastal wetlands both declined by approximately 35%, where data are available, three times the rate of forest loss. In contrast, human-made wetlands, largely rice paddy and reservoirs, almost doubled over this period, now forming 12% of wetlands. However, these increases are not enough to compensate for natural wetland loss.

Davidson et al. (2018) argue that ‘’globally, 92.8% of continental wetland area is inland and only 7.2% is coastal. Regionally, the largest wetland areas are in Asia (31.8%), North America (27.1%) and Latin America and the Caribbean (Neotropics; 15.8%), with smaller areas in Europe (12.5%), Africa (9.9%) and Oceania (2.9%)’’.

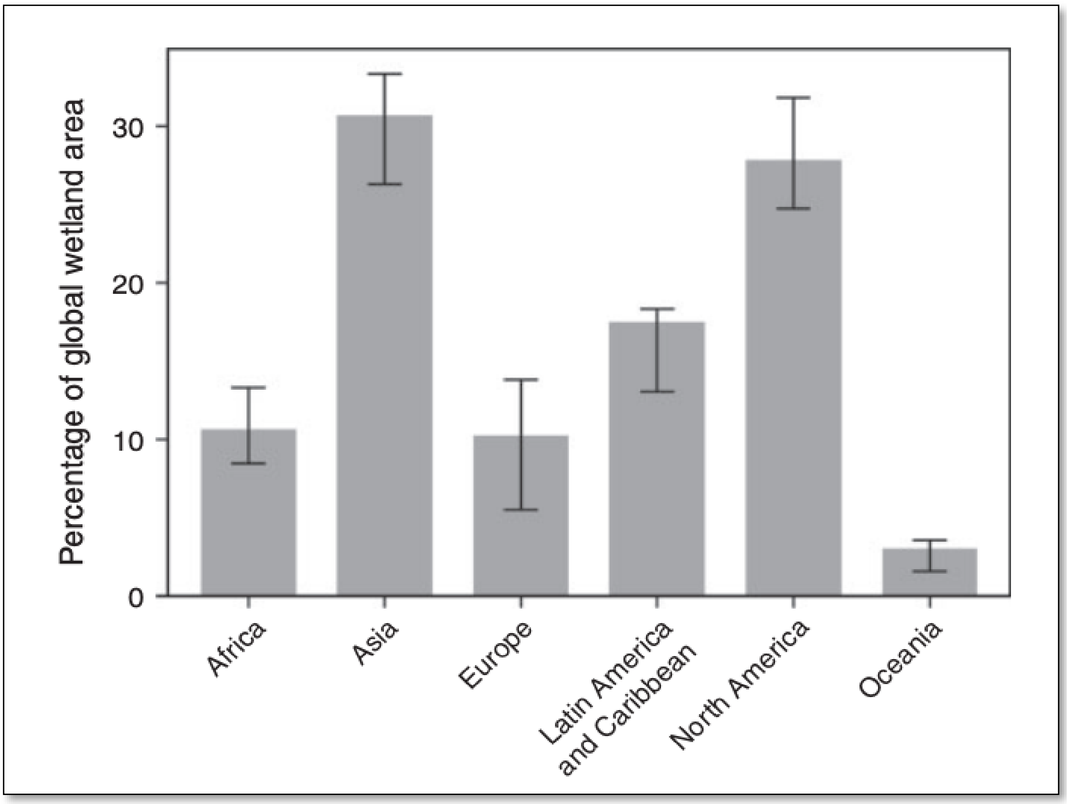

Figure 3: Percentage of global wetland area by region; whiskers are the 25th and 75th percentiles (Adopted from Davidson et al. 2018).

Intensification of agriculture and abandonment of land in less favourable regions are affecting natural and cultivated ecosystems all over the world, especially in industrialized countries (Kristensen ,1999).

Anthropogenic activities have been long recognized as the cause of wetlands loss and deterioration. In fact, Defries et al. (2004) affirm that the 20th century was characterized by considerable land-use change which led to wetlands ecosystems loss.

The world has lost a considerable area of wetlands and different authors have estimated the global loss. Davidson (2014) in his review that included 189 documents on wetland area change reported that '' long-term loss of natural wetlands averages between 54–57% but loss may have been as high as 87% since 1700 AD. There has been a much (3.7 times) faster rate of wetland loss during the 20th and early 21st centuries, with a loss of 64–71% of wetlands since 1900 AD. Losses have been larger and faster for inland than coastal natural wetlands. Although the rate of wetland loss in Europe has slowed, and in North America has remained low since the 1980s, the rate has remained high in Asia, where large-scale and rapid conversion of coastal and inland natural wetlands is continuing ".

Hu et al. (2017) simulated the potential distribution of global wetlands by employing a new Precipitation Topographic Wetness Index (PTWI) and global remote sensing training samples. Their results showed that if it were not for anthropogenic activities, the earth would have now approximately 29.83 million km² of wetlands. They report that "at least 33% of global wetlands had been lost as of 2009, including 4.58 million km² of non-water wetlands and 2.64 million km² of open water. The real extent of wetland loss has been greatest in Asia, but Europe has experienced the most serious losses".

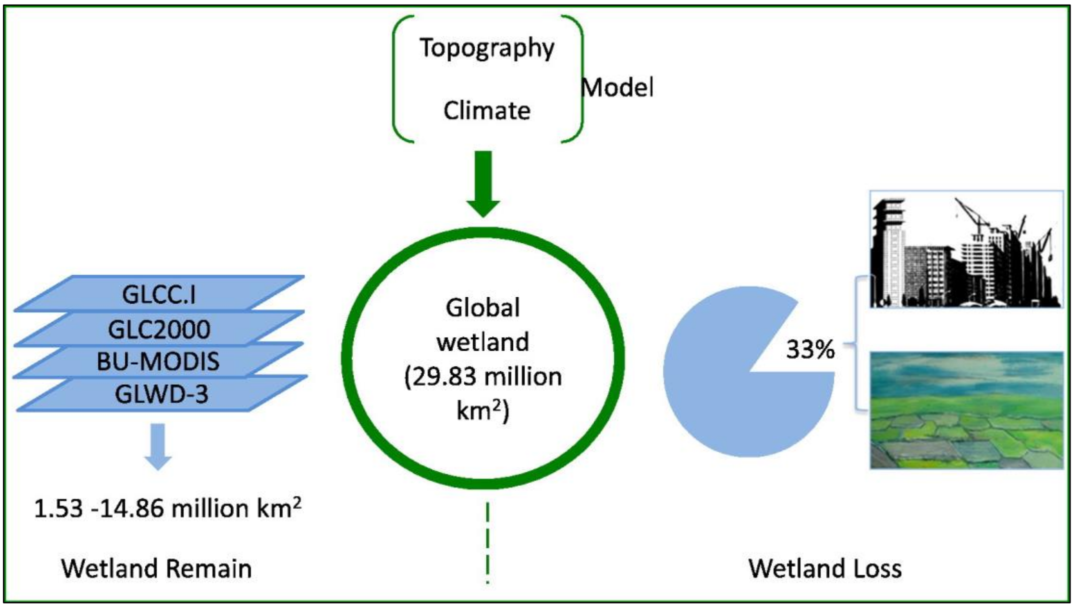

Figure 4:Global wetland loss (Adopted from Hu et al., 2017).

Furthermore, Anderson(2019) states that more than 50 percent of wetlands around the world are lost because of human activities, and many more are affected by water pollution and groundwater withdrawal. The conterminous (lower 48) United States has lost 53 percent of wetlands, which is probably the most accurate estimate available for any region. New Zealand has lost 90 percent, Europe and China 60 percent, and Australia 50 percent of their wetlands. Wetland loss is most rapid during periods of growth and development in countries. Coastal areas and agricultural regions have suffered the most rapid and extensive wetland losses because of high human populations, high land use conversion rates.

Hu et al. (2017) have compiled global wetlands loss estimations from different studies as shown in the figure 5 below:

Continent	Current work	OECD (1996)	Davidson (2014)
Period	Until 2009	Until 1985	Long-term average
World	33%	50%	54–57%
Asia	27%	27%	45%
Africa	16%	2%	4%
Europe	45%	56–65%	56%
North America	8%		56%
South America	32%	6%	–
Oceania	18%	–	44%

Figure 5 : A comparison of wetland loss ratio of continents among various studies and reports. (Adopted from Hu et al., 2017).

Yan & Zhang (2019), in their study in the Sanjiang Plain (Northeast China), they found that the wetland area has declined by 73.3% (about 2.77 million ha) since 1954 and the main driving factor behind the loss was agriculture. Consequently, the ecosystem services value reduced by $57.46 billion as result of wetland loss over the past six decades.

In coastal metropolitan regions, urbanization is the leading cause of wetland loss, threatening biodiversity, and key ecosystems services for urban areas. An example is the Concepción Metropolitan Area (CMA), located on the coast of Chile, which experienced noticeable wetland loss in recent decades. urban areas have increased by 28% between 2004 and 2014, while future increase is expected to reach 238%. In contrast, wetland area has decreased by 10% from 2004 to 2014 and is expected to decrease by up to 32 % (Rojas et al., 2019).

In the case of the Makhitha wetland, Limpopo province in South Africa, between 1978 and 2004, wetlands ecological state deteriorated. Poverty and population growth were the main driving forces. Agriculture, livestock grazing, and roads construction were found to be the main activities that led to wetlands degradation (Phethi & Gumbo, 2019).

In Australia, coastal wetlands are currently threatened by climate change especially sea level rises, which is associated with saline water intrusion and consequently, increased mangrove mortality rate during drought periods (Saintilan et al., 2019).

3.5 Wetlands in European context

Until one millennium ago, European continent had extensive wetland complexes such as peatlands especially in the north, floodplains, and estuarine wetlands in the lowlands. Europe has lost approximately 80% of its wetlands, however the remaining ones still cover large areas especially in the Northern part of the continent. (Verhoeven ,2014).

The continent suffered extensive wetland drainage at the expense of agriculture and urbanization especially in estuaries regions which were changed to arable land, ports, and industrial development (Davidson ,1991).

Wetlands are also overexploited for different purposes including agriculture (e.g. growing plants like common reed for livestock feeding) and for energy provision i.e. peat extraction for cooking and heating (Kracauer Hartig et al., 1997).

High population density in Western Europe countries like The Netherlands, Germany has also put pressure on wetlands. Coastal marshes at the North Sea were converted into polders and are used for pastures (Junk et al., 2013).

Finlayson & Spiers (1999) argue that although there are no formal assessments of wetland loss for the European continent, they can roughly be estimated to 80%.

In coastal and inland regions, wetlands losses mainly happened during the 20th and early 21st centuries. (Davidson,2014).

During recent decades, agriculture intensification and collectivization has been a key factor initiating land use change across the European continent, but its impacts differ from country to country depending on local context (Van der Sluis et al., 2016).

For the Canton Zurich (Switzerland), wetlands cover change was studied for the period of 1850 to 2000 using historical and current topographical maps and it was found that wetlands cover decreased from 13,759 ha in 1850 (more than 8% of the total study area) to 1,233 ha in 2000 (less than 1%). Half of wetlands were lost during the first half of 20th century. Furthermore until 1850 all wetlands were connected and formed one large network, but this network collapsed after 1950 and disconnected wetlands patches remained. Therefore the migration of Amphibians and other animal species that are prone to habitat fragmentation is limited (Gimmi et al., 2011).

Decleer et al. (2016) with the case of Flanders (northern part of Belgium) they estimated that Flanders lost 75% of its wetland ecosystems in the past 50–60 years and only 68,000 ha remains, often in a degraded state.

It is known that often socio-environmental costs associated with wetlands loss are overlooked in land use planning and the potential of wetlands restoration which can be expensive but surely is beneficial on long term perspective is undervalued.

Gómez-Baggethun et al. (2019) examined the impact of land use policies on ecosystem services provided by the Danube Delta. First, they identified, characterized, and measured the most important ecosystem services provided by the Danube Delta. Second, they assessed trends between 1960 and 2010, contrasting periods of economic development (1960–1989) and ecological restoration (1990–2010). The results indicate that i) the Danube Delta provides important services with benefits accrue from local communities to humanity at large, ii) that two thirds of the Delta's ecosystem service have declined over the studied period and iii) that ongoing restoration efforts have so far been unable to reverse trends in ecosystem service decline.

On positive note, wetlands conservation and restoration in Europe is rising and supported through Ramsar convention and other EU initiatives. In fact the EU has been a major funds contributor for wetland conservation projects both within and outside the Union (European Commission, 2007).

Several models and goals for wetland restoration exist. The most common methods used to boost ecosystems biodiversity in Central and Western Europe are rewetting and oligotrophication. Re-introduction of species is also often necessary (Pfadenhauer & Grootjans, 1999).

Wetlands restoration is a long-term process and often affected by several natural and socio-economic aspects such as land abandonment, food production, climate change, change in farming systems, recreation patterns and many more. These changes can create challenges or opportunities for landscape restoration (Ockendon et al., 2018).

3.6 Wetlands in Czech Republic.

Wetlands loss or degradation in Czech Republic happened as result of anthropogenic activities such as conversion of wetlands into agricultural land, large-scale and local drainage, straightening and deepening of riverbeds, construction of water reservoirs, urbanization, and peat extraction. The current form of intensive agriculture and the lack of natural vegetation in the landscape causes water pollution, soil degradation and erosion, with a consequent negative impact on the quality and biodiversity of wetlands. Another significant problem is the fragmentation of the landscape, urbanization, and the unsustainable development of tourism and consequently wetland habitats are degraded or completely extinct. (AOPK ČR, n.d.).

AOPK ČR recognizes different wetland types in Czech Republic:

- Springs
- Flow, flow section
- Alluvial lake, ponds
- Floodplain forest, alder, or other wetland forests
- Flooded or wet meadows
- Other aquatic and swamp habitats
- Reed, sedge meadows
- Peat bogs and fens
- Mountain lakes
- Salt marshes
- Canal, sewer, ditch Industrial sludge tanks
- Ponds, enclosures
- Pond systems
- Valley Reservoir
- Quarry, gravel pit, sand pit

3.7 LULC change and its impact on wetlands in Czech Republic.

The population of the Czech Republic in the past made use of wetlands in a sustainable manner without compromising their functioning. Amelioration ditches were used to maintain optimum moisture of the wetlands (Skaloš et al.,2017).

Also, the country used to have a lot of ponds until the end of 18th century but unfortunately most of them were drained out in 19th century for agriculture especially in Bohemia and Moravia's fertile lowlands. Specifically 31.2% of ponds that existed at the time of 2nd Military Survey are now extinct (Frajer et al., 2016).

Presently, wetlands are mostly extinct or represent only pieces of their original size in a sea of large fields, commercial mostly monocultural forests and built-up areas mainly buildings and roads.

Unprotected and small-area wetlands have been preserved in places where drainage was not possible because of different reasons such as too small areas, impossible drainage, or reclamation measures were not working, and the area was returned to its original state. The construction of ponds in unsuitable places and with unsuitable parameters also disturbs wetlands. A poorly chosen solution can cause damage or even the extinction of wet meadows and floodplains near small streams (AOPK ČR, n.d.).

In their study tour report, the Norwegian environmental agency, and the ministry of the environment of the Czech Republic stated that in the Czech Republic, the natural characteristics of wetlands and streams have been modified. They reported that 25% of agricultural land is drained by subsurface pipes. Out of 1,300,000 ha of wetland recorded in 1950, only 350,000 ha remained in 1995 (Norwegian Environmental Agency ,2015).

Skaloš et al. (2017) in their study that involved 86 cadastral districts in the lowlands of the Czech Republic over an area of 600.18 km² found that the wetlands area decreased from 5762 ha i.e. 9.5% of the studied area in 1825-1843 to 54 ha (0.9%) in 2014.Most wetlands are extinct (99.1%), recent and continuous wetlands are closely identical (0.5% and 0.4%, respectively).

In addition, Czech Republic landscapes are prone to droughts which resulted from landscape development and land cover changes over time. These changes often involved water areas and wetlands drainage at the expense of agriculture. Specifically, in Nové Dvory and Žehušice (micro-regions in Central Bohemia), ''water and wetland areas covered nearly 33.33% of the study area at the end of the 18th century and the present share of these areas is only 3.5%. The biggest loss occurred at the end of the 19th century '' (Šantrůčková et al., 2017).

3.8 Wetlands protection in Czech Republic

The Czech Republic currently has 14 Ramsar sites with a total area of 60,207 ha. The national protection status of these sites are national parks (RS1 and RS7), protected landscape areas (RS2, RS5, RS6, RS8, RS10, R11, RS13, RS14), and national nature reserves (RS3, RS4, and partly also RS9, R12). Most of the wetland biotopes inside the protected landscape areas are further protected as nature reserves.

Apart from the Ramsar sites, there are also other wetlands of national, regional, and local importance and in total, the Czech Republic wetland database contains information on more than 2000 wetlands (Vlasáková et al., 2017).

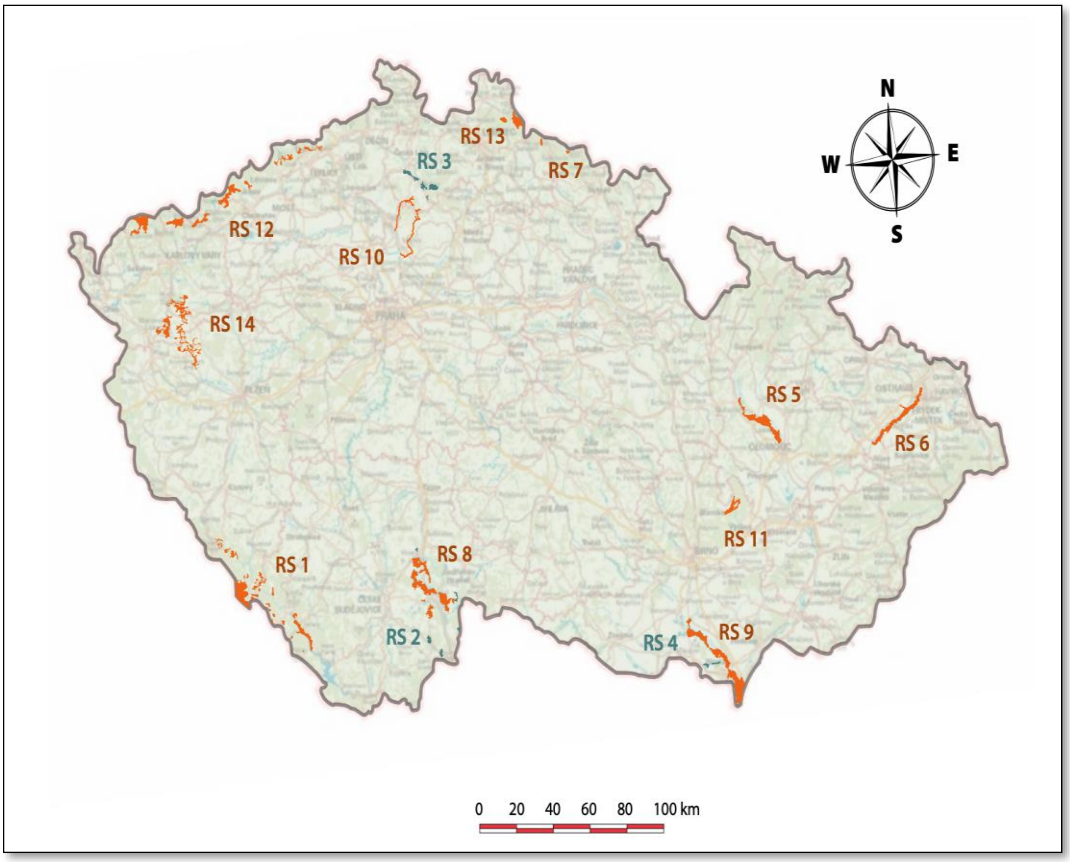

Figure 6: Ramsar sites in Czech Republic (Adopted from Vlasáková et al., 2017).

The division levels range from international to local as shown in table 1 below:

Division level	**Description**
RS - internationally important wetlands	The inclusion is given by the text of the Ramsar Convention and the adoption of certain amendments at the conferences of the countries of the Ramsar Convention.
N - supraregional	Localities with significance beyond the framework of the Czech Republic, so they are localities of national to Central European significance, all wetland localities declared as national nature reserves and localities registered in international inventories, wetlands with unique wetland ecosystems, unique plant and animal communities and wetlands of fundamental importance for the bioregion. This category also includes wetlands with the occurrence of critically endangered plant communities and critically endangered species of plants and animals, endangered species of European importance and localities of fundamental importance in terms of the function of the entire river basin.
R - regional	This category includes sites important in terms of the bioregion. This includes mainly wetlands already declared as nature reserves and national natural monuments, localities significant for the occurrence of specially protected species of plants and animals and localities important from the point of view of the function of the river basin in the given bioregion.
L - local	This category includes all remaining wetland sites, significant for smaller areas, the size of a district or PLA as well as wetlands registered as important landscape elements.

Table 1: Wetlands division level (Modified from AOPK ČR, n.d.)

4. Methodology

4.1 Description of the study area

The study area is in the district of Prague and it comprises four cadastral districts namely Běchovice, Dubeč, Uhříněves and Dolní Počernice. The total area of interest was 3268 hectares in 1841 at the time of stable cadastre.

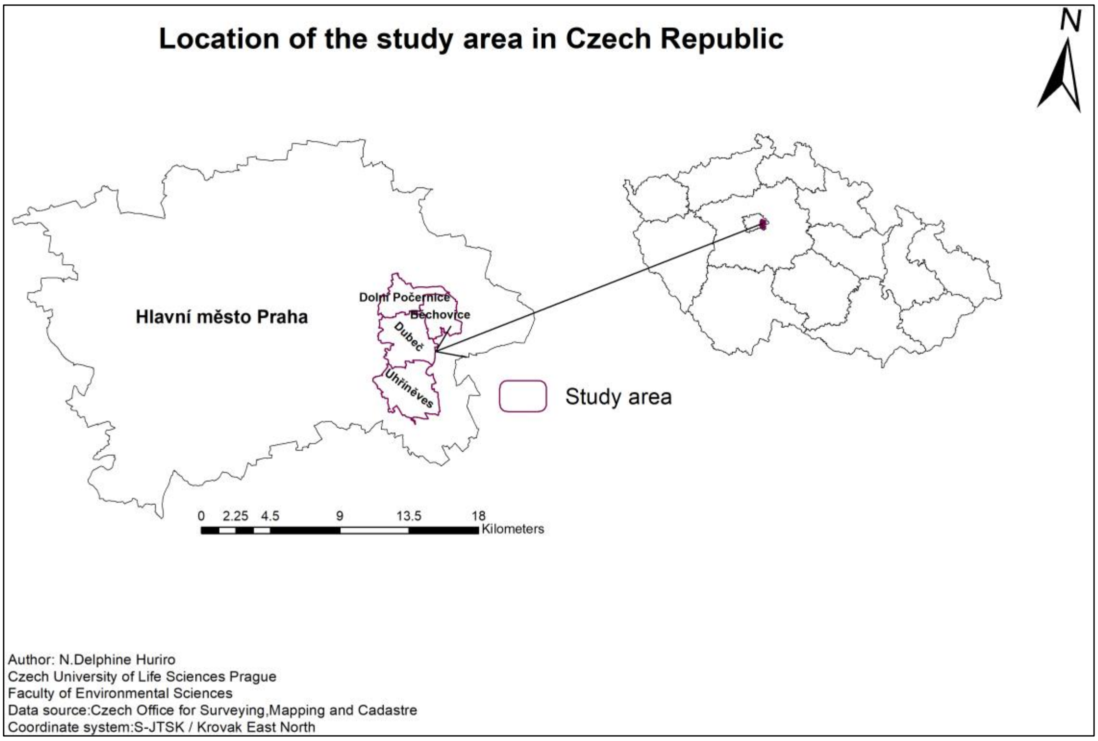

Figure 7 . Location of study area in the Czech Republic.

Cadastral district ID	Former name	Current name	Area(ha)
601527	Biechowitz	Běchovice	579
633330	Dubecz	Dubeč	981
773425	Aurzinowes (Auřinowes)	Uhříněves	1115
629952	Unt. Poczernitz (Dolnj Poczernice)	Dolní Počernice	593

Table 2 : Study area-cadastral districts

The rationale behind the selection of this study area was to gain insight into wetlands dynamics in sub-urban areas and to explore how urbanism and agriculture affected wetlands in this area. The availability of historical data, occurrence of wetlands in past at the time of the stable cadastre and the present times were also considered.

4.2 Data sources

4.2.1 Historical LULC

In Czech Republic historical land use data can be obtained from different sources such as original maps of the stable cadastre, imperial mandatory imprints of the stable cadastre, indication sketches, land registry maps, military topographic maps all stored in the Central Archive of Surveying and Cadastre.

In particular, the colour copies of the so-called imperial mandatory imprints of the stable cadastre were created in 1824-1843 and were originally intended for archiving in the Central Land Registry in Vienna, from where they were transferred to Prague after the establishment of the Czechoslovak Republic. Unlike the original maps of the stable cadastre, they capture the original state of the landscape without any additional plot of later changes. To this day, it is one of the most sought-after and most used archival documents. In some cadastral areas, however, have not been preserved (ČÚZK, n.d.).

Skaloš et al. (2017) state that the advantages of the imperial mandatory imprints of the stable cadastre include large scale mapping and existing classification of landscape segments.

Because of the above stated reasons, imperial mandatory imprints of the stable cadastre were selected as a historical land use source.

4.2.2 Current LULC

The current land use in the study area was identified using contemporary orthophoto which is accessible through ČÚZK inspire WMS browsing services supplemented by the following sources:

LULC types	Description	Data sources
Swamps and marshes	A vector layer of swamps and marshes: The DIBAVOD database is the basis for the ZABAGED® update - water category. All objects are downloadable in SHP format; the last update was in 2006.	Dibavod
Watercourses	A01 - water flow (flow model)	
Wetland areas	Delimitation of wetlands and coastal vegetation.	Agentura ochrany přírody a krajiny ČR
Forests	Delimitation of different forest types.	Ústav pro hospodářskou úpravu lesů Brandýs nad Labem
Agriculture	Vector layer of arable land, permanent grassland, bee's area, and vineyards.	Land Parcel identification system
Built up areas		data 200
Transportation network	Road, railways.	data 200

Table 3: Current land use data sources

4.3 Data analysis

4.3.1 Historical LULC categorization

Imperial mandatory imprints of the stable cadastre are dispatched as map sheets whose number differs depending on cadastral district. For each cadastre, map sheets were prepared (cropping excessive empty parts) and then merged into one image in Adobe photoshop 2021. The resulting image was georeferenced and manual vectorization of different LULC categories in ArcMap 10.8.1. followed.

Cadastral district	**Number of map sheets**	**Year of mapping**	**Scale**
Běchovice	4	1841	1:2880
Dubeč	6	1841	1:2880
Uhříněves	6	1841	1:2880
Dolní Počernice	4	1841	1:2880

Table 4:Imperial mandatory imprints details.

Regardless of current cadastral districts, the stable cadastre boundaries were used for this research.

Georeferencing is a process of transforming a scanned map or aerial photograph by associating known features (control points) on the image with their real-world x and y coordinates. Specifically, ‘’the coordinate system of the scanned map will be translated and / or rotated relative to the coordinate system in which the georeferencing process will be performed’’ (Rosca et al., 2020).

Manual vectorization is the most used method for creating LULC maps and often preferred because of high accuracy levels that can be achieved with this technique compared to automatic classification methods. However it is also associated with high time consumption (Machala et al., 2015).

LULC categories	Description
Forests	Deciduous trees
	Coniferous trees
	Mixed trees
Dry meadows	Meadows and meadows with trees.
Agriculture	Field with or without fruit trees, olives fields, orchards, vineyards, vegetable gardens, hop gardens.
Permanent Grassland	Pastures.
Transportation	All types of roads.
Built up areas	All types of buildings, buildings with yards.
Others	Cemeteries, sandbank, ditches, sand and clay pits.
Watercourses	Streams and rivers.
Wetland categories	**Description**
Swamps and marshes	Swamps
	Swamps with reeds
Wet meadows	Wet meadows without woody vegetation
Wet meadows with woody vegetation	Wet meadows with tree symbols.
Water areas	Ponds

Table 5 : Monitored historical LULC categories.

4.3.2 Current LULC categorization

Layers of different LULC categories from table 3 were added in the current LULC map and the remaining features were vectorized by visual identification on contemporary orthophoto.

LULC categories	**Description**
Built up areas	Buildings, houses with gardens, scattered houses, streets inside residential areas, parking spaces.
Agriculture land	Standard arable land, orchards, and vineyards.
Streams	Rivers, channels from Dibavod A01(Polyline vector layer).
Forests	ÚHÚL forests database excluding forests classified as enriched in water.
Non-forest woody vegetation	Linear trees along roads, linear trees that separate arable lands, tree patches not identified as forests by ÚHÚL, trees along rivers and streams.
Permanent grassland	Layer from LPIS.
Grassland	Grassland not classified as permanent grassland in LPIS.
Transportation	Highways, paved roads, pathways, railroads.
Recreation	Parks, golf, football fields and other recreational areas.
Wetlands categories	**Description**
Swamps and marshes	Layer of Dibavod

Waterlogged meadows	Areas classified as wetlands by AOPK ČR excluding swamps and marshes layer from Dibavod and covered with non woody vegetation.
Waterlogged forests	Forest classified as enriched in water by ÚHÚL excluding swamps and marshes layer from Dibavod
Water areas	Ponds

Table 6 : Monitored current LULC categories.

4.3.3 Spatial temporal change of wetlands.

Historical and current wetland maps were processed in the GIS environment to assess wetlands spatial -temporal changes.

- **Continuous wetlands**: Wetlands that are seen on both historical and current wetland maps. They were obtained by intersecting historical and current wetlands vector layers.
- **Extinct wetlands**: Wetlands that are seen on historical wetland map but not on the current one. They were obtained by using symmetrical difference tool between historical wetlands and continuous wetlands vector layers.
- **Recent wetlands**: Wetlands that are seen on the current wetland map but not on historical wetland map. They were obtained by using symmetrical difference tool between current wetland and continuous wetlands vector layers.

4.3.4 Wetlands change trajectories.

Further analysis was done to identify and quantify LULC categories that replaced extinct wetlands and LULC categories replaced by recent wetlands.

- **Extinct wetland trajectories**: LULC categories that replaced extinct wetlands. They are obtained by intersecting extinct wetlands with current LULC vector layer.
- **Recent wetlands trajectories:** LULC categories that were replaced by recent wetlands. They were obtained by intersecting recent wetlands with historical LULC vector layer.

5. Results

5.1 Běchovice.

5.1.1 LULC change in the period of 1841-2020

The cadastral district of Běchovice underwent considerable land use change over the course of past 179 years. This research attempted to establish similar LULC categories in periods of first half of 19th century when the stable cadastre was done and nowadays so that they can be compared.

This research found that agriculture which dominated in 1841 decreased from 439.05ha (75.83%) in 1841 to 226.46 ha (39.11%) in 2020. As anticipated in this research hypotheses, built up areas increased considerably from 6.90 ha (1.19%) to 122.49ha (21.16%). Forests also increased from 10.55 ha (1.82%) to 46.45ha (8.02%) and transportation from 14.84 ha (2.56%) to 23.91 ha (4.13%).

On other hand, Permanent grassland (pastures in the past) decreased from 43.39 ha (7.49%) to 20.99 ha (3.63%). Other LULC categories such as others in the past, grassland and non-forest woody vegetation in the present were not compared because they were only found in either of the two time periods.

		1841	2020	
LULC	**Area (ha)**	**%**	**Area (ha)**	**%**
Agriculture	439.05	75.83%	226.46	39.11%
Built up areas	6.90	1.19%	122.49	21.16%
Forests	10.55	1.82%	46.45	8.02%
Others	0.32	0.06%	–	–
Permanent Grassland	43.39	7.49%	20.99	3.63%
Transportation	14.84	2.56%	23.91	4.13%
Watercourses	3.53	0.61%	–	–
Wetlands	60.41	10.43%	4.98	0.86%
Grassland	–	–	53.89	9.31%
Non forest woody vegetation	–	–	65.22	11.26%
Recreation	–	–	14.59	2.52%
Total	**578.99**		**578.99**	

Table 7:LULC in two time periods of 1841 and 2020: Běchovice

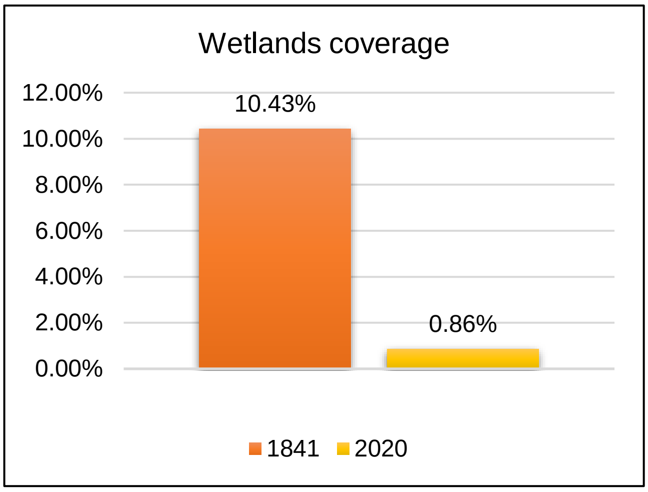

Figure 8:Wetlands coverage in 1841 and 2020

5.1.2 Wetlands categories in 1841

In 1841, wetlands covered a total area of 60.41 ha (10.43%). They were dominated by wet meadows which covered an area of 31.72ha (52.52%), followed by wet meadows with woody vegetation which covered 21.94ha (36.32%), water areas with 4.91ha (8.13%) and lastly swamps and marshes which covered 1.83ha (3.03%).

Wetland categories	**Area (ha)**
Swamps and marshes	1.83
Water area	4.91
Wet meadows	31.72
Wet meadows woody vegetation	21.94
Total	**60.41**

Table 8:Wetlands categories in 1841

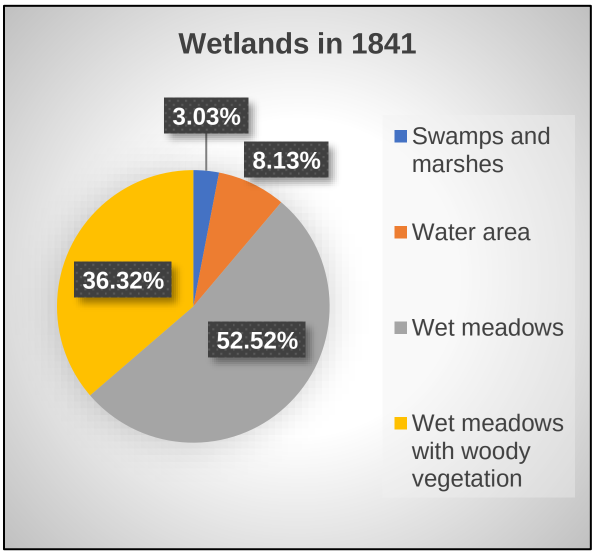

Figure 9:Percentage of wetlands categories in 1841: Běchovice

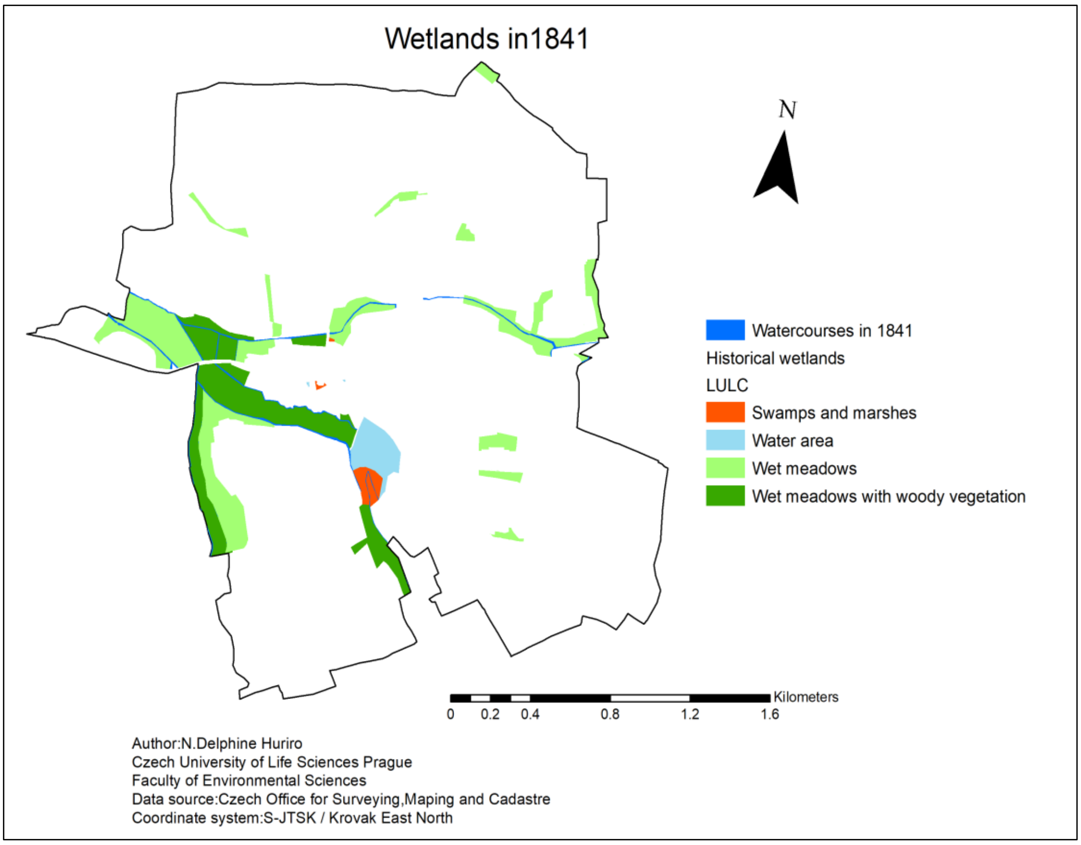

Figure 10:Wetlands map in 1841: Běchovice

5.1.3 Wetlands categories in 2020

The area covered by wetlands has decreased considerably from 60.41 ha in 1841 to a mere 4.98 ha(0.86%) in 2020.The dominant wetland category currently is waterlogged forests which cover 3.99ha(80.12%),followed by swamps and marshes with an area of 0.65ha(13.05%) and lastly water areas which cover 0.34ha(6.83%).

Wetland categories	Area (ha)
Swamps and marshes	0.65
Water area	0.34
Waterlogged forests	3.99
Total	**4.98**

Table 9:Wetlands categories in 2020

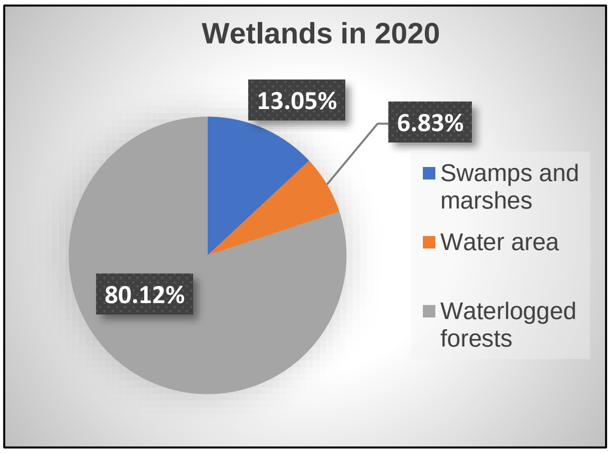

Figure 11: Percentage of wetlands categories in 2020: Běchovice

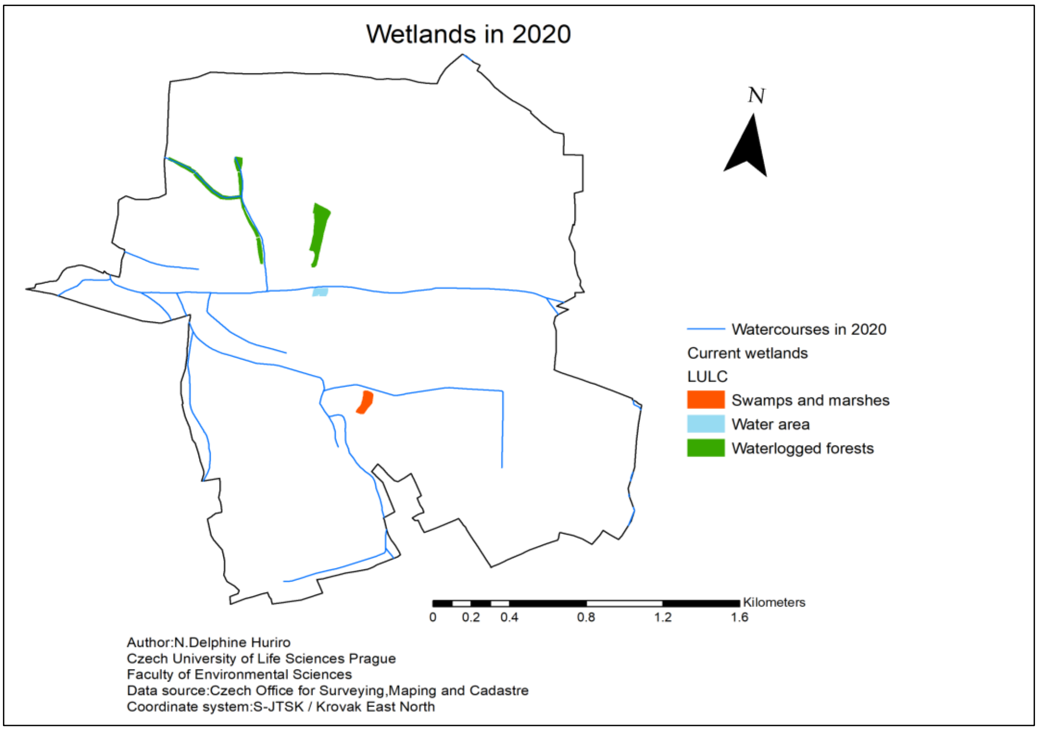

Figure 12: Wetlands map in 2020: Běchovice

5.1.4 Spatial-temporal change

After localizing and categorizing wetlands in both time periods, assessment of spatial temporal changes of wetlands proceeded. They were estimated as the size of extinct, continuous, and recent wetlands. Figure13 represent the localization of extinct, continuous, and recent wetlands in Běchovice.

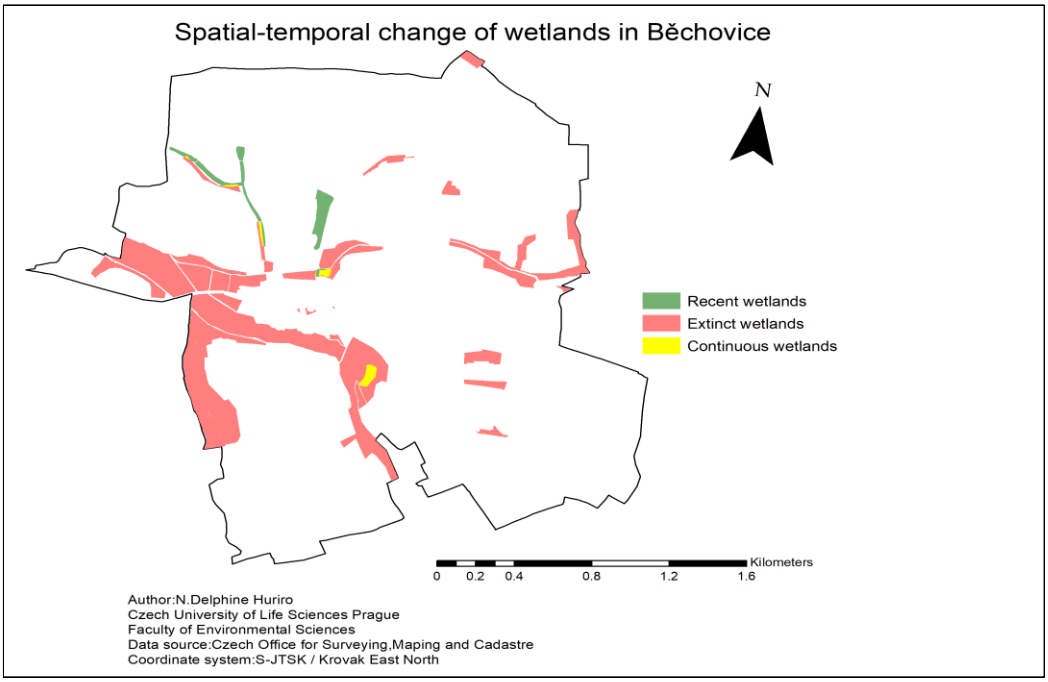

Figure 13:Spatial-temporal change of wetlands: Běchovice

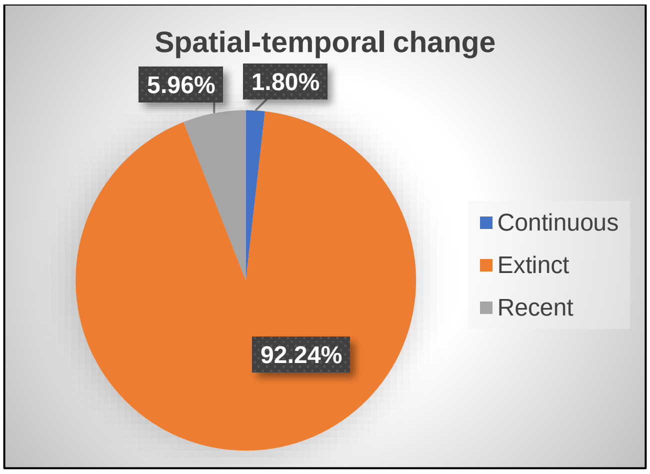

Figure 14:Percentage of extinct, continuous, and recent wetlands

A. Continuous wetlands

Continuous wetlands are those wetlands that existed at the time of stable cadastre in 1841 and 179 years later, they still exist. They cover an area of 1.15ha. They are dominated by water areas with 0.53ha (45.58%), followed by wet meadows that cover 0.45ha (39.40%), swamps and marshes with an area of 0.16ha (13.91%) and lastly wet meadows with woody vegetation on an area of 0.01ha (1.12%).

Wetland categories	Area (ha)
Swamps and marshes	0.16
Water area	0.53
Wet meadows	0.45
Wet meadows with woody vegetation	0.01
Total	**1.15**

Table 10:Continuous wetlands

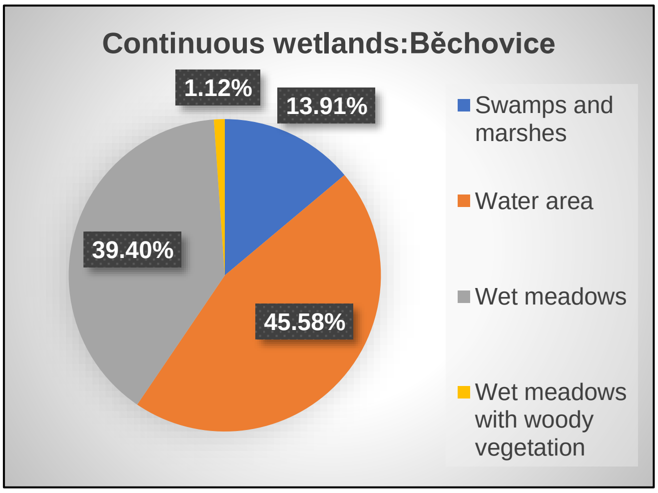

Figure 15:Percentage of continuous wetlands: Běchovice

B. Extinct wetlands

A total area of 59.25 ha was converted to other LULC other than wetlands. Among extinct wetlands, wet meadows dominate with 31.27ha (52.77%) followed by wet meadows with woody vegetation with 21.93ha (37.01%), water areas with 4.39ha (7.41%) and lastly swamps and marshes which covered 1.67ha (2.82%).

Wetland categories	Area (ha)
Swamps and marshes	1.67
Water area	4.39
Wet meadows	31.27
Wet meadows with woody vegetation	21.93
Total	**59.25**

Table 11:Extinct wetland categories

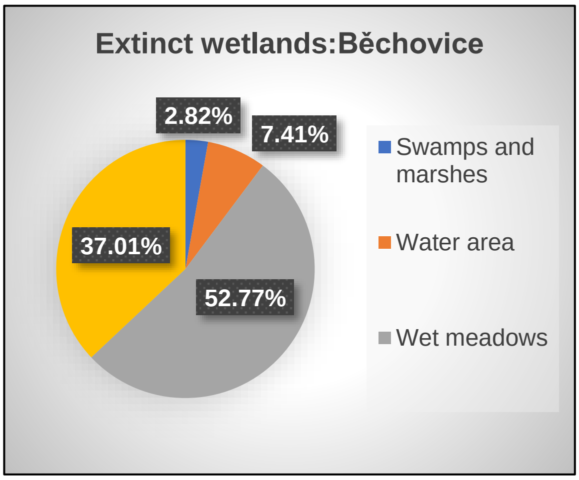

Figure 16:Percentage of extinct wetlands: Běchovice

C. Recent wetlands

Recent wetlands cover an area of 3.83ha and are mainly waterlogged forests with 3.74ha (97.70%) and water areas with 0.09ha (2.30%).

Wetlands categories	Area (ha)
Water area	0.09
Waterlogged forest	3.74
Total	**3.83**

Table 12:Recent wetlands categories

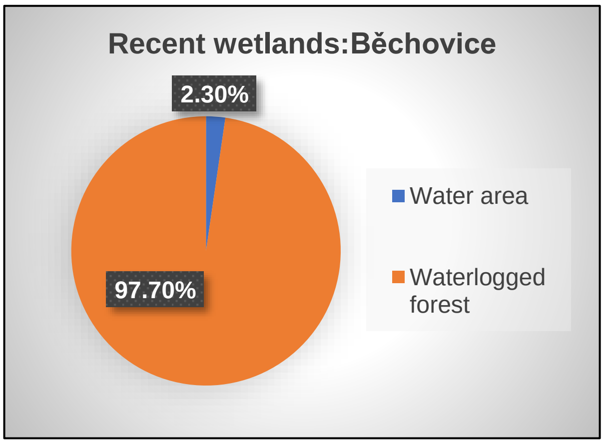

Figure 17: Percentage of recent wetlands: Běchovice

5.1.5 Wetland trajectories

A. Extinct wetland trajectories

Identifying and quantifying LULC categories that replaced extinct wetlands proceeded and this research found that out of 59.25ha of extinct wetlands,16.62ha (28.06%) were replaced by non-forest woody vegetation,11.36ha (19.18%) by agriculture, 9.18ha (15.49%) by permanent grassland ,8.65ha (14.60%) by grassland,8.26ha (13.94%) by built up area,3.85ha (6.49%) by transportation,1.20ha (2.02%) by forests, and 0.13ha (0.22%) by recreation.

LULC	Area (ha)
Agriculture	11.36
Built up areas	8.26
Forests	1.20
Grassland	8.65
Non forest woody vegetation	16.62
Recreation	0.13
Permanent Grassland	9.18
Transportation	3.85
Total	**59.25**

Table 13:Extinct wetlands trajectories

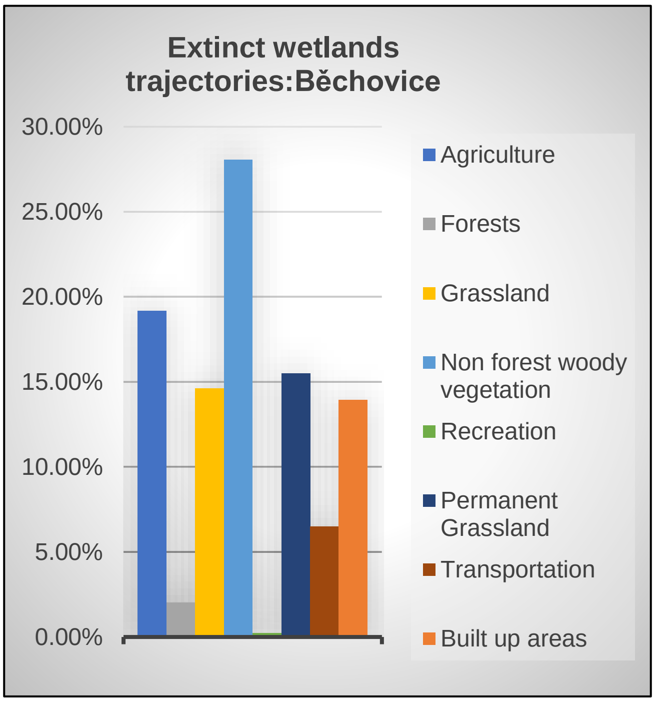

Figure 18: Percentage of extinct wetlands trajectories: Běchovice.

B. Recent wetland trajectories

Out of 3.83ha of recent wetlands,3.45ha (90.09%) replaced agriculture,0.24ha (6.34%) replaced transportation,0.12ha (3.05%) replaced permanent grassland and 0.02ha (0.53%) replaced watercourses.

LULC	Area (ha)
Agriculture	3.45
Permanent Grassland	0.12
Transportation	0.24
Watercourses	0.02
Total	**3.83**

Table 14:Recent wetlands trajectories.

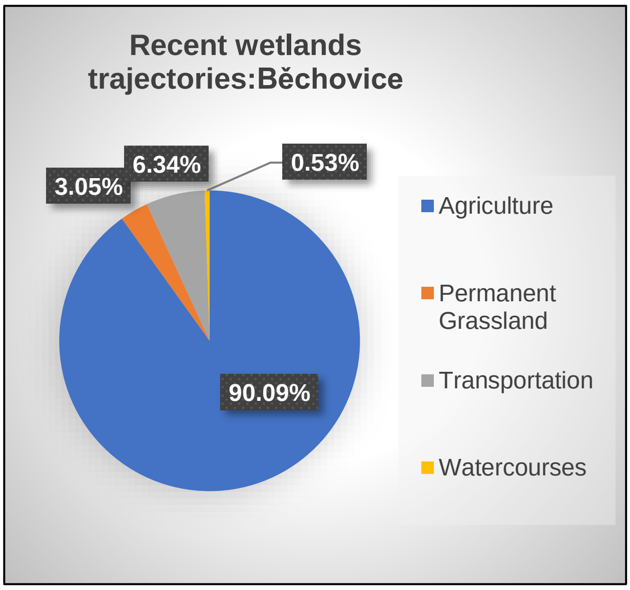

Figure 19: Recent wetlands trajectories: Běchovice.

5.2 Dubeč

5.2.1 LULC change in the period of 1841-2020

The LULC in the cadastral district of Dubeč changed considerably and this research found that agriculture decreased from 757.86 ha (77.25%) in 1841 at the time of the stable cadastre to 515.98ha (52.59%) in 2020.Forests also decreased from 46.09 ha (4.70%) to 29.01 ha (2.96%).

Conversely built-up areas increased from 9.33ha (0.95%) to 155.41ha (15.84%), and permanent grassland (pastures in the past) increased from 54.35ha (5.54%) to 56.48ha (5.76%).

		1841	2020	
LULC	**Area(ha)**	**%**	**Area(ha)**	**%**
Agriculture	757.86	77.25%	515.98	52.59%
Built up area	9.33	0.95%	155.41	15.84%
Forests	46.09	4.70%	29.01	2.96%
Permanent Grassland	54.35	5.54%	56.48	5.76%
Transportation	20.60	2.10%	10.77	1.10%
Watercourses	3.22	0.33%	–	–
Wetlands	89.62	9.14%	45.95	4.68%
Grassland	–	–	13.69	1.40%
Non forest woody vegetation	–	–	147.98	15.08%
Recreation	–	–	5.81	0.59%
Total	**981.07**		**981.07**	

Table 15:LULC in the two time periods of 1841 and 2020: Dubeč

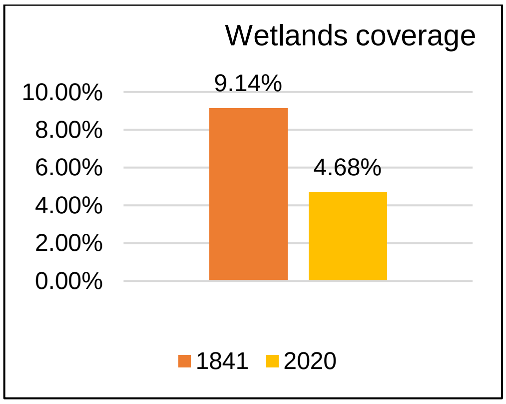

Figure 20:Wetlands coverage in 1841 and 2020

5.2.2 Wetlands categories in 1841

Wetlands covered an area of 89.62ha (9.14%) at the time of the stable cadastre in 1841 and the dominant wetland category was wet meadows which covered 46.73ha (52.15%) followed by wet meadows with woody vegetation which covered an area of 35.04ha (39.10%) and lastly water area with 7.85ha (8.76%).

Wetland categories	Area(ha)
Water area	7.85
Wet meadows	46.73
Wet meadows with woody vegetation	35.04
Total	**89.62**

Table 16:Wetlands categories in 1841

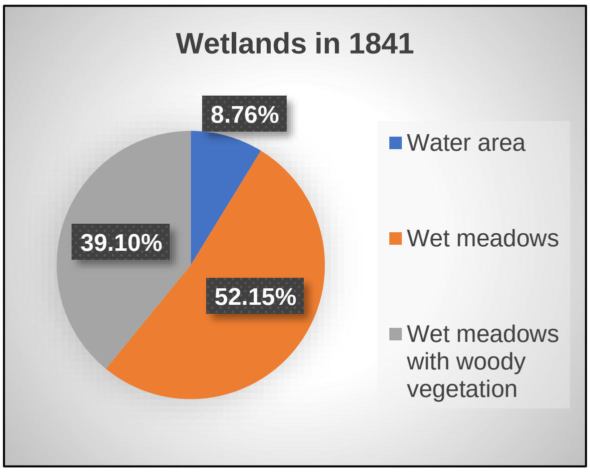

Figure 21:Percentage of wetlands categories in 1841: Dubeč

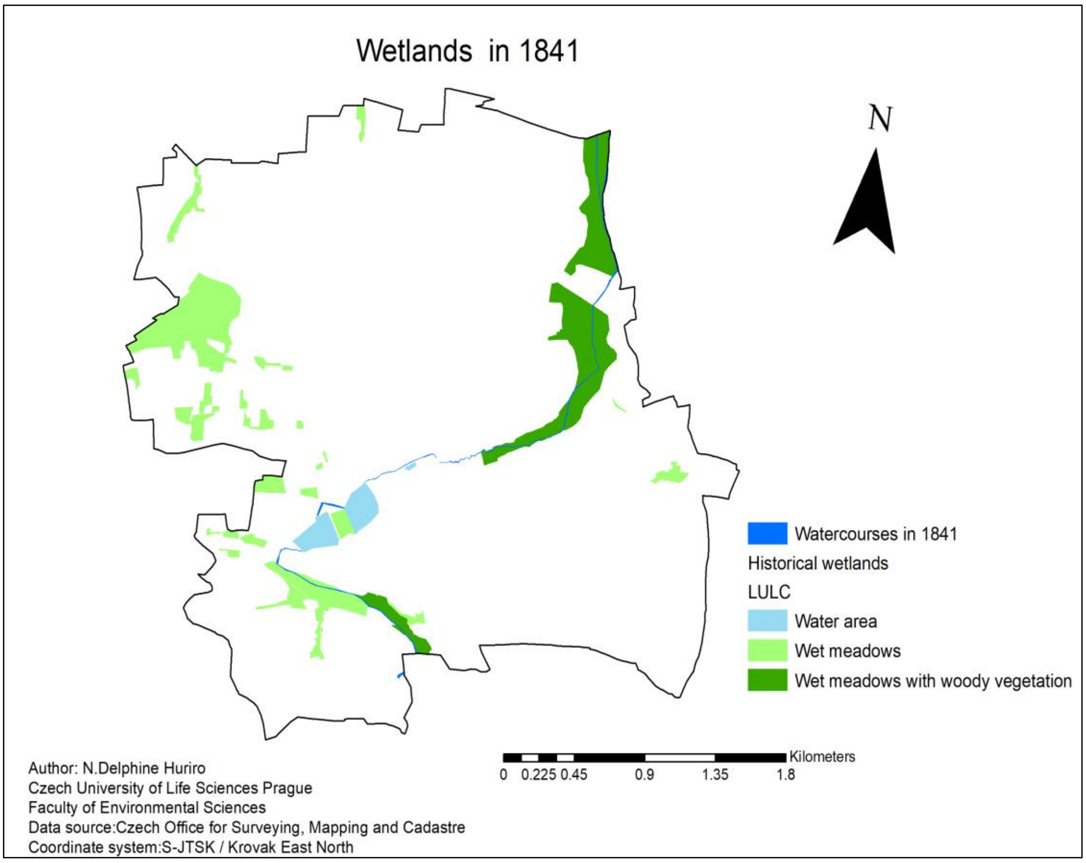

Figure 22: Wetlands map in 1841: Dubeč

5.2.3 Wetlands categories in 2020

The area covered by wetlands in Dubeč decreased from 89.62ha in 1841 to 45.95 ha (4.68%) in 2020.Presently waterlogged forests dominate with 28.46ha (61.93%) followed by waterlogged meadows with 9.58ha (20.84%), then water areas with 6.22ha (13.54%) and lastly swamps and marshes that cover 1.70ha (3.69%).

Wetland categories	Area(ha)
Swamps and marshes	1.70
Water area	6.22
Waterlogged forests	28.46
Waterlogged meadows	9.58
Total	**45.95**

Table 17:Wetlands categories in 2020

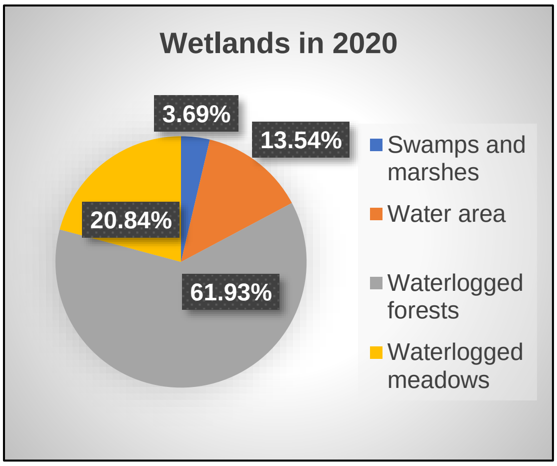

Figure 23:Percentage of wetlands categories in 2020: Dubeč

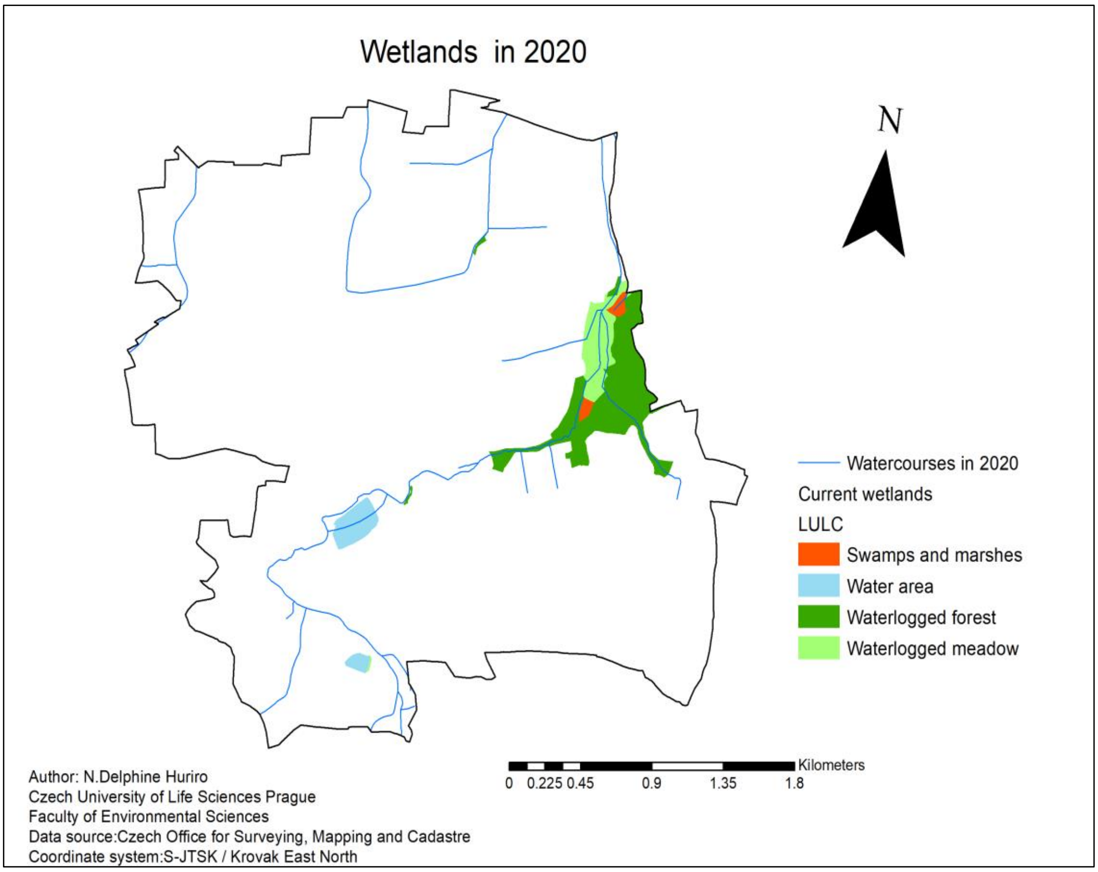

Figure 24:Wetlands map in 2020: Dubeč

5.2.4 Spatial-Temporal change of wetlands

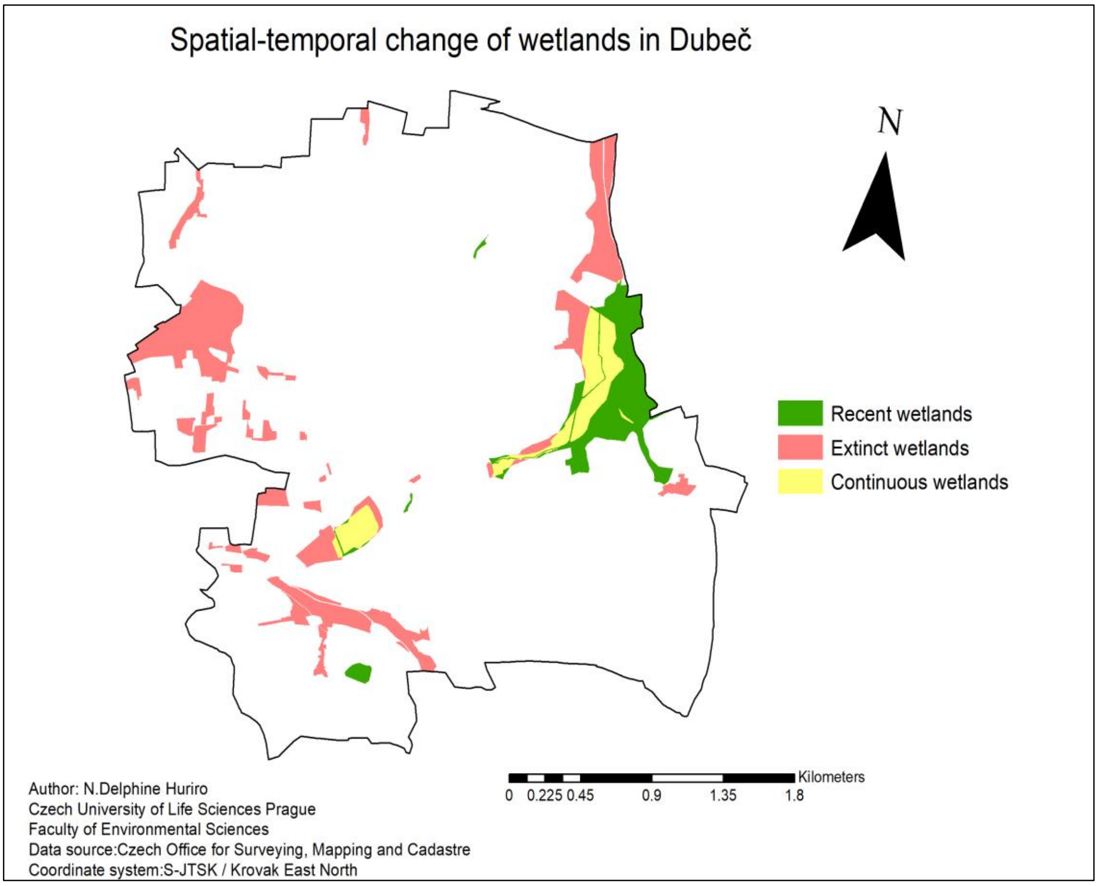

Figure 25: Spatial-temporal change of wetlands: Dubeč

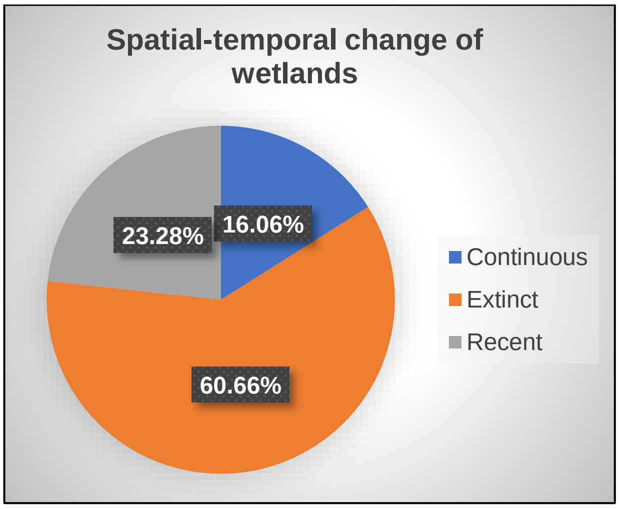

Figure 26:Percentage of extinct, continuous, and recent wetlands: Dubeč

A. Continuous wetlands

Continuous wetlands cover an area of 18.76 ha and they are dominated by wet meadows with woody vegetation with 13.98ha (74.55%) followed by water areas with 3.17ha (16.88%) and lastly wet meadows with 1.61ha (8.57%).

Wetland categories	Area(ha)
Water area	3.17
Wet meadows	1.61
Wet meadows with woody vegetation	13.98
Total	**18.76**

Table 18:Continuous wetlands

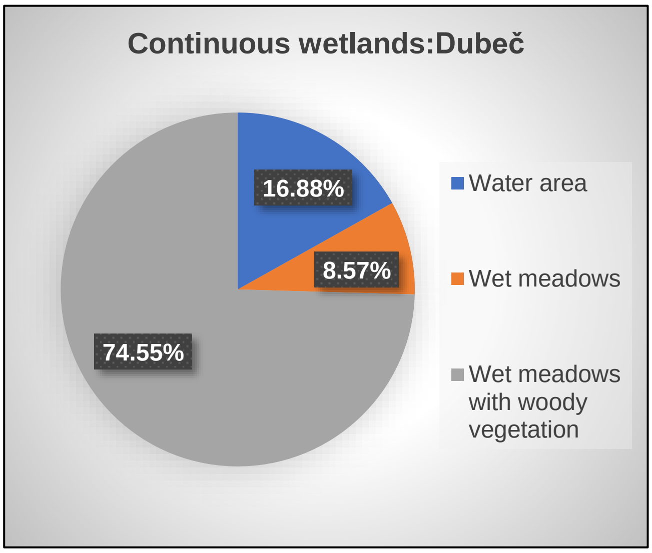

Figure 27:Percentage of continuous wetlands: Dubeč

B. Extinct wetlands

In cadastral district of Dubeč, a total area of 70.86 ha of wetlands was converted to other LULC categories and these extinct wetlands were wet meadows which covered 45.13ha (63.68%), wet meadows with woody vegetation which covered 21.06ha (29.71%) and water area with 4.68ha (6.61%).

Wetland categories	Area(ha)
Water area	4.68
Wet meadows	45.13
Wet meadows with woody vegetation	21.06
Total	**70.86**

Table 19:Extinct wetlands: Dubeč

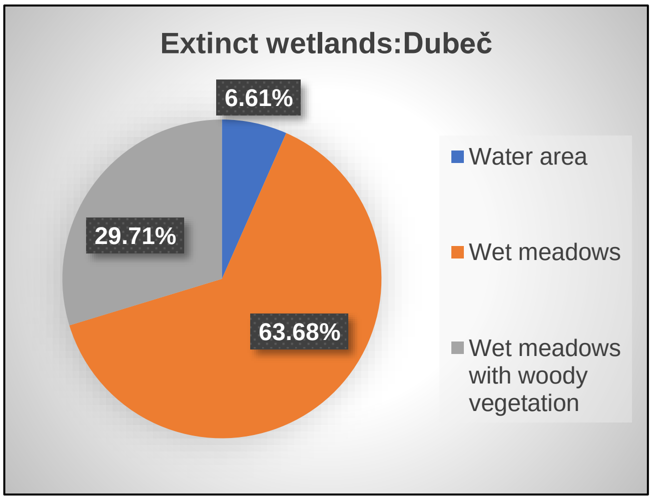

Figure 28:Percentage of extinct wetlands: Dubeč

C. Recent wetlands

Recent wetlands cover 27.19ha and comprise waterlogged forests with an area of 22.92ha (84.27%), waterlogged meadows with 1.74ha (6.40%), water area with 1.59ha (5.83%), and swamps and marshes with 0.95ha (3.5%).

Wetland categories	Area(ha)
Swamps and marshes	0.95
Water area	1.59
Waterlogged forests	22.92
Waterlogged meadows	1.74
Total	**27.19**

Table 20:Recent wetlands: Dubeč

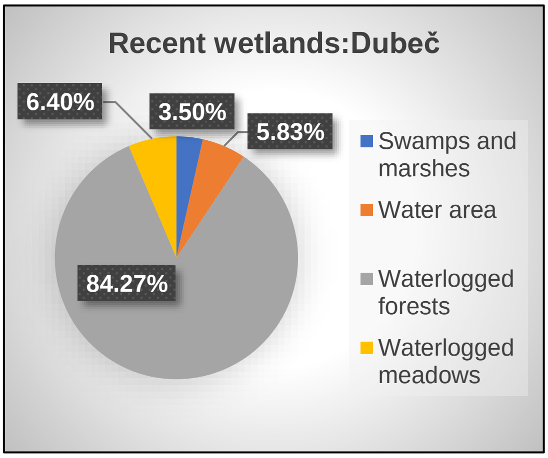

Figure 29:Percentage of recent wetlands: Dubeč

5.2.5 Wetlands trajectories

A. Extinct wetland trajectories

Out of 70.86ha of extinct wetlands, agriculture replaced 24.20ha (34.14%), non-forest woody vegetation replaced 24.09ha (34.00%), permanent grassland replaced 12.31ha (17.37%), built up areas replaced 4.74ha (6.69%), grassland replaced 3.56ha (5.02%), forests replaced 1.36 ha (1.92%), transportation replaced 0.36ha (0.51%) and lastly recreation replaced 0.24ha (0.35%).

LULC	Area(ha)
Agriculture	24.20
Built up areas	4.74
Forests	1.36
Grassland	3.56
Non forest woody vegetation	24.09
Recreation	0.24
Permanent Grassland	12.31
Transportation	0.36
Total	**70.86**

Table 21:Extinct wetlands trajectories

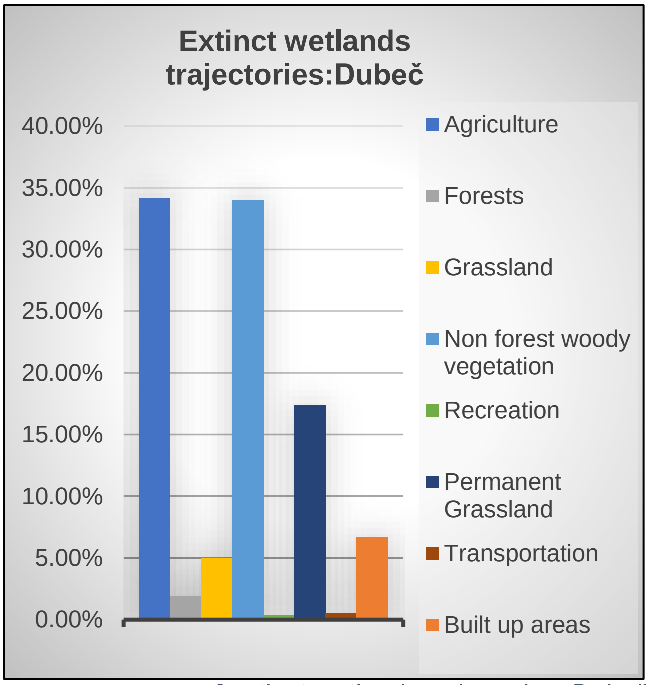

Figure 30: percentage of extinct wetlands trajectories: Dubeč

B. Recent wetland trajectories

Recent wetlands cover an area of 27.19 ha out of which 22.65ha (83.29%) was covered by forests in the past,3.12ha (11.48%) by agriculture, 0.98ha (3.60%) by watercourses ,0.32ha (1.17%) by permanent grassland, ,0.12ha (0.46%) by transportation.

LULC	Area(ha)
Agriculture	3.12
Forests	22.65
Permanent Grassland	0.32
Transportation	0.12
Watercourses	0.98
Total	**27.19**

Table 22:Recent wetland trajectories

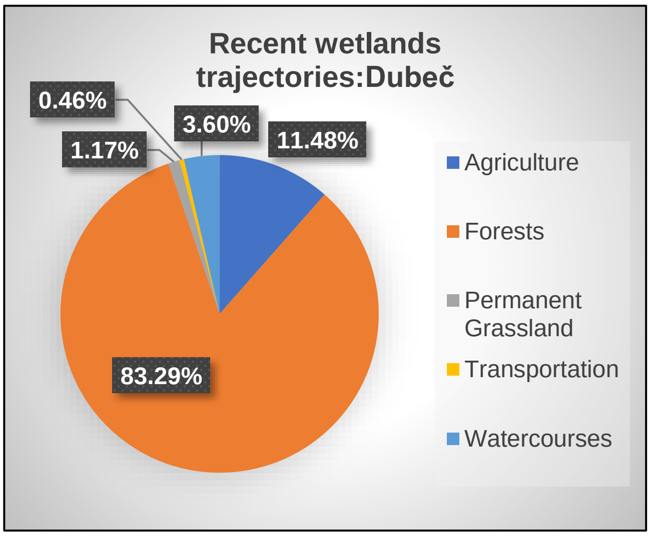

Figure 31: Percentage of recent wetlands trajectories.

5.3 Uhříněves

5.3.1 LULC change in the period of 1841-2020

This research found that in Uhříněves, agriculture which was dominant at the time of the stable cadastre in 1841 with 789.49 ha (70.78%) decreased to 497.40ha (44.60%) in 2020, forests decreased from 56.05ha (5.02%) to 36.82ha (3.30%), permanent grassland decreased from 128.30ha (11.50%) to 23.70ha (2.13%), On the contrary, built-up areas increased considerably from 9.78ha (0.88%) to 327.13ha (29.33%).

		1841	2020	
LULC	**Area(ha)**	**%**	**Area(ha)**	**%**
Agriculture	789.49	70.78%	497.40	44.60%
Built up area	9.78	0.88%	327.13	29.33%
Forests	56.05	5.02%	36.82	3.30%
Others	1.62	0.15%	–	–
Permanent Grassland	128.30	11.50%	23.70	2.13%
Transportation	38.47	3.45%	27.85	2.50%
Watercourses	2.32	0.21%	–	–
Wetlands	89.33	8.01%	22.52	2.02%
Grassland	–	–	99.92	8.96%
Non forest woody vegetation	–	–	74.20	6.65%
Recreation	–	–	5.79	0.52%
Total	**1115.35**		**1115.35**	

Table 23:LULC in two time periods of 1841 and 2020: Uhříněves

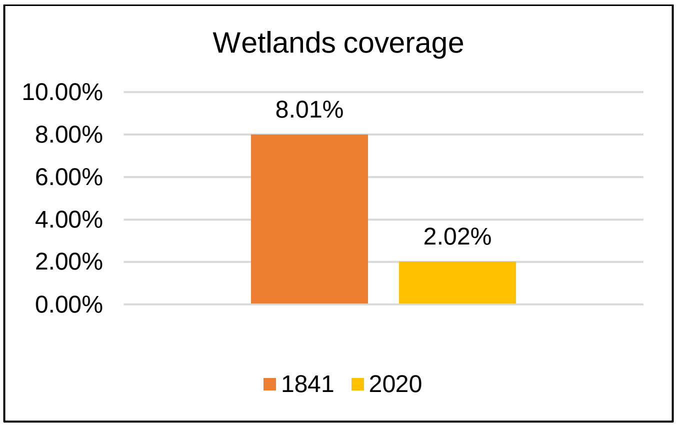

Figure 32:Wetlands in 1841and 2020

5.3.2 Wetlands categories in 1841

Wetlands in 1841 covered an area of 89.33 ha (8.01%). They were mainly wet meadows with 57.62ha (64.50%) and water areas with 31.71ha (35.50%).

Wetland categories	**Area(ha)**
Water area	31.71
Wet meadows	57.62
Total	**89.33**

Table 24:Wetlands categories in 1841

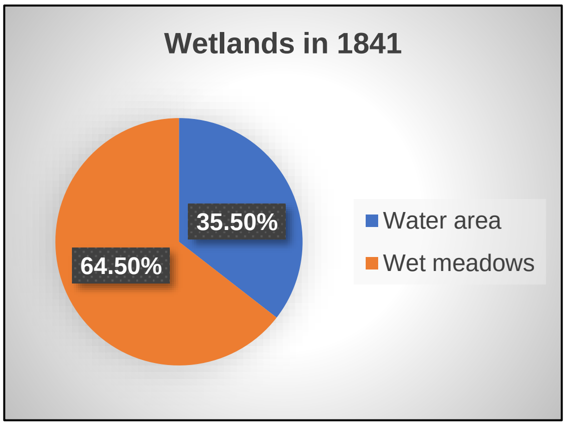

Figure 33:Percentage of wetlands categories in 1841: Uhříněves

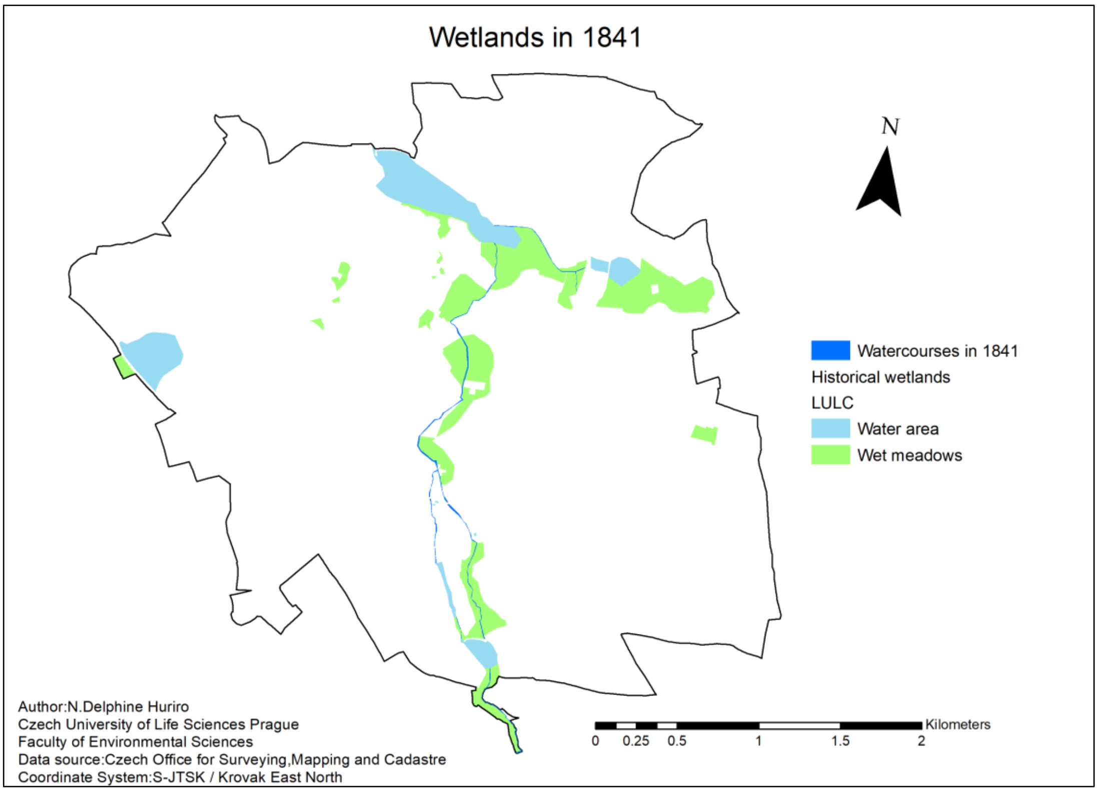

Figure 34:Wetlands map in 1841

5.3.3 Wetlands categories in 2020

Current wetlands cover an area of 22.52 ha (2.02%). They are dominated by water areas with 17.37ha (77.12%) followed by waterlogged forests with 4.28ha (19.01%) and swamps and marshes with 0.87ha (3.86%).

Wetland categories	Area(ha)
Swamps and marshes	0.87
Water area	17.37
Waterlogged forest	4.28
Total	**22.52**

Table 25:Wetlands in 2020: Uhříněves

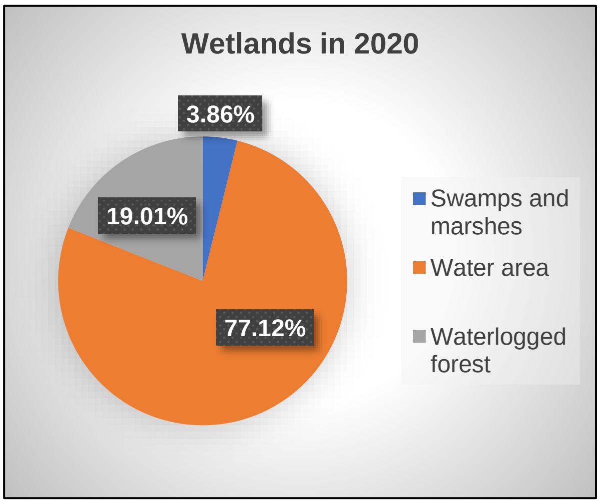

Figure 35:Percentage of wetlands categories in 2020: Uhříněves

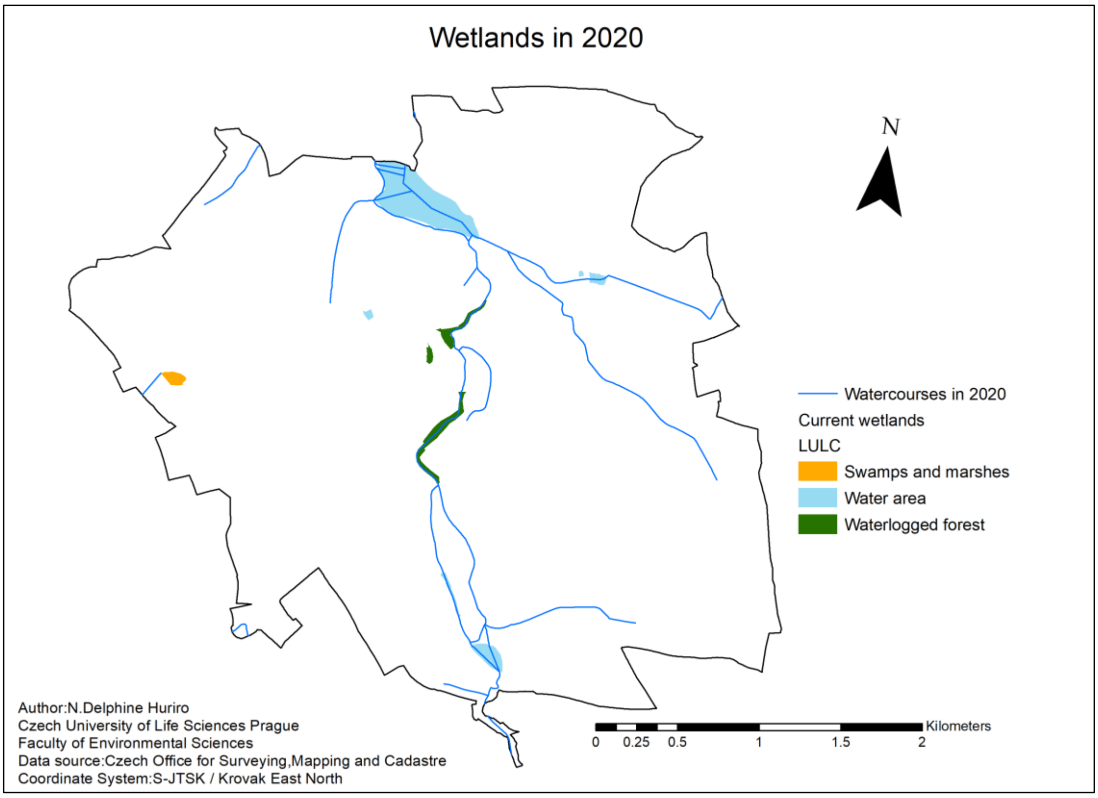

Figure 36:Wetlands map in 2020: Uhříněves

5.3.4 Spatial-temporal change of wetlands

The figure 37 shows the location of extinct, continuous, and recent wetlands.

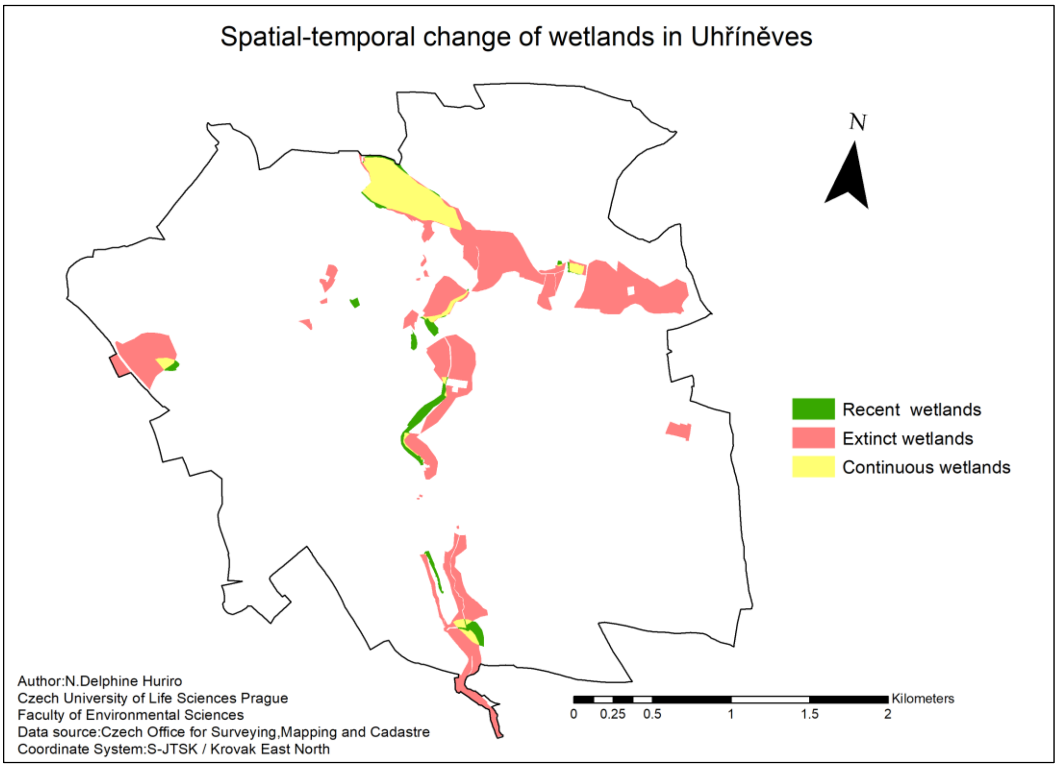

Figure 37:Spatial-temporal change of wetlands: Uhříněves

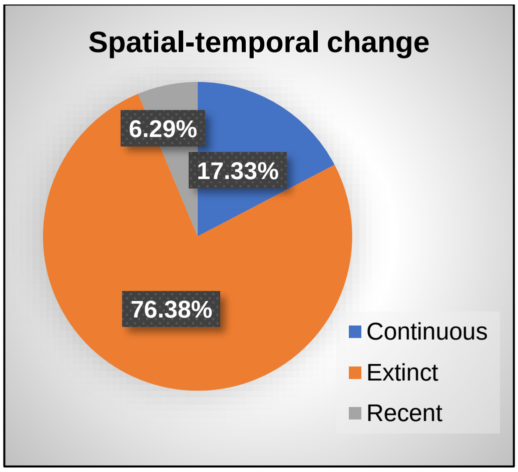

Figure 38:Percentage of extinct wetlands, continuous and recent wetlands

A. Continuous wetlands

Continuous wetlands cover an area of 16.52 ha and are mainly water areas with 14.68ha (88.84%) followed by wet meadows with 1.84ha (11.16%).

Wetland categories	Area (ha)
Water area	14.68
Wet meadows	1.84
Total	**16.52**

Table 26:Continuous wetlands

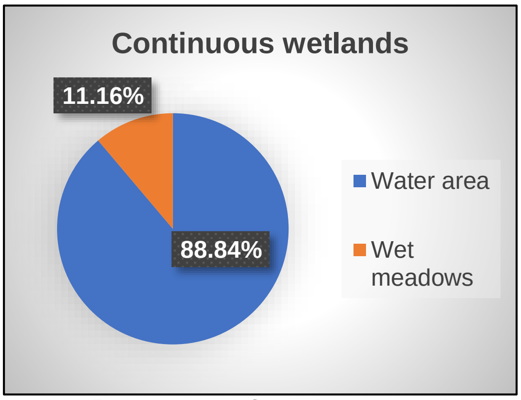

Figure 39:Percentage of continuous wetlands: Uhříněves

B. Extinct wetlands

The loss of wetlands in Uhříněves was found to be 72. 81ha.Out of this sum,55.78ha (76.61%) were wet meadows and 17.03ha (23.39%) were water areas at the time of the stable cadastre in 1841.

Wetland categories	Area(ha)
Water area	17.03
Wet meadows	55.78
Total	**72.81**

Table 27:Extinct wetlands: Uhříněves

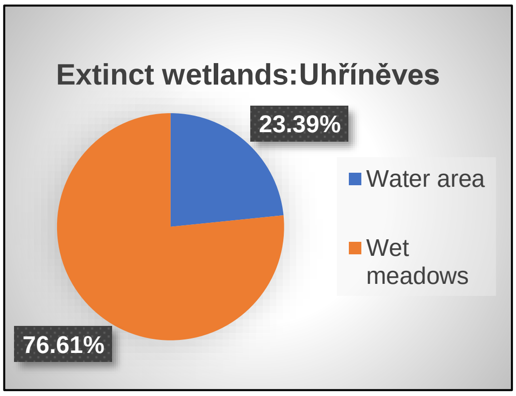

Figure 40:Percentage of extinct wetlands: Uhříněves

C. Recent wetlands

An area of 5.99ha was gained and out of this sum,3.17ha (52.81%) is presently covered by waterlogged forests,2.52ha (41.97%) by water areas and 0.31ha (5.22%) by swamps and marshes.

Wetland categories	Area(ha)
Swamps and marshes	0.31
Water area	2.52
Waterlogged forest	3.17
Total	**5.99**

Table 28:Recent wetlands: Uhříněves

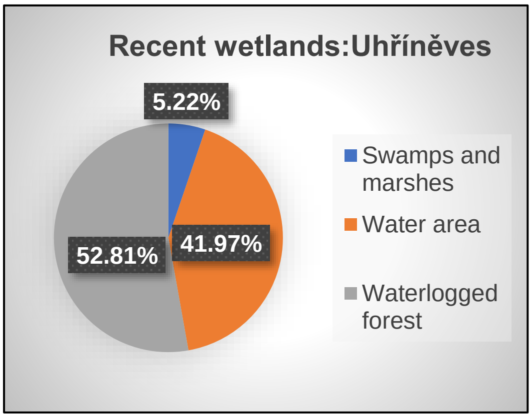

Figure 41:Percentage of recent wetlands: Uhříněves

5.3.5 Wetlands trajectories

A. Extinct wetlands trajectories

This research found that out of 72.81ha of extinct wetlands,24.68ha (33.90%) is currently used for agriculture ,16.97ha (23.31%) is covered by non-forest woody vegetation,9.66ha (13.27%) is covered by grassland,9.10ha (12.49%) by built up areas,6.10ha (8.38%) by permanent grassland,3.43ha (4.71%) by forests,1.84ha (2.52%) for recreation and 1.03ha (1.42%) for transportation.

LULC	Area(ha)
Agriculture	24.68
Built up area	9.10
Forest	3.43
Grassland	9.66
Non forest woody vegetation	16.97
Recreation	1.84
Permanent Grassland	6.10
Transportation	1.03
Total	**72.81**

Table 29:Extinct wetlands trajectories

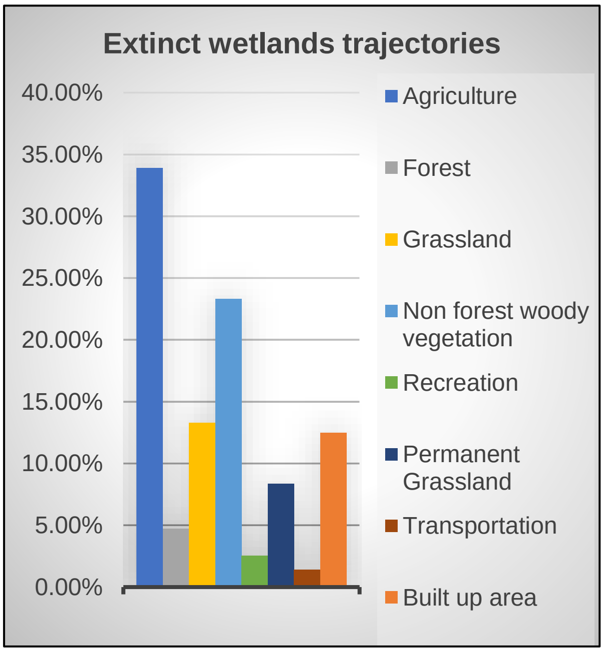

Figure 42:Percentage of extinct wetlands trajectories: Uhříněves

B. Recent wetlands trajectories

Out of 5.99ha of recent wetlands,2.50ha (41.70%) replaced agriculture,1.47ha (24.50%) replaced forests,1.13ha (18.80%) replaced permanent grassland,0.50ha (8.42%) replaced watercourses,0.24ha (3.97%) replaced others ,0.15ha (2.45%) replaced transportation and 0.01ha (0.17%) replaced built up areas.

LULC	Area(ha)
Agriculture	2.50
Built up area	0.01
Forests	1.47
Others	0.24
Permanent Grassland	1.13
Transportation	0.15
Watercourses	0.50
Total	**5.99**

Table 30:Recent wetlands trajectories

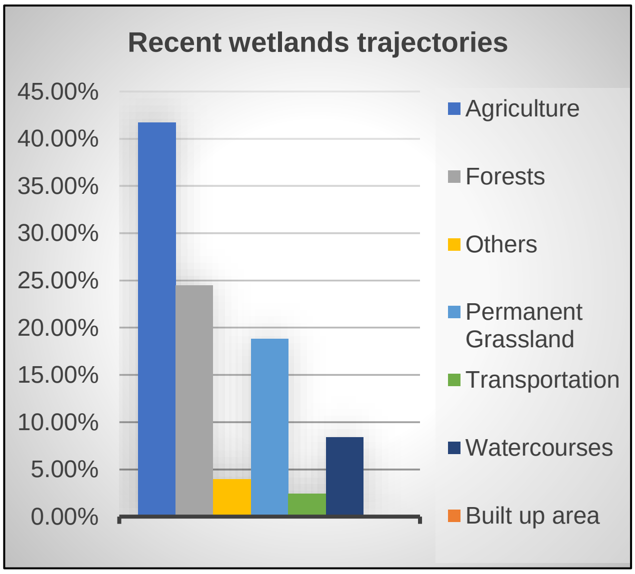

Figure 43:Percentage of recent wetlands trajectories: Uhříněves

5.4 Dolní Počernice

5.4.1 LULC change in the period of 1841-2020

This research found that in Dolní Počernice, agriculture which was dominant at the time of the stable cadastre in 1841 with 393.55 ha (66.42%) decreased to 96.79ha (16.33%), permanent grassland decreased from 48.81ha (8.24%) to 28.17ha (4.75%).

Conversely, built up areas increased considerably from 5.73ha (0.97%) in 1841 to 125.74ha (21.22%) in 2020, forests increased from 60.17ha (10.15%) to 138.53ha (23.38%), recreation increased from 2.55ha (0.43%) to 65.59ha (11.07%) and transportation from 13.02ha (2.20%) to 22.26ha (3.76%).

		1841	2020	
LULC categories	**Area(ha)**	**%**	**Area(ha)**	**%**
Agriculture	393.55	66.42%	96.79	16.33%
Built up areas	5.73	0.97%	125.74	21.22%
Permanent Grassland	48.81	8.24%	28.17	4.75%
Forests	60.17	10.15%	138.53	23.38%
Recreation	2.55	0.43%	65.59	11.07%
Transportation	13.02	2.20%	22.26	3.76%
Wetlands	65.96	11.13%	73.43	12.39%
Watercourses	2.66	0.45%	—	—
Others	0.12	0.02%	—	—
Non forest woody vegetation	—	—	32.15	5.43%
Grassland	—	—	9.90	1.67%
Total	**592.56**		**592.56**	

Table 31:LULC in two time periods of 1841 and 2020: Dolní Počernice

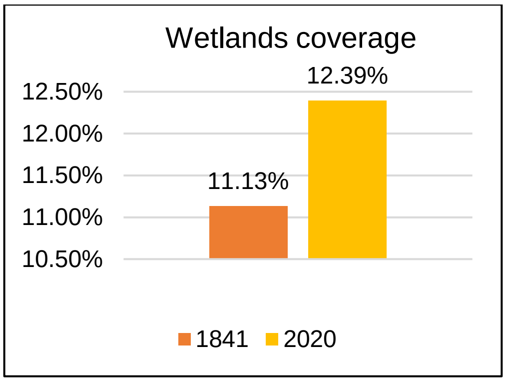

Figure 44:Wetlands coverage in 1841 and 2020

5.4.2 Wetlands in 1841

At the time of the stable cadastre in 1841,wetlands covered an area of 65.96 ha(11.13% of the total area) .They were dominated by wet meadows with 42.24ha(64.04%) followed by water areas with 21.98ha(33.32%) and lastly wet meadows with woody vegetation with 1.74 ha(2.64%).

Wetland categories	**Area (ha)**
Water area	21.98
Wet meadows	42.24
Wet meadows with woody vegetation	1.74
Total	**65.96**

Table 32:Wetlands categories in 1841

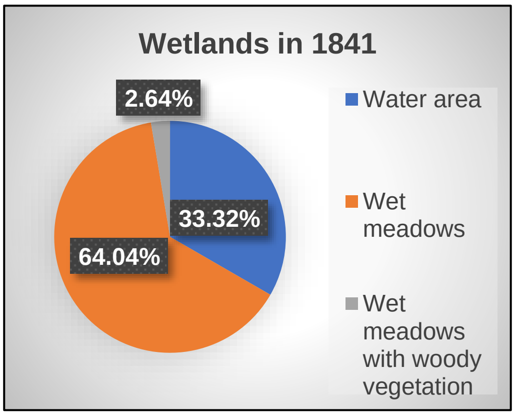

Figure 45:Percentage of wetlands categories in 1841

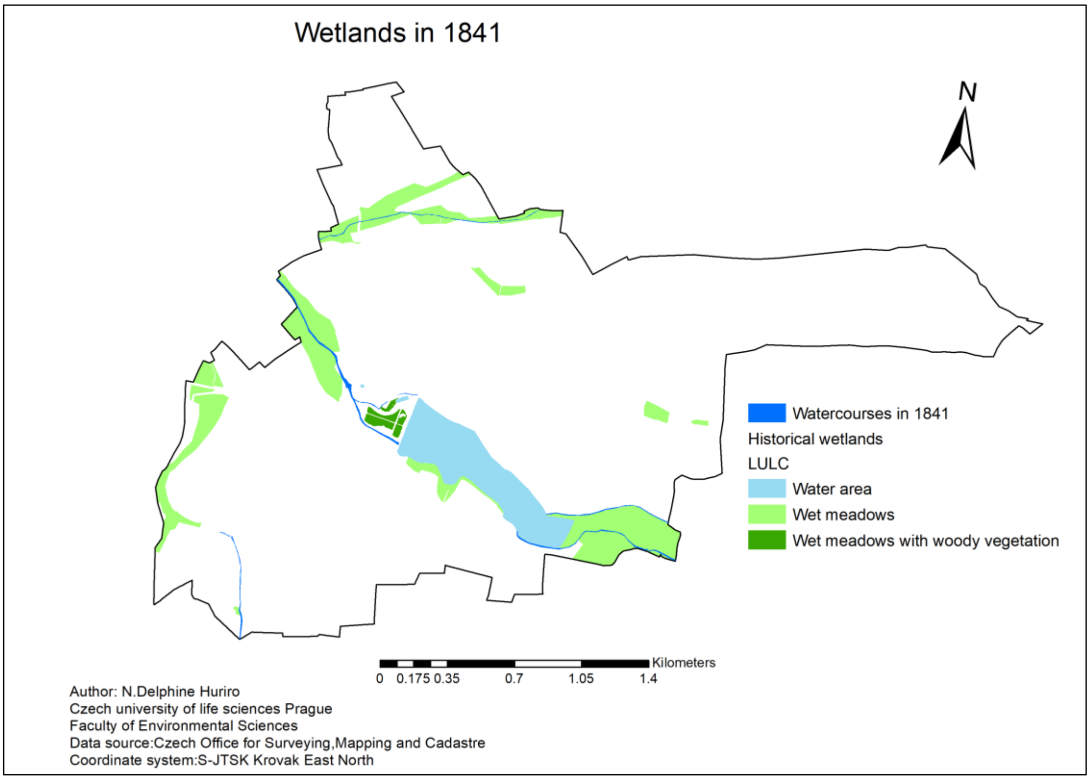

Figure 46:Wetlands in 1841: Dolní Počernice

5.4.3 Wetlands in 2020

Contrary to other cadastral districts, the area covered by wetlands in Dolní Počernice increased from 65.96ha (11.13%) in 1841 to 73.43 ha (12.39%) in 2020.Presently these wetlands are dominated by waterlogged forests with 38.18ha (51.99%) followed by water areas with 25.27ha (34.41%), then swamps and marshes with 5.30ha (7.21%) and lastly waterlogged meadows with 4.69ha (6.38%).

Wetland categories	Area (ha)
Swamps and marshes	5.30
Water area	25.27
Waterlogged forests	38.18
Waterlogged meadows	4.69
Total	**73.43**

Table 33:Wetland categories in 2020

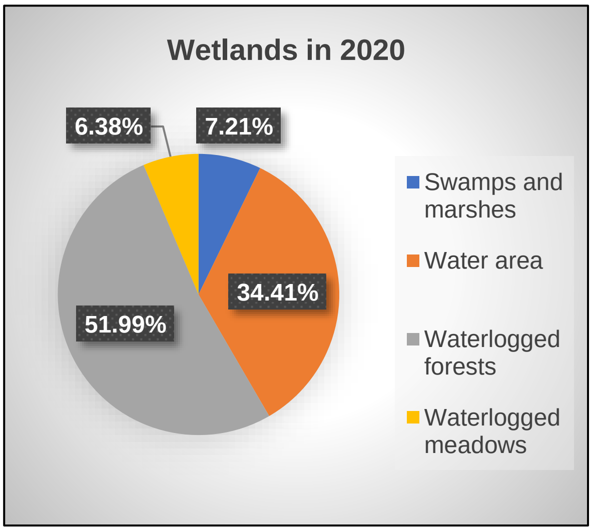

Figure 47:Percentage of wetland categories in 2020: Dolní Počernice

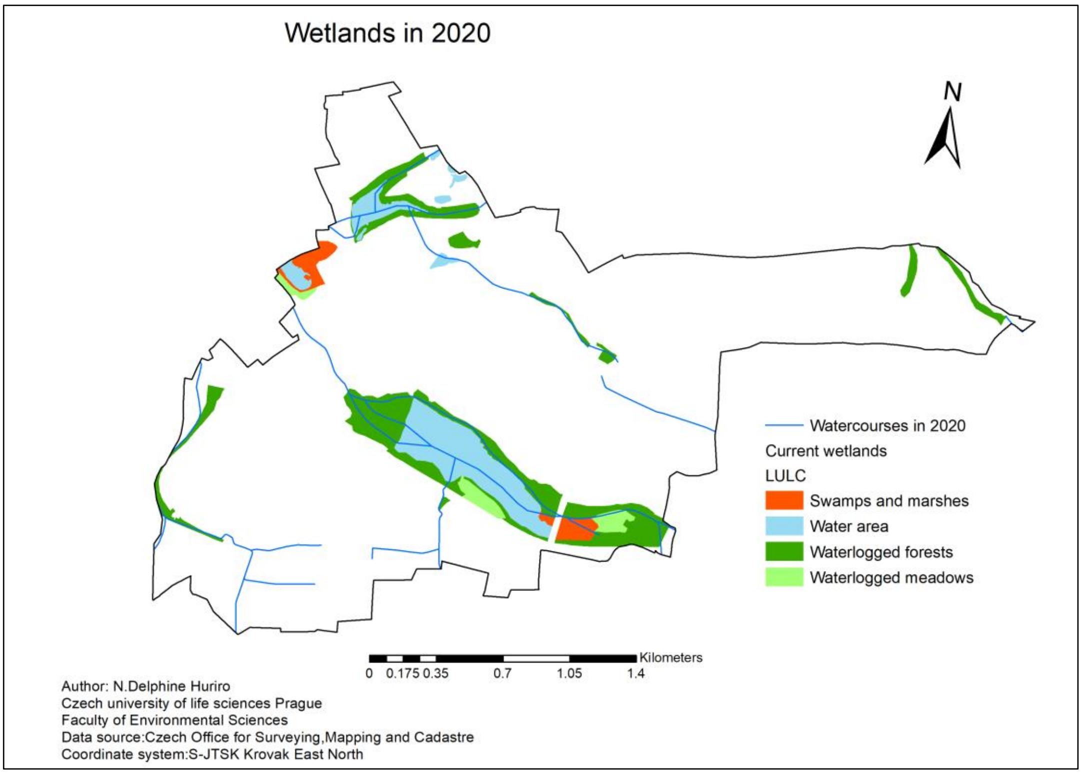

Figure 48:Wetlands in 2020: Dolní Počernice

5.4.4 Spatial temporal change of wetlands

The following map shows the location of extinct, continuous, and recent wetlands.

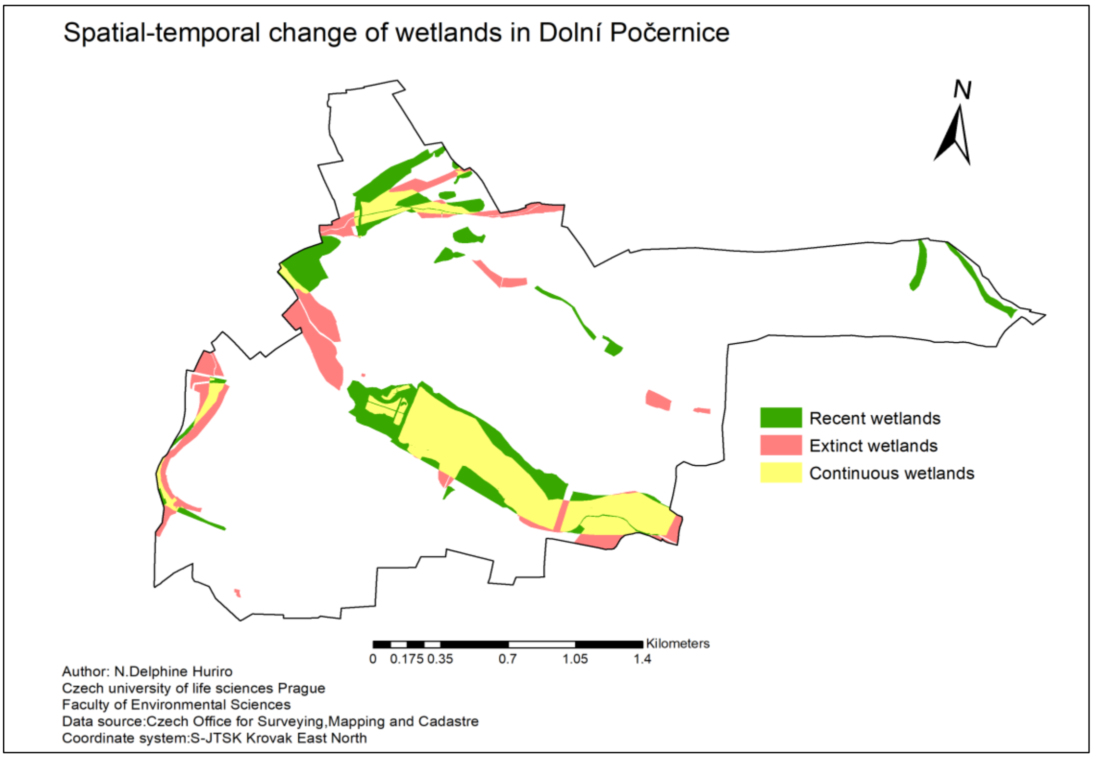

Figure 49:Spatial-temporal change of wetlands: Dolní Počernice

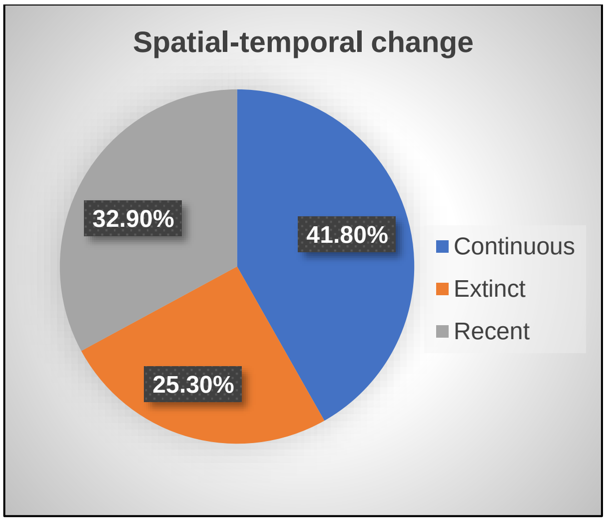

Figure 50:Percentage of Extinct, continuous, and recent wetlands

A. Continuous wetlands

Continuous wetlands cover an area of 41.08 ha and comprise water areas with 20.96ha (51.02%), wet meadows with 18.38ha (44.74%) and lastly wet meadows with woody vegetation with 1.74 ha (4.24%).

Wetland categories	Area (ha)
Water area	20.96
Wet meadows	18.38
Wet meadows with woody vegetation	1.74
Total	**41.08**

Table 34:Continuous wetlands

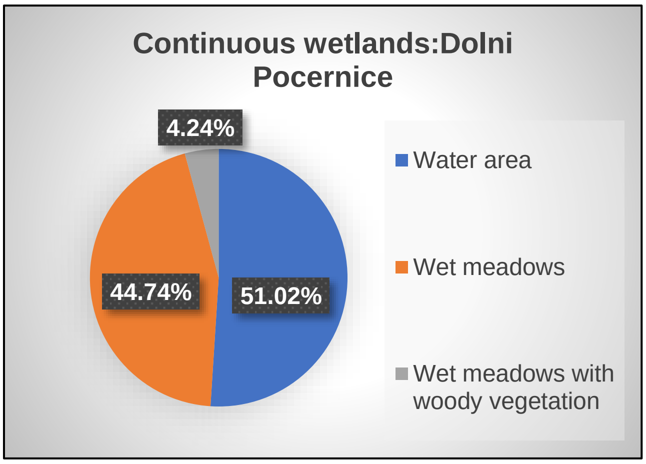

Figure 51:Percentage of continuous wetlands: Dolní Počernice

B. Extinct wetlands

The loss of wetlands in Dolní Počernice was found to be 24.87 ha. These extinct wetlands were wet meadows with 23.86ha (95.92%) and water areas with 1.01ha (4.08%).

Wetland categories	Area (ha)
Water area	1.01
Wet meadows	23.86
Total	**24.87**

Table 35:Extinct wetlands categories

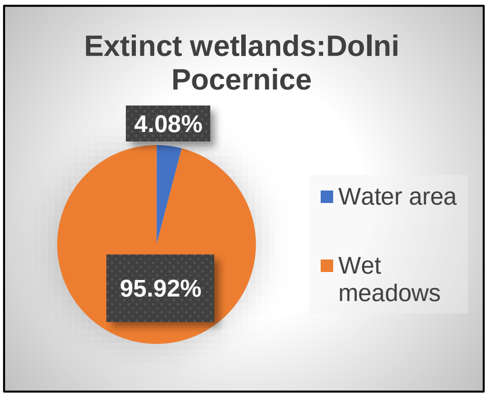

Figure 52:Percentage of extinct wetlands: Dolni Pocernice

C. Recent wetlands

Recent wetlands cover an area of 32.34 ha out of which 22.69ha (70.17%) are covered by waterlogged forests,4.64ha (14.33%) are covered by water areas,2.82ha (8.72%) are covered by swamps and marshes and 2.19ha (6.78%) are covered by waterlogged meadows.

Wetland categories	Area (ha)
Swamps and marshes	2.82
Water area	4.64
Waterlogged forests	22.69
Waterlogged meadows	2.19
Total	**32.34**

Table 36:Recent wetlands

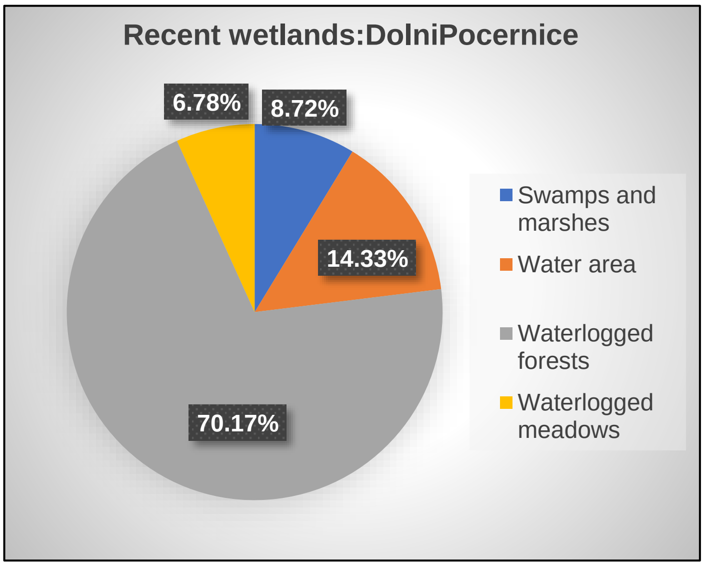

Figure 53:Percentage of recent wetlands: Dolni Pocernice

5.4.5 Wetlands trajectories

A. Extinct wetland trajectories

Out of 24.87ha of extinct wetlands,6.83ha (27.44%) was replaced by built up areas,3.90ha (15.67%) by recreation,3.43ha (13.77%) by forests,3.13ha (12.59%) by transportation, ,2.83ha (11.39%) by non-forest woody vegetation,1.97ha (7.93%) by Agriculture,1.79ha (7.20%) by grassland and 0.99ha (3.99%) by permanent Grassland.

LULC categories	Area (ha)
Agriculture	1.97
Built up areas	6.83
Forests	3.43
Grassland	1.79
Non forest woody vegetation	2.83
Recreation	3.90
Permanent Grassland	0.99
Transportation	3.13
Total	**24.87**

Table 37:Extinct wetlands trajectories

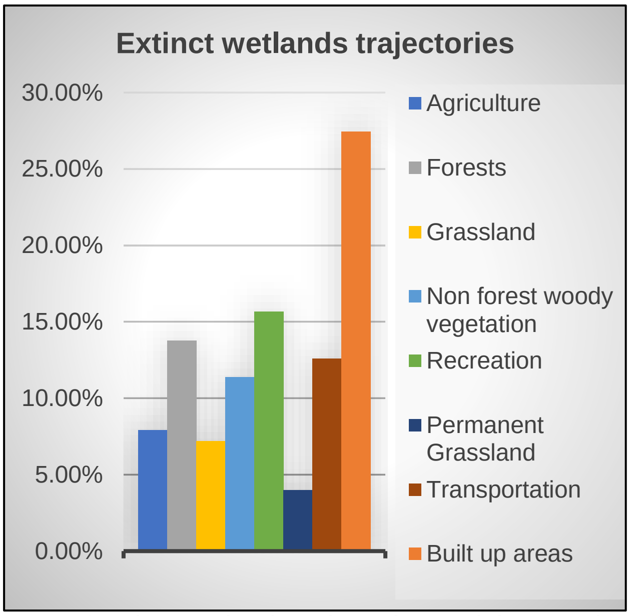

Figure 54:Percentage of extinct wetlands trajectories: Dolni Pocernice

B. Recent wetlands trajectories

Out of 32.34 ha of recent wetlands ,19.64ha (60.74%) replaced agriculture ,4.98 ha (15.38%) replaced permanent grassland, 2.86ha (8.85%) replaced forests,2.12ha (6.54%) replaced recreation,1.38ha (4.26%) replaced transportation,1.19ha (3.69%) replaced watercourses and 0.18ha (0.55%) replaced built up areas.

LULC categories	Area (ha)
Agriculture	19.64
Built up areas	0.18
Permanent Grassland	4.98
Forests	2.86
Recreation	2.12
Transportation	1.38
Watercourses	1.19
Total	**32.34**

Table 38:Recent wetlands trajectories

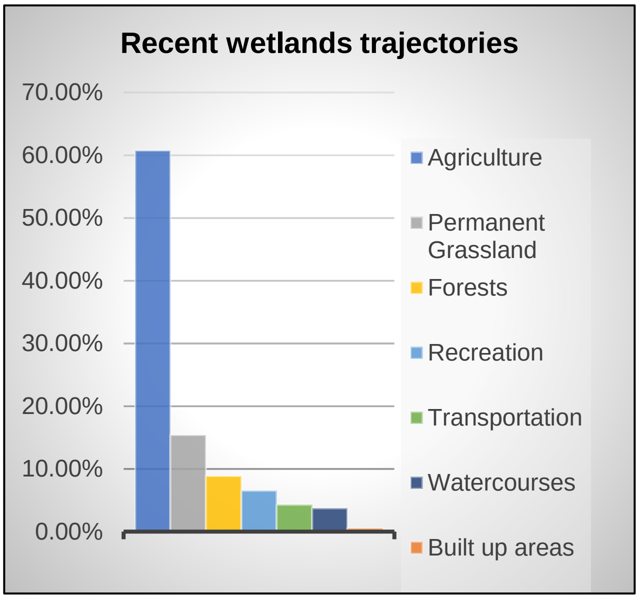

Figure 55:Percentage of recent wetlands trajectories

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6. Discussion

6.1 General results

Looking at general evolution of LULC in all four studied cadastral districts, the first observation is that agriculture land decreased while built up areas increased considerably. Yet agriculture remains dominant in most cadastral districts except in Dolní Počernice where forests and built-up areas are the dominant LULC. Therefore the phenomena of suburbanization is observed where people and businesses shift to the outskirts of the main city mainly because of social and economic factors such as real estate's prices, more space, peace and quiet, safe neighbourhoods, more outdoor spaces etc.

Coming back to wetlands which were the focus of this research, at the time of the stable cadastre in the first half of 19th century, they covered a total area of 305.32ha (9.34% of the total studied area) and presently they only cover 146.90 ha (4.5%), a decrease of 51.89%. Dolní Počernice cadastral district showed a different trend compared to other studied cadastral districts and an increase in area covered by wetlands was observed. Not only it has a high percentage of continuous wetlands (41.80%) but also the highest percentage in recent wetlands (32.90%).

Going back to other author's reports such as Davidson (2014) who in his review of 189 global reports of change in wetland area found that the reported long-term loss of natural wetlands averages between 54–57%.

Hu et al. (2017) also averaged global wetlands loss to 33%, specifically 45% in Europe and Anderson (2019) who states that more than 50 percent of wetlands around the world have been destroyed because of human activities, and many more are affected by water pollution and groundwater withdrawal. Therefore, it can be concluded that the results in current thesis (51.89% of wetland loss) is in line with above author's findings.

At the beginning of this research, it was hypothesised that the landscape development in the study area has negatively affected the wetlands. This hypothesis was found to be true in three cadastral districts and false in one cadastral district.

Cadastral district	Results (Wetlands loss/gain)	The landscape development in the study area has negatively affected wetlands.
Uhříněves	- 74.78%	True
Běchovice	-91.75%	True
Dubeč	-48.73%	True
Dolní Počernice	11.32%	False

Table 39:Research hypothesis testing

6.2 Extinct wetlands

A total of 227.80 ha of wetlands are extinct in four cadastral districts. Wet meadows and wet meadows with woody vegetation were the most affected (87.37% of extinct wetlands) followed by water area (11.90%) and lastly swamps and marshes (0.73%).

Frajer et al. (2014) argued that In the Czech Republic, there used to be many ponds until the end of the 18th century. However,31.2% of them were dried out during the 19th century at the expense of arable land. The result of this study showed that 11.90% of extinct wetlands were water areas(ponds). However, it is important to mention that the author cannot confidently say exactly in which period these ponds were drained because this study only assessed LULC in two time periods of 1841 at the time of the stable cadastre and 2020.

Skaloš et al. (2012) state that Czech Republic went through important change of land reforms such as agriculture intensification at the end of 18th century and collectivization throughout 19th century.

Therefore the losses may have happened during those land reforms.

6.3 Extinct wetlands change trajectories.

Extinct wetland trajectories results show that the main driving factor behind wetland loss is agriculture (27.31%). Several authors also have affirmed agriculture intensification to be the main cause of wetland loss (Davidson ,1991; Kristensen, 1999; Theo et al.,2015; Šantrůčková et al.,2017).

Non forest woody vegetation is the second driving factor and replaced 26.57% of extinct wetlands. When thinking of wetlands restoration, this category has potential as it is nor used for agriculture nor built up.

Built up areas also were found to have replaced 12.70% of extinct wetlands and thus it can be concluded that urbanization has been an important factor behind wetland loss in the study area. This statement goes in line with Davidson et al. (1991) who stated that land-use change in Europe especially agriculture and urbanization resulted in wetlands drainage and Junk et al. (2013) who reported that high population density was another factor pressuring wetlands ecosystems. In addition, this result was expected as the studied areas are considered as suburbs of the city of Prague.

In light of above results, the hypothesis that agriculture and urbanization are among the main drivers of wetland loss can be said to be true.
Other LULC categories also had a share in wetlands loss such as permanent grassland, grassland, forests, transportation, and recreation (12.55%,10.39%,4.13%, 3.67% and 2.68%) respectively.

Thinking of wetlands restoration, current water regimes in these areas which used to be covered by wetlands could be investigated to assess if there is a potential of wetland restoration.

6.4 Recent wetlands trajectories

Although a considerable share of wetlands is extinct, this research found that a total of 69.36ha of wetlands are recent in the studied area.

LULC categories at the expense of which these wetlands occur are mainly agriculture (41.40%), forests (38.90%), permanent grassland (9.42%) and other categories such as watercourses (3.89%), recreation (3.05%), transportation (2.73%), others (0.34%) and built-up areas (0.27%).

This proves that in the studied area, considerable efforts have been put into wetlands management and restoration. In fact, some wetlands revitalization projects were identified such as restoration of the Lítožnický pond in Dubeč which officially started in 2016 and works lasted till 2020 and it is expected that the new restored wetland system will help in water management in landscape, increase biodiversity in the area.

It is undoubtedly a positive contribution towards environment ecological stability and one can hope that this trend will sustain, nevertheless the gain is far less than the loss in the studied area and therefore there is need for more restoration/revitalization projects in attempt to restore extinct wetlands wherever possible.

6.5 Suggestions for future research

The availability and accessibility of LULC data in Czech Republic was found to be at above satisfying level and in effort towards understanding factors that led to wetland ecosystems loss, it is recommended that these types of studies should be continued and hopefully to cover the whole country and in other countries where such data is available and accessible.

Future research could include more temporal aspects i.e. including LULC data source such as archival maps or aerial photographs from the years that were characterized by important land reforms which make it possible to know in what periods of time changes happened.

Future research could also be focused on assessing water regimes in areas where wetlands used to be, to assess the restoration potential and importantly, they should assess current wetlands protection status to ensure that there are not threatened by agriculture or urbanization and other factors proven to be behind wetland loss.

Wu et al. (2006) assert that GIS provides a flexible environment for displaying, storing, and analysing digital data necessary for change detection. For this thesis, within GIS environment, all desired outcomes were accomplished and therefore GIS is recommended for studies focusing on monitoring LULC changes.

7. Conclusion and contribution of the thesis

This thesis aimed to assess long term LULC change and their impact on wetlands by estimating the size of extinct, continuous, and recent wetlands and by identifying and quantifying LULC categories that replaced extinct wetlands and those at the expense of which recent wetlands occur.

This study was performed on 4 cadastral districts considered as suburbs of Prague city that extended over an area of 3268 ha in 1841. The results have showed that half of wetlands is extinct and that they were converted to other LULC categories mainly agriculture, non-forest wood vegetation and built-up areas.

Although the wetland loss was high, it has also showed that current wetlands management and restoration efforts in Czech Republic have yielded results and that an appreciable area of wetlands was gained. These wetlands mainly replaced agriculture, forests, and permanent grassland.

LULC data in Czech Republic are easily accessible and used archival maps of the stable cadastre were of good quality and therefore useful in reconstructing historical land use maps.

Categorizing historical and current LULC in such way that comparison would be possible was problematic (e.g., present non-forest woody vegetation which is not managed as forests and grassland not managed as permanent grassland corresponded to none of the categories from the legend of the stable cadastre).

Further research is recommended to gain more insights into factors that are behind wetlands loss and take appropriate measures to preserve these precious ecosystems accordingly.

Assessment of protection status of current wetlands is also needed as part of wetland management and protection to ensure that they are not threatened by agriculture and urbanization which were found to be among the leading causes of wetland loss.

In effort to wetland restoration, further research focusing on water regimes and other prerequisites for wetlands is recommended in areas where wetlands used to be to assess if there is a restoration potential.

Lastly, the results of this thesis indicate in author’s view that the thesis objectives have been achieved and it can be said that this research contributed to existing scientific knowledge about historical development of wetlands in the Czech Republic.

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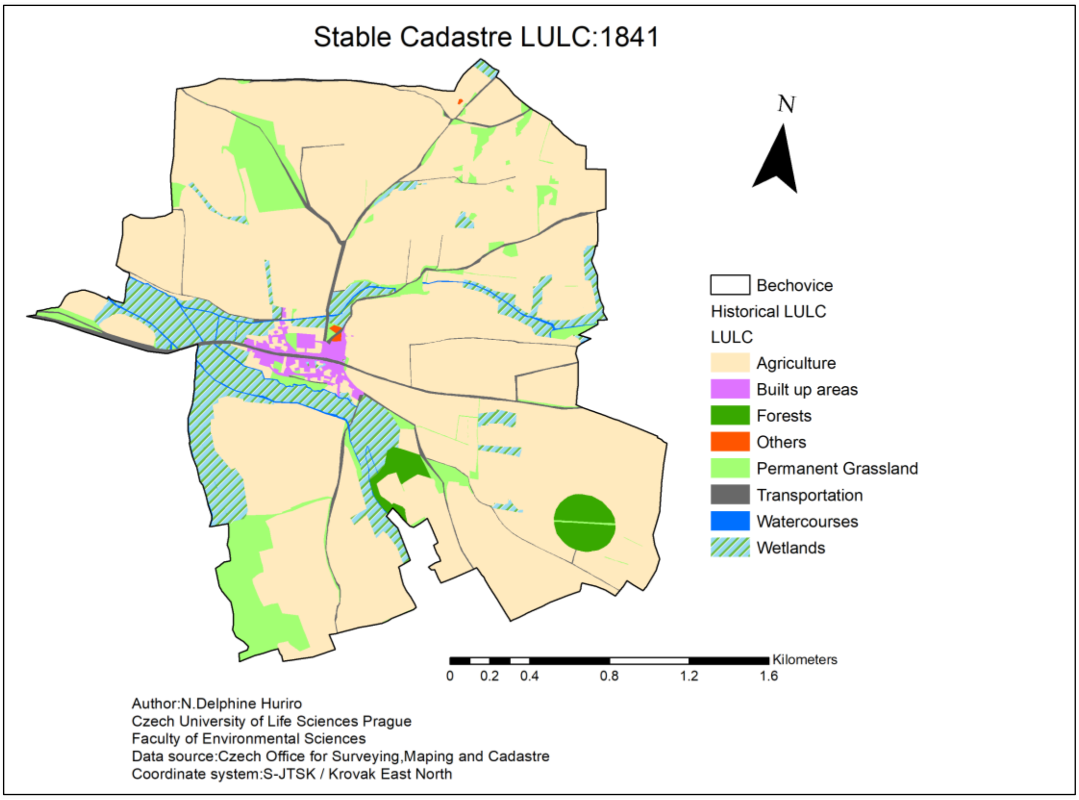
9. List of tables

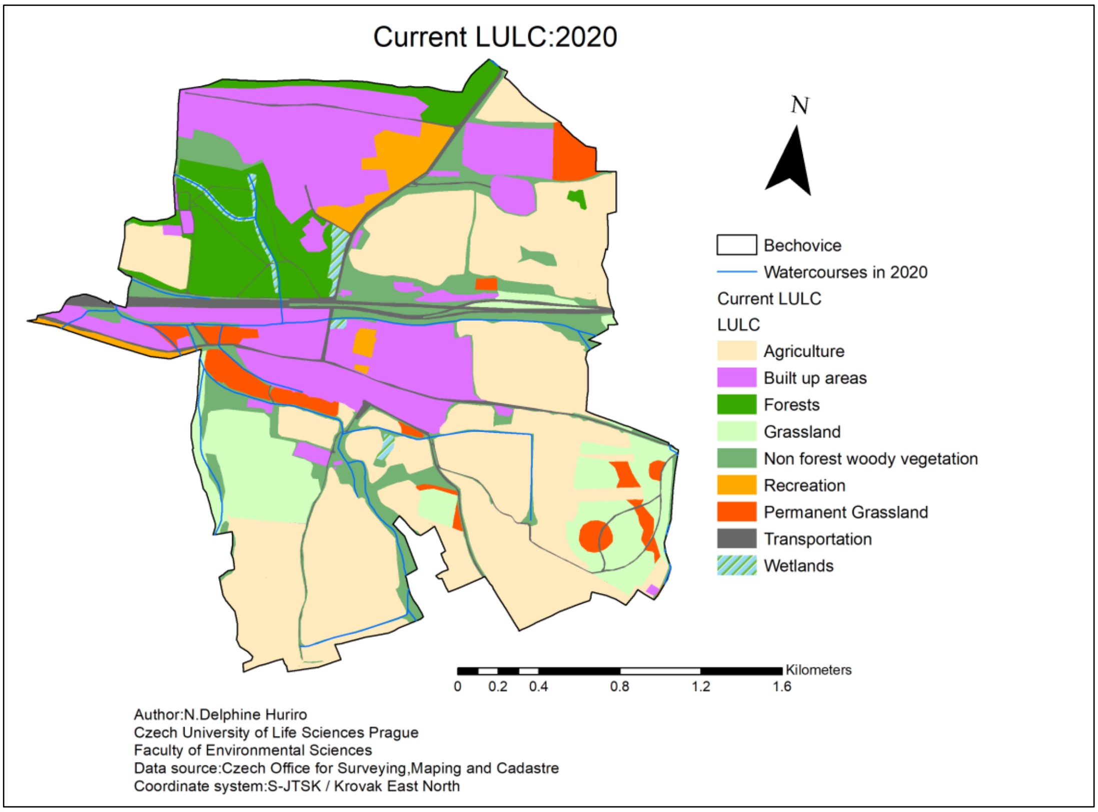
10. List of figures

11. Appendices

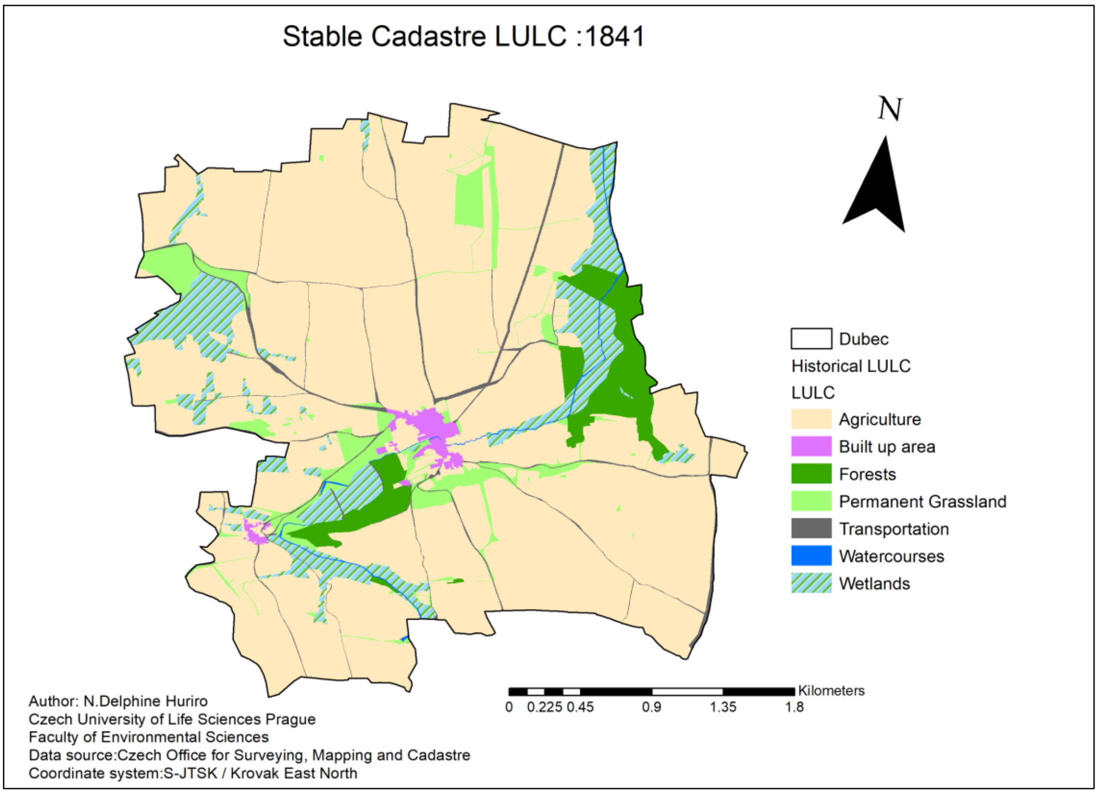
Appendix 1: LULC at the time of the stable of cadastre in 1841: Běchovice



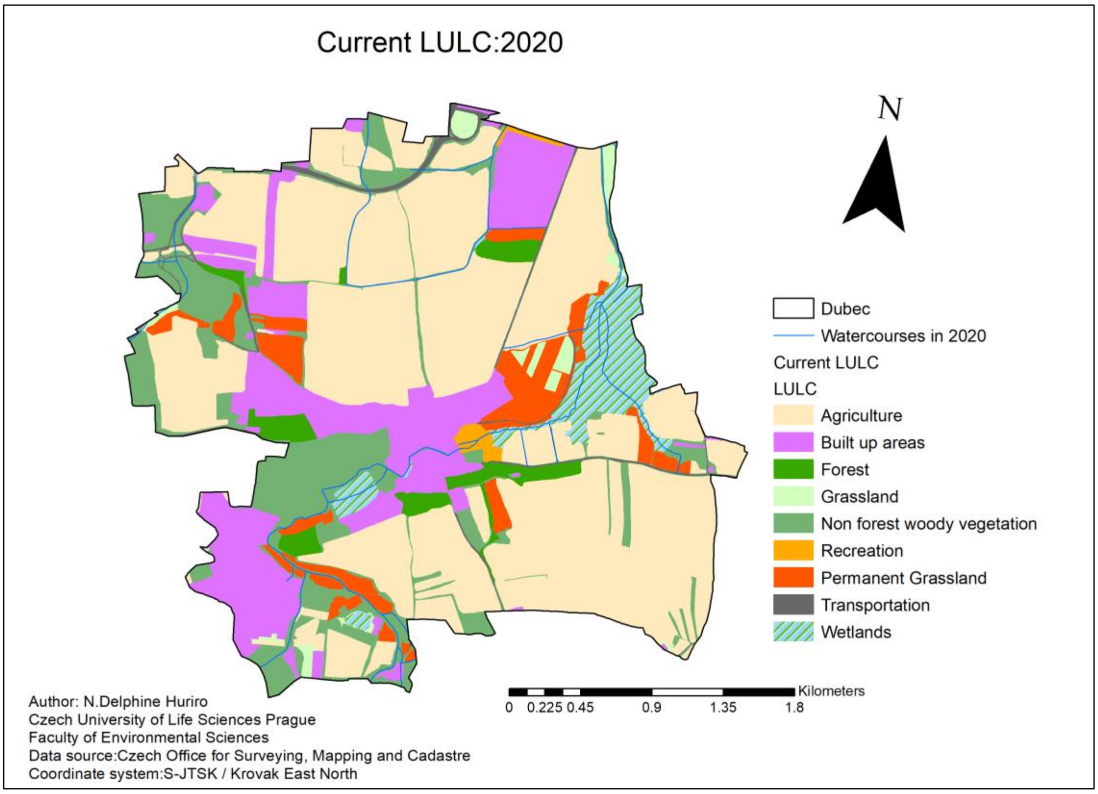
Appendix 2: LULC in 2020: Běchovice



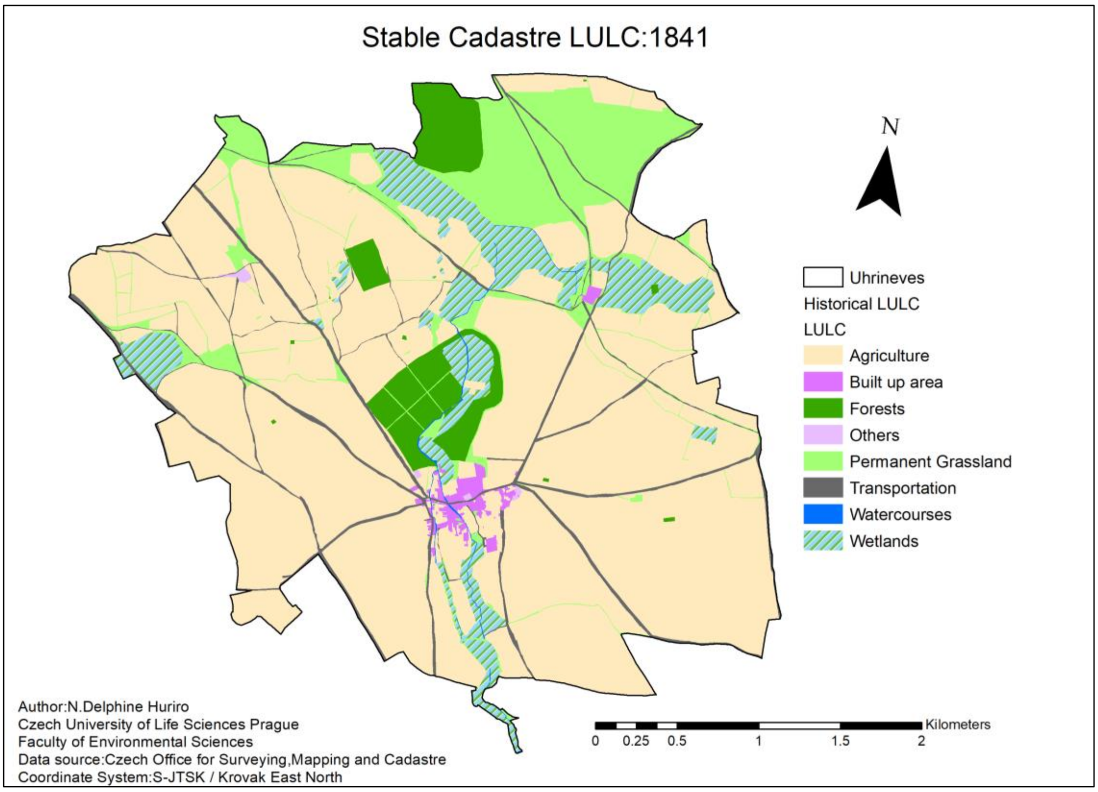
Appendix 3: LULC at the time of the stable of cadastre in 1841: Dubeč



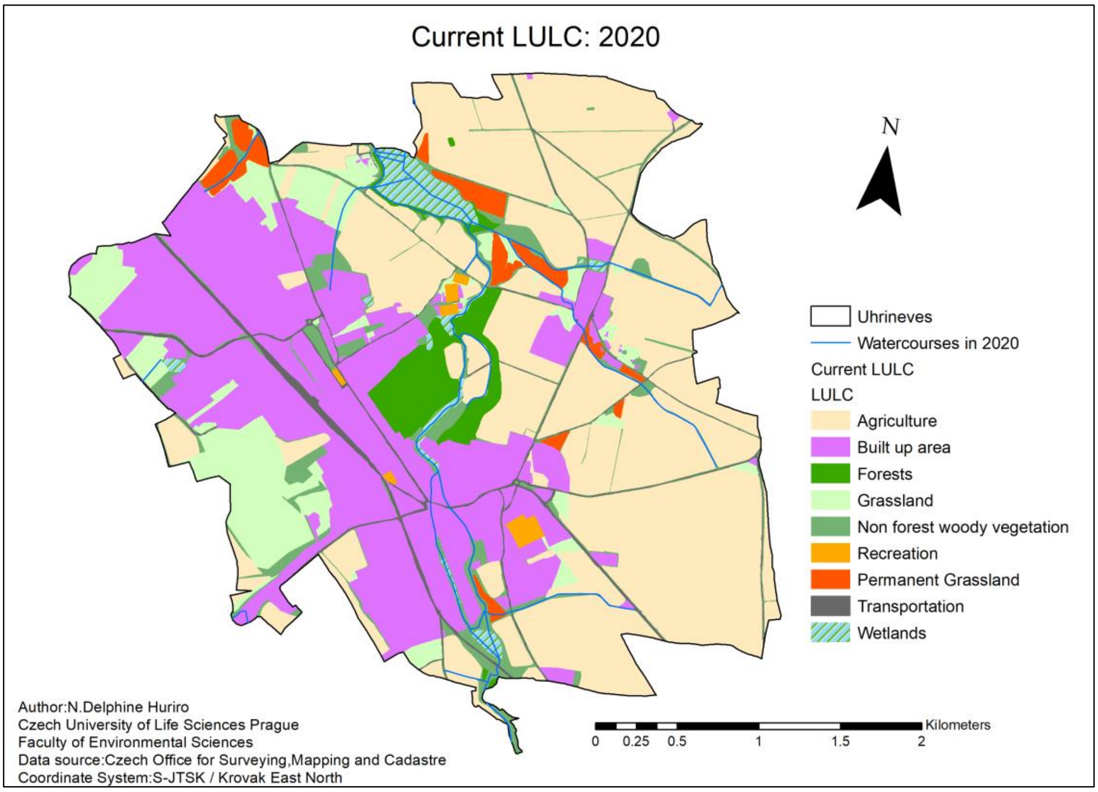
Appendix 4: LULC in 2020: Dubeč



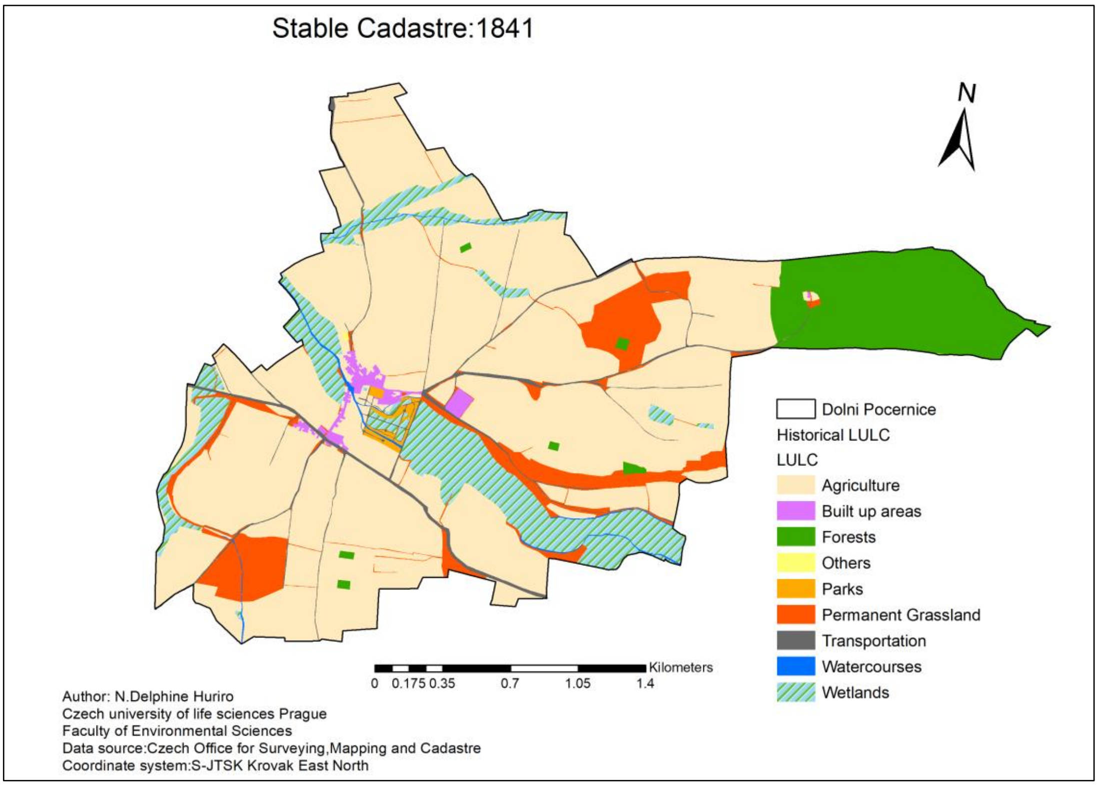
Appendix 5: LULC at the time of the stable of cadastre in 1841: Uhříněves



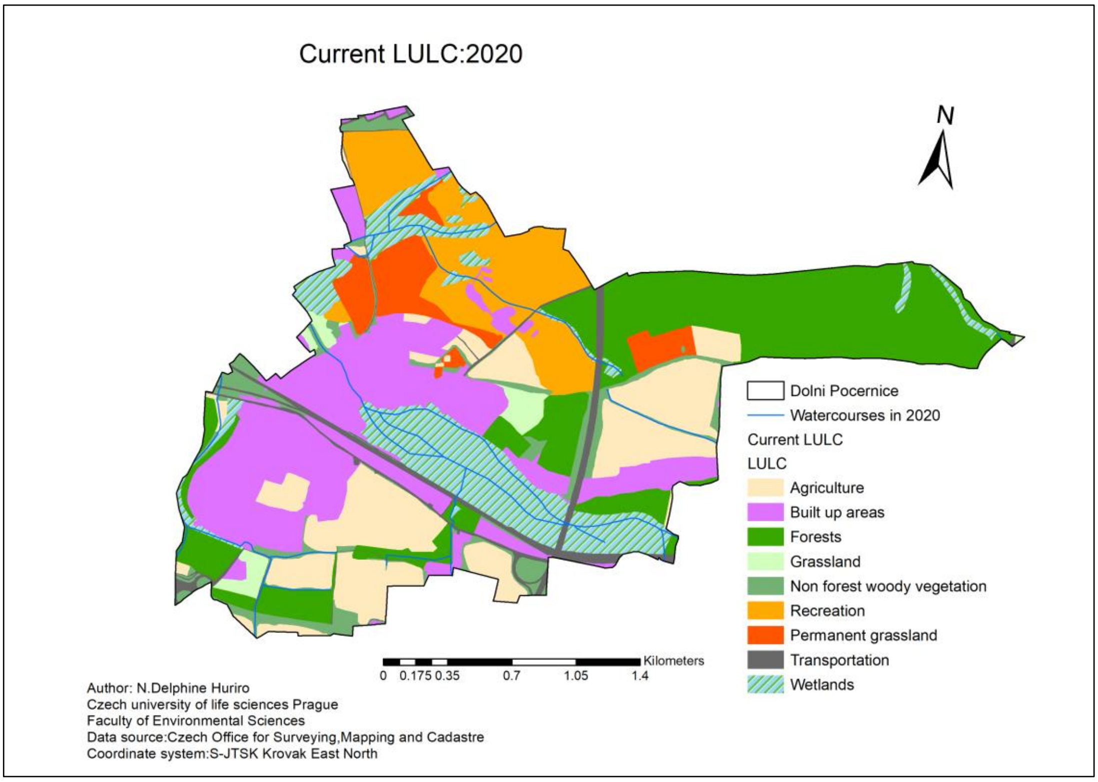
Appendix 6: LULC in 2020: Uhříněves



Appendix 7: LULC at the time of the stable of cadastre in 1841: Dolní Počernice



Appendix 8: LULC in 2020: Dolní Počernice



Appendix 9: Site visit photographs

Dolní Počernice pond system protected as natural monument

Waterlogged forest

Wetland vegetation-Phragmites australis (common reed)

Waterlogged meadow