CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

FACULTY OF ENVIRONMENTAL SCIENCES

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Environmental Sciences

Identifying activities leading to the worsening of the ecological status of the Botič Creek and proposal of restoration measures

MASTER'S THESIS

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DIPLOMA THESIS ASSIGNMENT

arch. Shruthi Vijay Kumar

Landscape Planning

Thesis title

Identifying activities leading to worsening of ecological status of Botič creek and proposal of restoration measures

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Objectives of thesis

This thesis focusses on two main objectives –
The first objective is to identify all the factors responsible for the worsening of the ecological status of Botič creek. Observing and documenting the activities leading to an urban stream syndrome would be the basis for the second main goal of the thesis. The customary approach by treating just the symptoms such as stabilization and modification of the stream channel will not provide a long-term solution for the urban stream syndrome. However, the restoration which focuses on the impervious surfaces, hydro morphology, chemical status, vegetation, storm water runoff and other parameters at the watershed level and then at the stream level would help in addressing the underlying long term repetitive problems and not just provide an ad hoc solution.
The second main goal of the project is to propose long term restoration methods for the improvement of the ecological status and management of Botič creek and its watershed area. The proposed methods would cover both general and specific solutions for long term restoration of the stream.

Methodology

The methodology in this thesis will involve three major parts-

The first part would involve gathering data of all categories such as: land use and land cover maps for identifying impervious surfaces, google maps, soil quality maps, assessing chemical status of water body from existing data, hydro morphological monitoring and identifying applied measures and strategies used by the municipality.

The second part involves analysing the accumulated data by correlating maps with other hydro morphological and chemical status of the stream to prepare a list of factors to be observed on site at the stream level and at the watershed level.

The third and final part of the thesis would be to prepare a proposal for long term restoration and management methods for improving the ecological status of the Botič creek and its watershed area.

The proposed extent of the thesis

60 pages

Keywords

Ecological status, Urban stream syndrome, hydro morphology, long term restoration, watershed

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Recommended information sources

Geoff J. Vietz, Christopher J. Walsh, Tim D. Fletcher (2015). Urban hydrogeomorphology and the urban stream syndrome: Treating the symptoms and causes of geomorphic change. Progress in Physical Geography: Earth and Environment, vol. 40, 3: pp. 480-492., 2015.

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Tim D. Fletcher, Geoff Vietz, Christopher J. Walsh (2015). Protection of stream ecosystems from urban stormwater runoff: The multiple benefits of an ecohydrological approach. Progress in Physical Geography: Earth and Environment, vol. 38, 5: pp. 543-555.

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Dean

Prague on 25. 03. 2024

Declaration

I hereby declare that I have independently elaborated the diploma thesis with the topic of: **Identifying activities leading to the worsening of the ecological status of the Botič Creek and proposal of restoration measures** and that I have cited all the information sources that I used in the thesis and that are also listed at the end of the thesis in the list of used information sources.

I am aware that my diploma 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.

In Prague date

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Shruthi Vijay Kumar

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I dedicate this thesis to the memory and teachings of Professor Ulhas Rane, Director of Envirodesigners Pvt. Ltd., who, although no longer with us, continues to inspire and, during his period, encouraged me to pursue my master's degree abroad. Professor Rane was a mentor and supporter, and I will always be grateful for his influence on my life.

Abstract

This thesis presents an in-depth analysis of the ecological health of the Botič Creek, the longest creek in the central Bohemia region and Prague. The study aims to identify the specific human activities that have contributed to the creek's ecological decline by investigating factors such as land-use changes in the surrounding floodplain, historical modifications, and potential sources of pollution.

To achieve this, the study employed various methods, including analyzing historical records and water quality data, mapping land use and land cover changes, identifying impervious surfaces, and conducting regular site visits to various locations on the watershed. The study's findings provide a comprehensive picture of the current state of the creek. They reveal the most detrimental activities and the factors contributing to the decline of the creek and its watershed's ecological status.

Moreover, this thesis explores potential long-term restoration measures for the Botič watershed and the creek channel. Based on the status of the watershed resulting from the map analysis and site visits, the research proposes interventions that promote ecological recovery. These interventions may include recommendations for improved water management practices, green infrastructure and solutions, public education and involvement, habitat restoration strategies, or even removing structures impacting flow and providing weighted overlay analysis using ArcGIS Pro according to the priority of the problematic aspects found at the watershed.

Overall, the thesis aims to contribute valuable insights into the long-term health of the Botič Creek. By combining a thorough assessment of threats with a vision for restoration, the proposed solutions can serve as a starting point in preparing a guide for local authorities and stakeholders to ensure a more sustainable future for this vital waterway.

Keywords: Watershed management, Urbanization, Botič Creek, Anthropogenic activities, Restoration.

Abstraktní

Tato práce představuje hloubkovou analýzu ekologického stavu potoka Botič, nejdelšího potoka ve Středočeském kraji a Prahy. Studie si klade za cíl identifikovat konkrétní lidské činnosti, které přispěly k ekologickému úpadku potoka, zkoumáním faktorů, jako jsou změny ve využívání půdy v okolní nivě, historické úpravy a potenciální zdroje znečištění.

K dosažení tohoto cíle studie použila různé metody, včetně analýzy historických záznamů a údajů o kvalitě vody, mapování využití půdy a změn krajinného pokryvu, identifikace nepropustných povrchů a provádění pravidelných návštěv na různých místech povodí. Závěry studie poskytují ucelený obraz o současném stavu potoka. Odhalují nejškodlivější aktivity a faktory přispívající k poklesu potoka a ekologického stavu jeho povodí.

Dále tato práce zkoumá potenciální dlouhodobá revitalizační opatření pro povodí Botiče a koryto potoka. Na základě stavu povodí vyplývajícího z mapové analýzy a návštěv na místě navrhuje výzkum zásahy, které podporují ekologickou obnovu. Tyto intervence mohou zahrnovat doporučení pro zlepšení vodohospodářských postupů, zelenou infrastrukturu a řešení, osvětu a zapojení veřejnosti, strategie obnovy biotopů nebo dokonce odstranění struktur ovlivňujících tok a poskytování vážené překryvné analýzy pomocí ArcGIS Pro podle priority problematických aspektů nalezených na povodí.

Celkově si práce klade za cíl přispět cennými poznatky o dlouhodobém zdravotním stavu potoka Botič. Spojením důkladného posouzení hrozeb s vizí obnovy mohou navrhovaná řešení sloužit jako výchozí bod při přípravě průvodce pro místní orgány a zúčastněné strany, aby zajistili udržitelnější budoucnost této životně důležité vodní cesty.

Klíčová slova: Management povodí, Urbanizace, Potok Botič, Antropogenní aktivity, Obnova.

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Abbreviations

BOD- Bio-chemical Oxygen Demand
COD- Chemical Oxygen Demand
EC- Electrical Conductivity
GI- Green Infrastructure
ISWS- Illinois State Water Survey
LULC- Land Use Land Cover
PLL- Playful Learning Landscapes
SS- Suspended Solids
SWAR- Stream and Watershed Assessment and Restoration program
SWS- Sub WaterShed
TP- Total Phosphorus
WFD-Water Framework Directive
WOA- Weighted Overlay Analysis

1. Introduction

Urbanization stands as one of the most transformative forces reshaping landscapes worldwide, imposing significant alterations on natural ecosystems, particularly the intricate networks of streams and watersheds. These changes could be wrought by a myriad of anthropogenic activities, ranging from the expansion of built environments to the intensification of industrial and agricultural practices (O’driscoll et al., 2010). As urban areas burgeon and infrastructural demands escalate, the ecological integrity and functionality of urban streams are increasingly compromised, giving rise to what is commonly termed as "urban stream syndrome" (Booth et al., 2016). This syndrome encapsulates a suite of challenges, including but not limited to, pollution, sedimentation, erosion, and alterations in hydrological patterns, which collectively threaten the health and resilience of urban aquatic ecosystems (Gillies et al., 2003).

The Botič Creek watershed in Prague reflects the challenges facing urban streams. Urbanization and historical land use changes have caused ecological stressors and environmental degradation, resulting in fundamental changes in the hydrological dynamics and ecological balance of the watershed. This poses existential threats to the integrity of the Botič Creek and its associated ecosystems (Sweco hydroprojekt, 2019). In addition, this has increased impervious surfaces such as roads, rooftops, and parking lots. Consequently, caused disrupted natural hydrological processes and worsened stormwater runoff, carrying pollutants into the Botič Creek, which degrades water quality and aquatic habitats. To address these issues, innovative and sustainable approaches are urgently needed for urban planning and design in the Botič Creek watershed (Nábělková et al., 2004).

In response to the increasing threats facing urban streams, there has been a growing interest in adopting regenerative approaches to urban planning and design. One such approach is regenerative architecture, which aims to use ecological principles and innovative technologies to restore and revitalize degraded landscapes. This is achieved through the implementation of green infrastructure, such as constructed wetlands, green roofs, bioswales, and permeable pavements, which are designed to mitigate the negative impacts of urbanization on stream ecosystems while increasing the resilience of urban landscapes (Palik et al., 2012).

Regenerative architecture offers a promising approach to address the challenges associated with urban stream degradation in urban streams and watershed. By implementing green infrastructure interventions including the restoration of riparian vegetation, wetland buffers, and permeable surfaces, it is possible to mitigate the impacts of urbanization on water quality and habitat integrity. These interventions can also provide additional benefits such as urban heat island mitigation, carbon sequestration, and recreational opportunities, contributing to more sustainable and resilient communities (Elmore et al., 1994).

This thesis employs an interdisciplinary approach to analyze the ecological dynamics in the Botic Creek watershed. The study aims to identify opportunities for improving environmental quality and socio-economic vitality by examining the interplay between human activities and ecological processes. The goal is to provide actionable recommendations for the revitalization and regeneration of urban streams, contributing to the evolving discourse on sustainable urban development and environmental stewardship. Through bridging the gap between theory and practice, this study seeks to inspire transformative change in how we perceive and manage urban waterways. The study's findings offer pragmatic solutions to foster healthier, more resilient, and ecologically vibrant cities for generations to come.

On this note, the Water Framework Directive (WFD) has established a regulatory framework for the measures of the European Community in the field of water policy. The WFD aims at reaching a good status of the surface and groundwater bodies. Procedures and instruments have been set up, which need to be implemented by the member states. The four countries in the Elbe River basin – Germany, the Czech Republic, Austria and Poland – have agreed to coordinate their approach for meeting the requirements of the Water Framework Directive in this river basin under the roof of ICPER (Water Framework Directive, 2021).

2. Literature review

2.1 Natural streams and anthropogenic impact

Natural streams are streams that human activities have not significantly altered. These streams have a well-developed ecosystem with diverse communities of aquatic and riparian species and are essential for maintaining water quality, preserving biodiversity, and providing recreational and aesthetic benefits (Green et al., 2022). In contrast to urban streams, human activities less impact natural streams and are typically characterized by a more stable flow and better water quality (Bhagat, 2011). In addition, natural streams provide important habitats for fish and other aquatic species, which can help maintain the creek's ecological balance (Coles et al., 2012).

The changing nature of the natural streams has continued to attract the attention of researchers and experts. The integrity and health of natural stream ecosystems are significantly affected by several anthropogenic activities such as agriculture and urbanization (Green et al., 2022). Therefore, measures are needed to mitigate the impact of such activities to ensure the sustainable use of natural resources. Anthropogenic activities driven effects vary on scale, time and space. A recent case study examined the impact and trends in stream biotic integrity and the anthropogenic factors over the last 19 years through spatial context data in Nebraska, USA. Changes in the macroinvertebrate indices characterized the changes in the natural streams and such changes were responsive to road density, elevation, latitude, and time. Furthermore, the changing stream diversity and the loss of integrity of the biosystems were preliminarily driven by a mix of factors including human activity and geography (Green et al., 2022). The stream profile of natural and urban streams are illustrated in (**Figure 1** & **2**).

Streams usually offer and support several ecosystem services. They host and support a significant portion of the faunal system and diversity in almost all continents. Aquatic animal population could significantly benefit the human population in terms of commercial fishing, recreational sports and improved water quality (Reid et al., 2019). However, human activities such as clearing land and building structures can affect aquatic ecosystems and may negate such benefits (Khatri & Tyagi, 2015; Raitif et al., 2019). Moreover, deforestation could further lead to habitat alterations, thus radically compromising the quality of the water in such catchment areas and interfere with the biotic communities and the channel morphology (Sweeney et al., 2004). Furthermore, the increasing human population and increasing land development have greatly impacted the global hydrologic systems and caused negative effects on aquatic organisms (Bhagat, 2011; Khatri & Tyagi, 2015). Therefore, there is a need for carefully managing and monitoring to understand how land use changes lead to habitat modification and causes changes in the natural stream systems (Finlay, 2011).

More recent synoptic investigations have also been done to explore the changes and trends in the stream communities and natural stream systems (Caletková et al., 2012; Tornwall et al., 2015). These studies rely on large-scale spatial systems to understand how land use changes and human activities affect the natural streams. For instance, an increase and decrease in stream invertebrates in different parts of the world has been reported (Crossley et al., 2002). Hatt et al. (2004) reported that the fish communities have become similar in the south-eastern parts of the U.S. It implies that agricultural activities and human practices are affecting the stream flows and interfering with the diversity of the ecosystem.

A recent study examined and documented the large spatial changes in stream ecosystems and their relationship with human activities and showed that human activities affected the natural streams in several ways, including alteration in water chemistry (Meador, 2020). In addition, the human activities also affected nutrient loads in the natural streams. Hatt et al. (2004) stated that the variability and changes might need to be better understood. Therefore, there is a need to carry out a constant analysis within different ecosystems to understand both local and global trends. In addition, there is a need to constantly monitor the natural stream changes to aid local policymakers understand the effects on natural streams by human practices and land use changes.

The other area that researchers have been focusing on when it comes to natural streams is the different land uses interfering with the natural stream ecosystem. Agriculture and urbanization are suggested to be the most impactful activities affecting the stream biota (Falcone et al., 2018). For instance, the impact of urbanization on the stream biota can be caused by sewage, and chemical pollution. The modern agriculture activities and systems could adversely affect the natural stream ecosystem through degradation, aquatic pollution, and deforestation (Reid et al., 2019). In other instances, agricultural activities can adversely affect the water cycles in the natural streams. Schmidt et al. (2019) concurred that agriculture and urbanization can result in hydrological alteration and increased channelization and at the end, they can interfere with the natural stream biota.

Researchers have a consensus that the expansion of agriculture and increased urbanization is affecting the natural streams (Khatri & Tyagi, 2015). The changes are supposed to increase because of the new farming methods, increasing customer demands, and the intense competition for space. Although the direct influence of intensive agriculture and land use are well understood, the indirect implication on the natural streams largely remains unexplored (Berger et al., 2017). In addition, the relationship between the stream biotic integrity and human activities requires intensive investigations. The inept understanding of the effect of human activities and human drive changes on the natural stream systems underpins the successful restoration and protection of such resources (Finlay, 2011). Understanding these changes will help making efforts that could be used as the basis for improving the ecosystem and managing anthropogenic disturbances as the number of natural streams are gradually dwindling due to urbanisation and land use changes (Lawler et al., 2014).

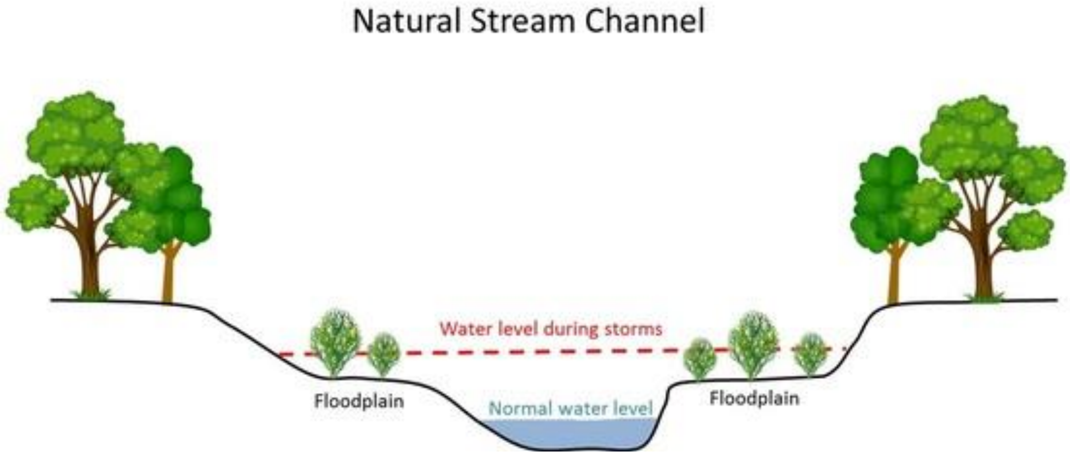


Figure 1. Typical Stream profile for a natural stream. Source: (Shannon White, 2016)

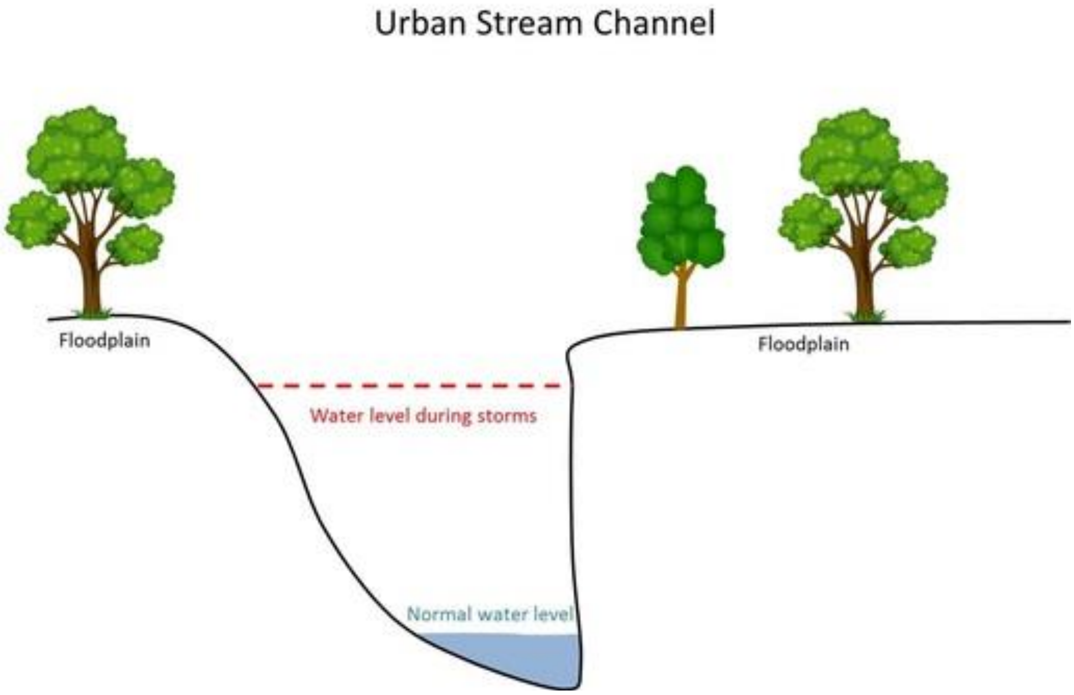


Figure 2. Typical Stream profile for an urban stream. Source: (Shannon White, 2016)

2.2 Land use changes

Land use changes refer to alteration in land for various purposes, including agriculture, urban development, and recreation. These changes have significant impacts on ecosystems, including streams and their biotic communities. They can disrupt natural water flow patterns, reduce riparian vegetation, and introduce pollutants into the water (Ellis, 2011). Such alterations often lead to degraded water quality and loss of habitat for aquatic species, consequently negatively affecting the ecological health of streams. Land use changes, such as deforestation and agriculture, have profound impact on the environmental condition of the Botič Creek (Bičík et al., 2006), and can result in an increase in soil erosion and runoff into the creek (Ellis, 2011). As a result, increased runoff carries sediment and pollutants, which can degrade the quality of the creek's water. Similarly, agricultural practices like intensive tilling and pesticide use can further exacerbate the degradation of the creek's water quality (Dramstad et al., 1996).

The current global extent, intensity, and impacts of land use are unprecedented in Earth's history. Human activities such as deforestation, urbanization, and agriculture have transformed vast areas of the planet and have significantly impacted the natural environment (Alshammari et al., 2023). Over the past century, the scale and speed of land-use changes have been enormous, with far-reaching consequences. Deforestation has led to declines in biodiversity, increased greenhouse gas emissions, and altered regional climates. Additionally, urbanization has resulted in the fragmentation of natural habitats, increased pollution levels, and loss of critical ecosystem services. Agriculture has also significantly impacted the land, with vast areas being converted to croplands and pasturelands, leading to the loss of natural habitats, and decreased biodiversity. The intensification of agriculture, through monoculture crops and the application of fertilizers and pesticides, has negatively impacted soil health, water quality, and the wider environment (Stenger-Kovács et al., 2020). It is crucial to note that these impacts affect the natural environment and have significant social and economic consequences, particularly for communities that rely on the land for their livelihoods (Theodosiou et al., 2023). Therefore, finding sustainable solutions to these challenges is crucial for preserving the planet's ecosystems and the well-being of its inhabitants. Thus, attempts are being made to understand the concept of land use and determine how it can be managed and addressed (Lawler et al., 2014).

Several studies have examined and explored the concept of land use change. For instance, according to Lawler et al. (2014), land use change tends to significantly alter the provisions and elements of the ecosystem services. At the global level, the ongoing conversion of forests, grasslands, and wetlands into plantations, developed areas, and croplands has resulted in increased production of commodities such as timber, food, and housing. However, the author noted that these changes have come at the cost of reducing biodiversity levels and the availability of ecosystem services to human beings. Ellis (2011) argued that recent land use changes have been rapid not only in the tropics but globally. The author added that these changes have impacted landscape patterns as well as ecosystem functions and services worldwide.

Such changes are significantly and adversely affecting human livelihoods (Jepsen et al., 2015).

A review of existing literature shows that the study and understanding of land cover and land use changes have transitioned from a focus on simplicity to realism (Bičík & Kupková, 2006). Additionally, attempts have been made to examine the complexities that define land use trends worldwide. Researchers have also realized that the land surface processes affect climate due to land cover and land use changes. Recent studies have focused on a broad spectrum of effects of land use changes, including soil degradation, the ability to support biological systems, and biotic diversity on the global stage (Falcone et al., 2018). Ding et al. (2015) underscored that mediating and monitoring the negative effects of land use changes while also working on ways of sustaining the production of critical resources has become a priority for many policymakers, experts, and researchers. Moreover, sustainable human activities have become a critical environmental concern since they can affect the kind of life people love. Thus, land use changes are portrayed in modern literature as a trend affecting human life and sustainability worldwide (Falcone et al., 2018).

The human population and the way people use land have significantly transformed the terrestrial biosphere into unique anthropogenic biomes. This transformation is generally caused by various ecological processes and patterns that emerge from different regions worldwide. Ellis (2011) emphasized that the recent issues related to land use changes had attracted the attention and interest of diverse groups of researchers. This ranges from the people who favour and support modelling of the spatiotemporal aspects of land conversion to the ones who are interested in understanding the causes, effects, and implications of the land use changes. The land use effects, and land cover changes have affected how people live and these changes generally leads to land degradation (Parveen et al., 2018). Similarly, the changes also affect water systems, biodiversity, and radiation budgets, which are critical to the biosphere and climate change management efforts (Langan et al., 2004). At the same time, human activities that are influenced and motivated by socio-economic factors result in the creation of new physical conditions and built-up environments that might not be suitable for delivery of the right biodiversity services (Crossley et al., 2020).

Worldwide alteration of the environment, including the farmlands, forest, and waterways, are usually driven by the desire to get shelter, food, water, and fibre for the billions of people living on the planet (Foley et al., 2005). The land has been expanded and overexploited to meet the increasing needs of the global population. However, the increase and land use changes are usually accompanied by increased fertilizer, energy, water, and crop consumption. These factors adversely affect the level of anthropogenic diversity. averred that the increased conversion of the previous croplands into new grasslands has led to environmental changes. Furthermore, demographic, institutional, and socio-economic changes around the globe also influence these changes. For instance, a study showed that the recent changes in land use trends are influenced by socio-economic factors and land reforms undertaken in different parts (Antrop, 2004). In addition, these land reform programs are clear large forest areas to make way for farming plots, homes, and the built environment.

A recent study examined land use changes over the past forty years and reported significant land use changes with increased creation of built-up environments in many regions including clearing of forests to facilitate new buildings and economic activities (Shankar et al., 2021). Similarly, settlements, uncultivated lands, and wastelands have also been reported to increase in recent years largely due to anthropogenic activities (Khan, 2016). These changes have significant ecological consensus and affect livelihoods. For instance, deforestation leads to the destruction of freshwater habitats, increased siltation and affect the carbon sink by changing the global environment and ecosystems. These changes can affect ecological sustainability and pose significant challenges within the context of human environmental science (Sweeney et al., 2004).

2.3 Urbanisation

Urbanisation refers to the development of urban areas by converting rural lands into urban. This process can significantly change streams' physical and biological characteristics and surrounding areas (**Figure 3**). It can increase runoff, sedimentation, nutrient loading, and temperatures, leading to a decline in the ecological status of streams (Smith et al., 2016). Urbanisation is a major factor contributing to the worsening of the ecological status of creeks and rivers. As urban areas expand, the creek's water quality is negatively impacted by runoffs containing pollutants such as oil, heavy metals. The increased flow due to various reasons can cause physical changes in the creek and increase erosion and sedimentation (Hawley et al., 2020).

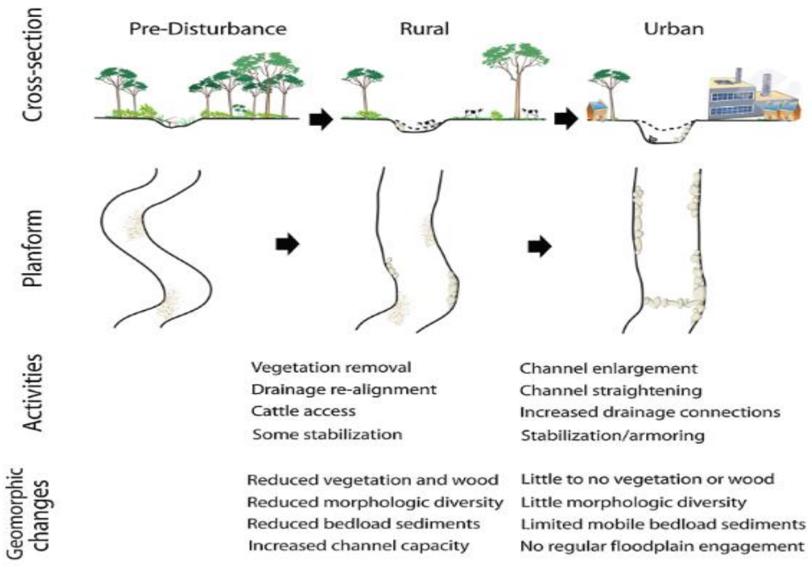


Figure 3. Examples of common physical impacts on stream channels prior to urbanization. Source: (Vietz et al., 2016)

Urbanization can increase impervious surfaces, such as roads and buildings, leading to increased runoff and decreased water infiltration into the soil. This, in turn, can result in increased flooding, decreased water quality, and altered flow regimes in streams. This is especially true for streams and their surrounding environments, as land use changes can significantly impact water quality, hydrology, and habitat conditions (Bhagat, 2011). For example, converting forests and wetlands into urban or agricultural lands to cater needs of expanding population can compromise water quality and habitat by increased runoff and sedimentation. In addition, the introduction of pollutants from human activities can further amplify these effects on the ecological status of streams. Therefore, it is crucial to understand the impacts of land use changes and urbanization to develop strategies for mitigating these impacts. This can involve better land use planning and policy measures as well as the implementation of sustainable management practices for agriculture and urban areas (EPA, 2005).

Urbanization mediated rapid industrialization have led to increased pollution levels in the creeks, primarily from industrial effluent, sewage discharge, and solid waste (Antrop et al., 2000). In some cases, unplanned urbanization often results in altered natural water flow patterns that can result in decreased water flow in the creek and cause the creek to dry up during summer periods (Vietz et al., 2012).

The development of urban areas has been affected by various changes since the 1970s including the collapse of centrally planned economies, the spread of democratic values, the recognition of self-determination, decentralization and citizen empowerment, citizens' pressure to hold governments accountable, and the rise of pluralism (Antrop, 2006).

The process of urbanization also decreases groundwater levels by preventing water to enter soil horizon in natural way or by altering water cycle (**Figure 4**). Consequently, more occurrences of heavy rainfall require more intensive flood protection measures. To divert rainwater away from urban areas, sewers are constructed, which can further exacerbate torrential rainfall and lower groundwater levels (Antrop, 1997).

Artificial reservoirs and straightened watercourses are common in urban areas, but they disrupt the natural movement of aquatic communities. These alterations negatively impact the ability of streams to handle floodwaters. In natural areas, floods occur every 1.2 to 2.4 years, but in urbanized areas, they can occur multiple times a year (Shao et al., 2020). It can result in excess loss of soil, increased toxicity, and increased amounts of suspended solids in the water. Further, it can lead to streambank erosion and channel siltation and hinder the natural progression of aquatic communities and cause destruction of habitats (Donohue et al., 2009).

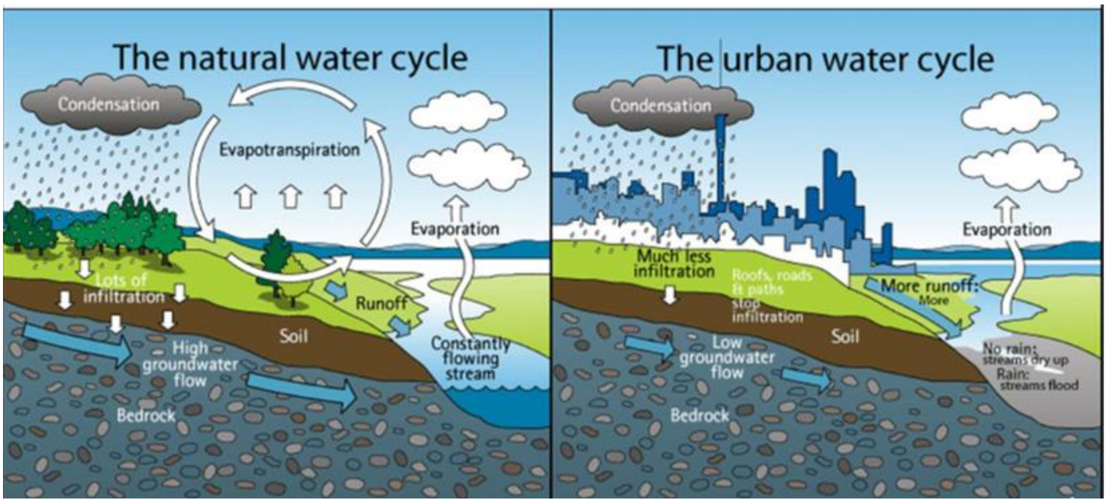


Figure 4. Schematic diagram showing the comparison between natural and urban water cycle. Source: (Auckland Council)

2.3.1 Urbanisation as a source of pollution

Human activities such as consumption, behaviour, and construction have a significant impact on the environment, leading to the depletion of natural resources and an increase in waste. The conversion of agricultural and forested land to urban infrastructure has resulted in extraction of materials like sand, gravel, and stone (Nations et al., 2018). Burning wood for fuel has also led to air pollution, which has affected both urban residents and ecosystems. Natural factors such as pests, insects, and extreme weather changes can also lead to the destruction of forests. The transportation and industrial production in cities are major contributors to this pollution (Raitif et al., 2019).

Urbanization related infrastructures such as industries and plants contribute significant amount of chemical and particulate wastes. Human activity contributes to surface water pollution mainly through the discharge of wastewater into receiving bodies of water, as well as agricultural runoff from fields and buildings. Nitrate, on the other hand, is produced as a secondary product through the nitrification of ammonium nitrogen (Foulon et al., 2020). Effluent discharges can have a significant impact on water chemistry, depending on the level of dilution. Water contaminants can affect factors such as water purity, dissolved oxygen concentration, and pH levels. The impacts of water quality changes are multifaceted, and some contaminants can have interrelated effects on ecosystems (Kim & Chung, 2022).

In certain instances, high levels of dust aerosols can reduce the harmful effects of some pollutants. However, dust aerosol is only beneficial in limited amounts since it contains organic matter that serves as an energy source for aquatic invertebrates (Malik et al., 2020). Changes in pH levels can have significant impacts on streams, as a decrease can cause the release of heavy metals or phosphorus, while an increase can disrupt biochemical processes. Excessively high nutrient concentrations can result in the overgrowth of aquatic plants, leading to reduced amounts of dissolved oxygen (Zhang et al., 2018).

Urban storm sewers are constructed to direct rainwater from rooftops and roads into drains that empty into receiving waters. These systems tend to gather and concentrate large amounts of debris and trash, which can then be transported to the receiving water (Claytor & Schueler, 1996). These larger debris are not as harmful to the ecological health of the water compared to chemicals and smaller chunks that are harder to get rid of. In addition, urbanization can impact water temperature by increasing surface run-off in cities, which can exacerbate algal growth (Paul & Meyer, 2001).

As for the level of urbanization, it can affect the peak flow rates in streams and lead to the disappearance of species that typically colonize the water during the dry season (Walsh et al., 2005). Insects and other small creatures are always exposed to harmful substances in the environment. The benefit of studying them instead of fish is that they are found everywhere, they are numerous, and they can live long enough to provide useful data. Additionally, they are affected in unique ways by different types of pollutants (Crossley et al., 2020b).

2.3.2 Sedimentation in urbanized area

Urban areas have a higher flow rate and therefore a greater ability to transfer materials, resulting in coarser sediment and a higher proportion of large particles in the bottom substrate than rural and natural areas (Russell et al., 2018). However, Wolman's (1967) model suggests that the transport of very fine sediment (suspended load) may not always be affected by urbanization, as the sediment load will decrease once an urbanized zone is established. In practice, this has not always been the case due to ongoing construction or surface reorganization (Wolman, 1967). Construction activities can cause sudden manyfold increase in sediment transport per year, but after construction is completed, there is a sudden extreme decrease due to the extensive disturbance of the soil pool in a limited area (Meyer et al., 2005).

2.4 Urban streams

Human activities, such as urbanization, industrialization, and agriculture, have created urban streams. These can be defined as waterway that flows through or adjacent to an urban area, such as a city or a town. These streams are often affected by human activities, such as land use changes, stormwater runoff, pollution, and alterations to the stream channel and flow regime. They are vital parts of ecosystem services, such as water supply, flood control, and habitat for aquatic and terrestrial species (Paul & Meyer, 2001).

Urban streams are impacted by various human activities, including land use changes, urbanization, and the discharge of pollutants into the water (Komínková et al., 2012). These effects can result in the degradation of water quality and the loss of habitat for aquatic species and decline the ecological status of urban streams. The range of negative impacts on the creek's water quality include increased sedimentation, decreased oxygen levels, and a reduced aquatic diversity (Paul & Meyer, 2001).

Highly urbanized regions are emerging in various parts of the world as major population lives in urban centres and cities. Streams in highly urbanized regions usually face significant environmental implications and diverse conservation issues as urban streams around the world (Zhang et al., 2015). Grimm et al. (2008) showed that urban streams had been affected by contaminants, discharge of waste waters, and degradation of the systems. The study further showed that the increased human activities, coupled with the lack of ecological awareness and willingness to protect the environment, caused significant damage to the urban streams (Komínková et al., 2012). Therefore, it is crucial to understand the functioning of such ecosystems and develop the right interventions for protecting them.

Several studies have investigated the nature of urban stream changes worldwide and the kind of interventions needed to respond to them. The status has shown that the urban streams are largely heterogeneous and such heterogeneity arises from biota, water quality, physical habitat, and hydrology differences (Booth et al., 2016). There are significant regional and local differences in terms of the environmental conditions in the urban streams and the kind of responses developed toward the issue. The differences arise because of the lack of uniformity in the factors that cause changes in the urban streams, implying that urban stream changes are complex and require complex management approaches (Walsh et al., 2005).

2.4.1 Urban stream syndrome

Various human activities, including land use changes, urban runoff, and the discharge of pollutants into the creek, can cause these impacts (Walsh et al., 2005). Urban streams are prevalent in all parts of the world and most of the existing urban streams are being degraded rapidly (Smucker and Detenbeck, 2014). In addition, the urban streams tend to have degraded biological, chemical, and physical conditions unsuitable for the ecosystem (Booth et al., 2016). The existing conditions in the urban streams are commonly referred to as the urban stream syndrome. The awareness of communities has motivated policymakers to work on avenues through which they can enhance the operations of the systems (Walsh, 2021). Human activities continue to alter the structure of such ecosystems, thus reducing the services that these systems offer exponentially (Vietz et al., 2012). In this regard, the urban stream syndrome offers an important conceptual framework for developing common responses and interventions for addressing watershed urbanization. Booth et al. (2016) further stated that urban stream syndrome had become a significant concept for experts and policymakers. The trend is attributed to the fact that urban stream syndrome affects the function of the ecosystems and the kind of services they provide. In cases with urban stream syndrome, there will be diminished ecosystem function and services as the urban streams will have a bad state compared to the natural streams (**Figure 5**).

Urban streams are waterways that run through urban areas and play crucial role in providing ecosystem services and supporting the health of surrounding communities (Smith et al., 2016). Over the past few decades, a growing body of research has focused on understanding the impact of urbanization on the ecology of urban streams. MacKenzie et al. (2022) further added that urbanization had been shown to profoundly impact urban streams' physical, chemical, and biological characteristics. Increased impervious surfaces, sewage discharges, and stormwater runoff can result in increased stream temperatures, decreased water quality, and altered nutrient and sediment loads (Donohue & Molinos, 2009). On the other hand, Parr et al. (2016) indicated that urbanization has been shown to alter the hydrology of urban streams, which can negatively impact aquatic organisms. Changes in flow regime, channel morphology, and water table levels can alter the habitat conditions for aquatic species and disrupt their migration patterns. Similarly, Booth et al. (2016) opined that urban streams are often characterized by a decline in biodiversity, as many native species cannot survive in altered conditions. Urbanization often impacts sensitive species such as macroinvertebrates, fish, and amphibians, which can reduce the overall ecological health of the stream. Therefore, restoring such streams and addressing the urban stream syndrome requires understanding the causative factors and creating the best management practices to reverse the trend (Walsh et al., 2005).

Overall, an extensive body of literature suggests that urban streams are vulnerable given the impacts of urbanization and there is a pressing need for effective management strategies to restore and protect these important ecosystems. Restoration of urban streams requires a multi-disciplinary approach and can involve a combination of methods (Hatt et al., 2004).

A significant portion of rainfall in forested watersheds is absorbed into soils (infiltration), is stored as groundwater, and is slowly discharged to streams through seeps and springs. Flooding is less significant in these conditions because some of the runoff during a storm is absorbed into the ground, thus lessening the amount of runoff into a stream during the storm (Miller & Hess, 2017).

As watersheds are urbanized, much of the vegetation is replaced by impervious surfaces, thus reducing the area where infiltration to groundwater can occur. Thus, more stormwater runoff occurs-runoff that must be collected by extensive drainage systems that combine curbs, storm sewers, and ditches to carry stormwater runoff directly to streams. More simply, in a developed watershed, much more water flows into a stream much more quickly, increasing the likelihood of more frequent and severe flooding. Frequent flooding causes problems for residents and the local government, which must clean up sand and sediment deposited after a flood (Miller & Hess, 2017).

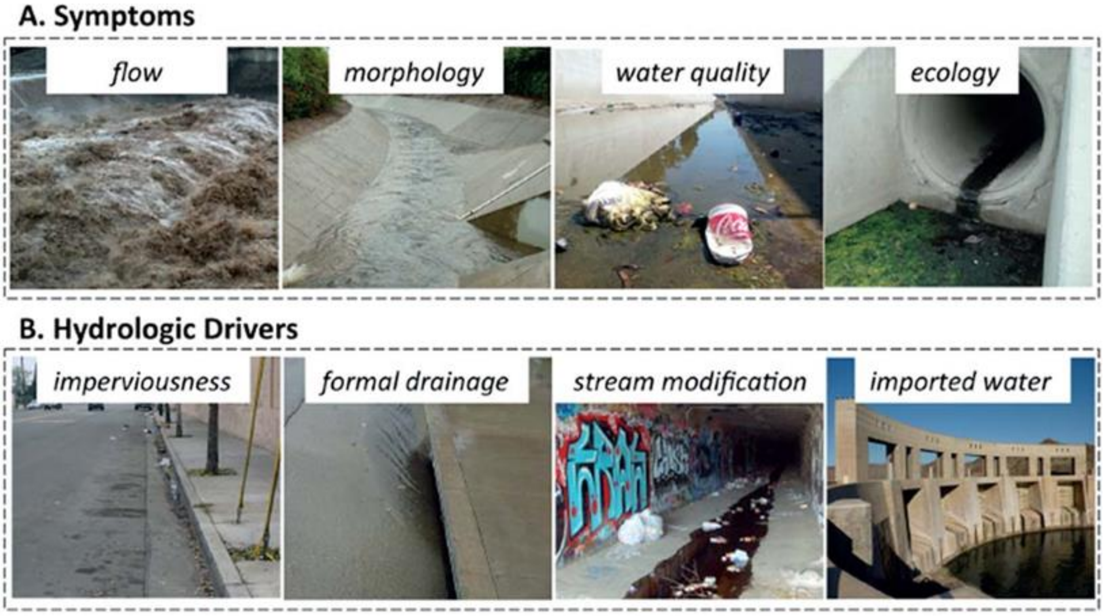


Figure 5. Symptoms and hydrologic drivers of urban stream syndrome. Source: (Feldman, 2017)

2.4.2 Symptoms of urban streams

2.4.3 Floods

Flooding of urban streams is a major problem in many cities worldwide. This could be partly due to increased impervious surfaces such as roads, buildings, and parking lots, which reduces the natural infiltration of rainwater into the soil. Instead, water runs off these surfaces into the stormwater drainage systems, which often discharge directly into urban streams. Under extreme rainfall event, the increased volume and velocity of water in these streams can cause flooding and damage to nearby infrastructure and properties (Miller & Hutchins, 2017).

2.4.4 Drying up during summer

Rivers drying up in summer is a common phenomenon in areas with arid or semi-arid climates around the world. The preliminary cause of this is a reduction in water flow due to low precipitation and increased evaporation during hot and dry summer (Arnell & Gosling, 2016). Human activities such as irrigation, damming, and water extraction can exacerbate the problem by further reducing the water available to the river. The impacts of drying rivers can be severe, including loss of aquatic habitat, reduced water quality, and impacts on local economies that rely on the river for agricultural or recreational purposes (Grill et al., 2015). Management strategies to address this issue include water conservation measures, improved water allocation and management practices, and restoration of degraded river habitats (Palmer et al., 2009).

2.4.5 Erosion

Erosion in cities is a growing concern due to urbanization and human activities. The increase in impervious surfaces reduce the natural infiltration of rainwater into the soil, leading to increased water runoff and erosion of soil and sediment. Impervious surfaces disrupt the natural hydrological cycle, increasing the volume and velocity of surface runoff (Sun et al., 2019). This intensified runoff accelerates soil erosion and sediment transport, causing the destabilization of slopes and contributing to the deterioration of urban infrastructure (Ferreira et al., 2021). Moreover, the removal of natural vegetation during urban development reduces the ability of root systems to hold soil particles in place, further exacerbating erosion rates (Whitney et al., 2015).

One of the primary drivers of erosion in urbanized areas is the alteration of land cover (Polovina et al., 2021). The loss of vegetative cover also diminishes the capacity of the landscape to absorb and store water, increasing the susceptibility of urbanized areas to flooding and sedimentation. Construction, excavation, and land development activities also contribute to erosion. Solutions to mitigate erosion in cities include green infrastructure, such as rain gardens and green roofs, and erosion control measures, such as sediment basins and silt fences (Norris & Greenwood, 2006).

2.4.6 Deeping and widening of the stream channel

Deepening and widening of a stream channel is a common technique used in river management to increase its capacity to carry water and reduce the risk of flooding. This involves excavating the riverbed and banks to create a wider and deeper channel, which allows the river to carry a larger volume of water during high flow periods (Podraza & Paul, 2000). While this approach can be effective in reducing the risk of flooding, it can also have negative impacts on the river ecosystem, such as habitat loss, erosion, and altered flow dynamics. Therefore, the decision to undertake channel deepening and widening should be based on careful assessment of the potential environmental impacts, as well as consideration of alternative management approaches that may be less disruptive to the river ecosystem (Gurnell et al., 2012).

2.7 Regenerative architecture

Regenerative architecture is a method of constructing structures and built environments that actively repairs and regenerates the environment while going beyond sustainable design principles. It includes designing structures and landscapes that blend in with the environment, utilizing renewable resources, and reducing waste, pollution, and energy usage. In a broader sense, it is a design philosophy that aspires to produce structures and settings that actively promote the health and welfare of the Earth and its inhabitants (Cao et al., 2022).

Regenerative design considers a buildings whole life cycle, from its construction, and use to its removal, when it servers the purpose. This strategy entails the use of environment friendly materials, energy-efficient design, the inclusion of green areas and natural ventilation, and the development of environments that promote a sense of connection with nature (Dehvari et al., 2023).

Scaling down to an urban watershed, regenerative architecture and infrastructure can contribute to mitigate various aspects in the watershed level even before the excess polluted water enters the stream channel. The load of mitigation measures and pollutants could be significantly reduced. At the channel level the riparian zone could be treated with various bio-engineering methods to help in self-maintenance of the stream (Gurnell et al., 2012).

2.7.1 Green infrastructure

Green Infrastructure (GI) is defined as a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings (Pitman et al., 2015).

Green infrastructure provides multiple benefits to people and the environment including improving air and water quality, regulating temperature, reducing urban heat islands, providing habitat for biodiversity, and enhancing the health and well-being of people. It can be created through the restoration and enhancement of existing green spaces, the creation of new parks and green areas, the incorporation of green roofs and walls into buildings, and the use of green corridors to connect different habitats (Moskvin, 2021). The Czech Republic has implemented several initiatives to promote green infrastructure, such as the development of national and regional green infrastructure strategies, the establishment of protected areas and wildlife corridors. Stakeholder engagement is essential for the success of green infrastructure initiatives, as it ensures that the needs and priorities of different groups were considered (MŽP ČR).

Storm water control and stream restoration are proven ways to reduce erosion along water channels. Land management practices with common goals might have a greater positive impact on erosion (Rees et al., 2023). Storm water management systems are necessary in nature, as precipitation falls onto forests, prairies and other soil-based areas and the water is soaked into the soil, down into the water table, and out into water bodies. In cities, pavement, rooftops, and other structures shift the water cycle. Newer storm water management approaches, called green infrastructure, could further improve the system (Murray, 2020).

2.7.2 Green roofs

Green roofs are vegetated roofs that reduce stormwater runoff by absorbing and retaining the water in the soil medium for plant growth. They are easy to incorporate into new construction and can be used on many existing buildings. They filter pollutants and carbon dioxide, reduce noise pollution, and serve as living habitats for birds and other wildlife (Thokchom et al., 2022).

Green roofs have the potential to reduce stormwater runoff and improve water quality, but their effectiveness depends on factors such as vegetation, soil depth, and drainage system (Vargas-Hernández et al., 2023). Green roofs also have the potential to facilitate habitat restoration in urban areas by providing additional habitats for plants and animals. The problem of habitat loss due to urbanization and the importance of creating green spaces in cities to support biodiversity is critical (Liberalesso et al., 2020). Examples of green roofs designed to support habitat restoration, such as green roofs that have been planted with native species, designed with specific microhabitats, or integrated with bird boxes and insect hotels. Proper design and management practices should be followed to address the challenges associated with green roof habitat restoration. Green roofs can play a key role in restoring biodiversity in cities (Šenfeldr et al., 2020).

2.7.3 Permeable pavement

The environmental performance of permeable pavement systems (PPS) and the key factors that affect their performance, such as pavement material, design and construction, maintenance practices, and climatic conditions. The need for long-term monitoring of PPS, understanding the interactions between PPS and underlying soils, and developing better design guidelines and maintenance practices. PPS have the potential to mitigate environmental impacts, however, more research is needed to fully understand their performance and develop best practices for their design and maintenance (Drake et al., 2013).

The European Union Water Framework Directive (WFD) was applied to California's Lower Sausal Creek Watershed to restore natural hydrology and ecological functions (Li & Wardani, 2008). Unpaying benefits of WFD include increased infiltration, groundwater recharge, improved water quality, and habitat restoration for native species (Li & Wardani, 2008). Challenges in urban areas involve community engagement, stakeholder involvement, limited funding, and regulatory barriers. A comprehensive approach to watershed management, considering social, economic, and ecological aspects, is essential. The WFD can serve as a useful model for addressing these challenges globally (Giakoumis & Voulvoulis, 2018).

The impact of impervious surfaces on urban streams and strategy to reduce the frequency of runoff events from these surfaces is critical to understand. The importance of stakeholder involvement and community engagement in the implementation of these techniques, consider the need for policy and regulatory support to incentivize the adoption. The benefits of the proposed strategy include improved water quality, reduced erosion and habitat destruction, and enhanced urban aesthetics. The challenges associated with the implementation include limited funding and resources, technical barriers, and regulatory hurdles (Ladson et al., 2006).

2.7.4 Bioswale

Bioswale is a type of green infrastructure designed to manage stormwater runoff from impervious surfaces such as roads, parking lots, and rooftops. It is typically filled with a mixture of soil, sand, and compost, which allows water to infiltrate and be filtered as it flows through the vegetation. Bioswales are considered a sustainable and cost-effective solution for managing stormwater runoff and provide several co-benefits such as improving air quality, reducing urban heat island effects, and providing habitat for wildlife. Proper maintenance is important to ensure their continued effectiveness (Ekka et al., 2021).

The design process also considers the desired water quality outcomes and the specific pollutants to be treated. Maintenance is a crucial aspect of bio swale performance and includes regular inspection, sediment removal, and vegetation management (Bioswales).

Bioswales is a sustainable and cost-effective solution to hydrological problems caused by urbanization. The main factors that need to be considered during the design phase, are the size and slope of the area, soil and vegetation selection, and the expected volume of storm life runoff (Lee, 2019).

2.7.5 Constructed wetlands

Constructed wetlands are man-made wetland systems designed to mimic the natural functions of wetlands. They can be used for various purposes, such as wastewater treatment, stormwater management, and habitat restoration. Different types of constructed wetlands have their own unique characteristics and are designed to address specific environmental challenges. The Guiding Principles for Constructed Treatment Wetlands provides information on designing and maintaining a constructed wetland, including selecting the appropriate plant species, monitoring water quality, and managing invasive species. It emphasizes the importance of proper design and maintenance to ensure the success of a constructed liquid land system.

Constructed wetlands for wastewater treatment, including the treatment of domestic and industrial wastewater, agricultural runoff, and landfill leachate. It provides examples of successfully constructed wetland projects and highlights their potential as a sustainable and effective solution for managing wastewater in a wide range of contexts. It also discusses the differences between constructed wetlands and their various applications, such as the need for large land areas and the potential for clogging or other operational issues. Despite the challenges, constructed wetlands are generally cost-effective and have lower energy requirements than other treatment technologies (Moshiri, 2020).

The potential of constructed wetlands lies in addressing environmental challenges in developing countries, such as industrial growth and climate change impacts. Examples of successful constructed wetland projects in Bangladesh, where they have been used to treat wastewater from textile factories. Such projects can potentially improve water quality and create economic opportunities for local communities. Partnerships between governments, NGOs, and private sector entities can help overcome the challenges of developing countries with limited resources and technical expertise to ensure their success (Helfield & Diamond, 1997).

Constructed wetlands are used as a tool for stream restoration in urban streams to restore the ecological health of urban streams. Challenges associated with using constructed wetlands include limited space and maintenance, and careful planning and management are essential for successful projects (Scholz & Lee, 2005).

Similarly, Phytodepuration is another sustainable and environmentally friendly approach to wastewater treatment that can be used in a variety of settings, including rural areas, small communities, and industrial sites. It is more cost-effective and energy-efficient than traditional wastewater treatment methods and can provide additional benefits such as enhancing biodiversity and creating new recreational opportunities. The different types of constructed wetlands, include surface flow and subsurface flow systems. It is important to select appropriate plant species, maintaining adequate water flow, and monitoring water quality to ensure the success of the system (Vymazal, 2004).

2.7.6 Restoration and regeneration of watershed and streams

Stream restoration involves the use of various techniques to repair and enhance damaged stream habitats, such as restoring stream banks, stabilizing eroding stream channels, and reintroducing native vegetation and fauna. There are two main approaches to stream restoration: channelization and natural channel design. Successful stream restoration requires careful planning and management, as well as ongoing monitoring and evaluation. Community involvement is an important aspect of stream restoration, as it helps to build support and ensure the needs and interests of local stakeholders are considered (SWAR program).

A comprehensive watershed approach to restoration involves the assessment of the entire watershed, including the identification of sources of pollution, potential threats, and areas in need of restoration. Resiliency in a watershed involves the ability of the ecosystem to adapt and recover from disturbances, such as floods, droughts, or pollution events. Restoration efforts should be designed to improve the overall health of the watershed, with a focus on creating a resilient and sustainable ecosystem (Murdock, 2008).

Watershed management is the protection and restoration of watersheds, which are areas of land that drain to a common water body. The Connecticut DEEP implements programs to manage watersheds, including the development of watershed management plans, the implementation of best management practices, and the restoration of degraded water bodies. The focus is on protecting water quality, enhancing aquatic habitats, preventing erosion and sedimentation, and reducing the impacts of flooding (Watershed Management).

The Stream and Watershed Assessment and Restoration program (SWAR) is a program implemented by the Illinois State Water Survey (ISWS) to assess and restore stream and watershed habitats. It includes several components, including watershed assessment, stream assessment, watershed planning, and restoration design and implementation. The program uses a combination of monitoring, modelling, and evaluation to ensure that restoration efforts are effective and that the health of the stream and watershed is improving (SWAR).

2.7.7 River Restoration

Process-based River restoration is an approach that aims to restore natural river processes rather than just adding structural elements. It is important to understand the underlying physical, chemical, and biological processes that drive river ecosystems and use this knowledge to guide restoration efforts. Practical guidance on implementing process-based river restoration, include selecting appropriate restoration techniques based on the specific processes that need to be restored, and the importance by involving stakeholders in the restoration process. Examples of successful case studies include the restoration of a river in Washington State and the need for long-term monitoring and adaptive management (Beechie et al., 2010).

In Switzerland, large, engineered wood structures were used in stream restoration projects, focusing on the ecological and hydraulic benefits with careful planning, appropriate design and implementation, and long-term monitoring and evaluation to ensure success (Neuhaus & Mende, 2021).

A sustainable approach to stream restoration that considers the interplay between geomorphology, ecology, and socioeconomics, is desirable. However, current stream restoration practices tend to prioritize structural solutions over process-based approaches and often fail to consider the broader socio-economic context. To implement a better sustainable approach, stakeholder engagement, long-term monitoring, and adaptive management are crucial. Restoration of a stream in the Pacific Northwest that involved removing a road and restoring natural channel processes resulted in improved water quality. Such an approach is essential for restoring healthy stream ecosystems in the long term (Hawley, 2018).

3. Methodology

3.1 Description of the Botic creek and watershed

3.1.1 Location

The Botič Creek is the longest creek in the Prague district of central Bohemian region of Czech Republic, and a significant waterway measuring ca. 34.5 km. It extends across a diverse landscape before eventually flowing into the Vltava River. The catchment area of the creek spans 134.85 km^2 and starts at an altitude of 478 m above sea level (a.s.l.) in the village of Čenětice. The Botič Creek meets the Vltava River at the Výtoň railway bridge, which is 186 m asl. The creek courses through various areas, including Újezd, Křeslice, Petrovice, Hostivař, Záběhlice, Michle, Vršovice, Nusle, and Vyšehrad (praha-priroda.cz; **Figure 6** & **7**).

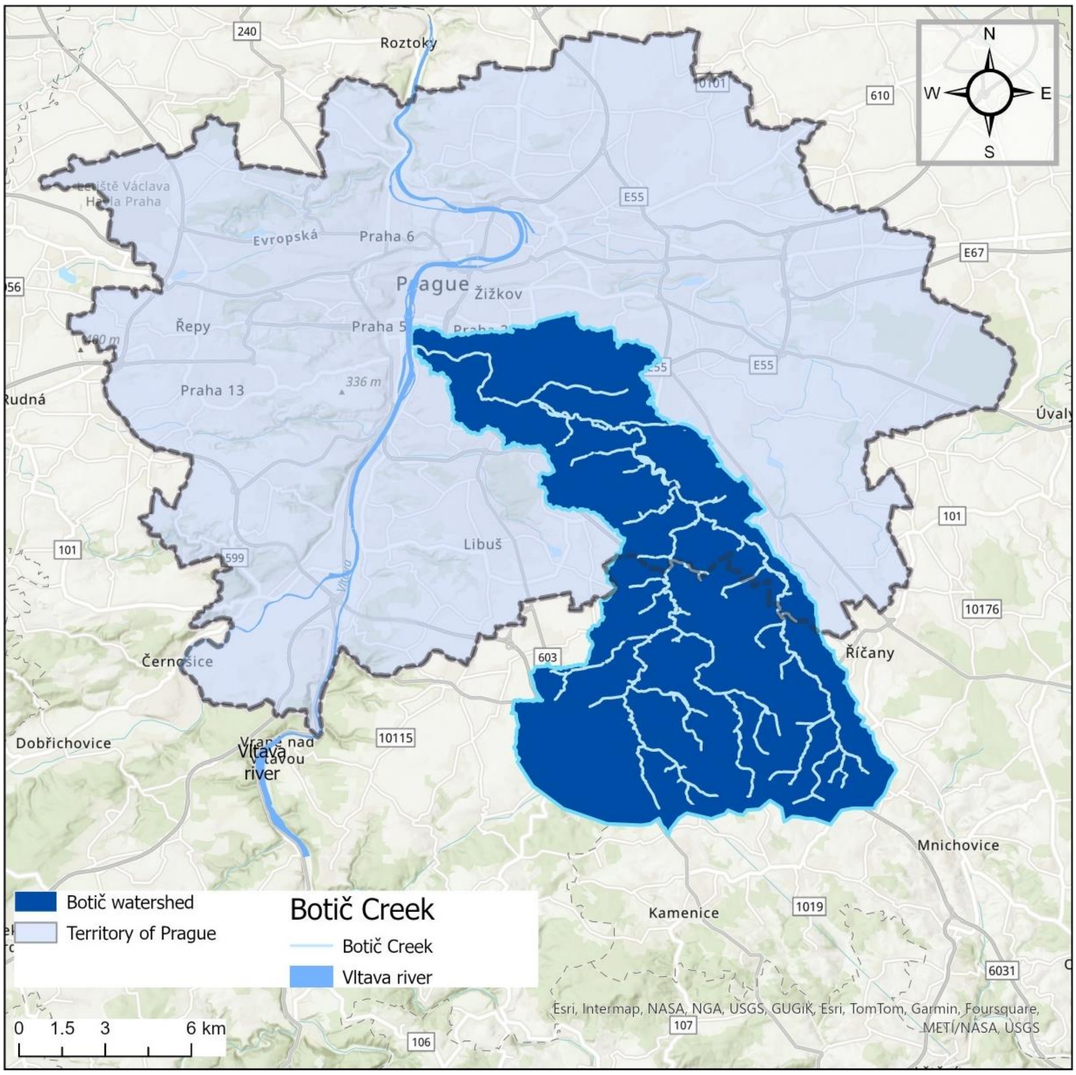


Figure 6. Location of the Botič Creek watershed in Prague, Czech Republic. Source: Author

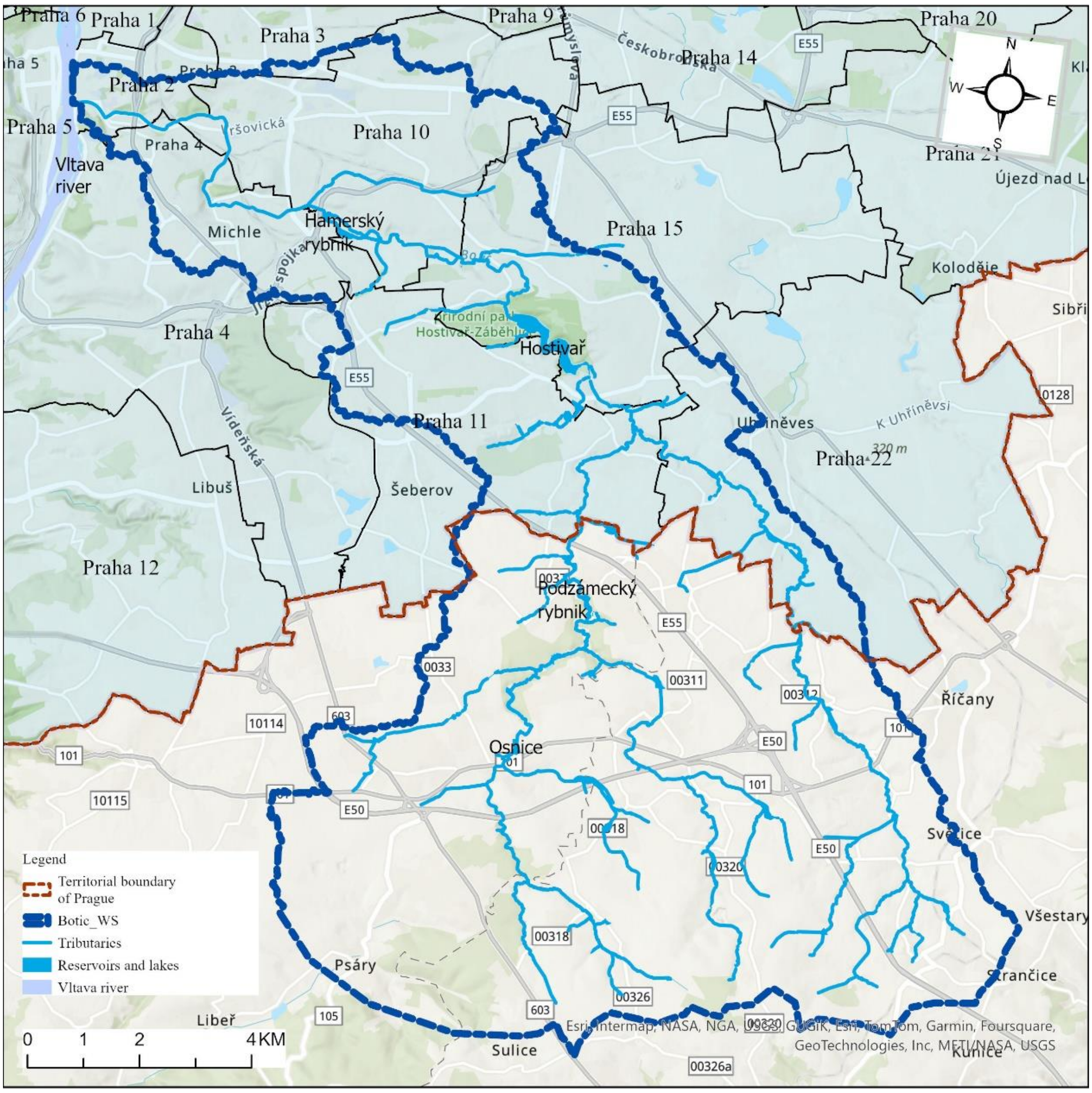


Figure 7. Administrative boundaries of Prague and Czech Republic in the Botič watershed. Data source: (geoportalpraha.cz), map: author

3.1.2 Connected tributaries and waterbodies.

Botič Creek is a significant watercourse that comprises a network of interconnected water bodies, ponds, and reservoirs, each serving a unique purpose. Several notable tributaries, including Jesenický potok, Milíčovský potok, and Měcholupský potok feed the creek. The ponds on the creek, such as Bořín, Labeška, Hamerský, and Práčský, are designed for fish farming and hold great ecological and landscape value. The largest water body on the creek is Hostivař reservoir, which has recreational, sport fishing, landscape, and environmental significance (**Figure 8**).

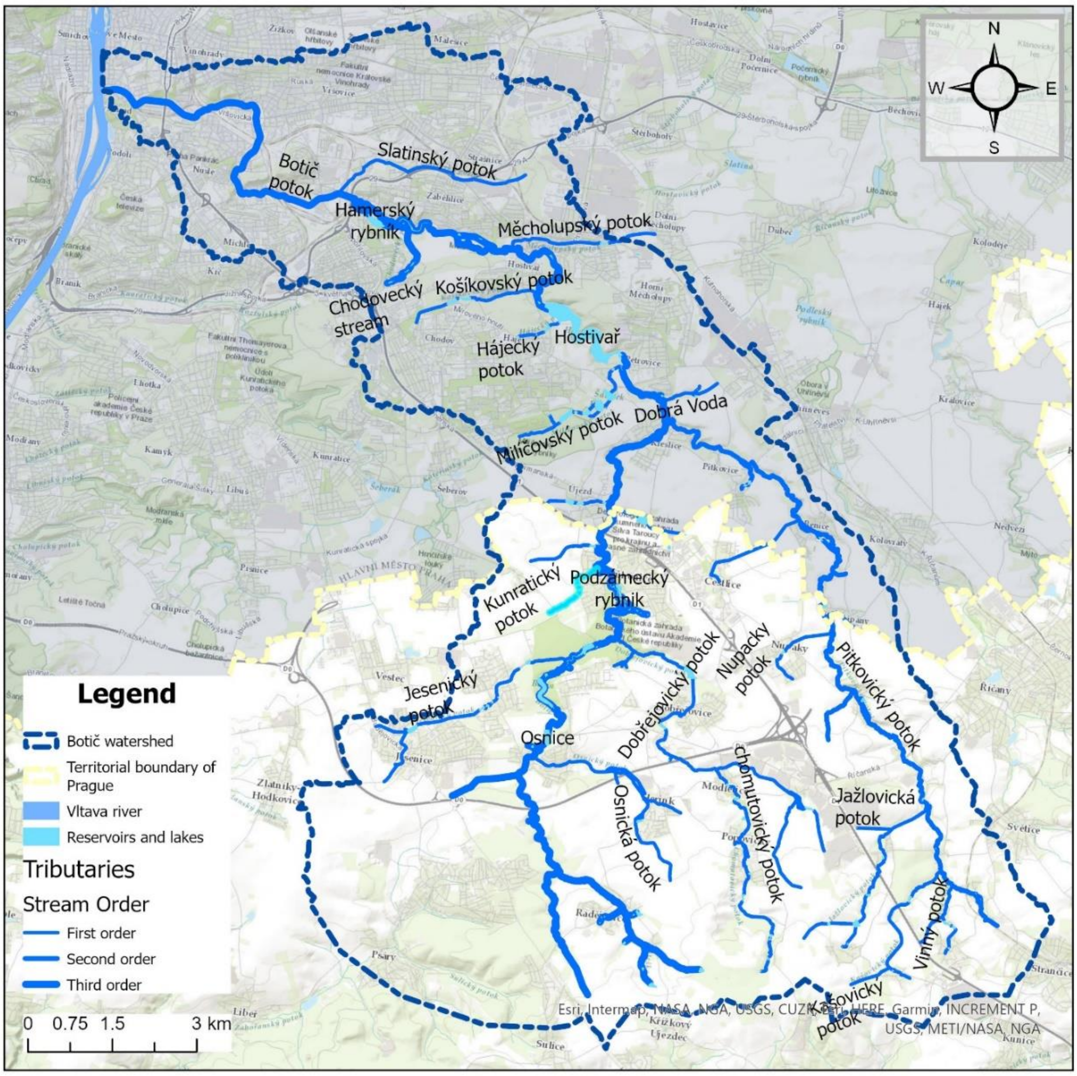


Figure 8. Stream Order and Waterbodies in Botič Watershed. Data source: (geoportalpraha.cz), Map: Author

3.1.3 Protected areas and Nature parks

The Botič basin in Prague is an ecologically important area not currently protected on a large scale. However, the city has designated three small natural monuments, namely the Meandry Botič Natural Monument, Milíčovský Forest, and Ponds, and Pitkovická stráň Natural Monument, as protected areas and two natural parks, namely Botič-Milíčov Nature Park and the Hostivař-Záběhlice nature park (Sweco hydroprojekt, 2019).

These nature parks are intermediaries between specially protected areas and general nature preservation. The Botič-Milíčov nature park covers the floodplains of Botič and Pitkovické streams, the Milíčovský forest and ponds complex, and a preserved historical cultural landscape that includes villages, courtyards, and mills. However, the park is at risk due to the large-scale construction of family houses. The Hostivař-Záběhlice nature park covers an area of 423.1 ha and includes the Botič corridor, old orchards, and two castle parks (**Figure 9**) (dibavod, n.d.-a).

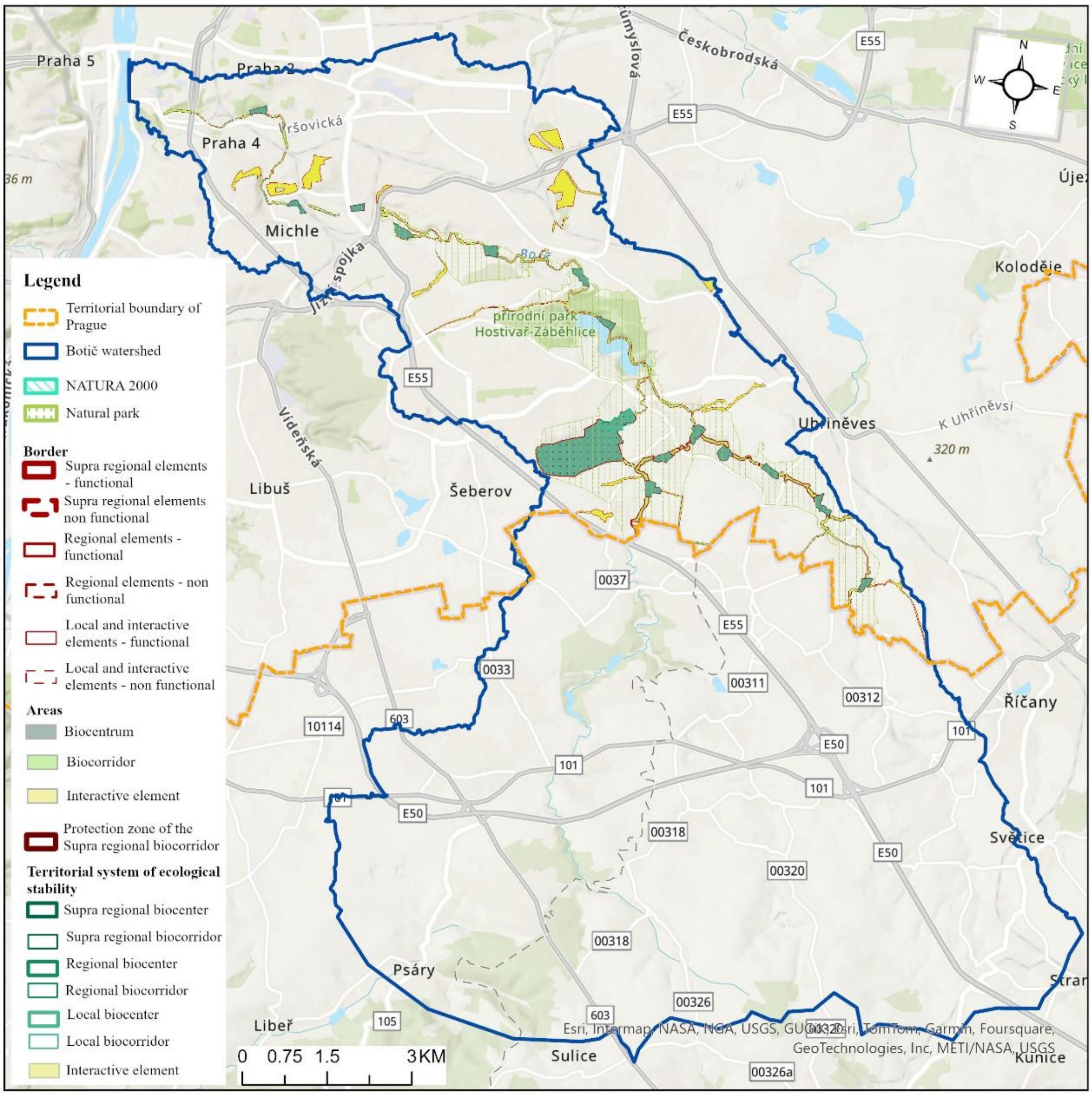


Figure 9. Protected Areas and Nature Parks Map of Botič Watershed. Data source: (geoportalpraha.cz), Map: Author

3.1.4 Flora and Fauna

The riparian zone in the region is primarily composed of alder and residual sedge ash, with numerous other plant species coexisting in this habitat. The herbaceous vegetation is dominated by common nettle, sedum, wild hemp, spotted sedge, wild sedge, and large-flowered sedge. The area supports diverse aquatic fauna, beetles, and butterflies, including the common green toad. Furthermore, the location is significant for ornithology, harboring several bird species, such as the white warbler, brown-winged warbler, and nightingale. Lastly, the stream sustains various fish species, such as common bream, sharp-bellied pearl minnows, and river perch (praha-priroda.cz).

3.1.5 Water quality

The Department of Environmental Protection in Prague has been actively monitoring the water quality of the city's waterways since 1990. They regularly measure the properties of water, such as sulfates, nitrates, total phosphorus, and dissolved oxygen. The department has identified runoff from paved surfaces, winter road salting, and sewage contamination as the primary sources of pollution. Poor functioning of small wastewater treatment plants, siltation of reservoirs, and inappropriate fish management also contribute to water quality deterioration.

The evaluation of surface water quality at 5 points as in (**Figure 10**) is based on the standard ČSN 75 7221 "Classification of surface water quality" (amendment from October 1998). In small streams within the capital city of Prague, the quality of surface water is evaluated by comparing individual concentrations with the limits for five classes (**Table 1**). The water quality is then described with color-coding (**Table 2**) (praha-priroda.cz)

Table 1. Chemical concentration analysis for five water quality classes. source: (Praha-priroda.cz)

Parameter	**Units**	**Class**				
		I	II	III	IV	V
Temperature	Deg C	-	-	-	-	-
pH		-	-	-	-	-
Conductivity	mS/m	<40	<70	<110	<160	≥160
SS	**mg/l**	**<20**	**<40**	**<60**	**<100**	**≥100**
O_2	**mg/l**	**>7.5**	**>6.5**	**>5**	**>3**	**≤3**
BOD$_5$	**mg/l**	**<2**	**<4**	**<8**	**<15**	**≥15**
COD$_{cr}$	**mg/l**	**<15**	**<25**	**<45**	**<60**	**≥60**
TOC	mg/l	<7	<10	<16	<20	≥20
N-NH4	**mg/l**	**<0.3**	**<0.7**	**<2**	**<4**	**≥4**
N-NO3	**mg/l**	**<3**	**<6**	**<10**	**<13**	**≥13**
TP	**mg/l**	**<0.05**	**<0.15**	**<0.4**	**<1**	**≥1**
Cl^-	mg/l	<100	<200	<300	<450	≥450
SO_4^{2-}	mg/l	<80	<150	<250	<400	≥400
Mn	mg/l	<0.1	<0.3	<0.5	<0.8	≥0.8

Fe	mg/l	<0.5	<1	<2	<3	≥3
Ca	mg/l	<150	<200	<300	<400	≥400
Mg	mg/l	<50	<100	<200	<300	≥300
E.coli.	KTJ/ml	<40	<100	<500	<1000	≥1000

Table 2. Water quality classification and colour designation with definition. Source: (Praha-priroda.cz)

I – Very clean water	Suitable for water supply purposes, the food industry, swimming pool, and salmon fish farming, has great landscape value
II – Clean water	Suitable for water supply purposes, fish farming, water sports, and supplying industry, has landscape-forming value
III – Polluted water	Only for supplying industry, conditionally for water supply if there is no more suitable source, it has little landscape-forming value
IV – Heavily polluted water	Usually only for limited purposes
V – Very dirty water	Usually not fit for any purpose

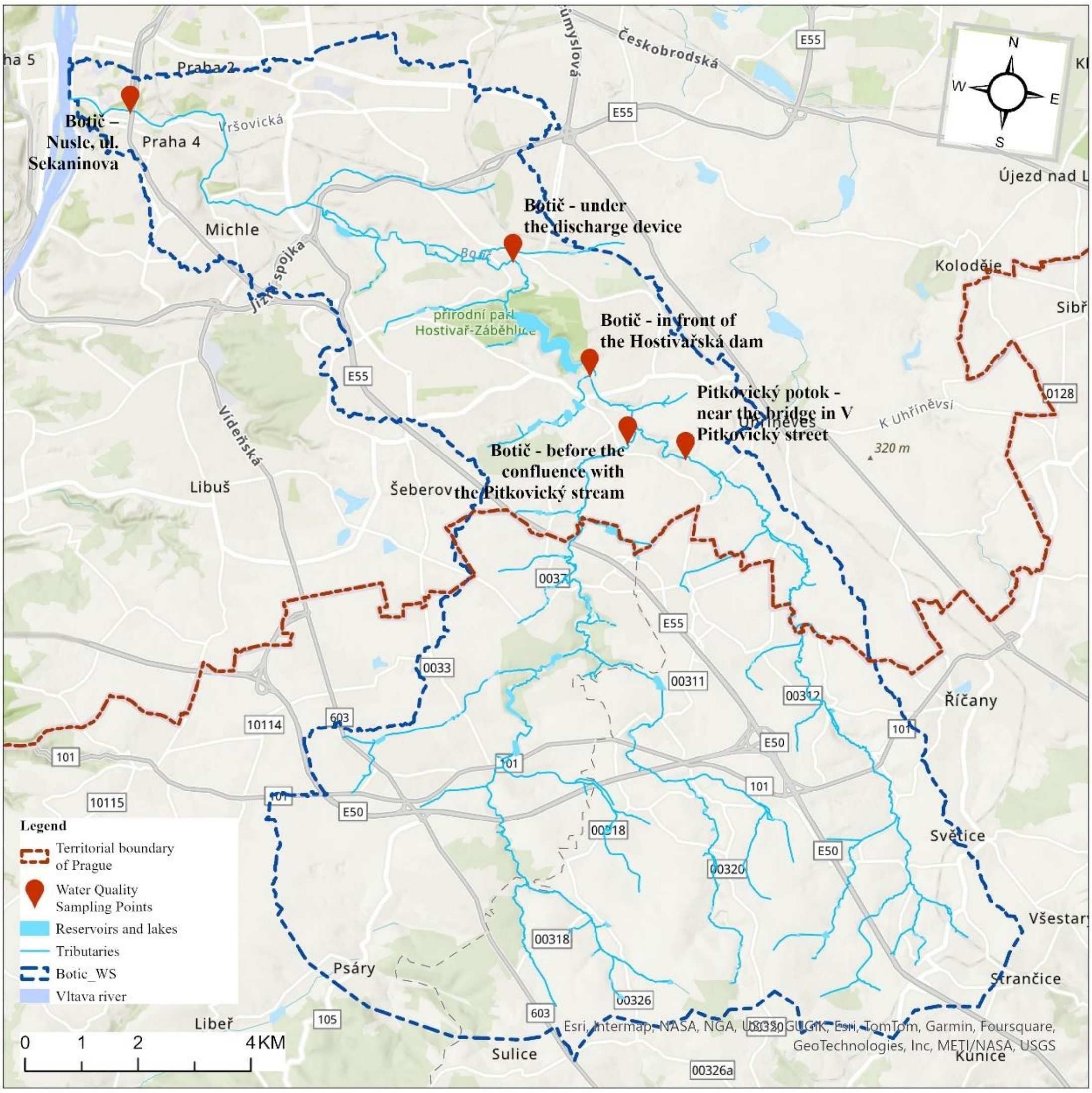


Figure 10. Water quality sampling points at the Botič Creek. Source of GPS point location. Source: (Praha-priroda.cz) map: Author

Over the years until 2020, 18 parameters were measured at all five points to understand the water quality. These parameters include water temperature, pH, conductivity, suspended solids, O_2, BOD_5, COD_{Cr}, TOC, $N\text{-}NH_4$, $N\text{-}NO_3$, TP, Cl, SO_4^{2-}, Mn, Fe, Ca, Mg, and F coli. From these 18 parameters, eight crucial ones were selected to determine the maximum values and analysed the changes in water quality (*Praha-priroda.cz*). The chosen parameters and their maximum values are presented in the (**Table 3**) for further reference.

Table 3. Water quality data of 8 parameters and its maximum recorded values. Source: (Praha-priroda.cz)

Pitkovický Potok - near the bridge in V Pitkovický Street

Maximum value recorded in the Year	EC mS/m	SS mg/l	O_2 mg/l	BOD_5 mg/l	COD_{Cr} mg/l	N -NH_4 mg/l	N - NO_3 mg/l	TP mg/l
Max. 2020	95.3	22.0	6.6	2.5	18.6	0.176	9.2	0.551
Max. 2019	128	19.6	8.3	4.7	24.4	0.087	7.3	0.231
Max. 2018	109	394.0	8.3	5.0	36.6	0.181	9.1	0.453
Max. 2017	103	43.2	8.3	5.7	18.6	0.467	7.3	0.548
Max. 2016	118	11.6	7.4	3.1	16.5	0.356	9.18	0.396
Max. 2015	90.8	13.6	6.3	4.4	18.4	0.62	8.98	0.37
Max. 2014	94.2	47.2	7.6	6.7	25.6	0.3	7.37	0.26
Max. 2013	110	15.6	6.1	5	17	0.78	9.88	0.15
Max. 2012	87.7	71.2	6.2	4.5	23.2	0.39	6.64	0.33
Max. 2011	89.5	21.2	8	4.3	32.3	0.304	11.8	0.22
Max. 2010	130	11.6	6.9	4.1	13.6	0.482	11.7	0.19

Botič - before the confluence with the Pitkovický stream

Maximum value recorded in the Year	EC mS/m	SS mg/l	O_2 mg/l	BOD_5 mg/l	COD_{Cr} mg/l	N -NH_4 mg/l	N - NO_3 mg/l	TP mg/l
Max. 2020	86.1	13.2	6.0	4.5	26.2	0.230	5.2	0.609
Max. 2019	109	22.0	7.7	7.7	36.4	3.900	6.6	0.466
Max. 2018	104	23.2	7.8	6.2	33.4	0.076	7.1	0.594
Max. 2017	102	34.0	7.3	7.4	31.8	3.24	6.51	1.27
Max. 2016	87.7	20.4	7.7	9.3	30.1	0.457	7.25	0.883
Max. 2015	87.4	18.0	5.7	6.4	35.5	0.255	8.07	0.839
Max. 2014	80.6	60.4	8.2	6.7	36.3	0.39	5.51	1.32
Max. 2013	80.4	30.0	6.2	4.9	30.5	0.25	11.2	0.43
Max. 2012	78.1	38.0	6.1	5.1	35.9	0.19	4.77	0.46
Max. 2011	87.8	21.2	7.5	6	33.7	0.31	11.4	0.45
Max. 2010	109	16.4	7.7	6.9	28.5	1.44	12.7	0.707

Botič - in front of the Hostivařská dam

Maximum value recorded in the Year	EC mS/m	SS mg/l	O_2 mg/l	BOD_5 mg/l	COD_{Cr} mg/l	N -NH_4 mg/l	N - NO_3 mg/l	TP mg/l
Max. 2020	89.7	16.4	6.2	4.3	20.6	0.1	5.6	0.5
Max. 2019	116.0	33.6	7.8	6.3	38.9	0.2	6.9	0.3
Max. 2018	96.2	32.0	13.6	4.0	36.1	0.2	7.4	0.5

Max. 2017	91.3	41.6	7.1	6.9	40.3	0.7	5.3	0.7
Max. 2016	101.0	12.8	16.3	6.2	30.5	0.4	7.3	0.4
Max. 2015	86.0	18.8	7.9	7.6	39.7	0.4	8.0	0.5
Max. 2014	80.4	50.4	7.7	6.6	33.3	0.3	5.2	0.6
Max. 2013	107.0	16.8	6.3	4.1	25.7	0.3	10.0	0.3
Max. 2012	81.1	48.0	6.2	4.8	31.4	0.2	4.9	0.4
Max. 2011	90.6	16.8	8.0	4.9	31.9	0.2	9.6	0.3
Max. 2010	112.0	26.8	7.7	5.3	24.4	1.0	11.7	0.5
Max. 2009	104.0	30.4	8.1	5.2	32.0	1.1	13.9	0.4
Max. 2008	81.5	15.6	8.4	8.4	29.4	0.5	7.7	0.7
Max. 2007	83.7	42.0	7.1	5.7	32.2	11.2	7.3	0.6
Max. 2006	109.0	43.2	14.1	7.9	39.6	1.2	6.8	0.4
Max. 2005	87.5	28.0	8.3	5.3	33.7	0.4	14.6	0.6
Max. 2004	119.0	15.6	8.2	6.2	41.3	1.6	9.0	0.6
Max. 2003	82.0	70.0	7.5	6.2	27.2	0.6	8.5	0.6
Max. 2002	80.9	180.0	7.3	5.3	39.0	0.5	10.1	0.5
Max. 2001	101.0	50.8	13.9	6.2	30.6	0.8	5.8	0.6

Botič - below the discharge facility of the Hostivařská dam

Maximum value recorded in the Year	EC mS/m	SS mg/l	O_2 mg/l	BOD_5 mg/l	COD_{Cr} mg/l	N -NH_4 mg/l	N - NO_3 mg/l	TP mg/l
Max. 2020	82.6	15.2	5.9	6.6	30.9	0.6	3.8	0.2
Max. 2019	109.0	14.0	7.8	5.9	27.9	0.5	3.9	0.2
Max. 2018	91.6	21.6	6.8	5.9	43.6	0.6	5.2	1.1
Max. 2017	90.3	24.0	7.2	10.2	28.8	0.5	6.4	0.5
Max. 2016	97.8	18.4	7.4	5.9	38.3	0.3	6.2	0.2
Max. 2015	83.4	16.8	5.1	4.1	32.1	1.1	7.1	0.2
Max. 2014	80.7	34.4	6.9	8.9	32.3	0.3	5.6	0.3
Max. 2013	86.5	22.0	6.5	5.9	37.7	0.2	10.0	0.2
Max. 2012	81.5	47.0	6.5	4.9	28.0	0.2	5.0	0.3
Max. 2011	96.7	227.0	7.2	4.7	33.5	0.3	10.9	0.5
Max. 2010	124.0	837.0	7.1	7.4	40.1	1.2	9.7	0.9
Max. 2009	90.8	25.2	6.7	5.3	36.9	0.7	11.9	0.3
Max. 2008	85.4	46.0	7.1	6.8	28.1	0.5	5.8	0.2
Max. 2007	102.0	74.0	4.1	7.7	34.6	0.6	5.4	0.3
Max. 2006	177.0	86.0	4.2	7.1	16.1	1.8	4.7	0.4
Max. 2005	81.9	40.0	7.4	7.4	101.0	0.6	12.7	0.3
Max. 2004	122.0	22.0	6.6	6.2	31.0	1.2	5.1	0.2
Max. 2003	99.7	44.4	7.4	4.9	45.8	4.8	8.0	1.9
Max. 2002	87.0	35.2	5.2	5.7	33.0	1.1	8.1	0.4
Max. 2001	84.2	25.6	7.6	5.3	27.2	0.9	4.3	0.3

Botič – Nusle, ul. Sekaninova

Maximum value recorded in the Year	EC mS/m	SS mg/l	O_2 mg/l	BOD_5 mg/l	COD_{Cr} mg/l	N -NH_4 mg/l	N - NO_3 mg/l	TP mg/l
Max. 2020	86.1	37.6	7.1	9.5	33.7	0.4	3.5	0.4
Max. 2019	114.0	526.0	7.2	8.1	41.2	3.2	3.7	1.5
Max. 2018	108.0	62.5	7.5	8.5	35.6	0.2	5.1	1.3
Max. 2017	97.8	38.8	7.8	9.2	31.5	0.5	6.8	0.3
Max. 2016	108.0	26.8	7.4	6.0	40.2	3.7	5.1	0.6
Max. 2015	88.2	55.5	7.2	12.2	31.4	2.7	6.8	0.8
Max. 2014	86.5	40.4	8.3	9.6	38.7	0.4	5.0	0.3
Max. 2013	104.0	35.6	6.2	8.4	45.0	0.6	9.8	0.3
Max. 2012	108.0	99.6	6.3	8.2	39.1	1.3	7.4	0.3
Max. 2011	97.0	79.2	8.5	9.7	33.1	0.3	10.8	0.5
Max. 2010	136.0	241.0	7.1	18.2	53.7	2.1	13.0	1.1
Max. 2009	127.0	52.4	7.8	9.7	41.6	3.0	12.7	0.6
Max. 2008	89.2	125.0	8.9	5.6	27.1	0.5	5.9	0.3
Max. 2007	184.0	98.5	6.7	28.0	52.4	26.9	4.7	2.8
Max. 2006	255.0	57.0	7.8	7.8	34.4	1.4	5.1	0.3
Max. 2005	96.4	108.0	8.5	96.0	214.0	9.2	8.0	2.4
Max. 2004	132.3	18.8	8.8	6.9	38.6	0.6	6.6	0.2
Max. 2003	101.7	81.0	8.2	7.4	29.7	0.3	7.9	0.8
Max. 2002	98.3	58.4	8.6	5.3	46.6	1.0	8.8	0.5
Max. 2001	98.1	237.0	9.2	28.8	36.4	1.7	7.5	1.2

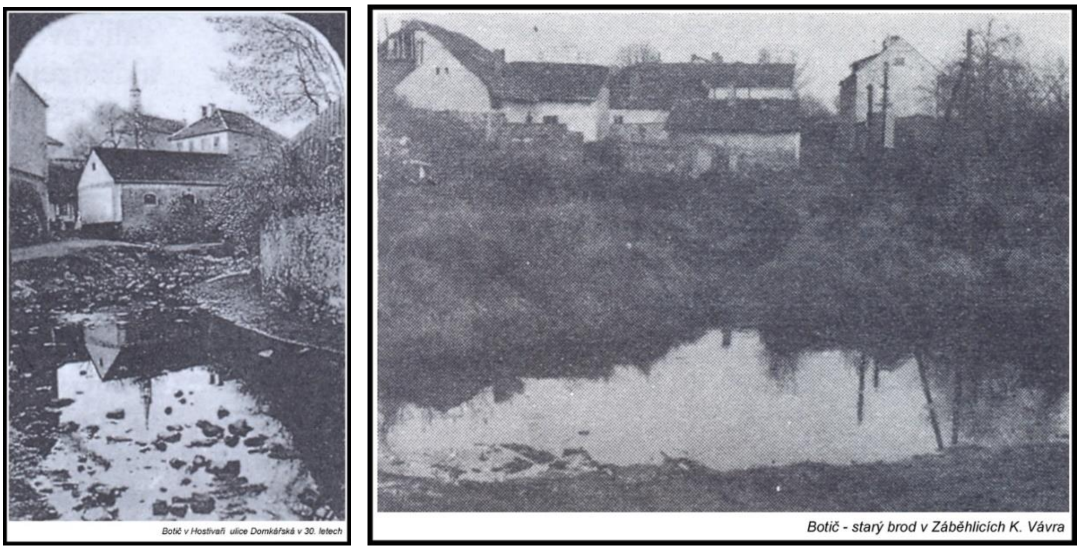
- Pitkovický Potok - near the bridge in V Pitkovičky Street: The SS mg/l varied from 11.6 in 2010 to 22.0 in 2020 (89.6%) increase. TP mg/l also increased from 0.19 in 2010 to 0.55 in 2020 (290%) increase. COD mg/l increased from 13.6 in 2010 to 18.6 in 2020 (36.7%) increase.
- Botič - before the confluence with the Pitkovický stream: The upper stream of Botič in 2018-2019 was also heavily polluted and rated as class IV. The concentrations of nutrients and organic substances have been increasing since 2010, and the inflow of municipal wastewater from old buildings was the likely cause. The TP mg/l has been consistently high and has been the highest in the years 2014 and 2017.
- Botič - in front of the Hostivařská dam: The water quality of Botič before the Hostivařská dam in 2018-2019 was rated as class III. TP concentration decreased after the confluence of Botič and Pitkovický Potok, and municipal wastewater from old buildings was the likely source of high phosphorus concentrations.
- Botič - below the discharge facility of the Hostivařská dam: The water quality of Botič in profile 12/4 in 2018-2019 is heavily polluted and rated as class IV. The concentrations of organic pollution and nutrients have slightly increased due to the inflow of municipal wastewater from old buildings. BOD mg/l had

increased from 5.3 in 2001 to 6.6 in 2020 (24.5%) increase. COD mg/l increased from 27.2 in 2001 to 30.9 in 2020 (13.6%) marginal increase.

- Botič – Nusle, ul. Sekaninova: The water quality of Botič in the final profile in 2018-2019 is very polluted and rated as class V. The concentrations of organic pollution and nutrients have slightly increased due to the contribution of municipal wastewater from old developments in some areas. The water quality had worsened in 2018-2019 compared to 2016-2017 (praha-priroda.cz).

3.1.6 Brief history of how the stream was used and maintained.

Botič Creek, also called Vinný Potok, played an important role in people's lives in the territory of Prague. There were around 30 mills on its banks whose rafts, outriggers, and shafts were cleaned and maintained by the millers. The stream had very clean running water used by the local breweries for brewing beer (**Figure 11**).



Botič v Hostivaři ulice Domkářská v 30. letech

Botič - starý brod v Záběhlicích K. Vávra

Figure 11. Historical images: Botič in the Domkářská Street in 1930s, Botic: Old Ford in Záběhlice K. Vávra Source*:* (Praha-priroda.cz)

3.1.7 Landscape changes

The Botič Creek in Prague is an example of a watercourse that transformed several times. The creek was once adorned with numerous mill buildings, the oldest of which dates to the 12th century. However, the picturesque surroundings were marred by intensive sewage discharge into the Botič Creek by the end of the 19th century. The polluted water had a strong odor and was a source of numerous diseases. Consequently, in 1904, the mouth of the Botič Creek was regulated into the Vltava River, and a few years later, the channelized covered section of the river, which is approximately 1.2 km long, was covered with a roadway (Hegar, 2018).

Although the Botič Creek underwent extensive modifications, some natural sections remain preserved as a meandering stream in an undeveloped floodplain. These areas have undergone a low degree of modification and are interspersed with sections that have undergone various channel modifications and flow regulation, particularly in the settlement territory. Compared to other water courses in the area of interest, the degree of modification of the Botič Creek is relatively low (Hegar, 2018).

The LULC data was obtained from open data source (Copernicus.eu) for over a 18-year period in 6 yearly intervals from the year 2000 to 2018. This data was used to estimate changes in each of the individual categories of Land Cover from 2000-2018 and identify transition of LULC observed between individual categories from the year 2000-2018 (**Figure 12**). The LULC data of the year 2020 obtained from open source (geoportalpraha.cz) were used to classify the types of LULC categories in the watershed, and the extent of urbanization in each sub-watershed (**Figure 13**).

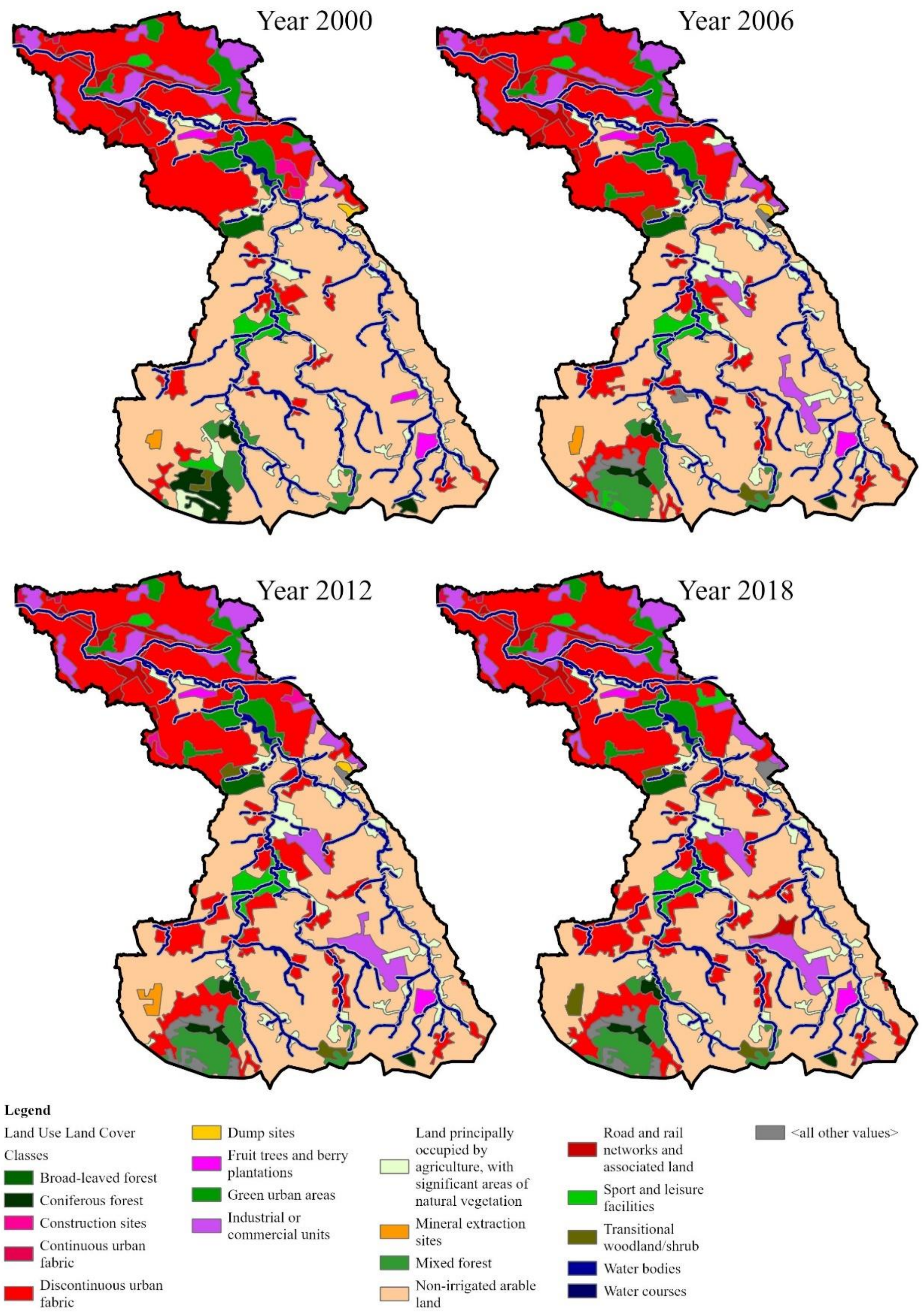


Figure 12. Land Use land cover changes from 2000-2018 in the Botič watershed. Data: (Copernicus.eu) map: Author

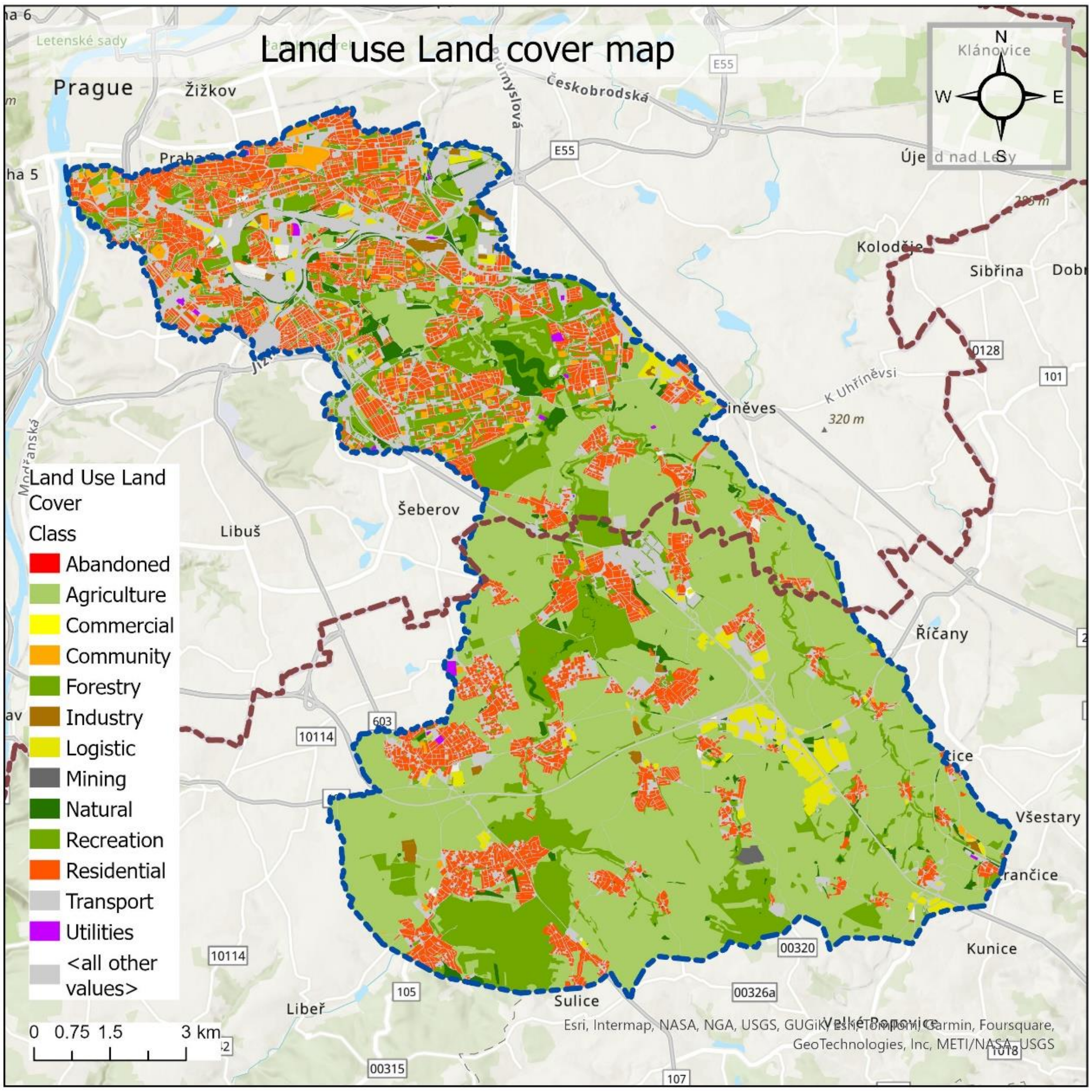


Figure 13. Land Use Land Cover map 2020, in the Botič watershed. Data source:(geoportalpraha.cz) map: Author

3.1.8 Climate

The climate in the Botič basin is gentle, warm, and temperate. The Průhonice region experiences significant precipitation, especially during the driest months. The climate in Průhonice is moderately warm and dry, with mild winters. The average temperature throughout the year is 8.5°C, which can vary between -25°C and over 35°C. The annual precipitation ranges from 400 mm to 700 mm, and the way it is distributed can hurt vegetation, particularly in April and May (Dendrologickazahrada.cz).

Other sources have somewhat similar climatic information about the areas falling into the Botič watershed, where the temperature is 9.4°C and yearly rainfall is 687 mm, according to statistical data. Precipitation is the lowest in February, averaging 37 mm. July experiences the highest precipitation, with an average value of 85 mm (**Figure 14**) (climate-data).

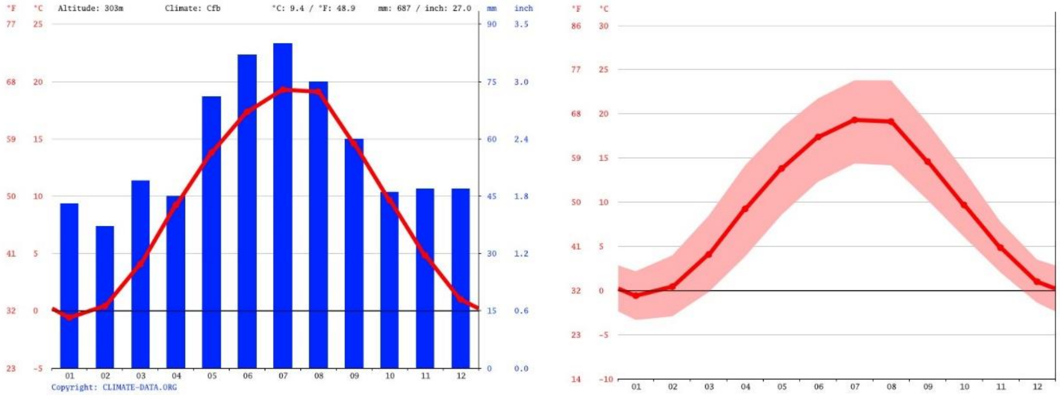


Figure 14. Visual Representation of Temperature and Rainfall Trends in Prague. source: (climate-data, n.d.)

3.1.9 Flooding events

The Botič Creek has a history of overflowing, dating back to the 16th century. While destructive floods are uncommon, the floods in 1958 caused the stream to overflow its banks and flood Hostivař and other parts of the city. This led to discussions and decisions on constructing the Hostivař dam. The primary goal of building the dam was to prevent flooding like that caused by the 1958 flood. However, it has since been primarily used for recreational purposes. The two major catastrophic flood events in the recent past are documented in the floods of 2002 and 2013.

- **Floods of 2002:**

The floods of 2002 represented one of the most significant natural disasters in the contemporary history of the Czech Republic. Despite the scale of the event, the Botic watershed remained unaffected. In normal circumstances, the flow of Botič in Vršovice ranges from 1 m³/s to 1.5 m³/s. However, during the flooding episode, a flow of 13.43 m³/s was discharged from the dam. The municipal water manager, Ilja Storoženko, estimated the flow at 50 m³/s in Vršovice. In contrast, the Botič Creek did not overflow in this section. Despite this, the basements of the houses located in Sekaninova street in Nuselské údolí suffered severe flooding. The total loss amounted to 50 million CZK, and 37 houses in the Hostivař region were flooded (Chamra, 2006).

- **Floods of 2013:**

The floods that occurred in the year 2013 can be attributed to three primary factors. Firstly, the excessive rainfall, which exceeded 100mm/24 hours, led to a considerable increase in water flow along the Botič. The already saturated soil, due to previous rainfall, compounded the situation. Secondly, the upper part of the Botič lacked natural or man-made regions to slow down water flow, thereby further exacerbating the issue. Thirdly, urban areas, with paved surfaces lacking retention tanks, contributed to faster rainwater runoff, directly into the river.

The regions that were most impacted by the floods included Benice and Průhonice, where water levels exceeded flood thresholds. Hostivař Dam was carefully managed to prevent overflow and a potential breach that could have flooded areas such as Michle, Vršovice, and Nuslí. Flooding occurred in specific areas, such as U brehu street, old Hostivař development, gardens in Záběhlice, and the Záběhlic castle area experienced backflow from a tributary stream. Buildings in old Záběhlice, sports facilities, and areas below the Hamerský pond were flooded. Water spilled into Hamerské pond from Botič. The marshalling yard, KARE buildings, and car repair shops were also impacted. While localized flooding occurred in specific areas of Michle, Vršovice, and Nusle, major bridges remained unaffected (**Figure 15, 16** & **17**; Daňhelka et al., 2013).

In response to the situation, the City of Prague allocated 50 million CZK for immediate response actions, such as cleaning, disinfection, equipment, debris removal, and food provision. Additionally, Prague received an additional 100 million CZK from the state budget for further flood damage recovery (Štěpánová, 2013).

Figure 15. Folimanka Park: Cafe flooded. Source: (Štěpánová, 2013)

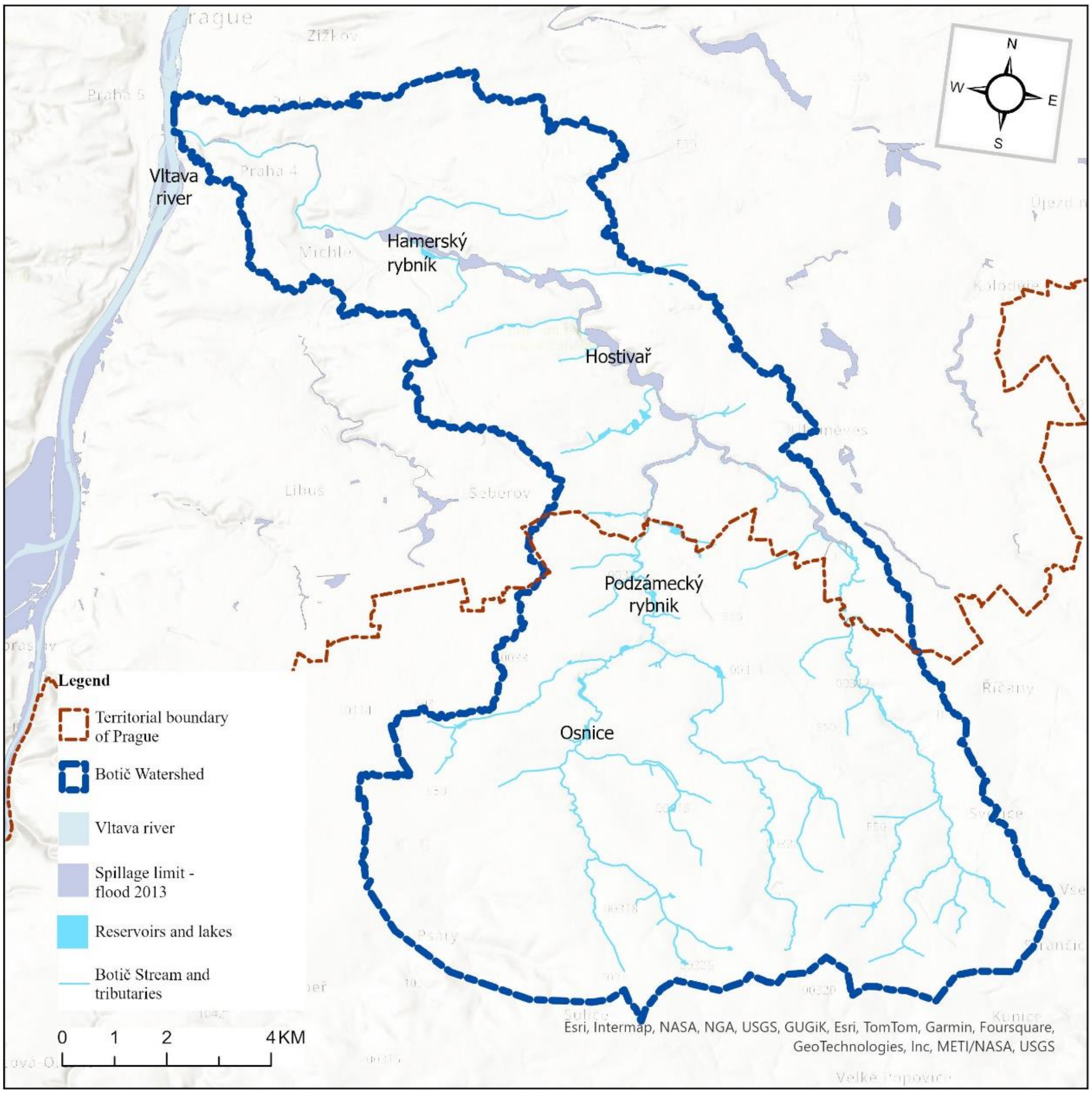


Figure 16. Spillage limit-flood of 2013 in Botič watershed. Data source:(geoportalpraha.cz) map: Author

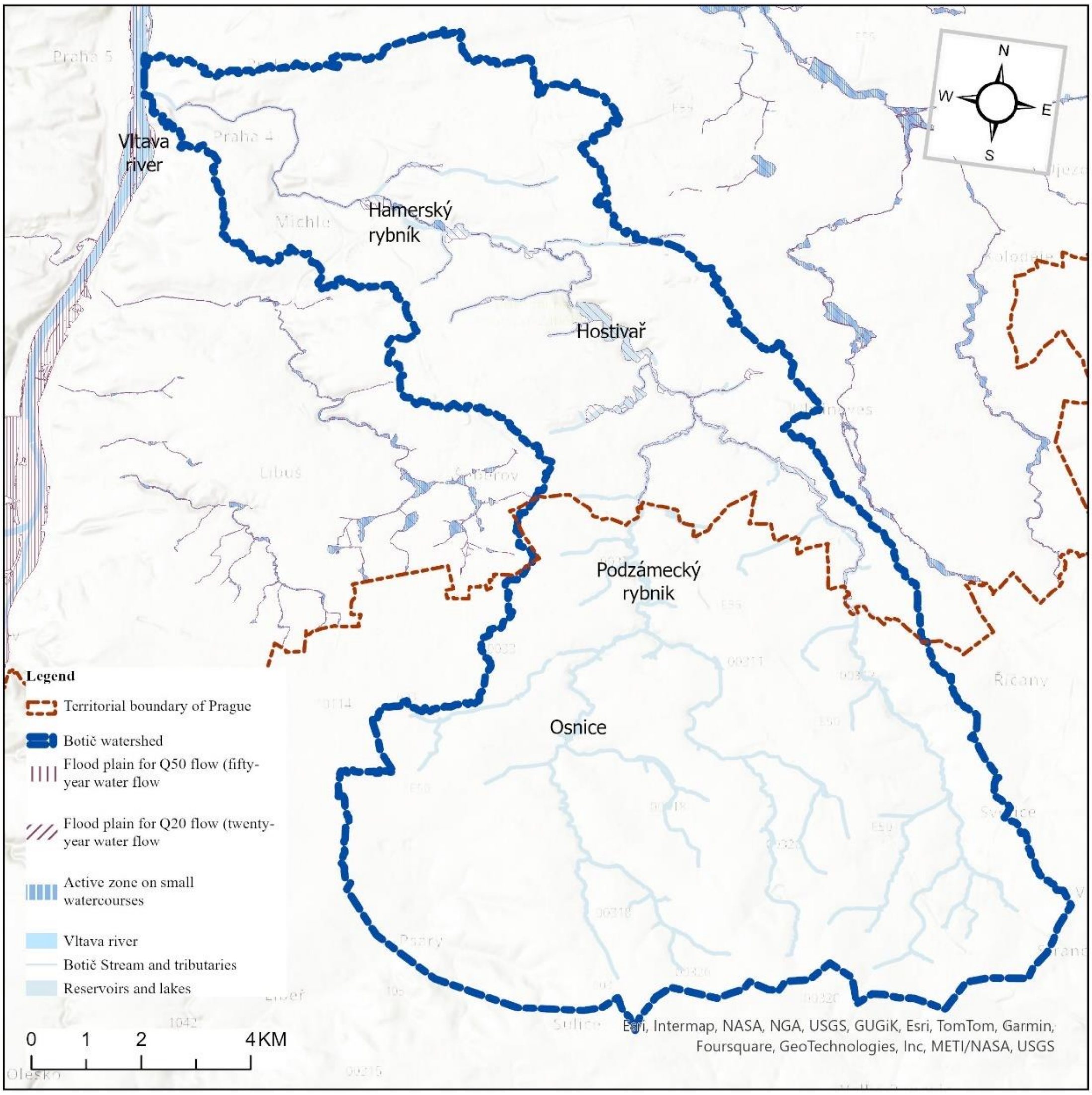


Figure 17. Flood plain for Q50 and Q20, and Active zones on small watercourses in Botič watershed. Data source:(geoportalpraha.cz) map: Author

3.1.10 Hydrological profile

The Botič basin terminates at the confluence with the Vltava (55.2 river km). The length of the Botič watercourse spans 34.5 km. Other waterways within the territory are of lesser significance. The total length of watercourses in the said territory is approximately 143 km. The watershed is estimated to have an area of 135.8 km^2. Other notable watercourses in the area include Jesenický stream, Pitkovický stream, and Dobřejovicky stream. As per the DIBAVOD, a list of all prominent waterways is provided in the following table (**Table 4**).

Table 4. Significant water courses connected to Botic Creek. Source: (dibavod)

Stream name	**Length of the territory of the administrative district in km**
Botič creek	34.5
Jesenický stream	5.2
Dobřejovicky stream	8.3
Pitkovický stream	14

The Jesenický, Dobřejovice, and Pitkovický streams are notable watercourses in the Prague region. The Jesenice stream starts from Jesenice, flows in a northeasterly direction, and converges with the Botič after passing through Průhonický Park. Its flow length is 5 km, and the catchment area is 5.52 km^2. The Dobřejovicky stream originates southeast of Popovice, flows west to northwest, and converges with the Botič after crossing Průhonický Park. The Pitkovický stream is sourced near Svojšovice and flows through Svojšovice to Otic. It converges with the Botič near Křeslice, after passing through Voděrádky, Kuří, and Benice. Its flow length is 14.3 km, and the catchment area is 31.4 km^2.

3.1.11 Management, Monitoring, and Revitalization practices

The management and maintenance of the streams in the Botič basin, located in the Central Bohemia region, is primarily handled by the state enterprise Povodí Vltava. However, the forest tributary Botič from Hlubočinka is managed by Lesy ČR, sp. The Environmental Protection Department of the MHMP represents the management and financing of stream maintenance in the Botič basin within the territory of the capital city of Prague.

Table 5. Manager of the streams of the Botič basin. Source: (Sweco hydroprojek, 2019)

Flow manager (performance of administration)	**Tributary and stream names**
Lesy hl. města Prahy	Botič: Slatinský, Chodovecký, waste outflow from Hamerský pond, Měcholupský, Košíkovský, Hájecký, Milíčovský, Dobrá Voda. Pitkovický: Stream from Pitkovice, Škaredka, Lipany, Kuří, and from Újezd.
Povodí Vltavy, s.p.	Botič: Pitkovický: stream from Čestlic, Nupacký, Voděrádky, from Jažlovic, Kašovický, Vinný, from Rozkoše, Dobřejovický, Chomutovický, Jesenický, Osnický, and Oleška.
Lesy ČR, s.p	Chomutovický:nameless stream from Hlubočinky.

Monitoring practices: In 2016, new pressure sensors and ultrasonic-level gauge technology were installed at seven limnigraphic stations in the Botič basin (**Figure 18**). In addition, each measuring profile was upgraded with a new water level batten, and certain areas of the watercourse bed underwent improvements to enhance measurement accuracy (**Table 6**). The Kocanda, Průhonice, Kuří, and Dobřejovice stations outside Prague monitor water conditions and flows in the upper Botič basin. This data is vital for predicting downstream flows and essential for water management, flood control, and environmental protection (Sweco hydroprojekt, 2019).

Table 6. List of the 7 limnigraphic stations in the Botič watershed. Source: (Sweco hydroprojek, 2019)

Station	Equipment	Watercourse	Operator	Manager of small watercourses
Jesenice - Kocanda	rain gauge (operator of the Forests of the City of Prague)	Botič	CHMÚ	Povodí Vltavy, s.p.
Průhonice	NA	Botič	CHMÚ	Povodí Vltavy, s.p.
Prague - Petrovice	NA	Botič	CHMÚ	Department of Environmental Protection of the MHMP
Prague - Hostivař	NA	Botič	CHMÚ	Department of Environmental Protection of the MHMP
Prague - Nusle	NA	Botič	CHMÚ	Department of Environmental Protection of the MHMP
Kuří	NA	Pitkovický stream	CHMÚ	Povodí Vltavy, s.p.
Průhonice	rain gauge	Dobřejovicky stream	Lesy hl. města Prahy	Povodí Vltavy, s.p.

Figure 18. Images showing the limnigraphic station at Prague - Nusle. Source: Author

Revitalization projects: The Environmental Protection Department of the City of Prague (MHMP) manages and funds the maintenance of 319 kilometers of streams within the city's jurisdiction and six kilometers beyond its borders. The "Streams for Life" project aims to revitalize and manage these streams to restore their life and natural beauty. The (**Table 7**) encapsulates the various types of revitalization projects in the Botič watershed and (**Figure 19**) defines the locations of these revitalization projects implemented (Praha-priroda.cz).

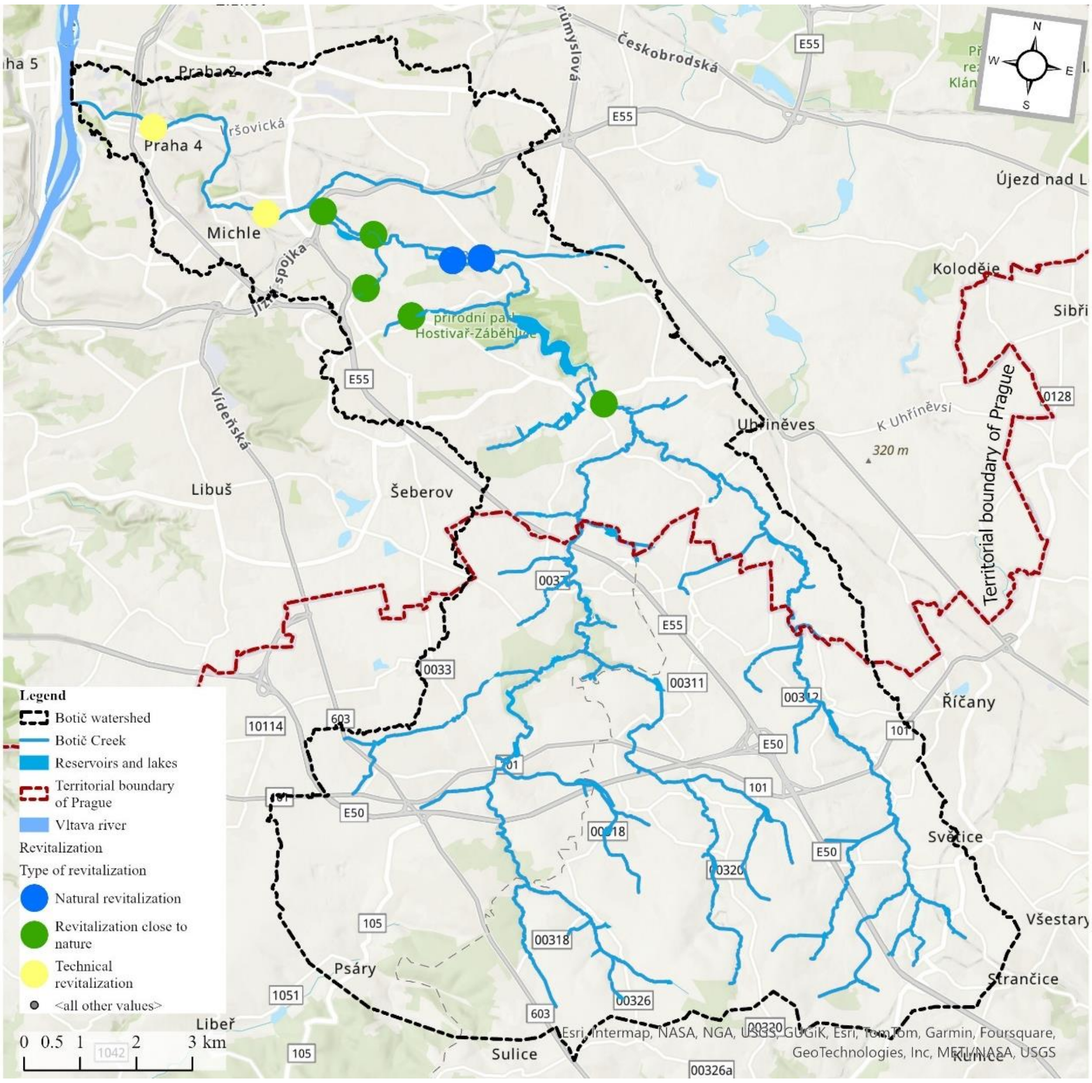


Figure 19. Location of revitalization and restoration projects in Botič watershed. Source: (Praha-priroda.cz) Map: Author

Table 7. Timeline of revitalization and restoration projects in Botic watershed. Source: (Praha-priroda.cz)

Year	Location	Type of revitalization	Details of restoration work	Length of treatment and location
2006	Petrovický dam	Revitalization close to nature	Construction of a boulder chute, embankment walls for the future cycle path, repair of bank embankments, and	NA

			vegetation adjustments.	
2007	Revitalization of the riverbed in front of Fidlovačka	Technical revitalization	Removal of concrete screed and replacement with stone paving to gravel, disturbance of motion, and placement of vegetation cassettes in the stream bed	183 m It starts at the bridge on Závišova Street before Fidlovačka and ends at the bridge on Na Folimance Street.
2009	Záběhlice	Revitalization close to nature	Stabilization of riverbed- removal of landfills and unauthorized structures from the riverbed, Cleaning the trough, and stabilization of the riverbed with stone fortification	400 m long section between Záběhlická and K Prádelně streets
	Kozinovo náměstí – Phase I	Natural revitalization	Anti-flood measures- Removal of historical anchorages and widening of the channel, creation of an ecological berm, construction of pools and islands and vegetation adjustments	Length of treatment 130 m
2012	Chodovecký stream	Revitalization close to nature	Stabilization of the damaged channel with a heavy stone level, construction of ponds on the stream and clean up around the stream	Length of modifications 256 m
2017	Kozinovo náměstí – Phase II	Natural revitalization	Increase in the capacity of the bed and, at the same time, a significant naturalization of the entire site.	Length of treatment 270 m
2019	Hellada in Michli, stage I	Technical revitalization	Repair and revitalization of the Botič riverbed- Removal of the original concrete fortification, stabilization of the riverbed with a heavy boulder plain, depth division of the bed and planting of wetland plants	Length of modifications 546 m
2020	Záběhlický stream	Revitalization close to nature	Stabilization of the riverbed with a boulder plain and construction of a boulder chute	NA

	Hellada in Michli. Phase II	Technical revitalization	Removal of the original concrete fortification, stabilization of the riverbed with a heavy boulder plain, depth division of the bed and planting wetland plants	Length of modifications 200 m
2022	Botič in Záběhlice	Revitalization close to nature	Expansion of the bed and restoration of the floodplain, stabilization by a boulder plane, and construction of islands	Treatment length 300 m

3.2 Map methodology

The study area (Botič watershed) was divided into 17 sub-watersheds to facilitate in-depth analysis. This approach allowed for a better categorization of the watershed area, which, in turn, helped identify specific issues in individual regions. By categorizing these areas, preparing practical solutions for mitigation at the watershed level becomes feasible. (**Table 8**) provides the size of each sub-watershed to aid in further studies and analysis. (**Figure 20**) encompasses a map showing the watershed and the Sub- watersheds divided.

Table 8. Name and area of each sub-watershed. Source: Author

Sub-watershed (SWS)	Area in Hectares
SWS1	950.20
SWS2	1275.28
SWS3	1097.43
SWS4	666.62
SWS5	304.06
SWS6	479.13
SWS7	735.10
SWS8	432.33
SWS9	570.83
SWS10	865.95
SWS11	693.07
SWS12	819.90
SWS13	556.58
SWS14	637.57
SWS15	2287.08
SWS16	1293.20
SWS17	765.92

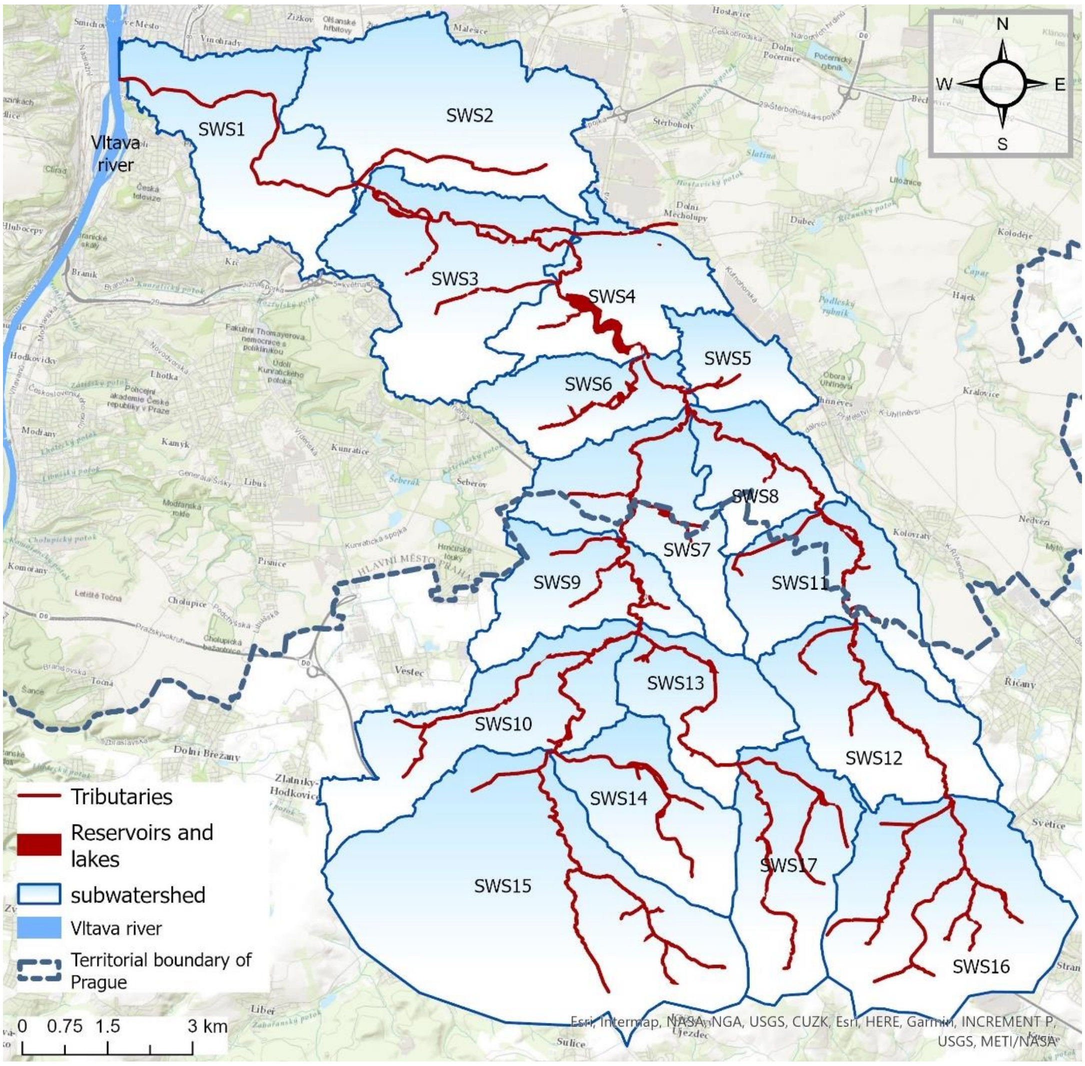


Figure 20. Division of Botič Watershed into 17 Sub-watersheds. Source: Author

3.2.1 Pervious and impervious surfaces

A spatial analysis study using ArcGIS employed open-source data to generate a map delineating areas characterized by impervious and pervious surfaces. The data was derived from materials classified as impervious, including highways, streets, pavements, driveways, building roofs, and land use, observed through aerial imagery and on-site visits. The outcome was a map showing pervious and impervious surfaces (**Figure 21**)

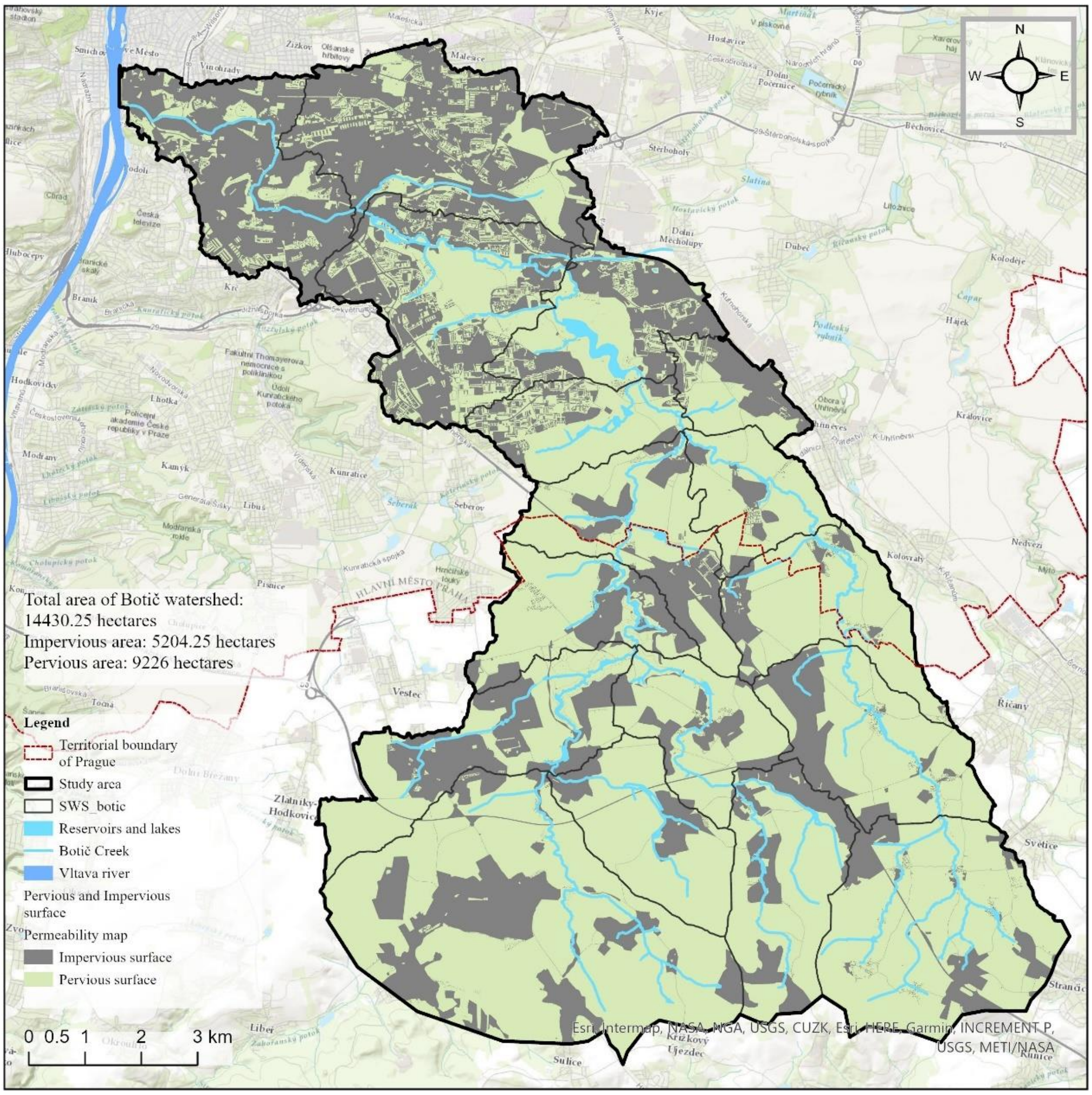


Figure 21. Botič watershed with pervious and impervious surface. Source: Author

Impervious surfaces determine the quick water flow into the stream from the surrounding watersheds, causing flash floods. However, from various floods and past flooding experiences, the soil in surrounding areas with previous surfaces could become saturated. The type of soil or the land use of the area could be one of the reasons for this.

3.2.2 Soil type

There are 4 significant types of soil found in the Botič watershed. Kambizemě (KA), Hnědozem (HN), Luvizemě (LU) and Antrozem (AN). The predominant type for the area of interest are soils from the reference class luvisols, primarily brown soil and luvizem. These soils occur in the southern part of the basin. In the central part of the watershed, acidic brown soils (cambisols) predominate, typical of hilly areas and highlands. The northern edge of the territory is the built-up area of Prague, where the soil horizon is "buried" or significantly modified, this area is referred to as urban -soil type Antrozem (**Figure 22**).

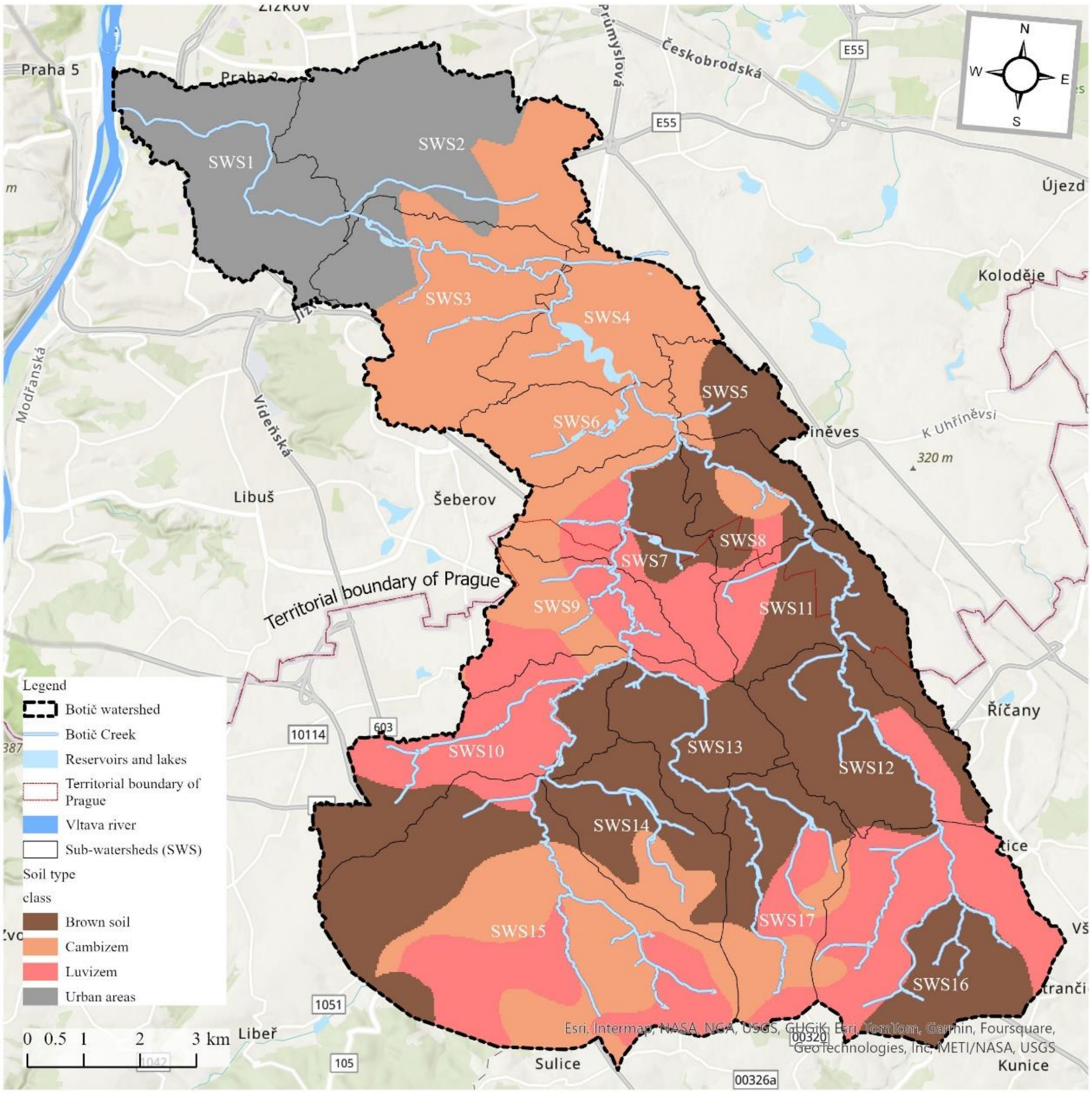


Figure 22. Soil types in Botič watershed. Data source:(geoportalpraha.cz) map: Author

3.3 Weighted overlay analysis

3.3.1 Identifying the most vulnerable areas

Five key factors were used to identify areas most vulnerable to the effects of urbanization within the watershed, including LULC, impervious and pervious surfaces, soil type, slope, and elevation. The determination of these factors, the development of ratings for each, and the ranking of the weights utilized a synthesis of previous studies conducted to investigate possible factors and their impact on the ecological status of the creek. The weights assigned for each factor were as follows:

25% LULC, 25% for impervious and pervious surfaces, 20% for slope, 15% for soil type, and 15% for elevation, as seen in (**Table 9**).

Table 9. Factors and its sub-criteria with weights and ratings used respectively for Weighted Overlay Analysis (WOA). Source: Author

Factor	Weightage in %	Sub-criteria	Rating
LULC	25	Agriculture	4
		Forestry	1
		Mining	7
		Industry	8
		Commercial	5
		Community	3
		Recreation	2
		Transport	7
		Logistic	6
		Utilities	5
		Residential	5
		Abandoned	3
		Natural	1
Pervious and Impervious Surface	25	Pervious	1
		Impervious	9
Slope	20	Class 1 (0 - 1.3)	1
		Class 2 (1.3 - 2.7)	3
		Class 3 (2.7 - 4.6)	5
		Class 4 (4.6 - 7.7)	7
		Class 5 (7.7 - 15.4)	9
Soil Type	15	Urban areas	8
		Cambizem	5
		Luvizem	4
		Brown soil	2
Elevation	15	Class 1 (191 - 263)	9
		Class 2 (263 - 316)	7
		Class 3 (316 - 366)	5
		Class 4 (366 - 417)	3
		Class 5 (417 - 505)	1

LULC: Weights reflect the general impact of each land use type on water quality, erosion, and other relevant concerns. Agriculture can have moderate impacts depending on practices, while mining and industry often have high negative impacts. Forestry and natural areas have lower impacts.

Distribution of Impervious Surface: Higher weights for classes with more impervious surfaces are based on the negative impacts of impervious surfaces on runoff, water quality, and infiltration.

Soil Type: Weights consider the behavior of soil types.

Slope: Exponential increase with angle reflects the significant influence of steeper slopes on erosion and runoff potential.

Elevation: Weights depend on whether flood mitigation is a primary concern. If so, lower areas are prioritized. Otherwise, weights can be uniform.

3.4 Site visits and observations

The study area was investigated on foot and covered approximately 30 km^2. Initial maps based on LULC data guided site visits toward locations with a high concentration of urbanization. The primary objective was to provide attention to these areas, which focused on mitigation and revitalization measures at both the watershed and channel levels. The observations obtained were tabulated (**Appendix 1** & **2**) at two levels, namely, the watershed and channel levels. To propose long-term revitalization measures, the method of observation focused on the watershed level, followed by the creek channel. The identified areas were marked on a map (**Figure 23**) using location points and radii surrounding the watershed. The radii covered on foot at the watershed around the creek channel varied between 1 km to 2.1 km. The numbers marked on the map from 1 to 10 indicate the corresponding location names and the radii around it (**Table 10**).

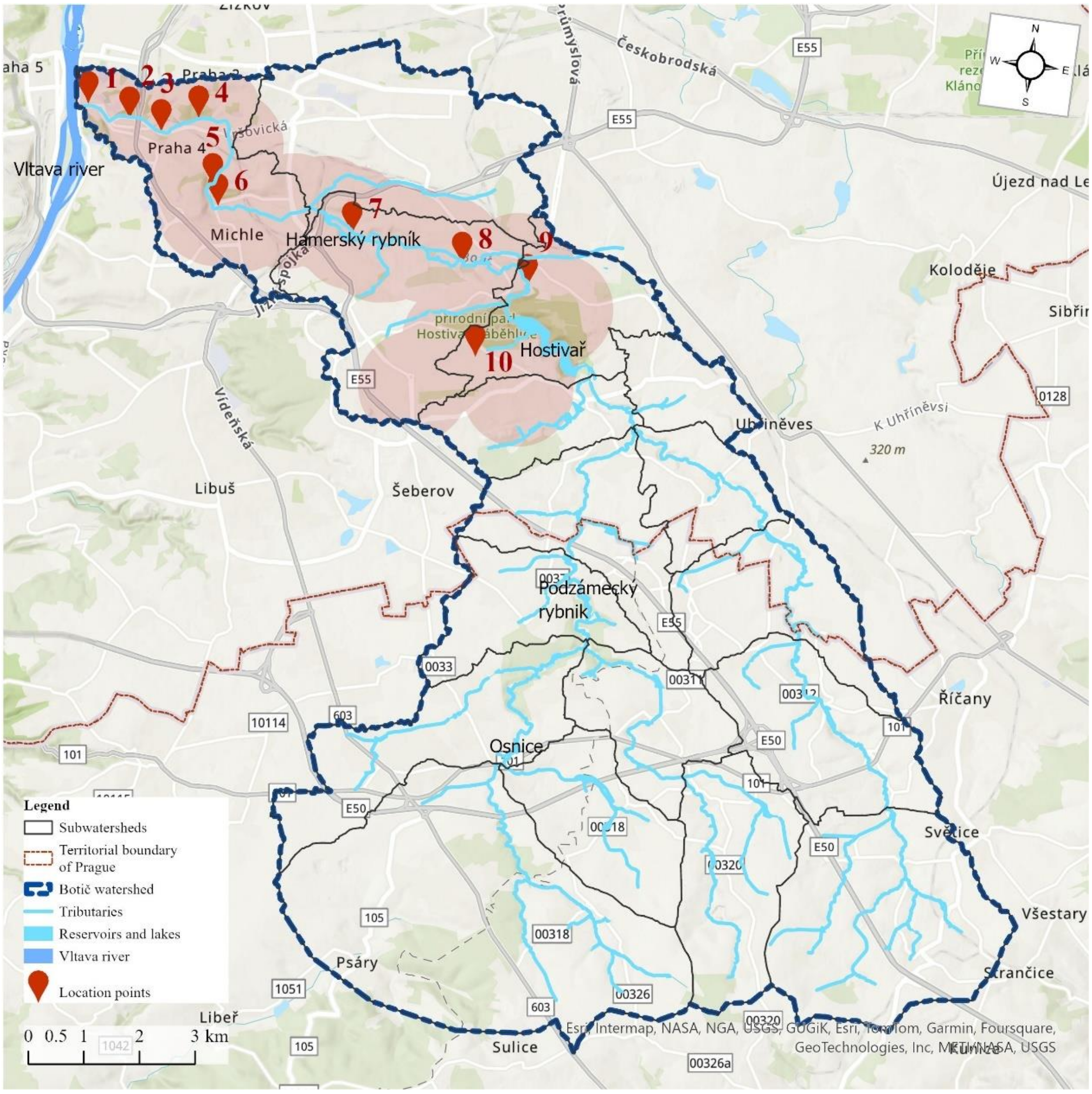


Figure 23. Map showing point locations and surrounding areas in the watershed covered during the site visit. Source: Author

Table 10. Legend for names of location points on the map in **Figure 23**

Location number	Name of location
1	Výtoň
2	Nusle to Folimanka
3	Park Fidlovačka
4	Grébovka (Havlíčkovy sady)
5	Michle
6	Dům Ochránců Přírody

7	Hamerský rybník
8	Meandry Botiče
9	Hostivař
10	Háje

3.4.1 Observations at the watershed level (macro level)

At the macro-level of the watershed, a range of factors were categorized as land use type, types of impervious surfaces and their texture, pervious surfaces such as natural and artificial surfaces, terrain slope, the hydrological connection between the watershed and channel, the presence of stormwater drain/sewer inlets into the channel, proximity of buildings to the channel, and man-made infrastructure.

These factors were identified and noted in all locations and their respective surroundings. Photographs were taken and the key factors and observations are represented. The photographs correspond to the various marked locations from 1 to 10 on the map displayed in (**Figure 23**).

After the completion of the field visits to the 10 locations, the photographs taken were categorized and grouped by incorporating the factors that were observed. The resultant findings were documented as images, and a detailed table (**Appendix 1**). These important factors are summarized below.

a. **Impervious surfaces observed in the watershed.**

The impervious surfaces included roadways, tram lines, train station, walkways, buildings, and parking areas. The numbers listed in the photographs correspond to the locations marked on the map (**Figure 23**) and labelled in (**Table 10**).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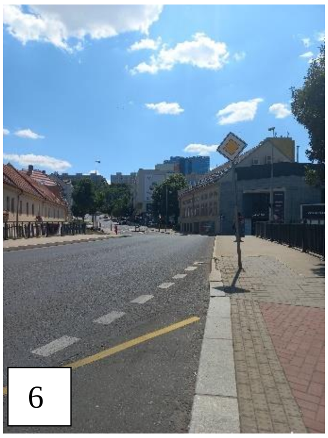
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b. Pervious surfaces observed in the watershed.

The pervious surfaces in the site locations included parks, retention ponds, boulevards, and parking spaces with permeable or semi-permeable surfaces. The numbers listed in the photographs correspond to the locations marked on the map (**Figure 23**) and labelled in (**Table 10**).


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c. Land use categories observed at the watershed.

The land use categories in the site locations included transport lines: railway lines and stations, tramways and roadways, built-up areas: residential, commercial, parking, sports complexes, recreation, and community spaces; natural areas: public parks, boulevards with walkways, natural parks, retention ponds, reservoirs. The numbers listed in the photographs correspond to the locations marked on the map (**Figure 23**) and labelled in (**Table 10**).


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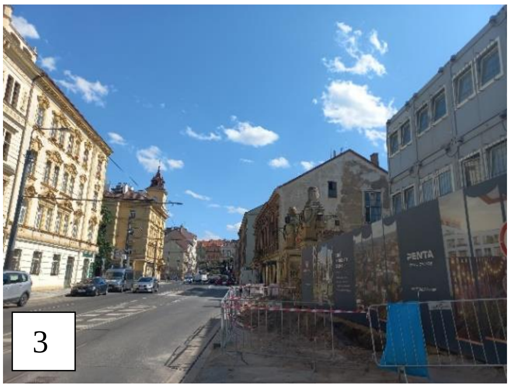
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d. Man-made infrastructure and hydrological connection between the watershed and the channel (presence of stormwater drain inlets in the watershed)

The infrastructure includes bridges, weirs, stormwater inlets, retention ponds, viaducts, a train station (the creek flowing in an underground channel), and a waterfront at the confluence of the creek and the Vltava River. The numbers listed in the photographs correspond to the locations marked on the map (**Figure 23**) and labelled in (**Table 10**).


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e. Slope and terrain in the watershed

The terrain had a prominently visible slope in certain areas, and in other areas of the watershed, they had a very gradual slope, making it appear flat in general. The numbers listed in the photographs correspond to the locations marked on the map (**Figure 23**) and labelled in (**Table 10**).

3.4.2. Observations at the channel level (micro level)

At the channel level, a range of factors categorized were the width of the channel, the shape of the stream bank, riparian vegetation, the physical composition of the stream, depth to the water surface from the bank, the physical appearance of water, substrates in the bottom, presence of dead wood and biota, shadowing, variability of the flow and man-made structures.

These factors were observed while traversing along the creek channel. Photographs were taken and the key factors and observations are represented and correspond to the marked locations from 1 to 10 on the map (**Figure 23**).

After the completion of the field visits, the photographs captured were categorized and grouped by incorporating the factors that were observed. The resultant findings were documented as images, and a detailed table (**Appendix 2**). These crucial factors are summarized below.

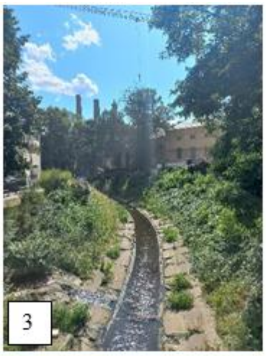
a. Physical composition and shape of stream bank

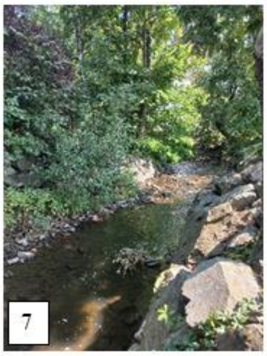
The morphology of stream banks varies significantly across various locations and is characterized by a range of distinct shapes that include gradual slopes and meanders, natural contours with meanders, trapezoidal cross-section with gradual slopes and meanders, trapezoidal configurations with steep slopes, and rectangular cross-section.

The trapezoidal section and gradual slopes of the channel's physical composition feature semi-pervious surfaces with minimal ground cover, trees, and few shrubs in the riparian zone. In contrast, the near-natural parts of the channel are characterized by boulders and a natural cross-section, ground cover, shrubs, and a substantial number of trees in the riparian zone.

The trapezoidal and rectangular channels lack ground cover and consist mainly of impervious surfaces such as paving or concrete, primarily added to provide structural integrity due to their proximity to buildings or roads. Apart from these parts of the channels, which were directly visible and accessible to the public, some of the locations have parts of the stream channel that are piped and flow underground, having no connection to the surrounding watershed.

The images capture these characteristics and observations on the two factors physical composition and shape. The numbers listed in the photographs correspond to the locations marked on the map (**Figure 23**) and labelled in (**Table 10**).





b. Riparian vegetation, presence of dead biota, and shadowing

The composition of riparian vegetation was influenced by pervious surfaces such as soil, gravel, and stones, which provided an environment conducive to the growth of ground cover, shrubs, and trees. The distribution of these plants varied depending on environmental factors, such as the slope of the channel and the availability of space. The stream channel was often heavily shaded in areas with sufficient space for tree growth. Deadwood and biota were most prevalent in channel regions with natural meanders along the riparian zones.

The images capture these characteristics and observations on the three factors riparian vegetation, presence of dead wood and biota, and shadowing. The numbers listed in the photographs correspond to the locations marked on the map (**Figure 23**) and labelled in (**Table 10**).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c. Man-made structures, retention ponds, stormwater drains, and weirs.

At certain locations, the channel was observed to have stormwater drain inlets, retention ponds equipped with dead biota traps, pedestrian bridges, and weirs. Although most streams have been anthropogenically modified and channelized, these specific areas can be classified as man-made structures.

The images capture these characteristics and observations of man-made structures, retention ponds, stormwater drains, and weirs. The numbers listed in the photographs correspond to the locations marked on the map (**Figure 23**) and labelled in (**Table 10**).

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4. Results

4.1 Land Use and Land Cover (LULC) Analysis

4.1.1 Types of LULC in the watershed

The recent LULC map (**Figure 13**) from data from the year 2020 provided the individual areas in hectares of each category of LULC for the whole watershed (**Table 11**).

Table 11. Area in hectares and percentage of categories of Land Use in the year 2020 in the Botič watershed

Land use land cover class	Area in hectares (year 2020)	Percentage
Agriculture	6492.49	**44.79%**
Residential	2173.80	15.00%
Transport	1538.47	10.61%
Forestry	1252.19	8.64%
Recreation	1172.87	8.09%
Transport	717.48	4.95%
Natural	364.29	2.51%
Logistic	306.78	2.12%
Community	222.75	1.54%
Commercial	89.39	0.62%
Industry	76.07	0.52%
Transport	42.16	0.29%
Utilities	30.26	0.21%
Mining	14.44	0.10%
Abandoned	0.85	0.01%
Total	**14494.29**	

Some of the instant observations included were that the total area of the watershed is 14494.29 hectares. There were 18 different land use classes (**Table 11**), including agriculture, residential, transport, forestry, recreation, industry, and abandoned land. Agriculture proved to be the dominant land use class, covering 44.79% (6492.49 hectares) of the watershed area. Other significant Land Uses were residential areas occupied 15.00% (2173.80 hectares), followed by transportation at 10.61% (1538.47 hectares), forestry at 8.64% (1252.19 hectares), and recreation at 8.09% (1172.87 hectares). Minimal Land Use was from the Industrial, mining, and abandoned land use each represented less than 0.1% of the total area.

Result-oriented Analysis:

Water Resource Management: The dominance of agriculture and the presence of transportation infrastructure suggest potential concerns for water quality due to agricultural runoff and pollutants from roads. Targeted management strategies might be needed to protect water resources, especially in areas with high agricultural activity or near transportation corridors.

Biodiversity and Habitat Conservation: The presence of forestry and recreational areas highlights the importance of biodiversity conservation. Understanding these areas' spatial distribution can help develop conservation plans and maintain ecological corridors.

Urban Planning and Development: The significant residential and transportation areas indicate urbanization pressures. Analyzing future development plans and potential land-use changes can help guide sustainable urban expansion and minimize impacts on natural areas.

Infrastructure Development: The distribution of different land uses can inform infrastructure development needs. Areas with higher populations (residential) might require water supply, sanitation, and transportation infrastructure investments.

4.1.2 Changes in the individual categories of Land Cover from 2000 - 2018

The change in area of LULC classes using the data from the maps (**Figure 12**) of total 18-year period (2000 – 2018). From the (**Table 12**) if the value was negative, it indicated a decrease in area of LULC class, if the value was positive, it indicated an increase in area and if the value was 0.00 it indicated no significant change in area. For example, considering Broad-leaved Forest between the year 2000 – 2006 there was a decrease in area by 0.34 hectares, between the year 2006 – 2012 there was no significant change and between the years 2012 – 2018 there was a decrease in area by 0.52 hectares. The relative change in area was computed to each 6-year period.

Table 12. Land use land cover changes of individual classes from 2000-2018

LULC Classes	**Change of area in hectares**			
	2000-2006	**2006-2012**	**2012-2018**	**2000-2018**
Broad-leaved forest	-0.34	0.00	-0.52	-0.86
Complex cultivation patterns	56.39	42.29	0.00	98.68
Coniferous forest	-168.10	0.00	0.00	-168.10
Construction sites	-41.22	23.20	-51.00	-69.02
Continuous urban fabric	-28.22	28.21	0.00	-0.01
Discontinuous urban fabric	455.49	342.29	244.89	1042.67
Dump sites	-0.56	-1.37	-16.65	-18.58
Fruit trees and berry plantations	-30.01	0.00	5.83	-24.18

Green urban areas	-11.84	0.00	-13.02	-24.86
Industrial or commercial units	209.89	128.58	53.42	391.90
Land principally occupied by agriculture, with significant areas of natural vegetation	104.30	-72.76	-2.48	29.06
Mineral extraction sites	7.34	19.36	-54.67	-27.97
Mixed forest	202.38	0.00	7.68	210.06
Non-irrigated arable land	-935.76	-448.41	-318.16	-1702.33
Pastures	102.09	-19.10	9.84	92.84
Road and rail networks and associated land	0.12	0.00	50.48	50.60
Sport and leisure facilities	25.02	-42.29	38.29	21.02
Transitional woodland/shrub	53.02	0.00	46.07	99.09

The observed surge in area was most notable in the discontinuous urban fabric, registering an increase of 1042.67 hectares. This indicates a significant upsurge in urban expansion and sprawl of built-up regions. There was notable increase in area observed in industrial or commercial units (391.90 hectares) and sport and leisure facilities (21.02 hectares) indicating growing industrial and recreational development within the watershed.

Conversely, the most significant decrease in area was observed in non-irrigated arable land, which decreased by 1702.33 hectares suggesting a significant conversion of agricultural land to other uses, potentially impacting food production and agricultural practices. There was a decrease in areas observed in coniferous forests (-168.10 hectares), fruit trees and berry plantations (-24.18 hectares), and pastures (-92.84 hectares). This suggests a loss of natural and semi-natural habitats, which could affect biodiversity and ecosystem services. The negative values indicated a reduction in area of the LULC class.

Result-oriented Analysis:

The significant increase in discontinuous urban fabric and decrease in non-irrigated arable land highlight the trend of urban sprawl and land-use change within the watershed. This could have various consequences, such as increased stormwater runoff, decreased water quality, habitat loss, and fragmentation. Expanding industrial and commercial units suggests growing economic activity in the area, potentially leading to increased pollution, traffic congestion, and resource demand. The loss of natural and semi-natural habitats raises concerns about biodiversity conservation and the sustainability of ecosystem services the watershed provides.

4.1.3 Transition of LULC observed between individual categories from the year 2000-2018.

The LULC is classified into different categories, such as construction sites, discontinuous urban fabric, non-irrigated arable land, and pastures. The (**Table 13**) is a summary of the (**Figure 24**) representing the shifting changes from one category of LULC to another in the Botič watershed from 2000 to 2018.

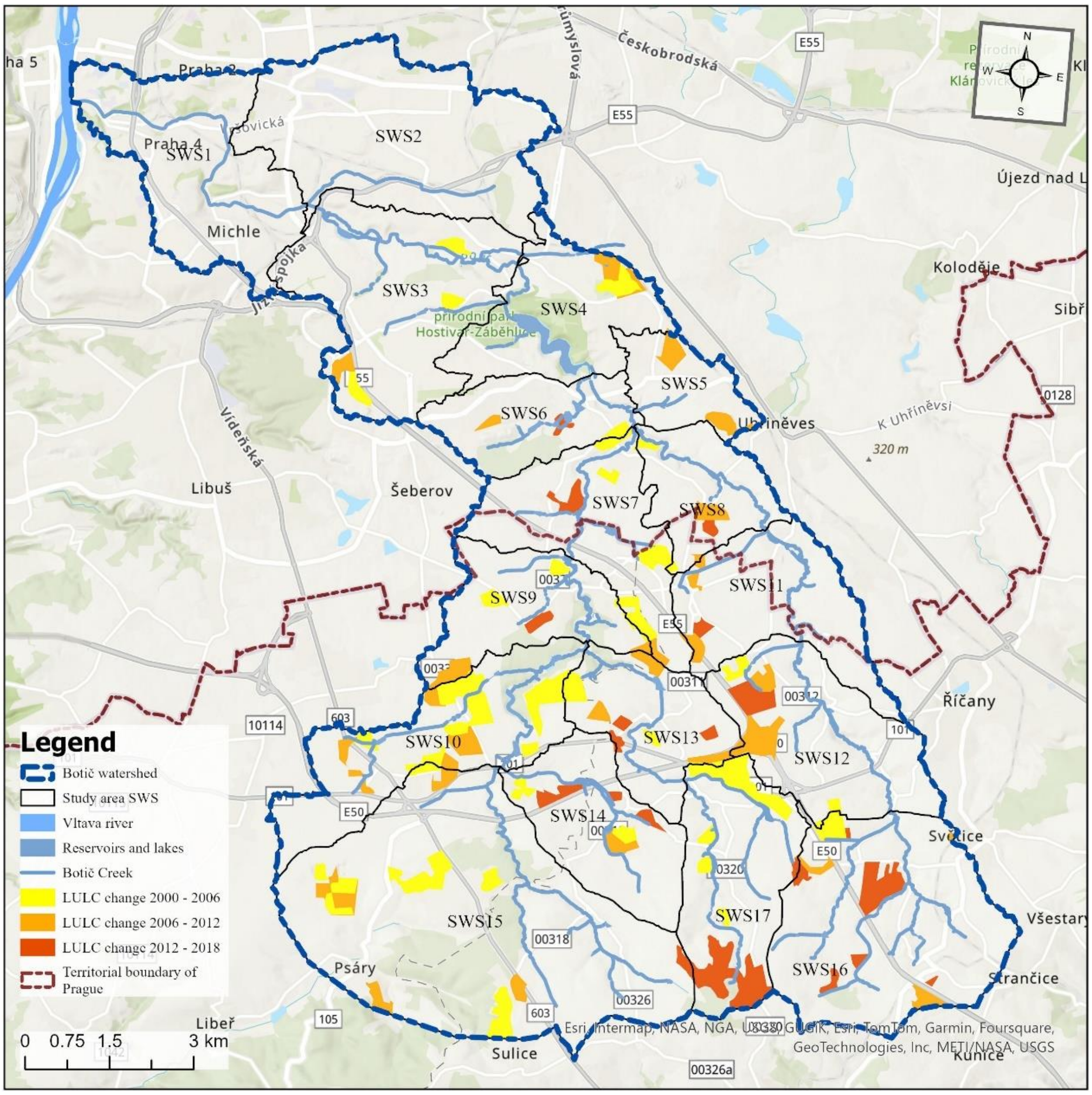

Figure 24. Analysis of Land Use and Land Cover Changes in the Botič Watershed between 2000-2018. Data: (Copernicus.eu) map: Author

Table 13. Comparison of LULC categorial change in area from 2000-2018. Source: Author

LULC Code	**Change of Land Use Land Cover (LULC)**	**Area change in Hectares**			
		2000-2006	**2006-2012**	**2012-2018**	**Total**
112-133	Discontinuous urban fabric to Construction sites	0	15.05	3.72	18.76
133-112	Construction sites to Discontinuous urban fabric	34.87	0.00	0.41	35.28
211-133	Non-irrigated arable land to Construction sites	147.47	45.74	91.33	284.54
211-112	Non-irrigated arable land to Discontinuous urban fabric	148.13	133.17	24.20	305.50
211-121	Non-irrigated arable land to Industrial or commercial units	84.69	23.15	51.78	159.62
211-131	Non-irrigated arable land to Mineral extraction sites	20.18	5.32	0.00	25.49
211-231	Non-irrigated arable land to Pastures	24.26	0.00	41.93	66.20
211-324	Non-irrigated arable land to Transitional woodland/shrub	0.00	28.74	5.43	34.17
231-112	Pastures to Discontinuous urban fabric	22.95	5.54	7.74	36.23
	Area in hectares lost to urban development	458.28	227.97	179.18	865.43
	Percentage Area lost to urban development	**52.95%**	**26.34%**	**20.70%**	

The areas that were converted to Discontinuous urban fabric, Construction sites, Industrial or commercial units, and Mineral extraction sites were summed up together to understand the total area lost to urban development. The effect of urbanization is calculated in percentage and is declining as seen in the graph (**Figure 25**).

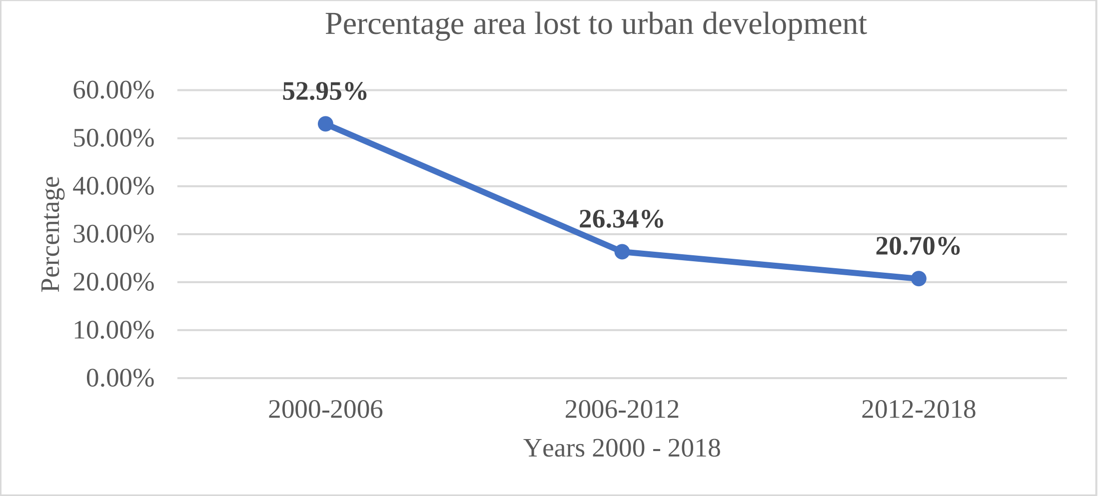

Figure 25. Area lost to urban development from the year 2000-2018. Source: Author

a) Specific observations between 2000-2018

Non-irrigated arable land to urban development: a total area of 775.15 hectares of non–irrigated arable land was converted to construction sites, discontinuous urban fabric, industrial or commercial units, and mineral extraction sites. This suggests that agricultural land is being lost to industrial and commercial development.

Pastures to discontinuous urban fabric: 36.23 hectares of pastures were converted to discontinuous urban fabric, which suggests that some grazing land is being lost to development.

Non-irrigated arable land to pastures and woodland/shrubs: a total area of 100.37 hectares of non-irrigated arable land was converted to pastures and woodland/shrubs. This suggests that some agricultural land is being abandoned and is reverting to pastures and natural vegetation.

b) Overall observations

There has been an overall decrease of 26.61% in urban development in the watershed between 2000-2012 and 5.64% between 2006-2018, which suggests that there has been a slowdown in urbanization. On the contrary, between the years 2006-2012 and 2012-2018, there has been an increase in conversion of non-irrigated arable land to construction sites from 45.74 ha to 91.33 ha, industrial or commercial units from 23.25 ha to 51.78 ha and discontinuous urban fabric from 5.54 ha to 7.74 ha. This could contribute to the future increase in urbanization.

4.2 Urbanization extent concerning each sub-watershed.

Urban areas are spread across the watershed and concentrated in certain areas more than others. The watershed is divided into 17 sub-watersheds, and this helps determine the extent of urbanization concerning area and percentage to categorize which sub-watershed has the highest urbanization and overlay the same data with the LULC data from the year 2020 (**Table 14**) and map outcome of the same (**Figure 26**).

Table 14. Percentage of urbanized area in the 17 sub-watersheds in the Botič watershed. Source: Author

Sub-watershed (SWS)	**Area of SWS in hectares**	**Urbanized Area in the SWS in hectares**	**Percentage urbanized area**
SWS1	950.20	741.35	78.02%
SWS2	1275.28	992.62	77.84%
SWS3	1097.43	678.28	61.81%
SWS4	666.62	325.29	48.80%
SWS5	304.07	136.33	44.84%
SWS6	479.13	166.67	34.79%
SWS7	735.10	227.49	30.95%
SWS8	432.33	80.92	18.72%
SWS9	570.83	152.23	26.67%
SWS10	865.95	297.15	34.32%
SWS11	693.07	117.57	16.96%
SWS12	819.91	194.11	23.67%
SWS13	556.58	127.10	22.84%
SWS14	637.57	102.10	16.01%
SWS15	2287.08	444.23	19.42%
SWS16	1293.19	214.66	16.60%
SWS17	765.92	160.69	20.98%
Botič watershed	**14430.26**	**5158.77**	**35.75%**

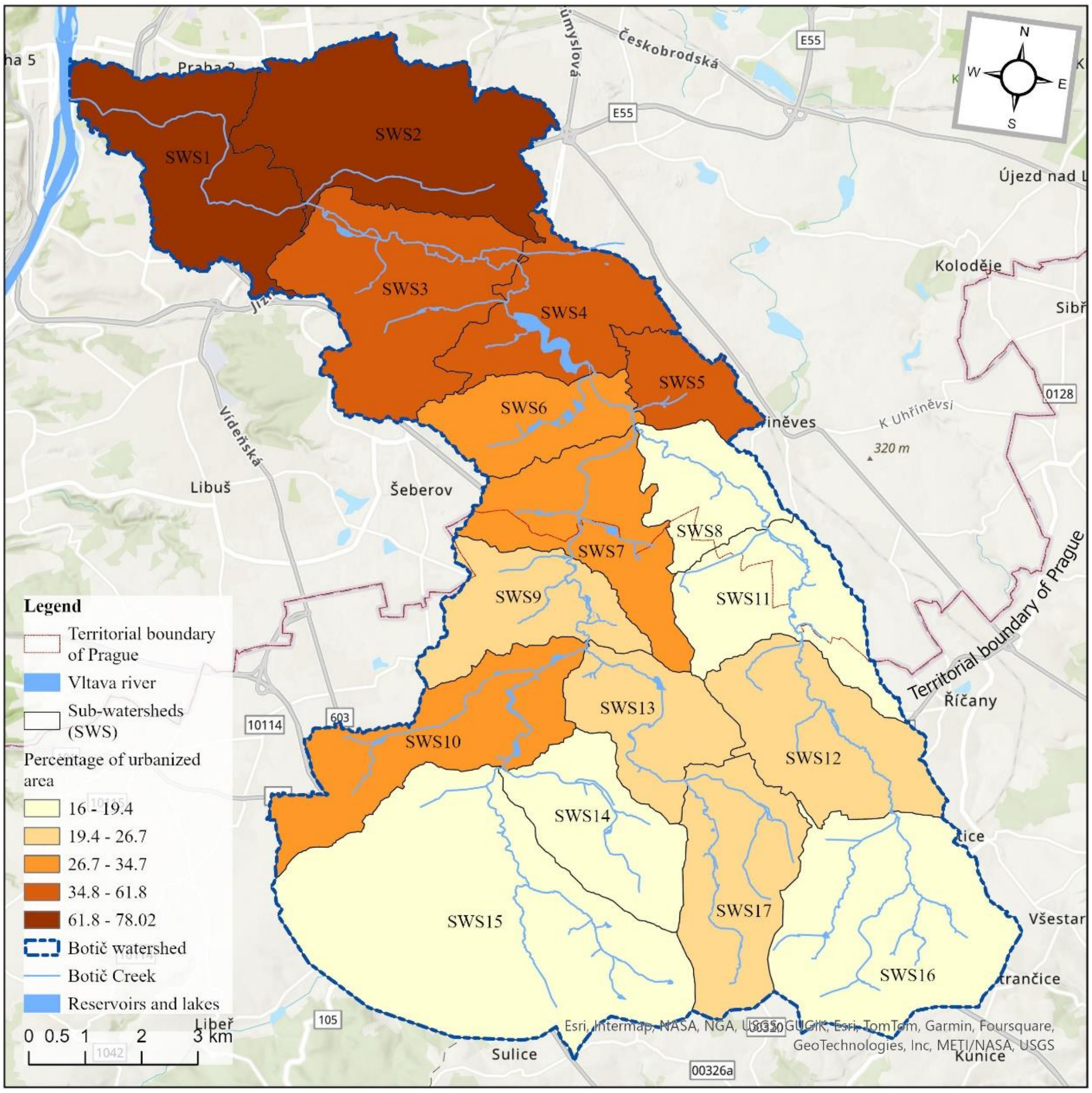

Figure 26. Extent of urbanization in the 17 sub-watersheds in the Botič watershed. Source: Author

Observations from the (**Figure 26**) and (**Table 14**) were:

The total area of the 17 sub-watersheds is 14,494.29 hectares, and the total urbanized area within them is 4,442.25 hectares, representing 30.74% of the total watershed. This indicates a moderately high level of urbanization across the watershed.

There is a significant variation in the percentage of urbanization among the sub-watersheds. It ranges from 16% in SWS14 to 78% in SWS1 and SWS2. This suggests that some sub-watersheds are considerably more urbanized than others.

Five sub-watersheds (SWS1, SWS2, SWS3, SWS4, and SWS5) have more than 45% of their area urbanized. These sub-watersheds are likely to experience more significant impacts from urbanization compared to others.

Result-oriented Analysis:

Impact on Water Resources: The varying levels of urbanization across the sub-watersheds suggest potential differences in water quality and quantity. Sub-watersheds with higher urbanization (like SWS1, SWS2, and SWS3) could have increased stormwater runoff, higher pollutant loads, and potentially lower water quality and require targeted water quality management strategies.

Increased Flood Risk: Impervious surfaces associated with urbanization can increase stormwater runoff and flood risk. Sub-watersheds with higher urbanization (like SWS1 and SWS2) might be more susceptible to flooding and could benefit from improved flood mitigation infrastructure or green infrastructure solutions.

Targeted Infrastructure Development: Considering the existing urbanization patterns, planners can prioritize areas within the watershed for future development based on factors like existing infrastructure capacity, potential environmental impacts, and proximity to existing urban centers. Sub-watersheds with lower urbanization might require more investment in infrastructure development as they experience growth.

Habitat Loss and Fragmentation: Urbanization can lead to habitat loss and fragmentation for aquatic and terrestrial species. Understanding the distribution of urbanization across sub-watersheds can help identify areas of critical habitat and inform conservation efforts. More urbanized sub-watersheds might require specific measures to protect sensitive habitats and wildlife corridors.

4.3 Extent of impervious surfaces concerning each sub-watershed

The urbanization extent study determined how much area is urbanized based on the type of LULC but failed to determine which surface allowed water to infiltrate into the ground. This is determined using the perviousness map, and data is prepared using detailed satellite maps and site visits as a basis. From impervious and pervious surface analysis, the maximum/minimum and percentage of the impervious surfaces in each sub-watershed were categorized as represented in (**Figure 27**) and (**Table 15**).

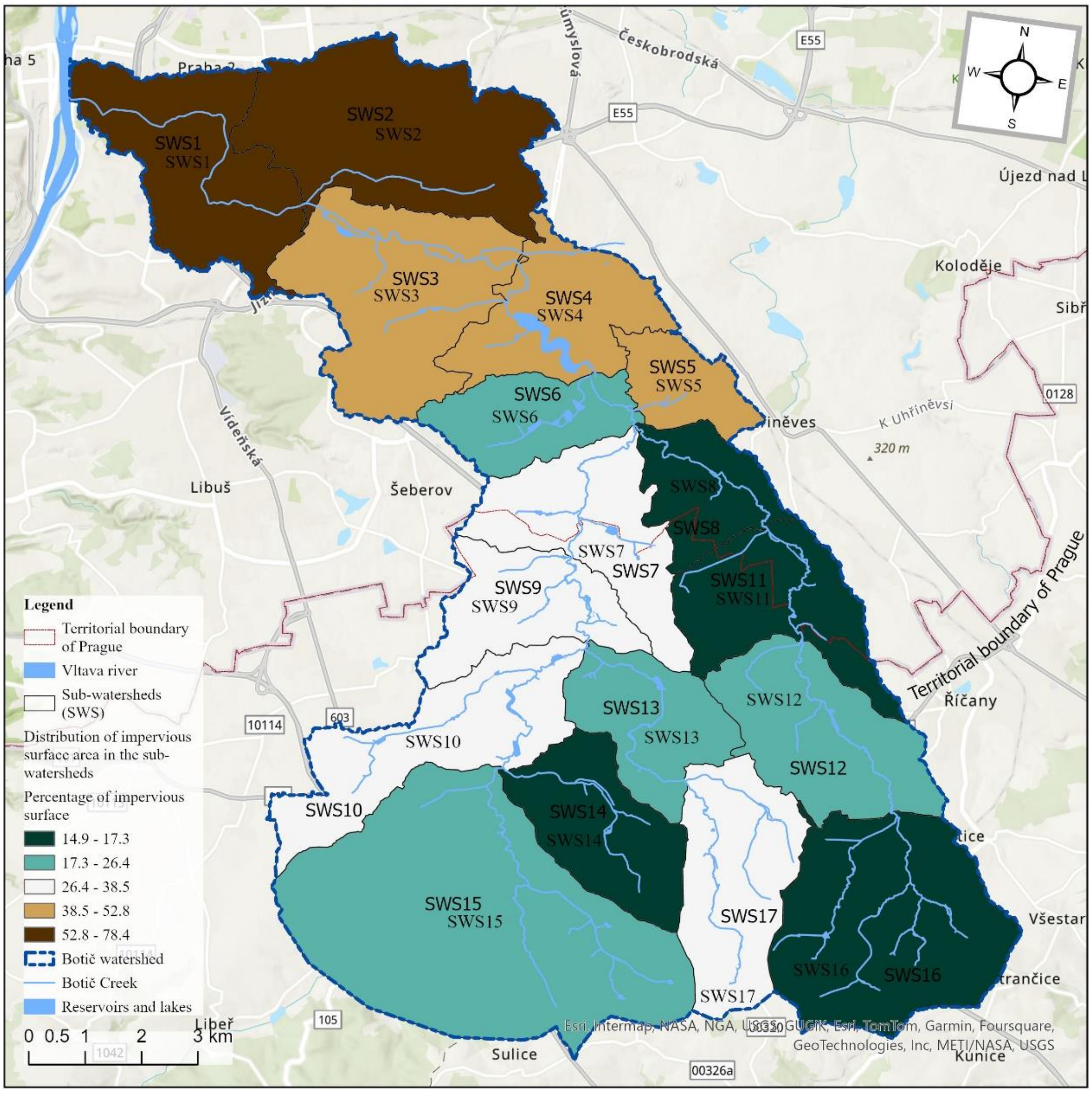

Figure 27. Extent of Imperviousness in the 17 sub-watersheds at the Botič watershed

Table 15. Percentage of impervious surface in the 17 sub-watersheds in the Botič watershed

Sub-watershed (SWS)	Total area in hectares	Impervious Area in hectares	Percentage Impervious surface
SWS1	950.20	744.73	78.4%
SWS2	1275.28	904.85	71%
SWS3	1097.43	580.34	52.9%
SWS4	666.62	318.93	47.8%
SWS5	304.07	144.10	47.4%
SWS6	479.13	125.71	26.2%
SWS7	735.10	221.47	30.1%
SWS8	432.33	65.94	15.3%
SWS9	570.83	170.93	30%
SWS10	865.95	333.69	38.5%

SWS11	693.07	103.91	15%
SWS12	819.91	216.63	26.4%
SWS13	556.58	125.33	22.5%
SWS14	637.57	110.56	17.3%
SWS15	2287.08	593.25	25.9%
SWS16	1293.19	202.43	15.6%
SWS17	765.92	237.70	31.03%
Botič watershed	**14430.26**	**5200.49**	**36.04%**

The **Table 15** and **Figure 27** show the total area and percentage of impervious surfaces for 17 sub-watersheds (SWS1 to SWS17) and the entire Botič watershed.

Some key observations made were:

The total area of the Botič watershed is 14430.26 hectares, of which 5200.49 hectares (36.04%) is impervious surface. Over a third of the watershed is covered by impervious surfaces like buildings, roads, and sidewalks, which can impact water flow and quality.

Impervious surface by sub-watershed:

SWS1 and SWS2 show the highest percentage of impervious surfaces at 78.38% and 70.95%, respectively, because of significant urban development, as observed from the LULC map. Whereas SWS12 and SWS11 show the lowest percentages of impervious surface at 14.99% and 15.65%, respectively, as a result of these sub-watersheds are dominated by the more rural or natural land cover as observed from the LULC map in (**Figure 28**).

Result-oriented Analysis:

Potential impacts: High levels of impervious surface have led to increased stormwater runoff, decreased infiltration, and higher pollutant loads in waterways. This negatively impacted the water quality and aquatic life and caused downstream flooding.

Targeted management: Identifying sub-watersheds with highly impervious surfaces could help target stormwater management efforts such as green infrastructure, rain gardens, and improved drainage systems. These measures would help mitigate the negative impacts of urbanization.

Land use planning: deeper understanding of the distribution of impervious surfaces could inform land use planning decisions to promote sustainable development in urban areas while protecting natural areas.

4.4 Weighted overlay (WOA) analysis

4.4.1 Identifying the most vulnerable areas

The weighted overlay analysis incorporated the factors LULC, impervious and pervious surfaces, soil type, slope, and elevation, their respective weights, and the ratings (**Table 9**). It resulted in a map highlighting the areas in the watershed most vulnerable to the effects of urbanization. Regions of very high priority, high priority, and moderate priority have been identified and require greater attention concerning revitalization efforts (**Figure 28**).

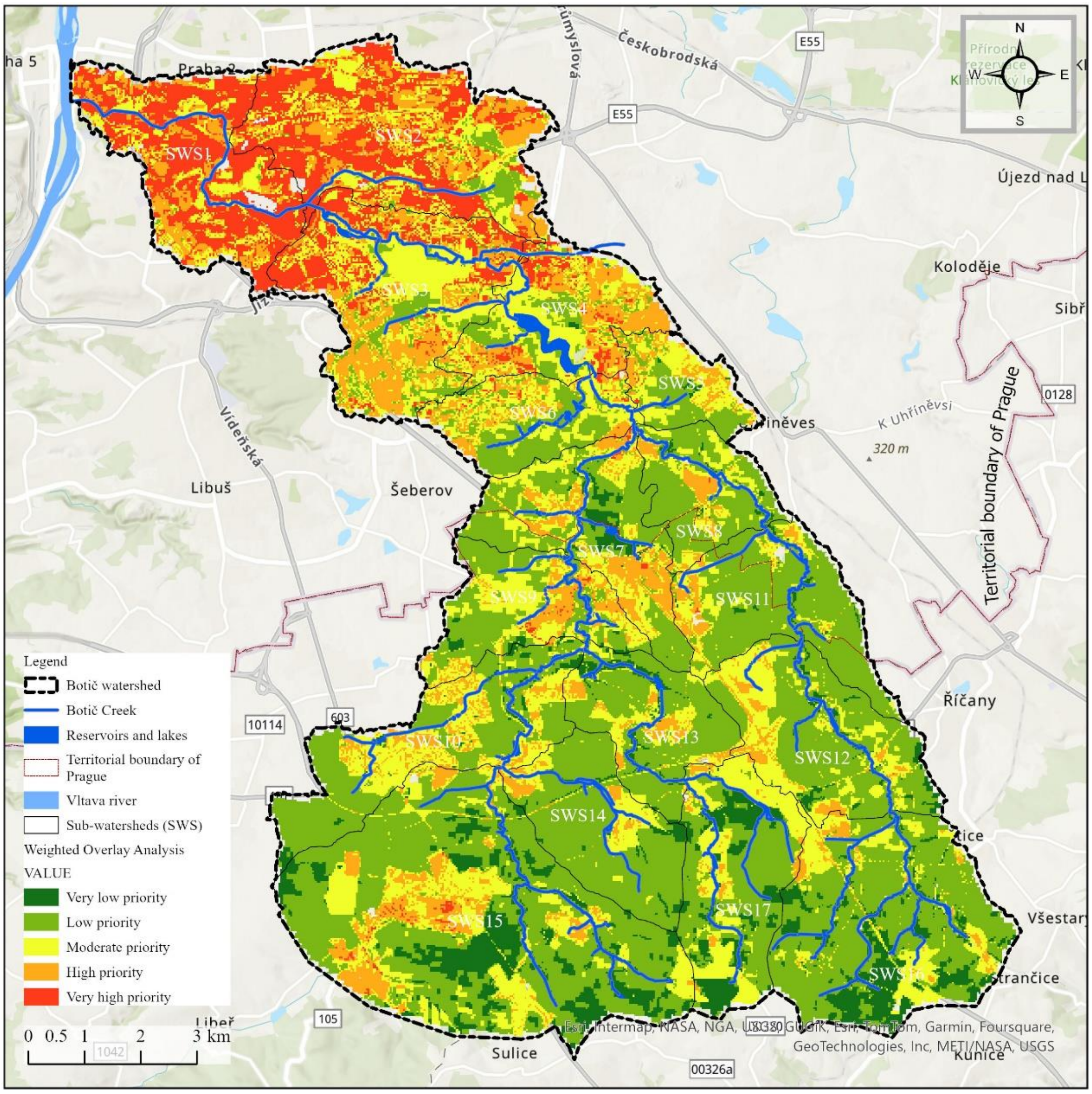

Figure 28. Weighted overlay analysis in the Botič watershed. Source: Author

The areas of very high priority are predominantly situated in the downstream portion of the watershed, close to the confluence of the Botič creek and the Vltava River. These areas are indicative of significant urban development as they are near the city center of Prague. The upstream areas are primarily encompassed by agricultural and natural LULC but display indications of moderate to high priority adjoining most of the stream path and its riparian zones owing to sub-urbanization. These regions present a substantial potential for preservation, and preventative measures could be implemented before further urban expansion takes place.

4.4.2 Identifying potential wetland areas

To identify areas that can be converted to wetland areas, layers of slope and elevation were used. The outcome of a weighted overlay analysis of the slope and digital elevation model for the watershed is depicted in map (**Figure 29**), which identified low-lying areas that have the potential to collect water from precipitation. The areas categorized with the value 5.0-9 were the low-lying areas with steep slope in the map's legend. The areas with values greater than 4.0 have been grouped into the areas with potential for wetland areas (**Figure 29**). The areas with value 1-4 were ignored as they are areas with low slopes and high elevation.

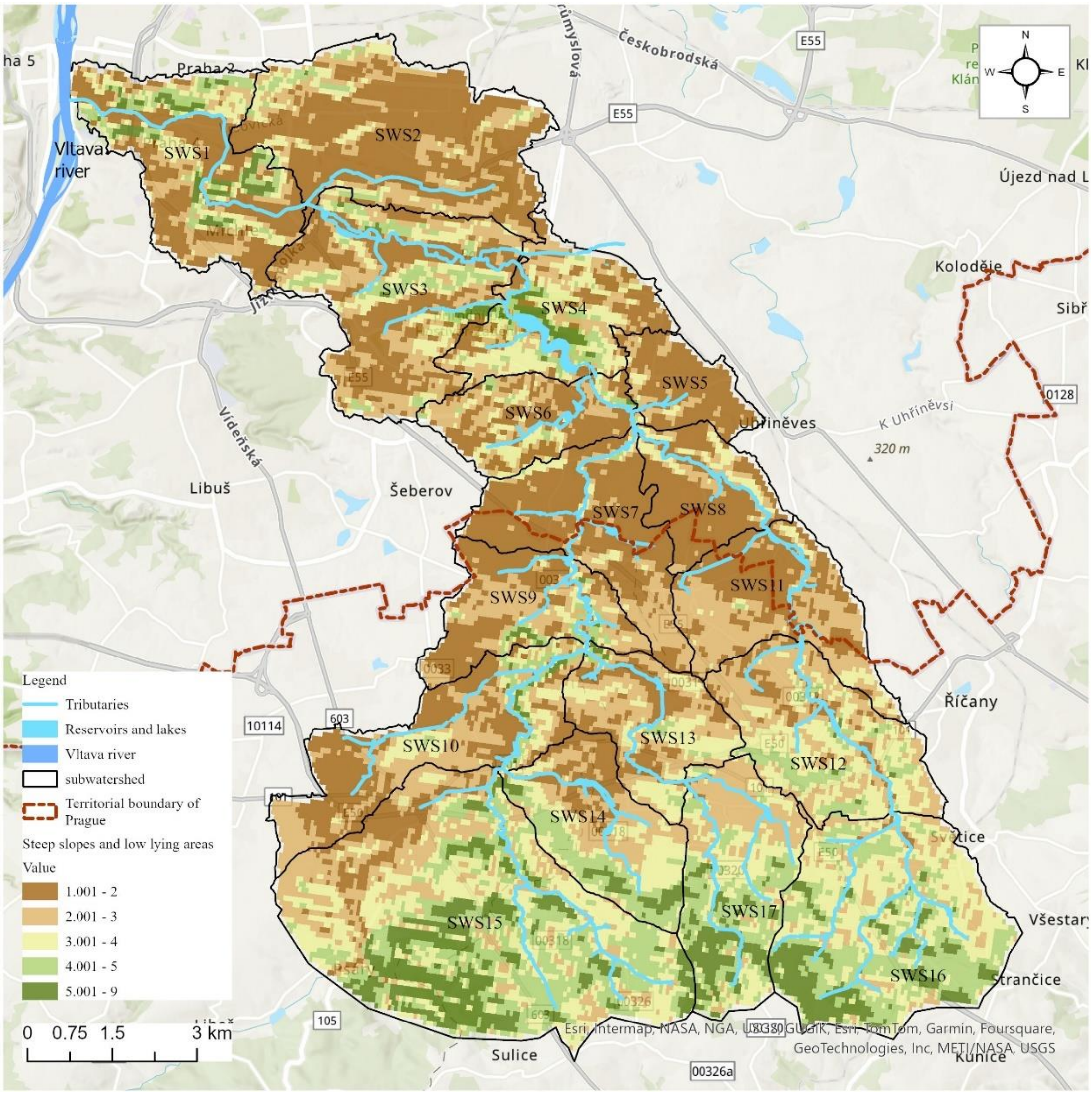

Figure 29. Weighted overlay analysis to determine potential areas for wetland. Source: Author

4.5 Site analysis

Upon completion of site visits and thorough analysis of the data gathered it has been observed that similar issues consistently arise across multiple locations despite variations in surrounding environments. However, it has been identified that the mitigation strategies that could be proposed for these situations remain similar. As such, these issues may be classified into specific typologies at both the watershed and channel levels, as in (**Table 16**) and (**Table 17**).

Table 16. Classification of issues and mitigation proposals based on the type at the watershed level. Source: Author

Sl no.	Locations	Typology of issue	Possible Mitigation proposals
Watershed level (macro level)			
1.	Hostivař, Michle	Low-lying areas close to the creek – underutilized	Constructed wetland, riparian zone, meadow
2.	Háje, Nusle to Folimanka, Výtoň	Underutilized roofs with good structure	Green roofs, green infrastructure
3.	Záběhlice, Háje, Výtoň, Nusle, Folimanka	Impervious surfaces such as parking areas, walkways, and plazas.	Conversion from impervious to semi-pervious surfaces or permeable surfaces.
4.	Záběhlice, Háje, Folimanka, Grébovka	Small green spaces in residential areas without a specific function	Rain garden, edible garden, orchard.
5.	Háje, Nusle, Folimanka, Hamerský rybník, Výtoň	Underutilized green spaces in crowded urban areas	Interactive urban spaces
6.	Areas outside Prague territorial boundary (upstream part of the watershed)	Land with agricultural land use	Riparian buffer zones, Bioswales, wetlands, meadows
7.	Nusle to Folimanka, Meandry Botiče, Grébovka (Havlíčkovy sady), Dům Ochránců Přírody, Hostivař	Stormwater drain inlets directly into the stream	Administrative and management protocols.

Table 167. Classification of issues and mitigation proposals based on the type at the channel level. Source: Author

Sl no.	Locations	Typology of issue	Mitigation proposal
Channel level (micro level)			
1.	Hostivařské náměstí, Folimanka Park area, between Nusle and Folimanka, Fidlovačka	Cross-sectional modification	a. Partial cross-sectional modification of stream channel
			b. Complete cross-sectional

			modification
2.	Locations of creek channel which have space available to create meanders	Morphological modification	Pools, riffles, bed material, and channel banks
3.	Hamerský pond and Záběhlice locality	Naturalization	Material/ textural modification with the addition of vegetation.
4.	Meandry Botiče, Dům Ochránců Přírody	Stream daylighting	Opening the stream to the surface wherever it is flowing underground to have better water quality and connectivity
5.	Michle locality	Maintenance and education	Field trips and nature walks with students of different ages to educate the importance of keeping the stream surroundings clean

4.6 Activities leading to the worsening of the ecological status of the Botič creek

Various aspects of the Botič watershed, such as the history and the landscape changes that occurred, distribution of tributaries, connected ponds and reservoirs, climate, flood-related history, protected areas, and nature parks, flora and fauna, water quality and its collection points, soil type, management, monitoring and revitalization practices, LULC changes, and its present status, documenting the pervious and impervious surfaces in the watershed and site visits were studied and analyzed. The outcome of this study helped identify some of the reasons for the worsening of the ecological status of Botič Creek and its watershed. These reasons could be identified as:

- Conversion of land use land cover from agricultural areas to urban fabric.
- Expansion of urban and sub-urban areas.
- Increase in impervious surfaces due to change in LULC.
- Flash floods and drought periods cause ecological instability.
- Physical and biological load from stormwater drains leading into the creek channel, resulting in increased sediments, and deteriorating water quality at the measured locations of the creek channel.
- Observed high and undesirable anthropogenic modification of the creek channel.
- The proximity of the built-up areas to the creek channel resulted in easy access to direct pollution by littering and stormwater drain inlet points.
- Lack of riparian zones around the creek channel in several areas leading to the degradation of the biodiversity in the long run.

5. Discussion

The analysis using map data sets and corresponding field observations led to potential areas being identified and prioritized for mitigation and restoration at the watershed and channel level. It is pertinent to note that certain areas may not be modifiable due to existing structural or architectural limitations. Conversely, certain areas offer opportunities for preservation. In the upstream areas, the sub-urban area is beginning to expand but possesses the potential to support riparian zones and improve water quality by further supplementing the existing monitoring stations.

Their potential for sustainable growth also makes them a desirable option for suburban development in the watershed. Even though these areas are located outside the city limits of Prague, they require due weightage for preservation and restoration so that they do not face the same issues prevailing at the city center of Prague.

Various methods exist for mitigating and restoring watersheds and creeks. However, an approach that involves modifying the watershed followed by a focus on the channel level offers a long-term solution to the problems associated with the watershed. This approach addresses the root cause of the issues and ensures sustained health of the watershed.

Agricultural land needs protection from being converted to other uses. To achieve this, policies such as zoning, agricultural easements, and sustainable land-use planning can be implemented. Regulations should also be developed and enforced to minimize environmental impacts from urban sprawl and industrial development, including stormwater management practices, pollution control measures, and habitat restoration efforts.

Some of the possible restoration measures at the watershed level and creek channel level have been discussed in the further chapters.

5.1 Restoration proposals at watershed level (macro level)

The mitigation measures have been proposed based on the typologies of the prevalent issues at the watershed. The measures are intended as examples of ideas that could work in selected locations rather than definitive proposals. They are also transferable to other locations within the watershed and can be replicated as deemed necessary. A few proposals have been made which could be solutions to the problems prevailing in the watershed area. These proposals are natural and constructed wetlands, green roofs and other green infrastructure, rain gardens and rainwater harvesting, interactive urban landscapes, and bioswales.

5.1.1 Proposal 1- Natural and constructed wetlands

The identification of areas with high slopes and low elevations is crucial in the determination of potential sites for conversion into meadows or wetland areas. These sites act as natural water sinks, allowing for adequate water infiltration into the soil, which is a critical component in maintaining a sustainable watershed link. Areas with the potential to be converted into wetland areas have been identified (**Figure 30**). However, several of these areas may not be practically converted due to their proximity to built-up areas or overlapping with other land uses. Therefore, careful consideration is required when selecting potential sites for wetland area development or meadow conversion.

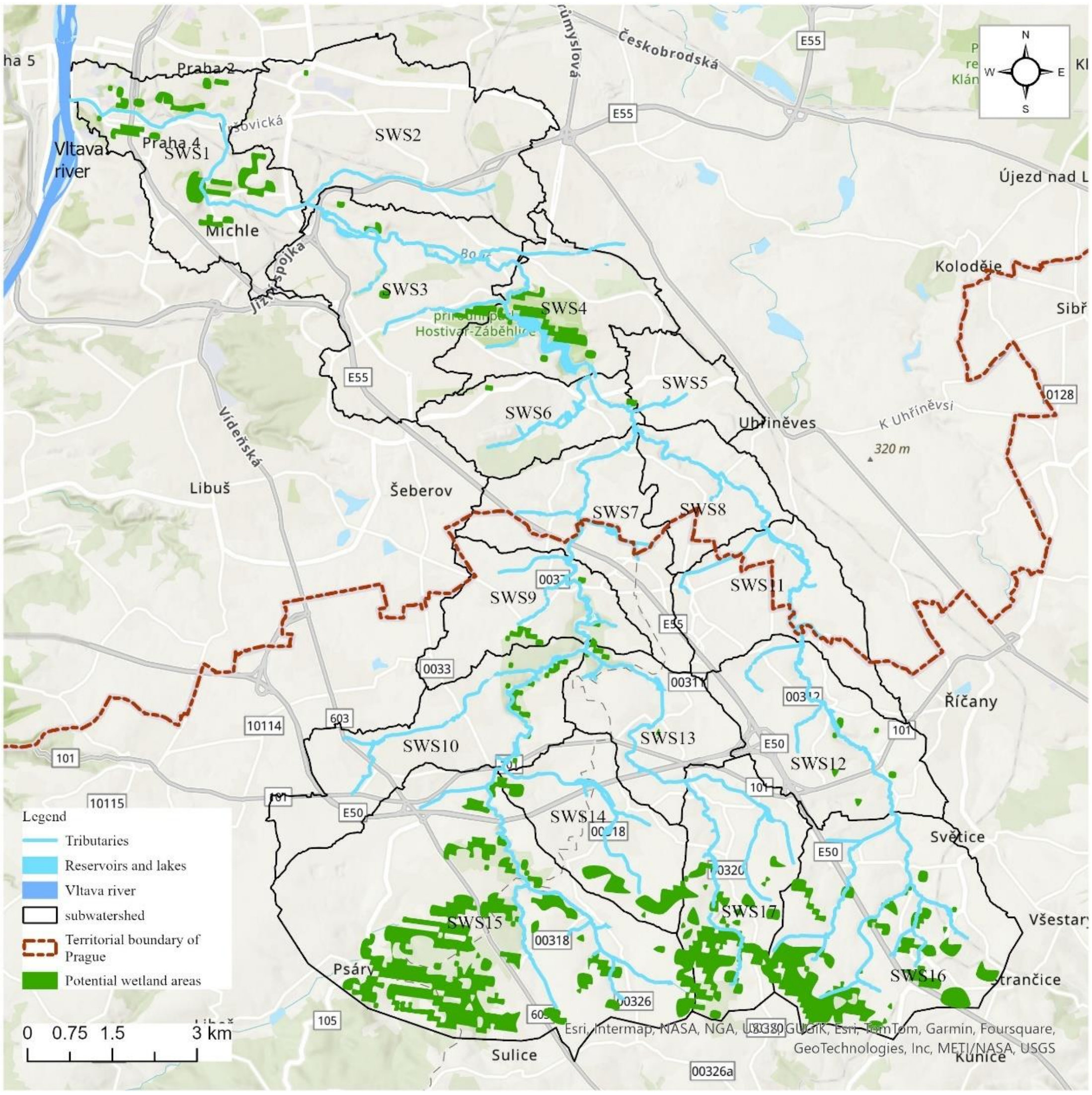

Figure 30. Identified potential wetland areas. Source: Author

One typical area was selected close to Hostivař reservoir as an example, marked in the map (**Figure 31**) for the proposal of a constructed wetland. The criteria for selecting the area for a constructed wetland were the poor water quality, numerous stormwater inlets draining surface runoff from the densely populated surrounding areas into the stream channel, availability of land, accumulation of sediments, and organic matter.

The constructed wetland is proposed in this area as it would provide a way to treat stormwater biologically by emulating a natural wetland ecosystem. Here, a subsurface constructed wetland (**Figure 32**) is proposed. Capacity of the proposed constructed wetland was calculated (**Table 18**).

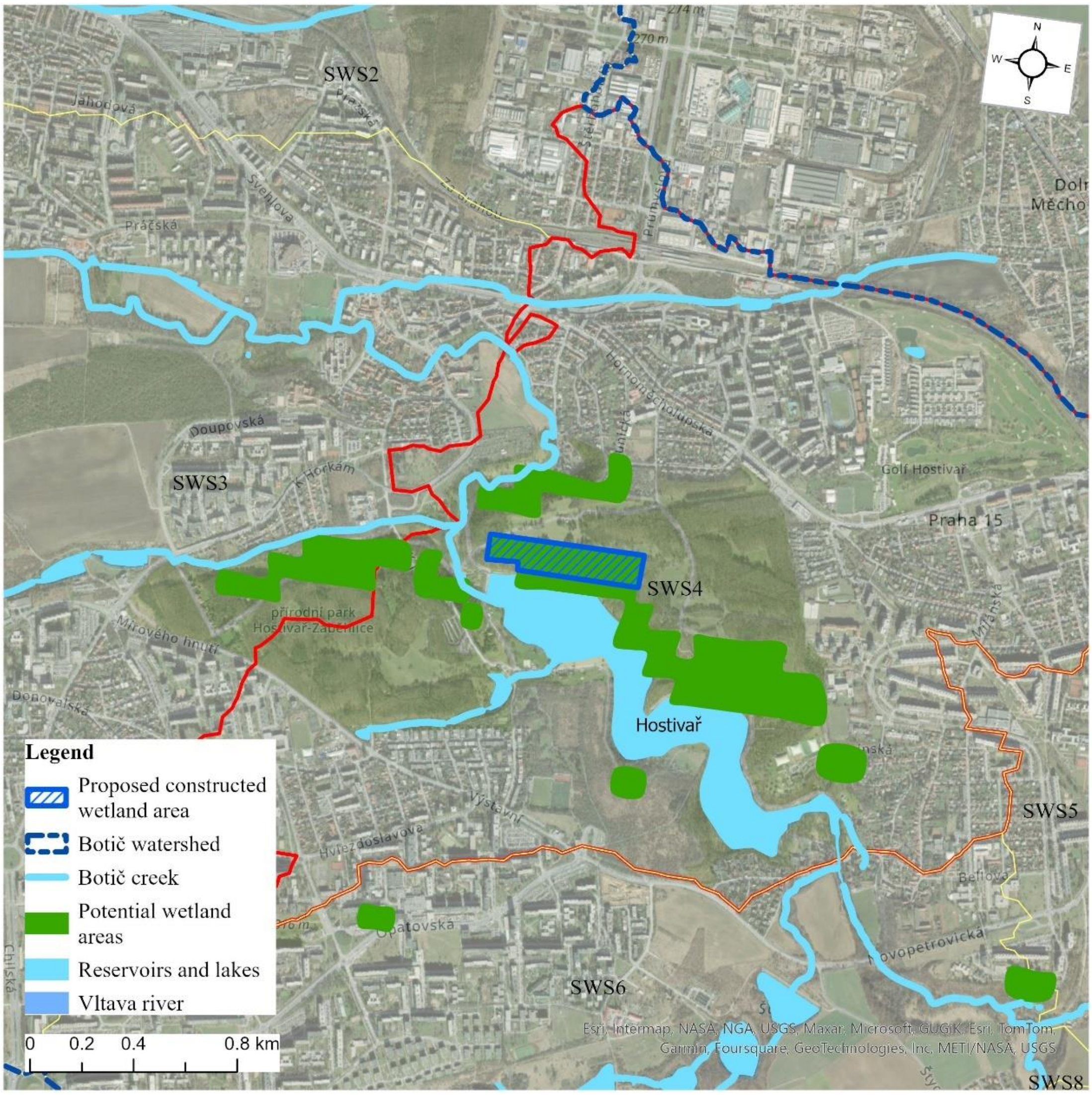

Figure 31. Conceptual idea: Proposed area for a constructed wetland

Table 18. Capacity of the constructed wetland. Source: (www.nesc.wvu.edu.) Table: author

Proposed constructed wetland	Area (m^2)	Area (hectares)	Depth (m)	Capacity (m^3)	Total capacity (sand+water) (litres)	Volume of water (void ratio 30%) (litres)
Area A1	70900	7.09	0.3	21270	21270000	**6381000**

The constructed wetland was proposed considering the following guidelines: For optimal performance, the size of the constructed wetland should be from 1% to 5% of the size of its drainage area (Jones et al., 1995). For this proposal, an average of 3% has been considered. This can adequately cater to a watershed area of 297400 square meters (29.74 hectares).

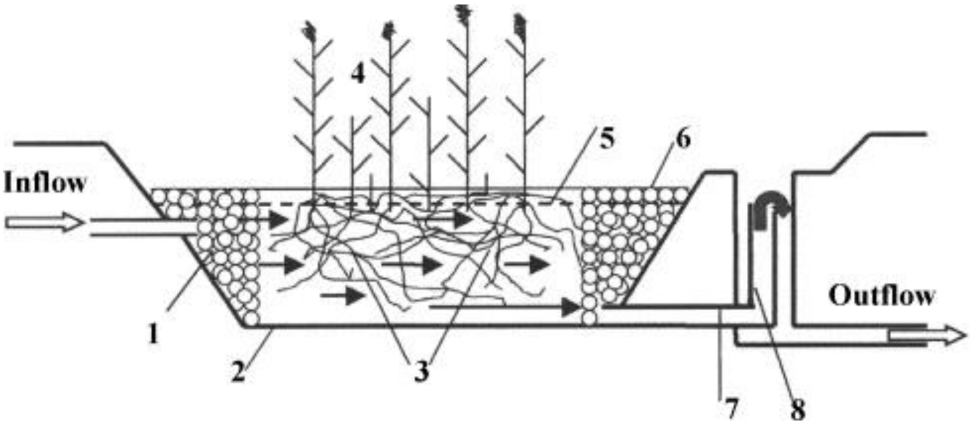

Figure 32. Schematic representation of a constructed wetland with sub-surface horizontal flow. 1 – Distribution zone with large stones, 2 – impermeable liner (usually PVC or HDPE), 3 – filtration substrate (gravel or crushed rock), 4- vegetation, 5 – the water level in the bed, 6 – collection zone with large stones, 7 – collection drainage pipe, 8 – outlet structure for maintaining of water level in the bed. The arrows indicate only a general flow pattern. Source: (Vymazal, 2004)

5.1.2 Proposal 2- Green roof

Green roofs could be an excellent solution for localities with high density in urban land use, especially with apartments. Green roofs collect runoff water from the roof surfaces in urban areas and reduce the stormwater loads on surrounding water bodies. They act as urban landscapes by providing conducive pollinator habitats and improving the microclimate in dense urban areas. However, after observation, it is evident that most residences and apartments have sloped roofs due to climatic conditions. Among the identified flat-roofed buildings, determining the structure's age, stability, and strength would help decide whether the roof can support green roofs and, if so, what type. This would take immense education and cooperation from the community, which could be a time-consuming process. New development and construction could include structural stability for the inclusion of types of living roofs. Háje metro station (**Figure 33** & **34**) was an example of proposing an extensive type of green roof.

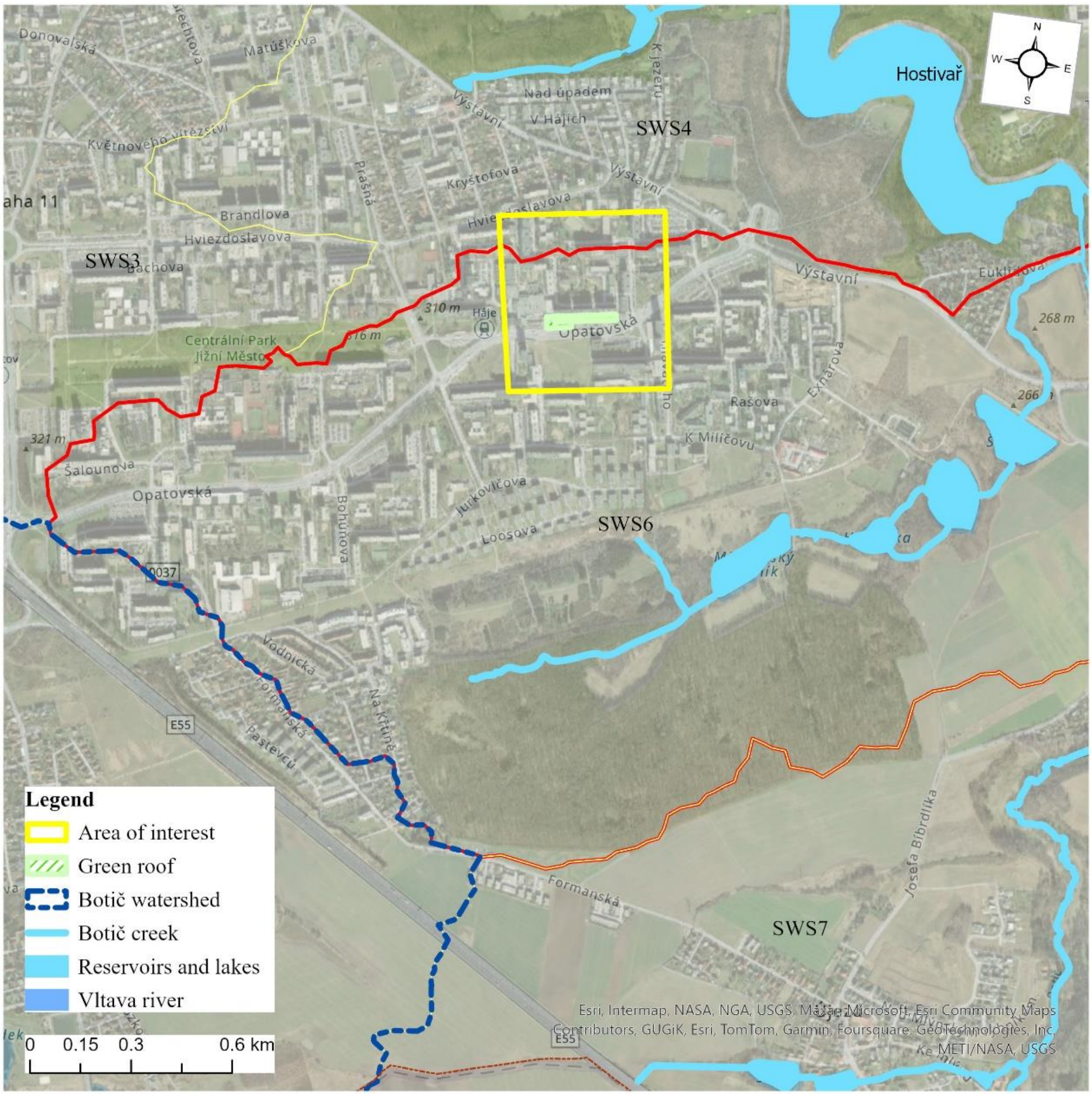

Figure 33. Area of interest, example of proposed green roof at Location: Háje metro station. Source: Author

Figure 34. Satellite image of Proposed green roof at Háje metro station. Source: Author

This potential area was located during the field visit adjoining the metro station at Háje. It was inadequately maintained (**Figure 35**) and could be developed into an interactive public green roof space. Apart from reducing stormwater runoff, this interactive green roof proposed at this location would create awareness among the public about the presence of water bodies and their ecological value. It could alternatively be used for community gardening (edible garden) or planting native species of plants to attract pollinators.

Figure 35. Potential area at Háje metro station for extensive green roof. Source: Author

Based on the structural adequacy of the building, the type of green roof can be chosen among intensive, semi-intensive, and extensive. Háje metro station is one of the oldest structures built in Prague. It could be feasible to house an extensive green roof with cross section (**Figure 36**) with additional structural support and utilize the existing planting areas. Layer placement may vary depending on the type and design of the green roof system.

Green roof areas can be designed to capture the entire Storm Water Retention volume (SWRv). In some cases, they could also be designed to capture larger design storm volumes. The required size of a green roof will depend on several factors, including maximum water retention of the growing media and the underlying drainage and storage layer materials. The storage volume retained by a green roof was calculated using the formula (Clar et al., 2004) given below:

$\mathbf{S_v = SA \times [(d\times\eta_1) + (DL\times\eta_2)]}$

S_v = Storage volume (m^3)

SA = green roof area (m^3)

d = media depth (m) (minimum 0.76 m)

η_1 = verified media maximum water retention (use 0.15 as a baseline default in the absence of verification data)

DL = drainage layer depth (m)

η_2 = verified drainage layer water retention (use 0.15 as a baseline default in the absence of verification data)

Table 19. Calculation of storage volume capacity of extensive green roof. Source: Author

Proposed green roof	**Area (hectares)**	**SA in (m2)**	**d (m)**	**η_1**	**DL in (m)**	**η_2**	**Sv in (m^3)**
Area (Area1+2)	0.465	4650.00	0.0762	0.15	0.00762	0.15	58.46

Table 17. Calculation of storage volume capacity of intensive green roof. Source: Author

Proposed Green Roof	**Area (hectares)**	**SA in (m^2)**	**d in (m)**	**η_1**	**DL in (m)**	**η_2**	**Sv in (m^3)**
Area (A1+A2)	0.465	4650.00	0.3048	0.15	0.1016	0.15	**283.46**

Green roofs can be implemented in various phases focusing first on public buildings and areas followed by commercial buildings and spaces. Residential buildings can be encouraged to adopt green roofs at later stages. For new construction, the structure could be planned with capacity to withstand an intensive type of green roof as from the calculations observed in (**Table 19** & **20**) intensive green roofs have better storage volume capacity.

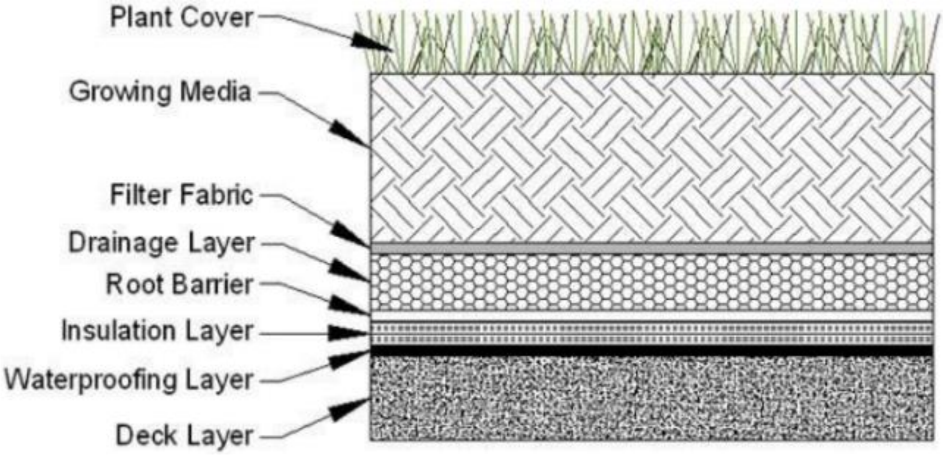

Figure 36. Typical layers of an extensive green roof. Source: (Clar et al., 2004)

5.1.3 Proposal 3: Rain Gardens

The area selected was an open parcel of land close to the creek channel and surrounded by dense urban areas in the Záběhlice region. The runoff water would enter this area before draining into the creek channel. The selected area of interest (**Figure 37**) measured 1.13 hectares of green space with the potential to be converted into a Rain Garden.

Rain gardens serve as a practical alternative to green roofs in areas where sloped roofs or old buildings lacked structural stability, making the installation of green roofs impractical. These urban areas are prone to runoff from impervious surfaces and roofs, which can be collected and diverted into rainwater harvesting ponds or rain gardens. As the water percolates into the soil, the environment functions as a natural filter, removing many hazardous chemicals and compounds and enhancing the quality of nearby water. The benefits of a rain garden extend beyond water purification, as it acts as a sponge in urban landscapes, mitigating temporary flooding and replenishing groundwater reserves.

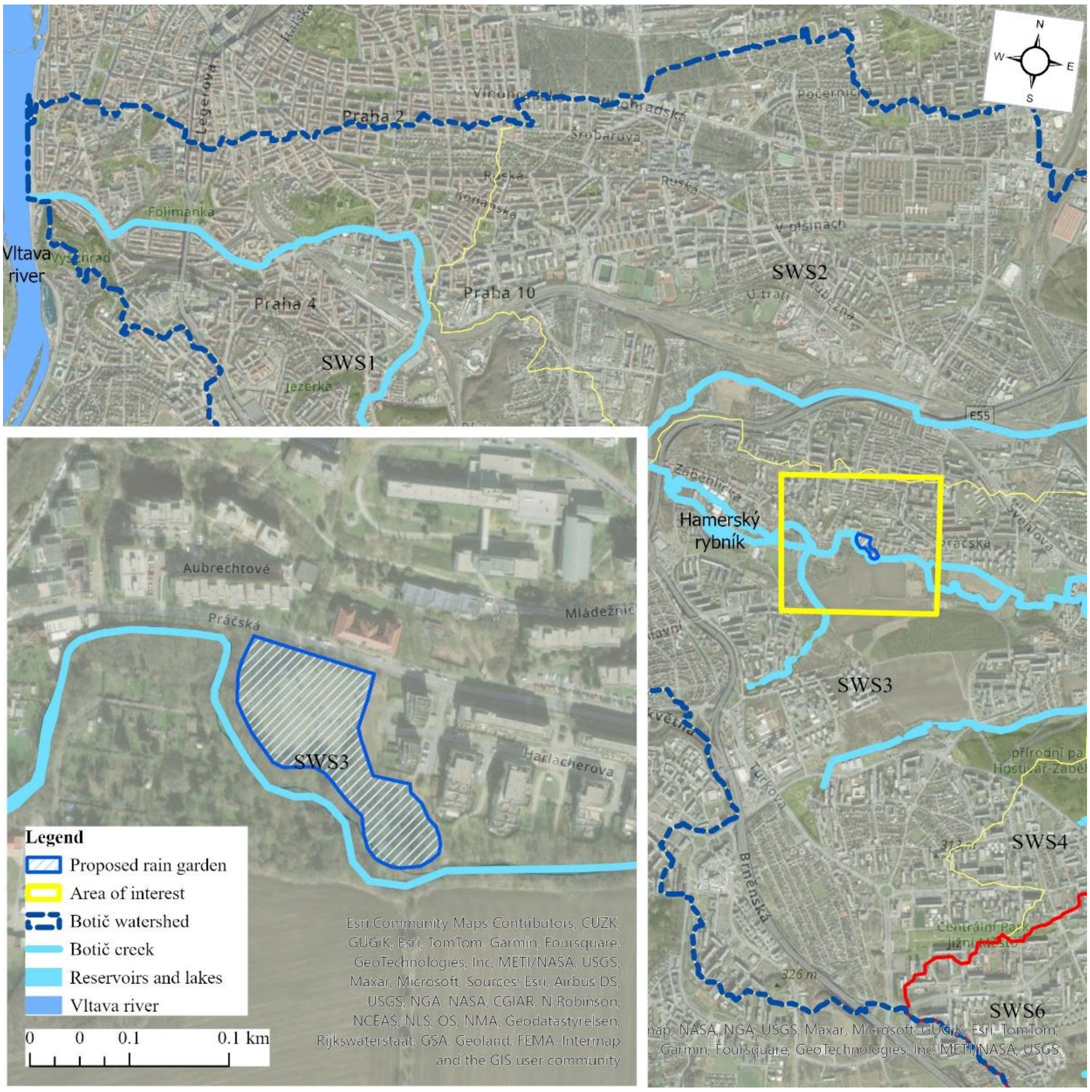

Figure 37. Area identified for potential rain garden at Záběhlice. Source: Author

5.1.4 Proposal 4 - Interactive urban landscape

Certain public parks possess significant potential for being transformed into interactive urban landscapes. Such parks can stimulate public involvement and environmental education by presenting a range of interactive activities, including community gardens, mini-orchards, and small water bodies. The community gardens can be designed to cultivate edible, pollinator, and other seasonal plants, thereby encouraging families in densely populated regions to utilize green spaces to grow fruits and vegetables. Pollinator gardens can function as ecological sinks, absorbing surface water runoff and fostering self-sustaining meadows.

Community initiatives, such as planting and maintaining native pollinator species, can lead to an increase in pollinators. This serves as the foundation for implementing the concept of Playful Learning Landscapes (PLL) in landscape planning (Ra et al. 2021). Certain alleyways and walkways can be transformed into mini orchards and boulevards, providing a platform for people in the neighborhood to engage in multifaceted community activities. Small water bodies can serve as hydrological links, filtering runoff water to prevent it from being discharged into the streams directly while facilitating recharge, water retention, and water purification. The area selected for such a proposal was in the Háje region as an example (**Figure 38** & **39**).

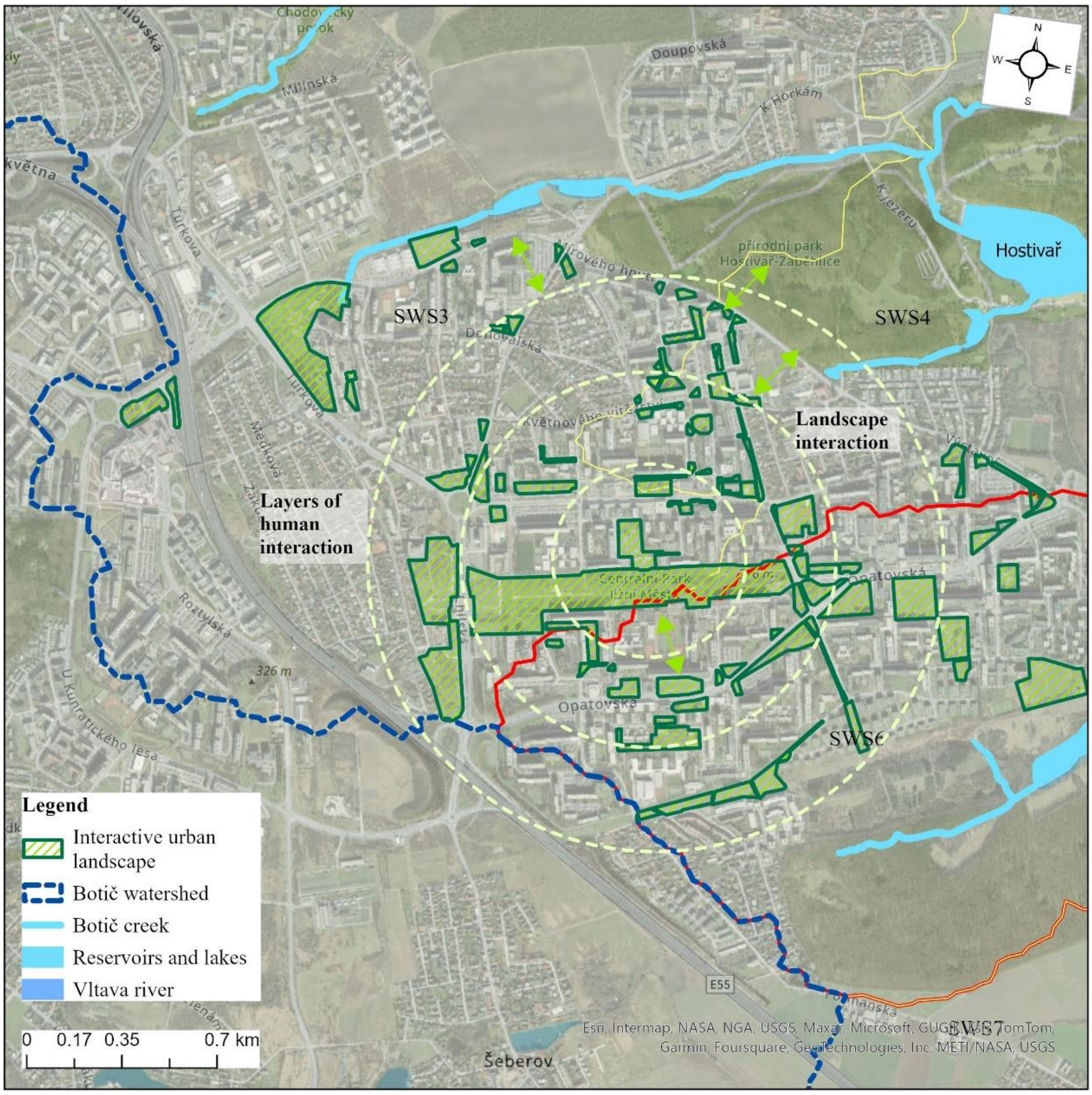

Figure 38. Area of interest for proposed Interactive urban landscape at Háje region. Source: Author

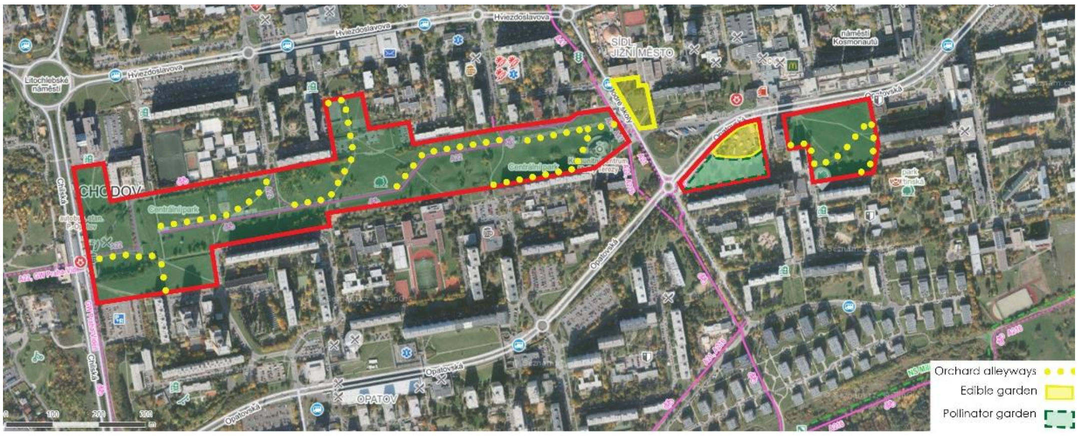

Figure 39. Selected areas of parks and open spaces to represent interactive urban landscape. Source: Author

5.1.5 Proposal 5- Bioswales

The study identified several areas that could be converted to bioswales, including those located near agricultural land, areas with built-up spaces in proximity to streams, parking areas that lack pervious surfaces, areas close to highways and transport lanes, and those that have the potential to contribute polluted run-off water to the stream channel. The potential locations for the construction of bioswales could significantly improve the quality of water and reduce the risk of flooding in the surrounding areas.

The area selected as a typical example having a steep slope that could contribute to polluted runoff water was chosen below the vineyard at Grébovka (Havlíčkovy sady) (**Figure 40**).

Figure 40. Area of interest for proposed Bioswale at Grébovka Park. Source: Author

The yellow marked segments have been identified for bio-swale implementation (**Figure 41**). Bioswales would collect runoff water containing residual pesticides, insecticides, and fertilizer from the vineyard. Typical design guidelines to be considered for a bioswale (**Figure 42**) are as follows:

- Maximum drainage area should not exceed 2 hectares.
- They should be installed on slopes ranging between 1% to 2%, enabling a slow and shallow flow.
- The permissible flow velocity should not be more than 1.2 m/s.
- The minimum bottom width of the bioswale is a minimum of 0.6 m and a maximum of 2.4 m.
- Bioswale surface side slopes are 4 horizontal :1 vertical

Considering the design by contributing area, the entire surface of the bioswale should be greater than or equal to 1% of the entire drainage area.

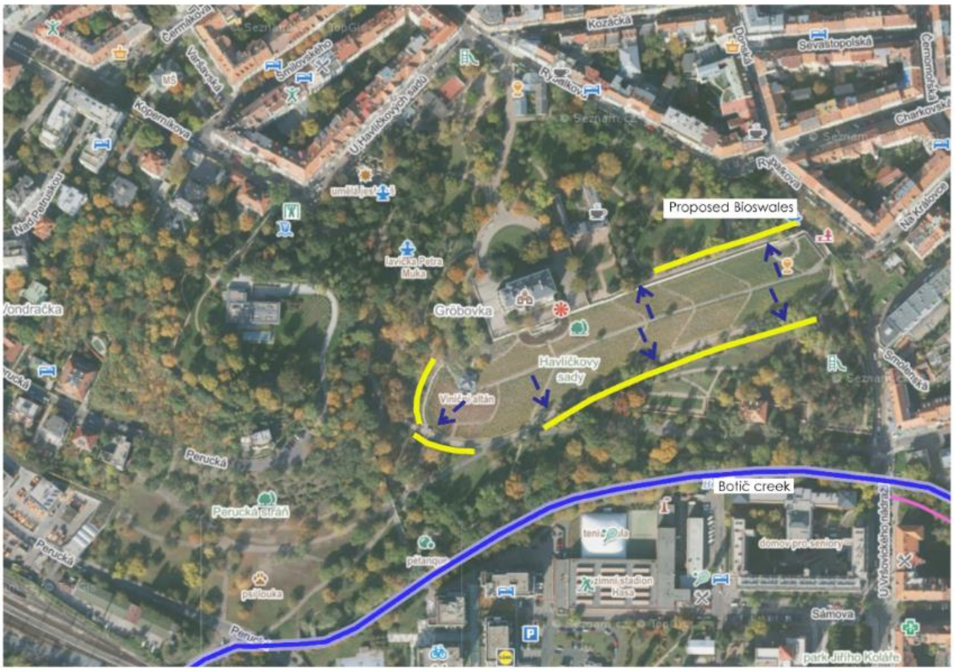

Figure 41. Proposed Bioswale at vineyard at Grebovka. Source: Author

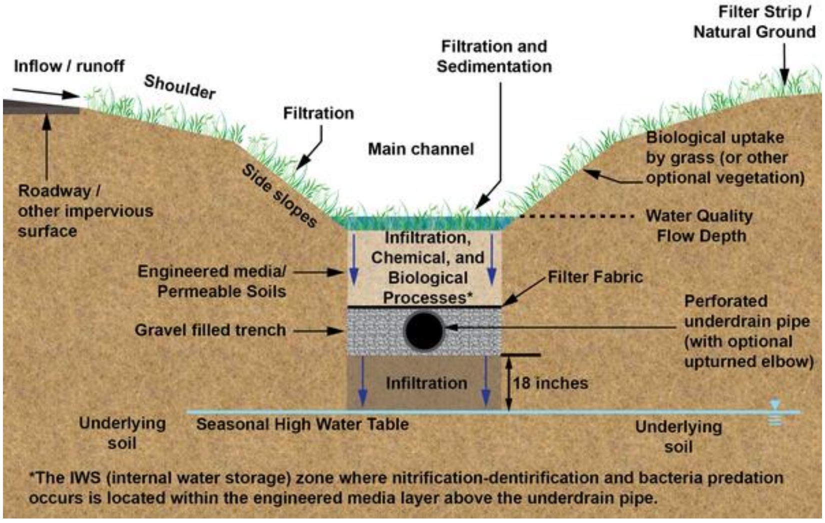

Figure 42. Typical cross section of a bioswale and storm water treatment process. Source: (Clar et al., 2004)

5.2 Restoration proposals at Stream level (micro level)

The locations of the Restoration proposals at the channel level were located and categorized on a map (**Figure 43**) the locations are areas where the issues were observed, and the proposals could be a viable solution for mitigation.

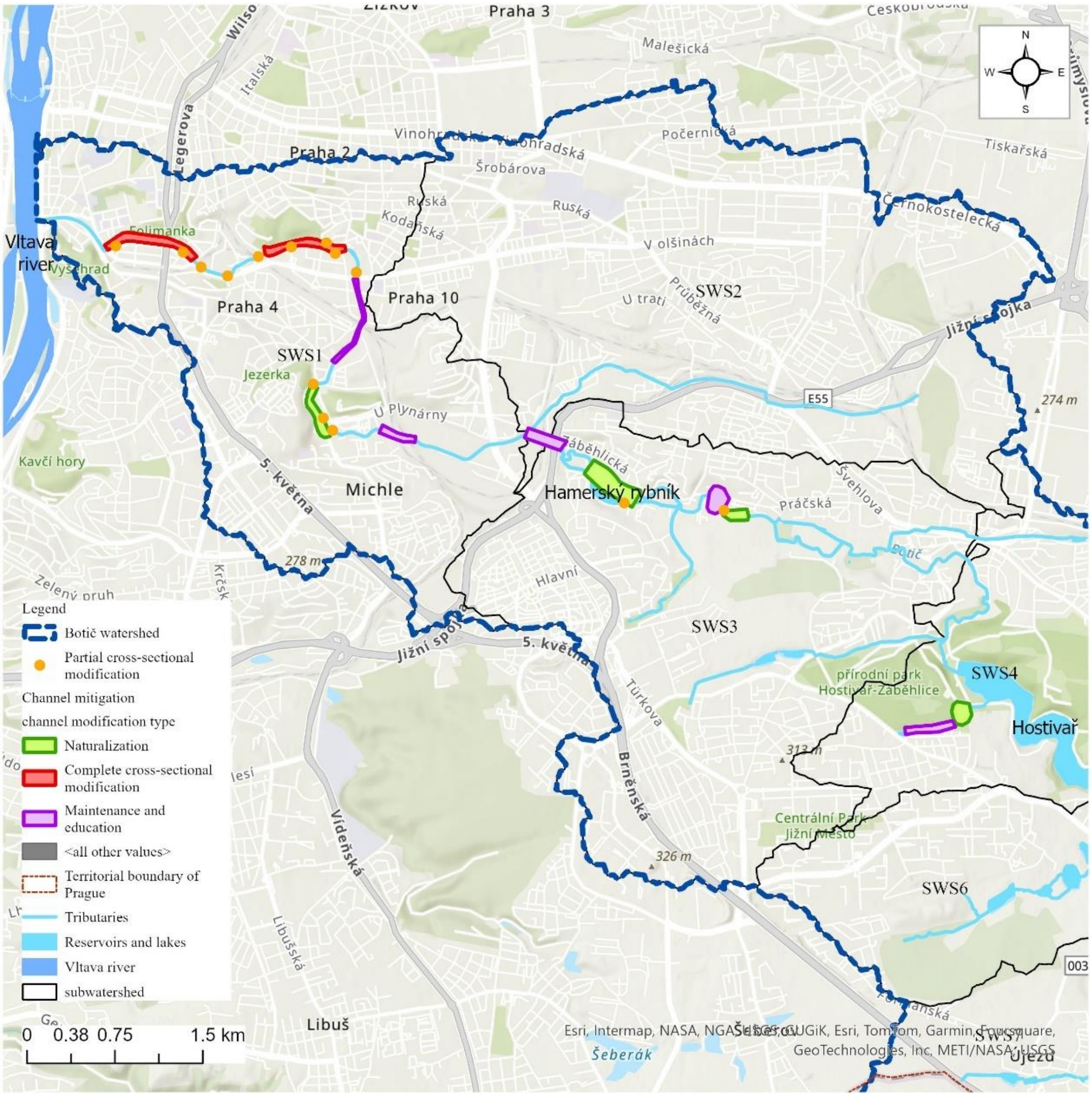

Figure 43. Locations of the typology of restoration proposals at the Channel level. Source: Author

5.2.1 Cross-sectional modification

A. Partial cross-sectional modification

Observations: The channel of the Botič creek comprised of impervious vertical sides with rectangular cross sections, including the impervious bottom bed surface, which contributed to the increase in the velocity of flowing water. There was less opportunity for vegetation growth due to the absence of soil (**Figure 44** & **45**).

Proposed Solutions: The creek edge on the side of the park had the potential to be modified with a gradual slope towards the stream bed with layers of vegetation comprising of trees, shrubs, semi-aquatic plants, and some ground cover to introduce pervious surface area at the creek channel. Some selected areas could have access to the creek for recreation purposes. Modifying the creek edge on the side of the road and adjoining structures would not be recommended to retain the existing structural stability. Two locations were identified as the creek channel close to Hostivařské náměstí and at the channel close to park Fidlovačka considered as examples of partial cross-sectional modification (**Figure 44** & **45**).

Figure 44. Example 1 – Observed problems at creek channel & Proposed solution close to Hostivařské náměstí. Source: Author

Figure 45. Example 2 – Observations and proposed solution at creek channel close to park Fidlovačka. Source: Author

B. Complete cross-sectional modification

Observations: The creek channel at the respective locations showed similar symptoms, such as steep slopes, lack of permeable surfaces, and low disturbance from anthropogenic activities and structures (**Figure 46** & **47**).

Proposed Solutions: These areas possess good potential for complete channel modification that can be planned and implemented in stages. The channel modifications could include gradual slopes towards the stream bed with layers of vegetation comprising of trees, shrubs, semi-aquatic plants, and ground cover to introduce pervious surface area at the creek channel. Certain areas may be modified with meanders, riff-raff, stones, and more shallow areas wherever there is sufficient space available (**Figure 46** & **47**).

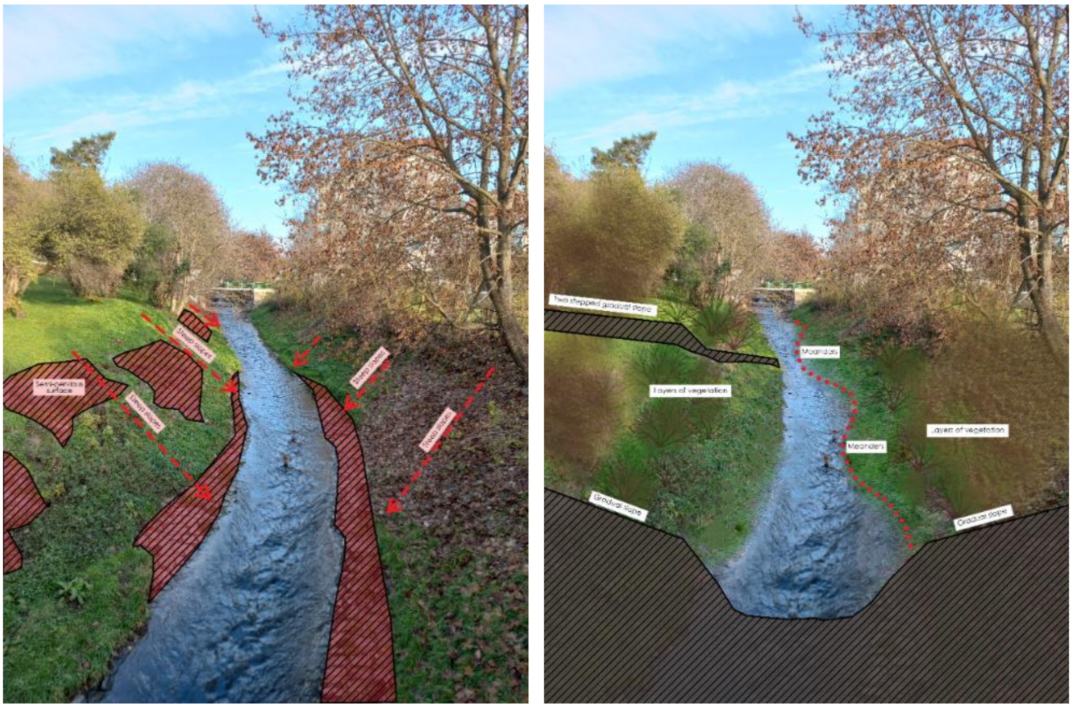

Figure 46. Example 1 – Observation and proposed solution at creek channel between to Grébovka and Folimanka. Source: Author

Figure 47. Example 2 – observation and proposed solution at creek channel in Folimanka Park area. Source: Author

5.2.2 Naturalization

Observations: In the mentioned example 1 the riparian zone showed signs of erosion due to the steep slope (**Figure 48**). Residential zone was also observed to be present in the area which is supposed to be designated as riparian zone of the creek channel. In the example 2 the retention ponds and creek channels had impervious surfaces such as concrete slopes and stone masonry (**Figure 50 & 51**). The slope of the retention pond had minimal or lacked vegetation. The runoff water from the surrounding areas with the pollutants directly flows into the water body.

Proposed Solutions: In the case of example 1 the slope could be made more gradual and have shrubs and ground cover to hold the soil together preventing erosion (**Figure 49**). Other modifications, such as creating meanders and modifying the creek channel, may not be practical due to lack of space or the risk of disturbing the structural stability of the buildings near the creek channel. In the case of the example 2, a textural intervention from impervious to semi-pervious or pervious surfaces with the addition of vegetation could be beneficial to slow down the flow of runoff water into the waterbody (**Figure 50** & **51**).

Figure 48. Example 1- Location: riparian zone of creek channel at Záběhlice locality and Erosion at riparian zone of creek channel at Záběhlice locality. Source: Author

Figure 49. Example 1- Location: Proposed solution for erosion at riparian zone of creek channel at Záběhlice locality. Source: Author

Figure 50. Example 2 – observations and proposed solutions for naturalization at Hamerský pond. Source: Author

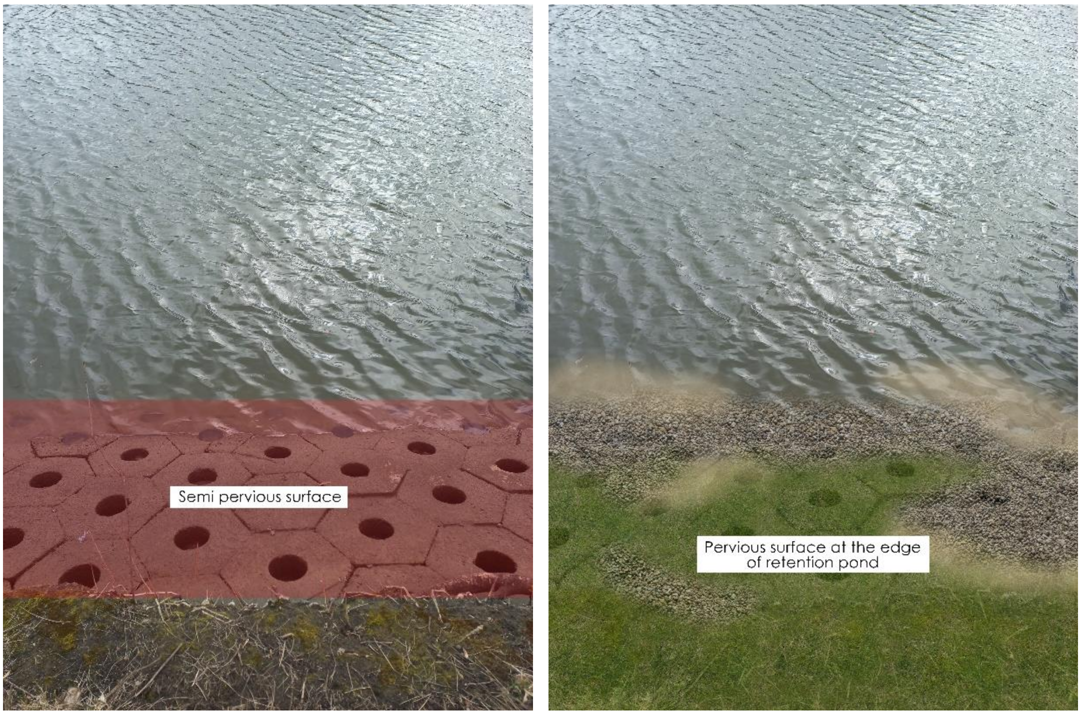

Figure 51. Example 2 – Observation of semi-pervious surface at the pond banks and Proposed solution of textural change, respectively, at Hamerský pond. Source: Author

5.2.3 Maintenance and Education

Observations: These locations were prone to littering, low maintenance, and misuse of public sign boards at the creek channel. In some cases, numerous stormwater drain inlets discharging into the creek channel were observed. Some of the locations were examples of these prevailing problems.

Solution proposals: Creating public awareness through education and voluntary works involving public participation, including children and families, in de-littering and cleaning the creek would reduce direct negative human impact on the creek and its surroundings. Periodic maintenance of the stream channel and regular tracking of the number of stormwater drain inlets discharging directly into the creek would be beneficial in long-term maintenance.

Example 1: Michle's locality had train tracks (**Figure 52**) The creek flows underground and resurfaces at a different point. These areas could be better managed by including buffer strips of vegetation and bioswales to protect the creek channel from pollution.

Figure 52. Example 1 - Observations at Michle locality with train tracks and low maintenance. Source: Author

Example 2: Evidence of littering at various locations could be avoided with better education and public awareness regarding the harmful effects of pollution of creeks in urban areas due to human activity. The public would be capable of contributing to the maintenance of the creek channel and watershed level to help improve the ecological status of the creek (**Figure 53**).

Figure 53. Images documenting observations of littering at various localities. Source: Author

6. Conclusions

An attempt was made to understand the delicate balance that exists between the Botič watershed and creek. In the present study the Botič Creek and its watershed were analyzed at 2 levels. At the field level data was collected both at the watershed and creek level followed by studying and analyzing data sets. A combination of the two helped in identifying the factors responsible for the worsening of the ecological status of the Botič Creek and the watershed.

The water quality of the creek is deteriorating due to several factors, including sewage contamination, siltation of reservoirs, and inappropriate fish management. It is essential to take immediate measures to address these issues and preserve the ecological balance of the region. It is pertinent to note the increase in TP concentration over the years based on water quality data and suitable remedial corrections have to be in place.

The individual analysis of LULC data with respect to land use classes, changes in the individual categories of Land Cover from 2000 – 2018 and increase or change in categories between the years 2000 – 2018 gave an expected results of signs of urbanization concentrated on the downstream portion of the watershed. An analysis of the extent of urbanization and distribution of impervious surfaces concurred with the same showing minor variations in the results. Combining these results with soil type, slope, and elevation, a WOA analysis which gave a cumulative effect of the factors and an interesting outcome.

The WOA gave valuable insights into locating the critical areas near the creek and away from the creek. The areas of very high priority are predominantly situated in the downstream portion of the watershed, close to the confluence of the Botič creek and the Vltava River. These areas are indicative of significant urban development as they are near the city center of Prague. The upstream areas are primarily encompassed by agricultural and natural LULC but display indications of moderate to high priority adjoining most of the stream path and its riparian zones owing to sub-urbanization. This is because there is observed to be significant growth in the upstream part of the watershed which is outside the territorial boundary of Prague. These regions present a substantial potential for preservation, and preventive measures could be implemented before further urban expansion takes place. These areas showed a trend of urban expansion by looking at the LULC change maps over the years. Agricultural land is being converted to urban fabric rapidly, hence this is the stage at which preservation plays a key role in the watershed.

Following a comprehensive analysis and evaluation of the maps and field visit outcomes, various proposals were discussed at both the watershed and creek channel levels. These proposals are generic in nature and can serve as a pilot for other areas, with potential expansion based on the outcomes obtained. However, it is important to note that these proposals will require an iterative process, tailored to meet local situations and conditions within the municipal framework, and aligned with the water framework directive. While the green infrastructure proposals at the watershed level are a few examples of potential implementations, it is also possible to propose and implement more sustainable developmental techniques that are specific to the area. As for the creek channel, the proposed modifications can be implemented in stages, following detailed and intensive site visits and availability of funds. A more significant focus on the upstream part of the watershed due to sub-urban development would help prevent the repetition of the effects of urbanization observed downstream.

The Water Framework Directive (2000/60/EC, WFD) provides the most comprehensive legislative framework for water protection in Europe. The default objective of the WFD is to achieve good water status and good ecological status of all water bodies, initially by 2015 and then by 2027.

To accomplish these goals, Member States (MS) were required to publish River Basin Management Plans (RBMPs) which contain information both on the status of their river basins and on the Programme of Measures (PoMs) they intend to implement to improve water ecosystems. Moreover, the WFD introduced a set of economic concepts and instruments. The main economic provisions refer to: (i) understanding the economic issues and tradeoffs at stake in a river basin, (ii) assessing the economic impacts of proposed measures aimed at improving water status, (iii) incentivizing an efficient use of water through water pricing policies, and (iv) assessing regions or water bodies where less stringent environmental targets need to be applied to account for economic and social impacts.

6.1 Future scope of work

Botič Creek is the longest and one of the most significant watercourses in Prague and the Central Bohemian region, comprising a network of several interconnected waterbodies, protected areas, and nature parks. The Botič basin has ecological, environmental, and landscape value.

The current WOA study has its limitations as it was confined to 5 selected factors but could be expanded by conducting an intensive study to add more parameters and assign weightage. This could be achieved by detailed site visits and the involvement of researchers with multidisciplinary backgrounds.

An in-depth analysis of the agrochemicals used in the suburban areas outside Prague's municipal boundaries could aid in identifying the factors that contribute to their usage and developing effective management strategies. This investigation could provide valuable insights into the use of agrochemicals in the region and inform future policy decisions aimed at promoting sustainable agricultural practices and protecting the watershed.

It is recommended to add water quality sampling points outside Prague before the stream enters the urban area due to the expanding city in the suburbs. Proposed measures should not only focus on present urban areas, but also on areas with expanding urbanization and agricultural conversion. This proactive approach will reduce costs and act as a buffer before further development occurs.

For a more detailed analysis and targeted proposal of converting impervious surfaces to pervious surfaces it would be beneficial to have information on the specific types of impervious surfaces in each sub-watershed (e.g., buildings, roads, parking lots, walkways). Comparing this data to historical data or data from other watersheds could provide insights into changes in impervious cover over time or differences between regions.

A detailed benefit cost analysis of the proposed measures is recommended. Such an analysis can only be done after a more comprehensive investigation of the watershed in all seasons over a reasonable period and observing human interaction with one such installed prototype. This would bring a realistic understanding of the measures, ensuring their suitability and effectiveness.

Targeted site studies and visits to the areas with identified categories of problems could be focused on maps and site visits. Visits to these areas in regular intervals at all seasons throughout the year would help in creating specialized solutions for the problems considering the impact of changing weather conditions, the social behavior of people, and the behavior of the stream channel. A holistic way of proposing mitigation solutions will control the problems from recurring or resurfacing.

7. References

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8. Appendices

Appendix 1. Observations from site locations at Watershed level (macro level)

Appendix 2. Observations from site locations at the creek channel level (micro level)