WETLAND SUITABILITY MAPPING USING GEOGRAPHICAL INFORMATION SYSTEM: A CASE OF WESTERN UUSIMMA FINLAND

By

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Abstract

This study aimed to conduct wetland suitability mapping in the Western Uusimaa region of Finland to address water quality issues in proximity to the Baltic Sea. The specific objectives included an overview of historical wetland distribution, identification of priority areas for wetland formation or restoration, and the development of a comprehensive wetland suitability mapping framework.

The study area, Western Uusimaa, is characterized by coastal areas, archipelagos, and proximity to the Baltic Sea, with significant agricultural and forested areas which have impacted water quality. The methodology for this research employed Scalgo Live and ArcGIS Pro for potential wetland suitability mapping, integrating key criteria such as soil type, depression or slopes, catchment considerations, stream flow and runoff risk, and restoration feasibility.

Data gathering involved retrieving information from various sources, including living atlas in ArcGIS, the National Land Survey of Finland, Finnish Environmental Institute Syke and Scalgo Live. The criteria used for geo-spatial analysis included Flow accumulation slope and depression data, catchment areas, risk runoff, with soil type being considered, although limited data was available.

Selected results showed that there were fifteen (15) catchment areas with a considerable amount of downstream runoff risk for potential wetland restoration and development in accordance with the key suitability criteria involving the presence of streams, runoff risk proportions, gentle slopes, and appropriate depression volumes. Notably, an old wetland in Smedsedevägen, western Uusimaa was identified as a suitable area for restoration based on historic land use change, depression volume, catchment area, and run-off risk analysis.

The use of geospatial analysis in this study helped to create a comprehensive and robust mapping framework which could guide the process of identifying suitable wetland's location in enhancing water quality and protecting the landscapes and ecosystems of the Western Uusimaa region.

Language: English
Key Words: Wetland Mapping, Water Quality, Geographical Information System, Western Uusimmaa.

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1 Introduction

The issue of water contamination is not just an environmental problem, it also affects the economy and the wellbeing of humans. Medland et al. (2020) also highlighted that the water quality of numerous economies is affected by the problem of diffuse water contamination. In addition, the National Resource Defense Council (NRDC9 (2023) asserts that water pollution is a common challenge that jeopardizes the health of millions of people, water pollution kills more people each year than war and all other forms of violence combined.

Ouyang et al. (2011) pointed out that the negative consequences of agricultural intensification are palpable that wetland loss is one of the consequences of increasing crop cultivation, which leads to increased erosion, poor retention, and increased fertilizer input into water basins, ultimately leading to eutrophication (Ouyang et al., 2011; Widis et al., 2015). Moreover, Qu et al. (2019) noted that wetlands are considered to be the most effective approach for mitigating water pollution, especially that produced by agricultural nutrient losses, by capturing and absorbing sediment and nutrients in flow before they access surface waters.

On the foregoing, wetlands are ecosystems that have seasonal or permanent water, which creates a special habitat wherever the land joins the water (Mitsch et al., 2013). Wetlands are areas where water continually saturates the land or stays near the surface of the earth all through the year or even during growing season in some cases (Kingsford et al., 2016). Such regions include bogs, swamps, and marshes among other sorts of habitat. Wetlands are essential environments supporting incredibly diverse plants and animal species, while also playing a role as breeding grounds for many breeds. Wetlands are also imperative in maintaining water quality, flood control, and providing invaluable ecosystem services. Wetland formation and restoration have become an international phenomenon owing to the various important environmental services that wetlands provide such as pollutant retention and nutrient leaching (Xu et al., 2019). In addition, Valk (2012) demonstrates that the unique features of wetlands make them suitable for denitrification; a process through which nitrogen is permanently removed from the ecosystem. In addition to being nutrient extractors, wetlands perform other roles including water storage and nutrient cycling as well as supporting life for both flora and fauna. Wetlands for water treatment is thus the reason why wetlands have fascinated scientists and policymakers. Uuemaa et al. (2018) posit that the need to identify potential sites for construction or restoration of wetlands offering multiple benefits to large areas of a watershed has been recognized widely and sought after thus meeting various objectives such as minimizing stream nutrient levels, flooding peak flows, and wildlife habitat availability. Before efficient wetland rehabilitation approaches are put into practice, the identification of potentially suitable locations is critical (Qiu et al., 2020). The geographic diversity of the landscape, however, complicates such a process (Uuemaa et al., 2018). Mitsch et al. (2015) also observed that proper wetland identification should involve multidisciplinary approach of scientific expertise, field competency, and technical methodologies. Therefore, the identification of suitable wetland location is important in conserving them, setting aside land for future generations, and adhering to environmental rules that protect these biologically invaluable locations (Kingsford et al 2016)

Hence, this thesis focuses on wetland site suitability identification in the Western Uusimaa Finland. Western Uusimaa is characterized by its coastal lands, archipelago, and proximity to the Baltic Sea. The area has 5 (Hanko, Ekenas, Karis, Inko and Siuntio) major municipality with a high amount of agriculture and forest area. The area's water body and lake are exposed to pollution from the agricultural activities and other waste sources, thus deteriorating water quality. As such, the mapping of wetlands in the region becomes very important. Consequently, the main focus of this study is to find out appropriate locations for wetland suitability mapping mostly in the WesternUusimaa region of Finland.

1.1 Research Problem

All Baltic states were compelled to act with the threat of eutrophication in the Baltic Sea and improve the quality of their runoff discharging into the sea. The pollutant load inflow of a river reflects all the activities in its basin as well as the physical factors around the watershed, including the climate, soils and other biogeochemical processes that takes place in that area (Mao et al., 2018). The Baltic Sea has been said to be among the most polluted seas in the world, and a larger part of these pollution is coming from the inland based activities over the coastal region (Samuelson, 2018). The agricultural activities around the

Baltic states have been accused of being the main cause leading to the source of water pollution (Hammer, 2014). Highlighting this observation, the European Commission (2019) reveals that surface water bodies in Finland experience the largest effect of nutrient contamination from diffuse agricultural pollution. Supporting this claim, Snickers et al (2016), points out that the situation is more prevalent in Western Uusimaa Finland due to its coastal nature and vast agricultural and inland anthropogenic activities in the region.

Jalkanen et al. (2020) emphasized that there is a persistent trend regarding intensified agriculture, which has sparked questions about the sustainability of this strategy from an environmental standpoint. This is especially true given the nutrient contamination that results in surface and groundwater, especially on land used for extensive dairy farming. These agro-related activities expose the water quality and sustainability of the underground waters.

On the foregoing, wetland restoration and creation is a key way to achieving ecological security and long-term viability, as mentioned in the United Nations SDGs 6.6 and 15.1 (Qiu et al., 2022). Wetland restoration and formation are on the rise around the world due to the numerous significant environmental services supplied by wetlands, particularly because of their capacity to trap contaminants and leached nutrients (Nummi and Holopainen, 2020). Substantiating this claim, Qui et al. (2022) noted that China is rapidly recognizing the importance of wetlands and has developed a National Wetland Conservation Project (NWCP) with a number of commendable and ambitious goals, including the restoration of 14,000 km2 of wetlands. Furthermore, wetlands ecosystems are vital because they provide habitat for a diverse range of plants and fauna (Alikhani et al., 2023). In wetlands, the mix of water and different plants creates a rich habitat that supports a diverse range of species, many of which are uniquely adapted to these unusual conditions. Moreover, the provision of habitat for birds, amphibians, reptiles, and other aquatic species, and the habitats' high biodiversity adds to the general health and resilience of the ecosystem as a whole (Xu et al., 2019). Similarly, Craft (2022) posits that wetlands act as efficient flood barriers by absorbing and delaying water circulation and operate as natural sponges when there is heavy rainfall or storms, minimizing the possibility of downstream flooding. Their ability to gently hold and release water aids in minimizing the effects of intense weather occurrences. Kingsford et al. (2016) emphasized that because communities near wetlands benefit from natural flood management, wetland formation and preservation are critical for the risk of disaster reduction.

However, mapping suitable sites for the Wetland creation/construction process is complicated and requires technicality due to the landscapes' spatial diversity. According to Van Coppenolle and Temmerman (2019), the suitability of a site for wetland creation is determined by a variety of factors, including the following: the underlying geology, because wetlands require the existence of unchanged organic layers or lithic strata, which are both saturated with or impermeable to water; topography because a wetland area must generally be flat, but natural structures such as swales and gullies can aid in wetland construction. Also, Xu et al. (2019), noted that another important factor for consideration is land availability. This factor is important because its current uses and ownership can prohibit this type of management (Xu et al., 2019). Other factors to consider include the land's encompassing and upstream uses, which can determine the best design for removing pollutants and nutrients, the location of the sources of the pollution, the type of drainage systems, and the opinions of the local populace and landowners (Nummi and Holopainen, 2020). Additionally, sites differ in their ability to reduce pollution from diffuse sources if transformed into wetlands and in the cost of purchase and restoration because they require space that is not frequently available, and landowners are reluctant to part with productive land. Because of the technicality and the complexity of identifying suitable wetlands, this study seeks to map suitable wetlands in Western Uusimaa Finland using the geographical information system.

1.2 Aim

The overarching aim of this study is to conduct wetland suitability mapping based on a set of criteria with the aid of geographical information system (GIS) in the Western Uusimaa region of Finland.

1.3 Specific Objectives

Following the overarching objective, the specific objective of this thesis is presented as thus.

a. Identify key priority areas for the formation of wetlands in Western Uusimaa Finland using a geographical information system.
b. Conduct a comprehensive overview of the distribution and extent of historical wetlands areas for restoration purposes in the western Uusimaa region.

2 Literature Review

This section of the thesis reviews extant literature, beginning with the conceptualization of the key terms of the research, theoretical background and overview of past evidence.

2.1 Conceptual Literature Review

2.1.1 Conceptualizing Wetland

Wetlands are areas of land where water meets land that is continually or occasionally saturated with water (Qu et al., 2019). They are important to the Earth's water cycle and constitute the most productive regions on the planet (Parde et al., 2021). Living things depend on water. According to Juvonen and Kurikka (2016), over one-third of the value of ecosystem services on earth is thought to be derived from the natural resources and ecosystem services that shallow coastal and inland waterways worldwide supply. Wetlands are valuable because of their function in preserving earth's biodiversity and the numerous advantages and services they offer to humans (Xu et al., 2020).

Wetlands purifies water because fine-grained soil, heavy metal and nutrient particles, can fall to the bottom or be taken in by vegetation when there is a slow water flow (Maleki et al., 2016). Wetlands significantly affect the water cycle. Among other things, wetland regulates floods, recycles nutrients, offers freshwater supplies and help shield beaches from storm-related erosion damage. Additionally, Medland et al. (2020) emphasised that wetlands provide recreational activities as well as game, fish, wood, and peat and also help to moderate the rate of climate change.

On the foregoing, it has been determined that wetlands are the world's most vulnerable habitats (Widis et al., 2015). Globally, their natural worth has diminished, and their sizes have shrunk. According to estimates, two-thirds of Europe's wetlands from the turn of the

20th century have vanished (Juvonen and Kurikka, 2016). Many species face the threat of extinction as a result of declining habitats. The three biggest factors endangering the world's biodiversity are changes in land use, freshwater body degradation, and climate change (Qu et al., 2019). Wetlands are dynamic environments, but human activity has led to eutrophication and overgrowth of water bodies, which has reduced the diversity of flora and other species in wetland populations (Davis et al., 2019).

2.1.2 Natural and Constructed Wetland

Wetlands vary greatly due to regional and local changes in soils, terrain, climate, hydrology, water chemistry, flora, and other factors such as human disturbance. These ecosystems are either formed naturally or constructed by humans. Natural wetlands are primarily found in floodplains adjacent to rivers and streams, in solitary depressions encircled by arid terrain, along the edges of ponds and lakes, as well as other low-lying regions where precipitation adequately saturates the soil or where groundwater meets the soil surface (EPA, 2018). Natural wetlands include swamps with a predominance of shrubs, wooded swamps with a predominance of trees, and marshes and wet meadows with herbaceous plants dominant. Ensign and Noe (2018) posited that natural wetlands offer numerous ecological advantages, such as carbon storage, flood control, water filtering, and habitat for a variety of plant and animal species. Therefore, by retaining nutrients and sediments and assisting in the preservation of water quality, they also support the general wellbeing of catchment.

On the other hand, constructed wetlands, also known as artificial or engineered wetlands, are man-made systems designed to replicate the functions of natural wetlands (Knowles et al. 2011). They are typically created to treat wastewater, control pollution, and enhance water quality. Unlike natural wetlands, which have formed over hundreds or thousands of years, constructed wetlands are intentionally designed and built by humans.

One of the key advantages of constructed wetlands is their ability to treat wastewater effectively (Waly et al. 2022). These man-made systems are designed to mimic the natural processes that occur in natural wetlands, such as filtration and biological degradation. Almuktar et al. (2018) posited that constructed wetlands can remove pollutants from wastewater, transforming it into clean, reusable water for irrigation purposes since more than 70% of water are consumed for irrigation. This can be particularly beneficial in agricultural areas where wastewater treatment facilities are needed for plant production.

Furthermore, constructed wetlands also play a significant role in controlling pollution and enhancing water quality. By acting as a natural filter, they can reduce the amount of excess nutrients, sediment, and chemicals that enter water bodies. This, in turn, helps to prevent eutrophication, the degradation of water quality due to excessive nutrient enrichment.

Moreover, EPA (2018) argued that both natural and constructed wetlands suffer a variety of hazards, including habitat loss, contamination, and hydrological changes caused by human activity; conservation efforts are critical to protecting and preserving these valuable ecosystems.

2.1.3 Wetland Mapping Methods

There are several methods and options that have been explored in the literature when mapping wetlands site suitability. According to Swan (2019), digitizing wetlands using digital imagery or high-quality aerial photos is one of the most accurate yet resource-intensive methods. Therefore, to counteract the accompanying costs, agencies and organizations may desire to work together on a regional scale to gather imagery (which has numerous uses other than wetland mapping) and map wetland resources (Kalacska et al., 2017). Land trusts, non-profits, transportation and utility divisions, colleges, federal and state organizations, private consultancies, and regional councils of government are all possible partners (Swan, 2019). The various wetland mapping methods are summarized in Table 1 following Swan (2019).

Table 1: Wetland Mapping Method

Method	Description	Drawback
“Manual stereoscopic interpretation”	Stereoscopic processing of aerial images in order to analyse them in three-dimensional format and delineate wetlands	Photo translators that can see in stereoscopic and understand surface water hydrology and wetland ecology are required.
“Addition of potential wetlands to existing wetland maps”	Use wetland indicator layers to locate places where wetland presence is likely or suitable.	Field validation of wetland presence and borders is required.
“Heads-Up method of wetland delineation”	Wetlands can be immediately digitised using digital imaging.	Image analysts with competence in identifying and classifying wetlands are required.

According to Munoz et al. (2009), the strategy of "addition of potential wetlands to existing wetland maps" can be particularly effective in places with a known abundance of isolated wetland types that are under-mapped. However, the procedure may need to be modified for the region's isolated wetland kinds. This approach is suited for application with GIS. Sinha et al. (2017), noted that searching for potential wetlands locations through GIS is a cheaper way of improving local wetland mapping.

2.2 Theoretical Background

The hydroperiod theory provides a background insight in understanding suitability mapping of wetlands. One of the most important concepts in wetland ecology is the hydroperiod theory, which focuses on the flooding or saturation periods of wetland ecosystem (Kissel et al., 2020). The theory recognizes that the length and duration over which water is available has a significant effect on the ecological features and functions of Wetlands. The duration over which wetlands remain saturated is its hydroperiod, and it is important in the formation of the physical and ecological traits of the wetland ecosystems (Daniel and Rooney 2021).

The changes in hydroperiod are instrumental in affecting biogeographic distribution of different kinds of wetland and the species of plants and animals found there. According to hydroperiod theory, various wetland types have different hydroperiods, this ranges from permanently flooded areas to periodically inundated or saturated areas (Daniel and Rooney, 2021). For instance, marshes are extensively flooded on a regular basis, which is considered good for cattails and bulrushes. Seasonal wetlands, on the other hand, such as vernal pools only hold water for a short duration during different times of the year which also affects the types of species that are found there. The hydroperiods also possess some effect on the profile of soil, which defines wetland physiology, nutrient cycling and oxygen supply (Murray-Hudson et al., 2015).

Furthermore, the argument of wetland suitability mapping based on hydroperiod theory can be effective in helping to plan and implement land use development and management. This is because the assumption of the theory can assist in identifying the locations where particular land uses that interfere with the natural hydrological system of wetlands has the least impact on these invaluable ecosystems leading to sustainable development (Daniel and Rooney, 2021). For example, Foti et al. (2012) noted that hydroperiod information assists in estimating habitat suitability to different flora and animals. This also encourages conservation through increasing awareness and highlighting biodiversity hotspots. Therefore, the hydroperiod framework underpins the identification and mapping of suitable wetland locations in this study.

2.3 Previous Research

There are previous studies that have documented the issues concerning wetland mapping. For instance, Ouyang et al. (2011) conducted an assessment to determine appropriate wetland restoration sites by examining the possible impacts of wetland restoration efforts at the watershed scale. The Yongdinghe River upstream is used as an example in the study to suggest a GIS-based multi-criteria comprehensive evaluation technique for wetland restoration suitability assessment. According to the statistical evidence, 979 km2 of wetlands, or 2.18% of the total study area, had the highest suitability for restoration. And the majority of them, covering an area of roughly 131.586 km2, are found in Yangyuan country. Reservoir and river wetlands are the two primary forms of wetlands, and of the entire region, they make up 11.75% and 11.33%, respectively.

Zhu and Gong (2014) estimated the average annual surface water level at 30 arc-second squares over the globe's continental areas except Antarctica using hydrologic and meteorological variables in conjunction with Compound Topographic Index (CTI) data. According to the modelling results, the total area of around the globe wetland is 3.316107 km2. Our product's overall accuracy is 83.7%, according to remote-sensing-based confirmation based on an overview of wetland areas from numerous sources.

Maleki et al. (2016) used Hamun wetland to build a spatial conservation prioritising approach based on satellite imagery and a GIS to identify regions of a wetland that require specific protective measures during the nesting season of waterbirds. After extracting spatial information from Landsat 8 time series data, "the maximum entropy and weighted linear combination (WLC)" algorithms were applied to identify places with higher conservation priority. First, a map of wetlands habitat suitability in Hamun Wetland during nesting season was created. Then, variations in habitat appropriateness were evaluated until the conclusion of the nestling phase, and locations with acceptable circumstances for longer periods were discovered. Furthermore, locations with favorable conditions at the start of the breeding season but inadequate ones (due to wetland drying) throughout the nestling stage were identified.

Singh et al. (2017) proposed and applied for wetlands in the Begusarai district of the north Bihar plains, India mapping and classification procedure has been, in an effort to better understand the vast network of riverine wetlands and how they differ from other floodplain water bodies, primarily the moist areas. The suggested hydro-geomorphic categorization system can be quickly developed by processing satellite photos merged with the least amount of auxiliary data. It is hierarchical, straightforward, and resilient.

Uuemaa et al. (2018) explored the factors needed for the identification of wetlands utilising the Light Detection and Ranging (LDR) digital model. The study showed that the suitability of a site for wetland restoration or construction is determined by a variety of factors, including the underpinning geology, soils, terrain, hydrology, drainage, and property ownership. Among the most important considerations are local hydrology and soils. However, inventorying and characterising a site's soils and hydrology sometimes necessitates large, costly, and time-consuming inspections of the ground, limiting it to small regions. Furthermore, the study demonstrated that terrain analysis employing high-resolution topographical data, i.e. LDR, can offer suitability mapping for wetlands that can be conveniently used by decision-makers and planners in managing catchment.

Qui et al. (2020) applied multisource geospatial data to characterize hydrological, topographical, management, and policy factors such as maximum groundwater coverage, agriculture time, human-induced disturbance, and wetland protection level in the Sanjiang Plain (SJP), China's largest swamp distribution and a hotspot wetland loss region. The results showed that between 1990 and 2018, 11,643 km2 of wetlands were transformed into agricultural land for agricultural use. Additionally, the study estimated that 5415 km2 of croplands in the SJP were appropriate for the rehabilitation of wetland ecosystems, with 4193 km2 (77%) having a high priority for rehabilitation.

The summary of past literature indicates various methods and approaches have been used by researchers across various geographies in an attempt to map wetlands for the creation and restoration of sites. However, the mapping of suitable wetlands focusing on Western Uusimma Finland using Scalgo Live and ArcGIS remains unique to this study.

3 METHODS

3.1 POTENTIAL WETLAND SUITABILITY MAPPING

To map out suitable area for constructing wetlands Scalgo Live was utilized for analyses of relevant catchments, catchment, flow accumulation and water ways. Depressions database was downloaded as a vector file format from Scalgo Live and was imported to Arcgis pro for analysis. Dataset on Agricultural areas in Finland were also downloaded from the National land survey of Finland and was used to get land use for agricultural activities in Finland. Furthermore, historic aerial photographs that's dates to the 30's were used to get an overview of land use change and classification on former wetland areas for restoration. Finally, to ensure the accuracy on potential wetland feasibility, run-off risk maps and streamlines were utilized from Arcgis pro, this served as an additional confirmation for potential wetland creation and restoration particular in areas where risk of sea runoff were deemed significant.

3.2 THE CRITERIA FOR MAPPING A FEASIBLE WETLAND LOCATION.

3.2.1 Soil type

According to Trepel and Palmeri (2002) the most important properties of wetland soils are organic matter content (organic carbon) and clay. Organic soils and soils with high clay content do not allow water to pass through rapidly and generally they hold more water than mineral soils (Mitsch and Gossenlink, 2000). The Peat soil is described to be effective in controlling floods and soil erosion, aside from its strong capacity to sequester carbon (Harenda, K. et.al, 2018). Therefore, the area or location should have an organic soil property or a fine-ground clay soil.

3.2.2 Depression or Slopes

The site must have a topographical feature of natural depression or slopes sufficient in holding or storing water. Low slope angles are more suitable for wetland developments than steeper slopes (Uuemaa, E et.al 2018). Therefore, this study considered maximum slope of 3 degrees or maximum depression volume of 1ha as an ideal condition for wetland development as these criteria facilitate water retention and movement.

3.2.3 Catchment consideration

To ensure a targeted source of water inputs, the location should be within the catchment where there is higher proportion of downstream runoffs. This concept will help capture both natural runoff from forests and potential runoff from agricultural areas.

3.2.4 Streams and runoffs

In this report we will be considering proximity of wetland to streams and runoffs. According to Olszewska Dorota Olga (2005) streams influence the probability of inundation and hence – the abiotic and biotic components of the wetland. Since the primary objective of wetland establishment is water treatment, therefore it is important to locate them to a distance closer to streams and runoffs.

3.2.5 Restoration Feasibility

If the site has previously served as a wetland but changed due to land use activities, the feasibility of restoring the wetland ecosystem within the site's current condition will be evaluated.

Combining all these criteria and analysis contributes to a great deal in mapping out potential areas for wetland feasibility in the western Uusimaa region of Finland.

3.3 STUDY AREA

3.3.1 General description of the study area

The study Area employed for this study is Western Uusimaa a region located in southern Finland also known as Länsi-Uusimaa in Finnish (figure 1). Western Uusimaa is part of the larger Uusimaa region, which includes Helsinki, the capital of Finland. Western Uusimaa is characterized by its coastal areas, archipelago, and proximity to the Baltic Sea. This region comprises of 5 major municipalities (Hanko, Ekenas, Karis, Inko and Siuntio) all of which has a substantial amount of both Agriculture and forest areas

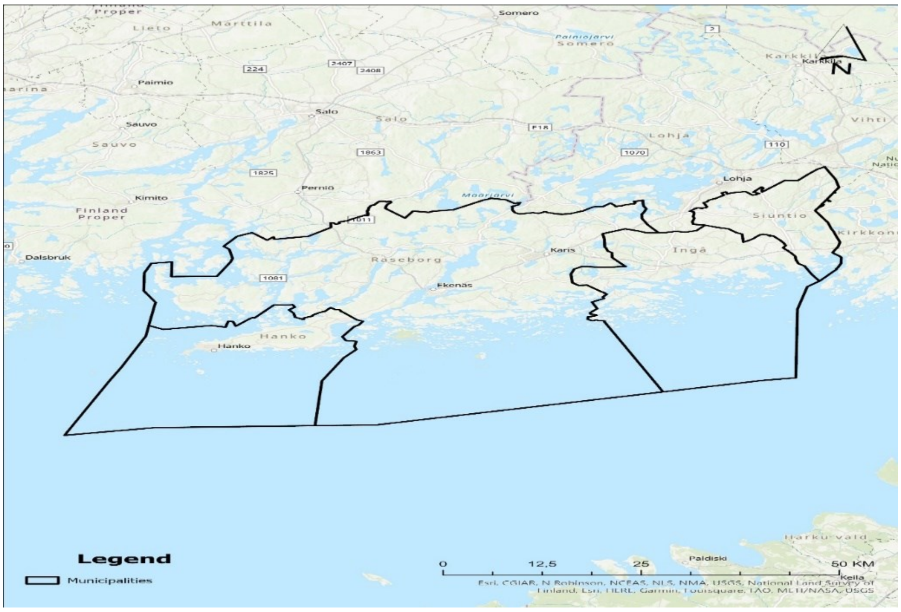

Figure 1. Western Uusimaa. Source (Argis 2023)

3.3.2 Land Use

To analyse land use in Western Uusimaa area, data were retrieved from the Living Atlas in ArcGIS with a particular focus on identifying the predominant land use changes in the years. The initial step involved acquiring land use data for the broader Uusimaa region, spanning from 2017 to 2022 (Figure 2), where forests stood out as the highest land use at 62% in 2022, followed by cropland, built up area and bare land. This information contributed to a comprehensive understanding of regional land use trends in Uusimaa region overall. Subsequently, a narrower focus on Land use for Western Uusimaa in 2022 (Figure 3) revealed that trees and agricultural areas were more prominently represented in this specific region as it were in the bigger picture of the whole Uusimaa area, signifying their significance as major sources of nutrient flow into local water bodies.

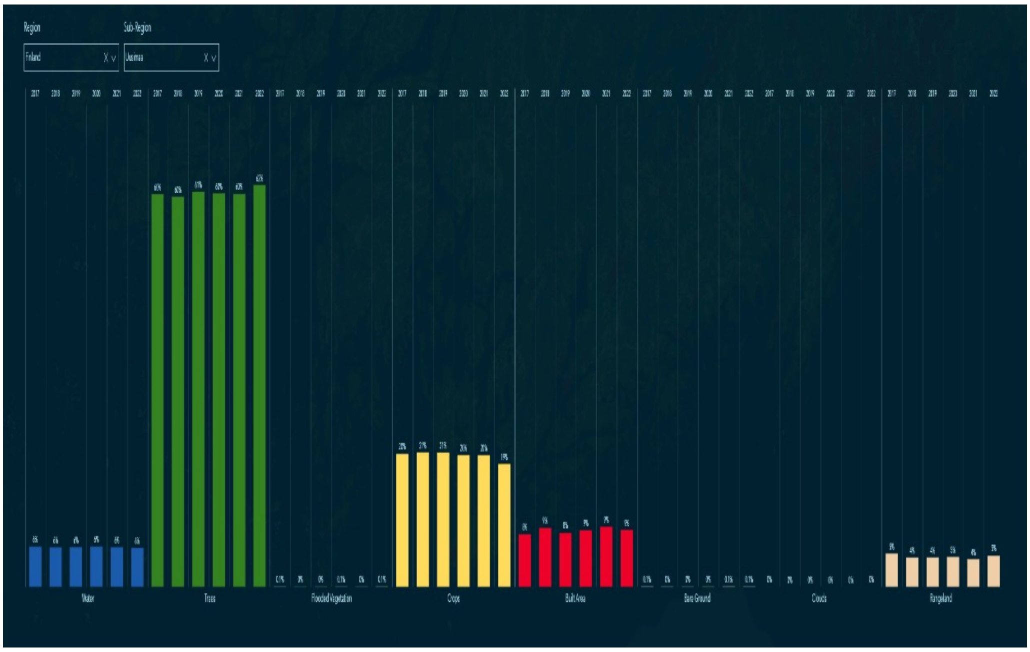

Figure 2. Land Use Uusimaa region 2017-2022. (Source: Living atlas arcgis)

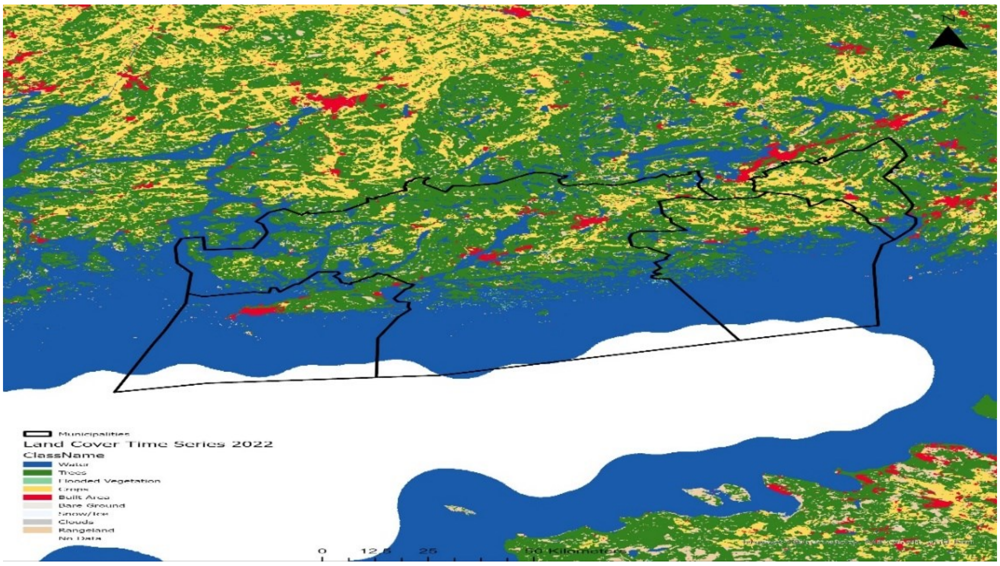

Figure 3. Land Use Western Uusimaa region 2022. (Source: Living atlas arcgis)

3.4 DATA GATHERING

The data used for mapping potential wetland area were gathered from the following sources:

- Land use map was retrieved from living atlas in Arcgis
- Soil Map from National Land Survey of Finland
- Agricultural areas and Digital Elevation Model (DEM) were gotten from National Land Survey of Finland

- All other datasets were downloaded from Scalgo Live and then imported to Arcgis.

3.5 SITING BY USING THE SET OF CRITERIA TO FIND SUITABLE WETLAND LOCATION

3.5.1 Stream Flow and runoffs

Flow accumulation data were downloaded from Scalgo Live 2023; these datasets were obtained from the depression free flow tool in Scalgo Live with a slider for selecting desired flow network detail. For this report, we specifically selected datasets within the catchment sizes ranging from 0.20 km² or 20 hectares (figure 4) up to 3.0 km² or 300 hectares (figure 5) to account for potential wide array of catchment and water inflow sources, and subsequently imported this data into ArcGIS. This can be done under the in Scalgo live and In ArcGIS, I extracted the 3.0 km² (300 hectares) flow accumulation as a standalone layer with the main focus on the smaller flows ranging from 20–299 hectare as potential sources for wetland construction. It is also important to note that several existing wetlands such as the ones located in Söderlandsvägen and Furuborsvägen had the same amount of flow consideration, so it was ideal to incorporate these criteria in finding potential wetland inflow sources.

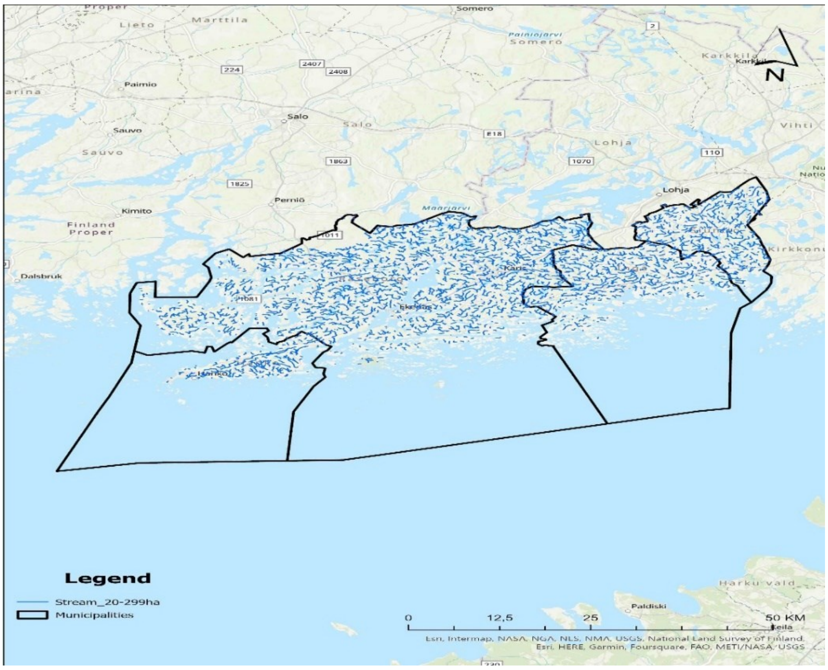

Figure 4. Flow Accumulation 0.20 km² or 20 hectares calculated in Scalgo Live

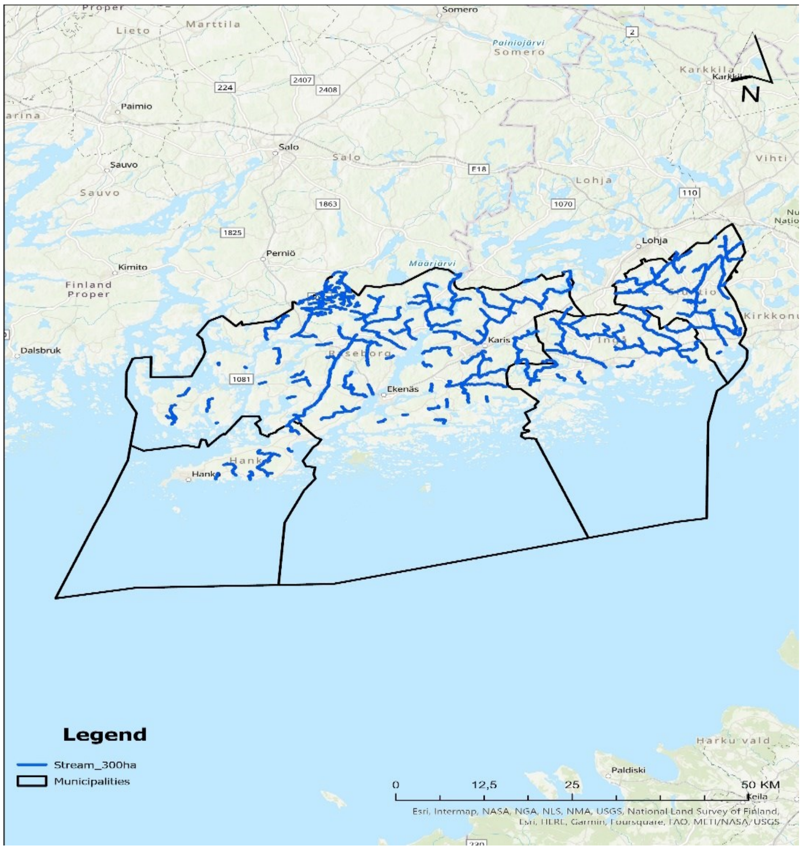

Figure 5. Flow Accumulation 0.3 km² or 300 hectares calculated in Scalgo Live

3.5.2 Slopes and Depression

To acquire slope and depression data for a project, I initiated the process by downloading a Digital Elevation Model (DEM) (Figure 6) of the Western Uusimaa region from the National Land Survey of Finland. A Digital Elevation Model (DEM) is a digital representation of terrain and topography which helps to visualize and analyse the Earth's surface in a digital format. This information provides a grid of elevation values at regularly or spaced intervals, typically representing heights above sea level. Furthermore, I employed ArcGIS Pro to create a slope layer from the DEM, filtering and selecting only slopes measuring less than or equal to 3 degrees (Figure 7), which met our project's suitability criteria. Subsequently, I obtained a depression map with 1-hectare volume from Scalgo Live and imported it into ArcGIS Pro. To facilitate the depression analysis, I applied a unique value symbology to the depression data for distinct visualization of depression characteristics within the project (figure 8)

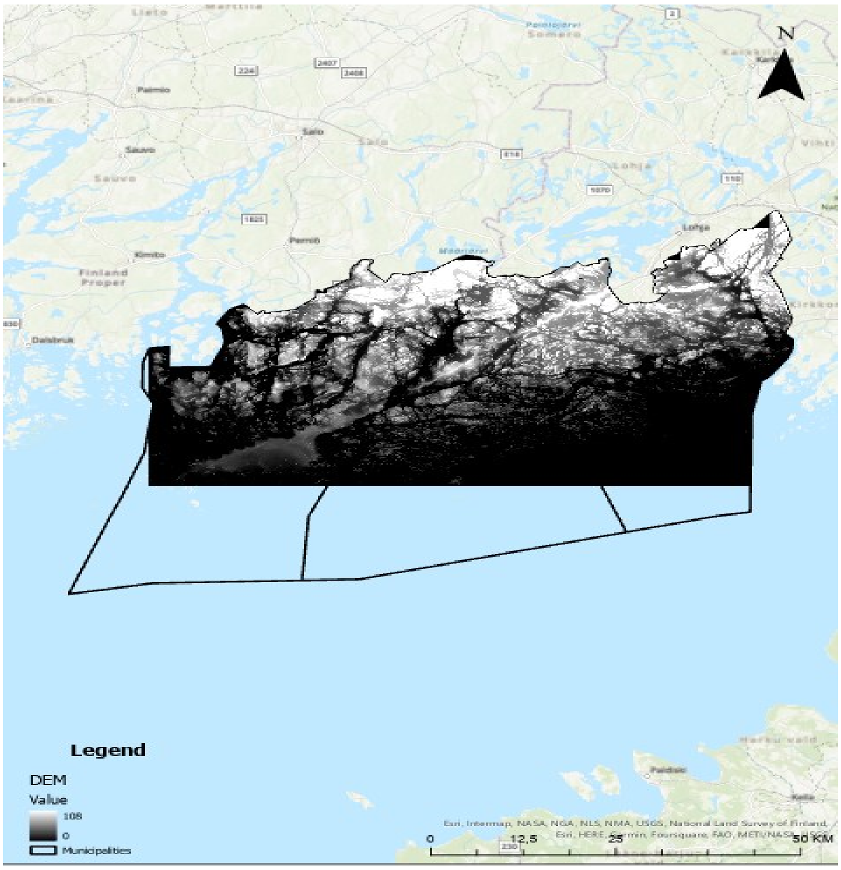

Figure 6. Digital Elevation Model DEM. (Source: National Land Use Survey of Finland)

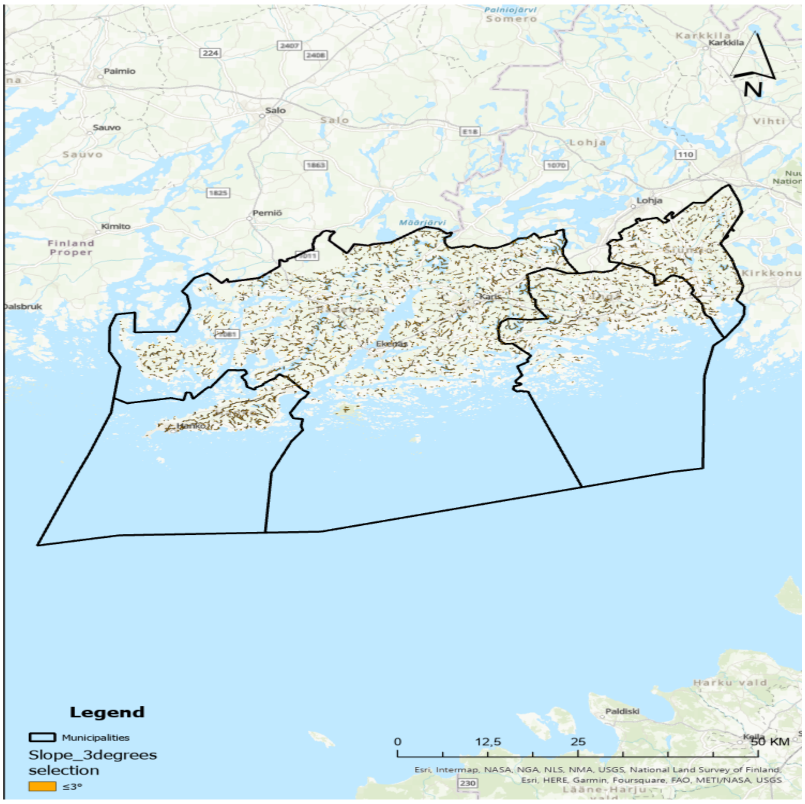

Figure 7: Slope calculated based on DEM

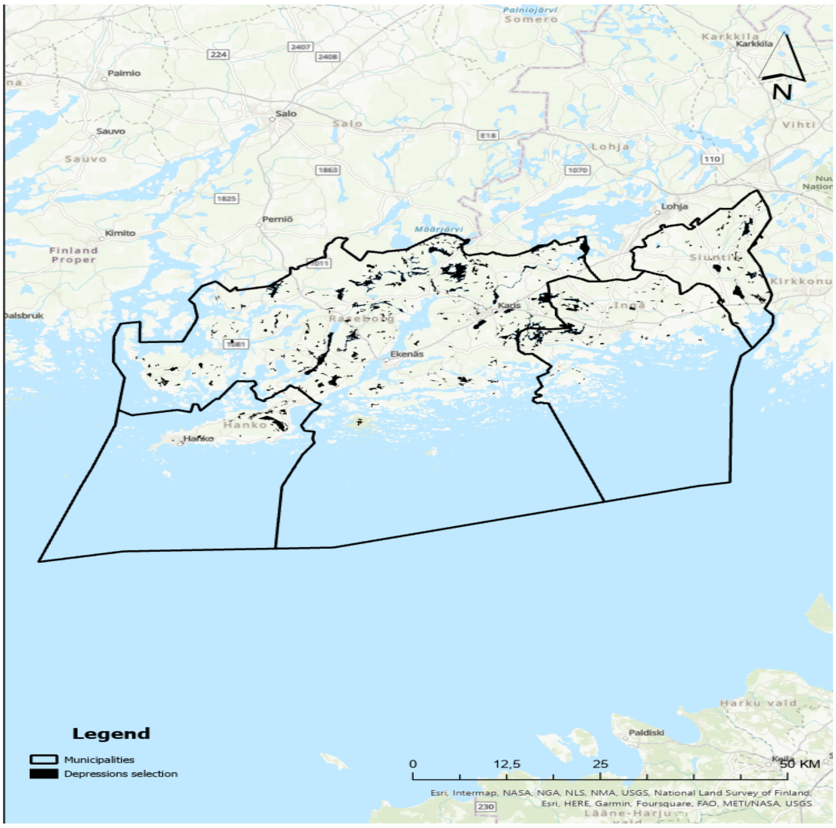

Figure 8. Depression map calculated in Scalgo Live

3.5.3 Catchment Area Considerations

A catchment or drainage basin is a geographical area where all surface water from rain and snowmelt flows to a common point, such as a river, lake, or ocean. Catchments are fundamental in understanding the movement of water, contaminants, and nutrients across the landscape, which is essential for wetland suitability mapping and environmental management. The catchment area dataset for this report was acquired from the downloadable spatial dataset available at syke.fi, which was last updated on May 23, 2023 (Figure 9).

To further address nutrient flow reduction within catchment areas, the study focused on catchment containing a considerable proportion of agricultural land, and this report has earlier outlined the key considerations in this regard. The process involved identifying downloading agricultural lands from the National Land Survey of Finland, after which those data were imported to Arccgis and represented in (Figure 10).

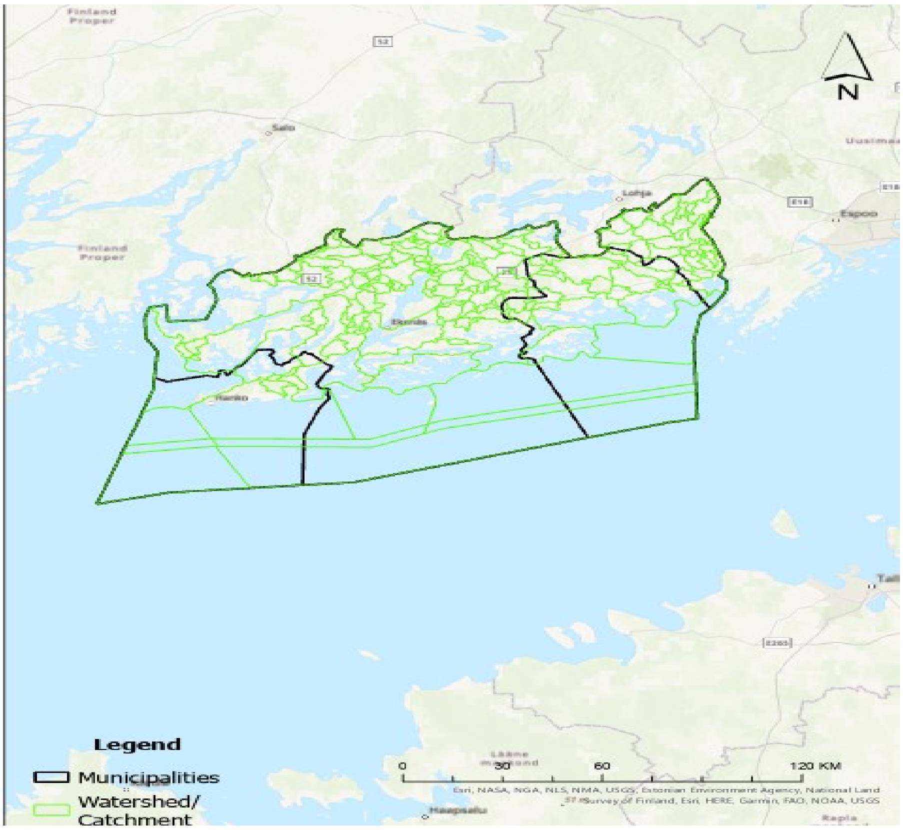

Figure 9. Catchment Areas (Source: Syke.fi)

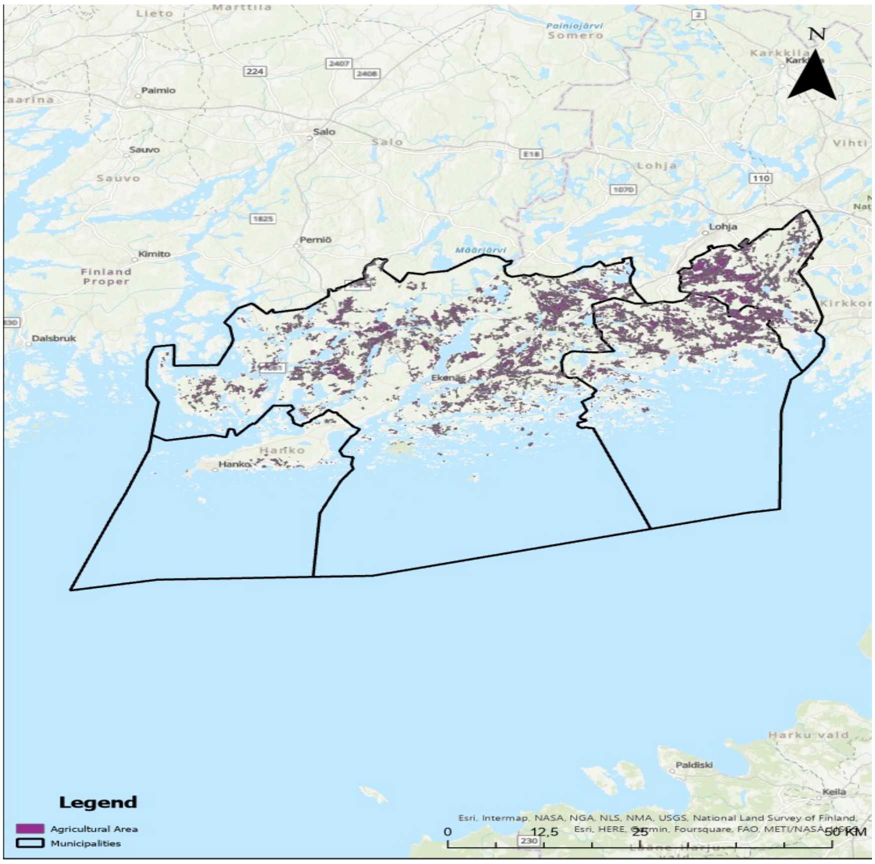

Figure 10. Agricultural Areas (Source: National Land survey Finland)

3.5.4 Risk of Runoffs

To get a narrower approach to our wetland suitability mapping, I incorporated the risk buffer data provided by Maria Velmitskaya (2023) who worked on risk map for the runoff of the total suspended solids and total phosphorus for Southwestern Finland. The Runoff risk modelling used in her study was developed by Ake Sivertun and Lars Prange (2003). The model uses a simplified version of the original Universal Soil Loss Equation (USLE) to estimate the total phosphorus (TP) and e total suspended solids (TSS) load, which are essential elements for estimating pollution from agricultural areas and assessing water quality.

The simplified Universal Soil Loss Equation (USLE) model was developed by Sivertun et al. in 1988 and updated in 2003. This simplified model relies on four key factors with the formula designated as P = K*S*W*U. Where P is the Resulting runoff Risk Map, K is the soils factor map, S is the slope length and steepness factor map, Wis the watercourse factor map, and U is the land use factor map. To validate the reliability of the updated model, a one year measuring programme in the Svartå river basin in the province Östergötland, Sweden, was used. This showed that estimated loads of loaded suspended solids and phosphorus were highly correlated with the critical areas, from 91%-98%. Therefore, the model is reliable (Sivertun & Prange, 2003).

The risk of runoff data gave a comprehensive approach in identifying areas with an increased risk of runoff within the catchment. To proceed with the risk analysis, first, I conducted a summary of the risk area data, this was done by the summarise within tool in Arcgis pro and the summary was based off on the area of the risk summarised within the catchment in square kilometres (Figure 11). After summarizing the risk area data, I proceeded to symbolize the classes of the risk areas. This involved categorizing the risk areas into different classes based on the size of risks they represented. The category of risk was grouped into 5 classes ranging from 1 to 10km2. By symbolizing these classes, our attentions were more focused on specific areas with a higher risk of runoffs, which are critical for wetland suitability mapping.

Additionally, to get an understanding of the proportion of risks within the catchments, I proceeded with further analysis. This process was done by creating a new field in the attribute table of the summarized risk area shape file with the name 'Proportion'. The new field created was further calculated to get the risk proportions value for each catchment (Fig 12). I achieved this by dividing the total area of the summarized risks within the catchments with the total area of the catchment size in square kilometers. After that I proceeded to symbolize the risk area proportion value based on risk classes ranging from low risk to high-risk areas.

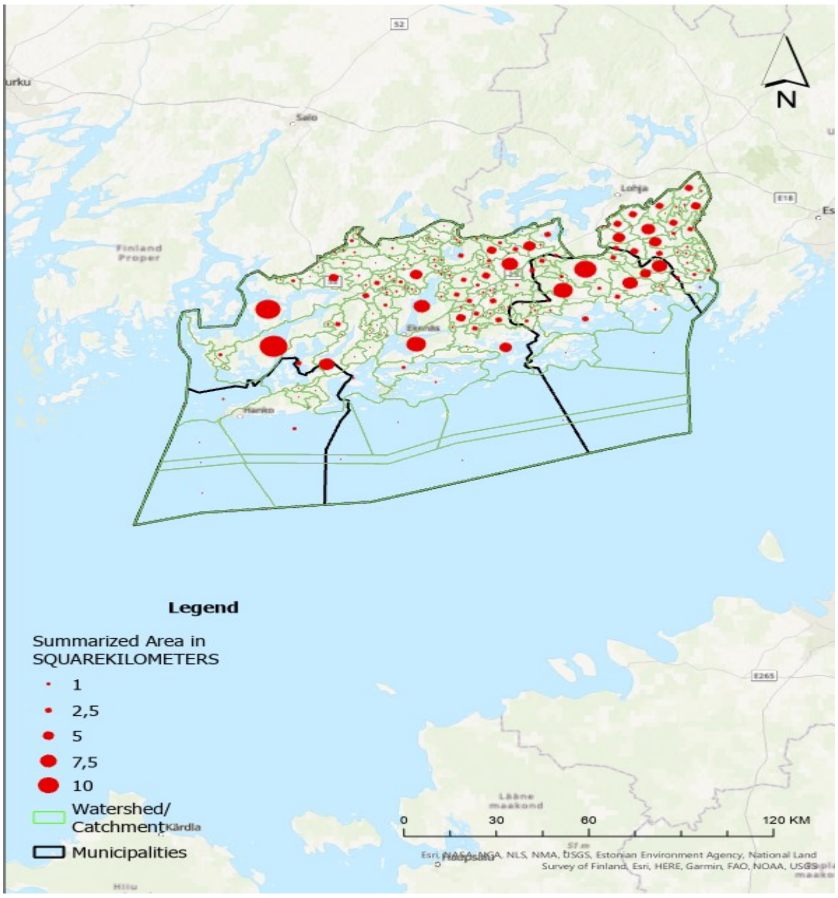

Figure 11. Risk areas summarised in KM2 within catchment.

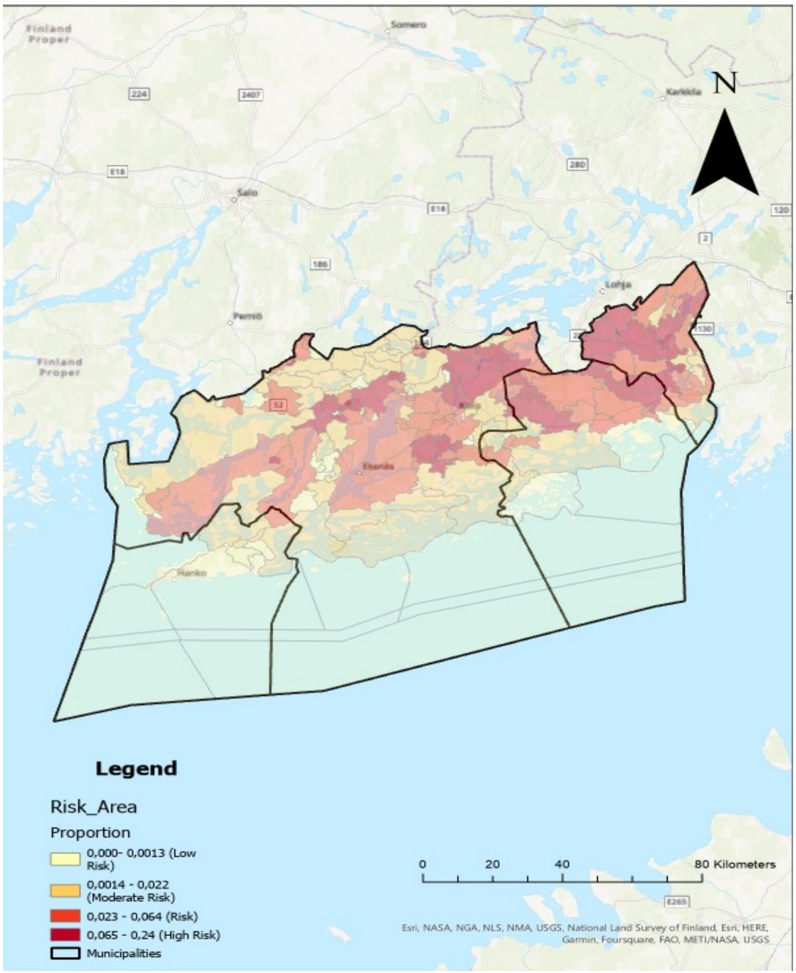

Figure 12. Risk proportions for each catchment

3.5.5 Soil Type

The most important properties of wetland soils are organic matter content (organic carbon) and clay (Trepel and Palmeri 2002). Therefore, our aim is to get such soil layer that will promote the sustainability and effectiveness of the wetland area. The soil layer for this report was downloaded from the National Land Survey of Finland (Figure 13). After downloading the layer, it was symbolised to show different types of soil that is present in our study area. Although the soil data are not fully represented for our study area.

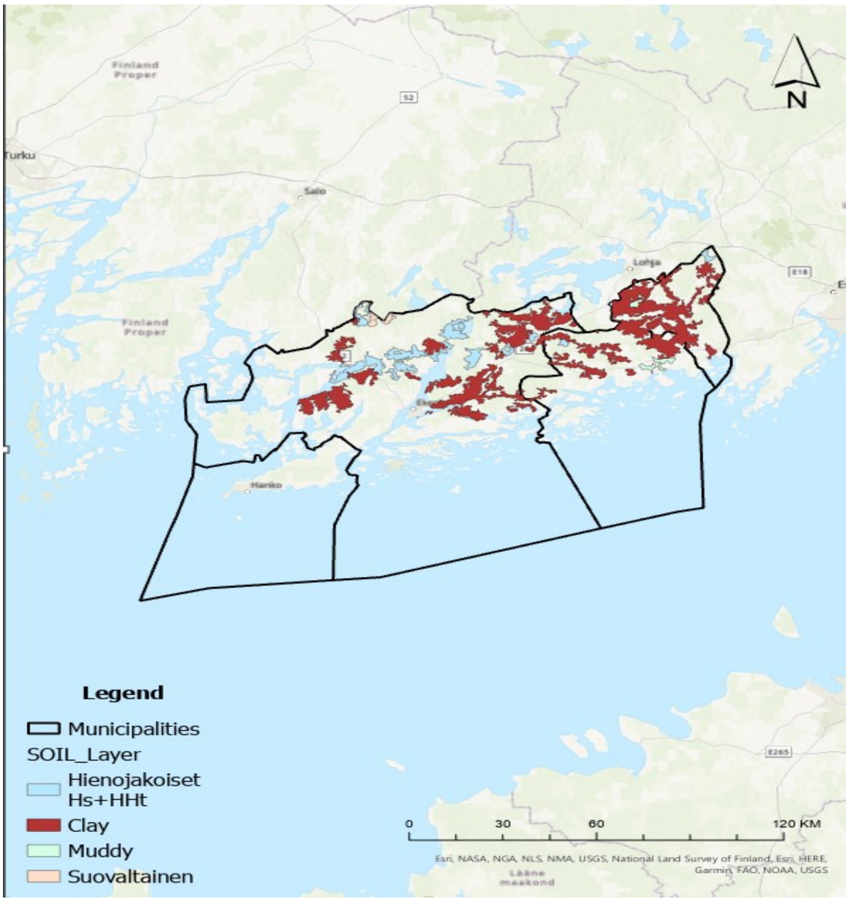

Figure 13. Soil Layer. Source (National Land Survey of Finland)

4 RESULTS

4.1 WETLAND MAPPING

The western Uusimaa region of Finland, characterized by its proximity to the Baltic Sea has faced a significant challenge of deteriorating water quality over the years. This is a contributing factor from the historical effect of land use change including increased urbanization, agriculture, and various environmental activities which have impacted the level of nutrient that flushes down to water bodies and significantly posing threat to both local ecosystems and the delicate balance of the Baltic Sea. The sole aim for constructing wetland in this critical region is so that they can act as natural filters effective for nutrient removal and help mitigate the environmental impact of deteriorating water quality. Therefore, as part of the objective for this study I embarked on a task of Identifying feasible sites and locations for wetland construction and development. This was done following a set of predefined criteria that served as basis for not only restoring the water quality in the Western Ussimaa region but also ensure the long-term sustainability of this invaluable ecosystem.

This study aims to present a comprehensive framework for wetland development in this critical region through a combination of geospatial analysis and topographical assessment. The following assessment was conducted for our final selection of potential location:

4.1.1 Soil Type

The soil data was not utilized in our analysis as the soil layers available online contains few data and are not fully represented for our study area. Although it is recommended by Trepel and Palmeri (2002) to prioritize areas with fine-grained clay soils and peat type of soils. These soils, rich in organic matter, facilitate water retention and filtration.

4.1.2 Stream flow and Runoff Risk

Our findings revealed a close association between feasible wetland locations and nearby accumulated flows and runoffs of 20-299ha, as these aligned with inlet water flow capable of meeting our primary objective of water treatment and ensuring an efficient hydrological connection to the mainstream. The selected accumulated flow were erased from lakes and sea using the erase function in Arcgis, this allowed us filter only flow sources within targeted areas. Furthermore, our analysis prioritized catchments with a larger proportion of runoff risk areas. Therefore, catchments with high-risk class or proportions fit our suitability criteria. A total of 15 catchments were selected having a higher class of risk area that is greater than or equal to 5 km^2 or and a risk proportion of 0.020 and above. This gave us a strategic selection of lager catchments having a moderate to high risk of runoff in the western Uusimma region of Finland.

4.1.3 Depression or Slopes

We looked for sites with natural depressions or on low gentle slopes. According to Uuemaa et al. (2018), low slope angles were a crucial element consideration. In this study, a number of areas met this criterion with slope angles of less than or equal to 3 degrees or 1hectare depression volumes; creating an ideal condition for effective water retention and circulation. The selected depressions and slopes were further erased from lakes and sea using the erase function in Arcgis, to narrow our focus only to depressions and slopes within targeted areas.

4.1.4. Catchment Area Consideration

For a reliable water source, the consideration of this study was areas located at the catchment of upstream areas connected to forest and agricultural land. This strategic choice ensures the collection of natural runoffs from forests and potential agricultural runoff, improving wetland sustainability and reliability. Following these rigorous criteria and comprehensive analysis, this study has identified a selection of potential wetland locations in the western Uusimaa area (Figure 14) that promise to be effective tools in dealing with water quality issues and assist in the preservation of this valuable Finnish landscape.

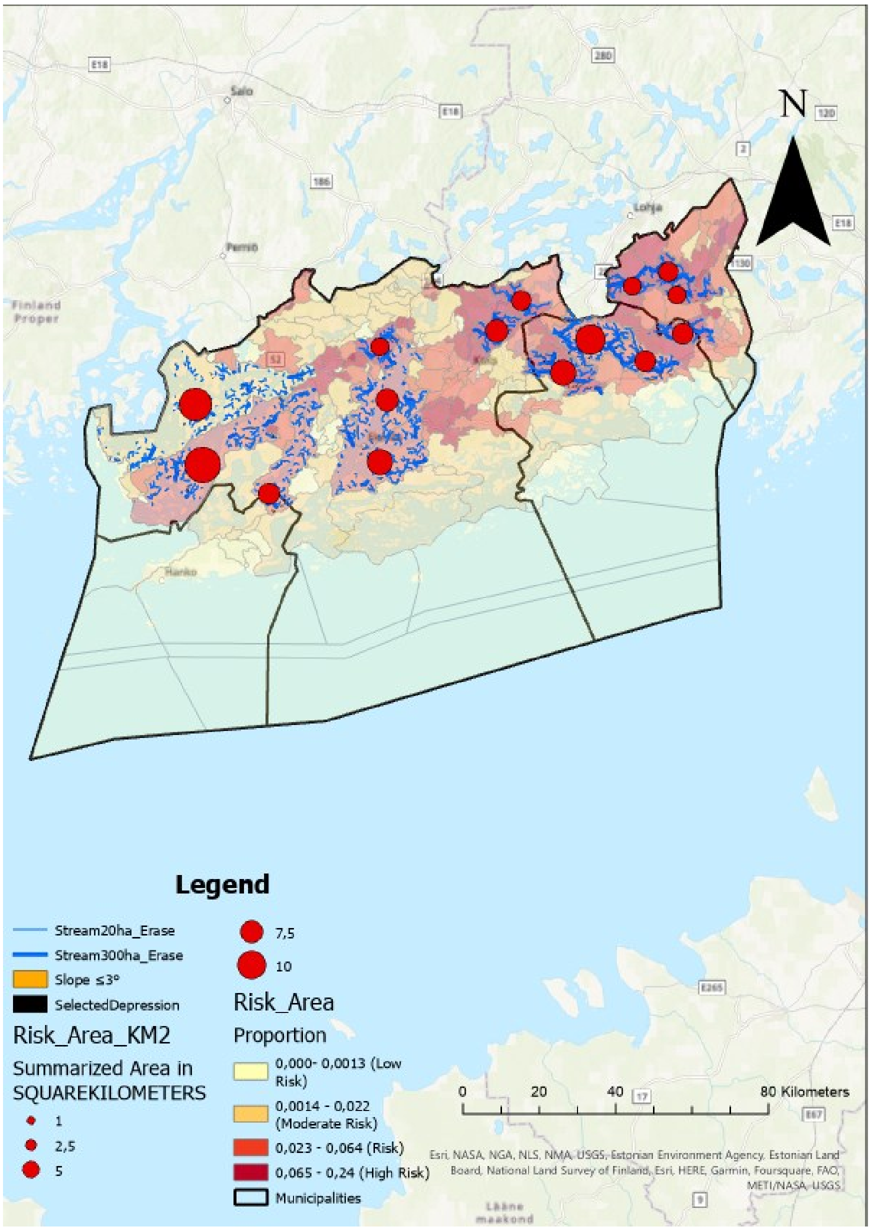

Figure 14. Selection of Potential wetland Locations.

4.2 Mapping Old Aerial Photographs of Former Wetland Area

The wetland identified with this analysis is located in Smedsedevägen Western Uusimaa Finland (figure 15). The following factors contributed to this selection:

4.2.1 Land Use Change

In 1949, an aerial image shows a wetland existing in Smedsedevägen area which has presently been converted to agricultural land. This reflects the change in land use contributing to the potential for wetland restoration.

4.2.2 Depression Volume

The maximum depression in the area with a volume of 99,482.88 m^3 is considered sufficient for flood retention. This implies that the site has a potential for storing excess water during heavy rainfall periods, reducing the potential for downstream flooding.

4.2.3 Catchment Area

The location has a catchment area of 73 hectares in total, which accounts for up to 69% forested area and 26% of Agricultural lands. This distribution is regarded as optimal for targeted catchment inputs. For instance, forests can help in preventing erosion and associated nutrients and sediment loads to the wetland.

4.2.4 Runoff Risk

As shown in the runoff risk analysis from Arcgis, this area has a high level of downstream runoff risk. This underscores the importance of restoring wetlands since wetlands act as filters for runoffs and absorb the nutrients from these runoffs by slowing them down which in turn helps to reduce the consequences of flooding downstream.

Based on these criteria and the analysis conducted, it is reasonable to conclude that this location is suitable and optimal for wetland restoration work.

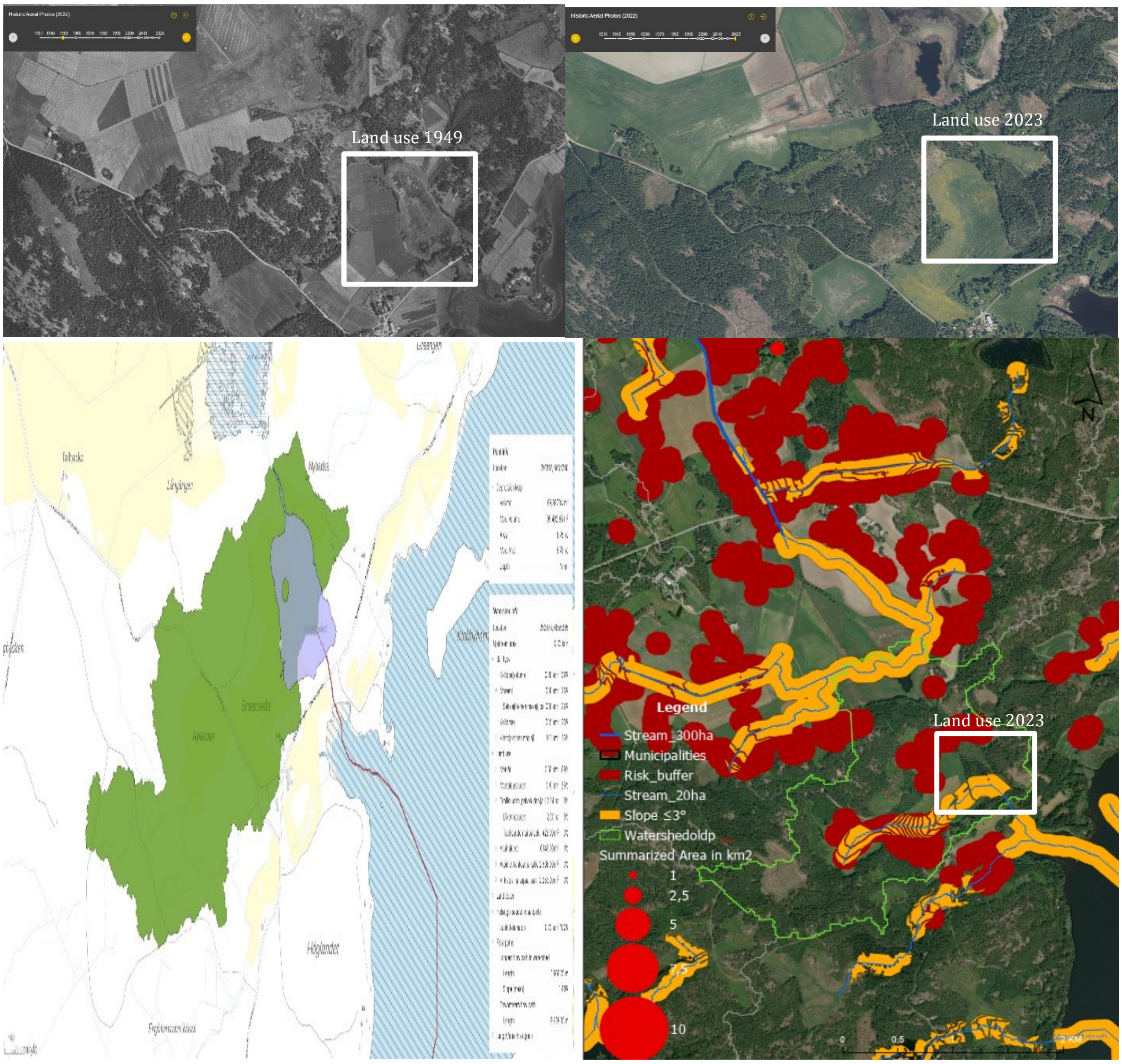

Figure 15. Former wetland mapping in Smedsedevägen (Source: Scalgo Live, kartta.paikkatietoikkuna.fi and Arc Gis pro)

5. DISCUSSION

Similarly, like other research conducted in various geographical areas, the result of this study has contributed greatly to a broad understanding of wetlands mapping and restoration.

The existing literatures has employed various methodologies; from GIS-based multi-criteria evaluation (Ouyang et al., 2011) to hydrologic and meteorological modeling for global wetland estimation (Zhu & Gong, 2014). Similarly, Maleki et al., (2016) asserts that a number of studies have utilized satellite imagery and GIS for spatial conservation prioritization. For instance, Singh et al., (2017) explored hydro-geomorphic forms classification systems in riverine wetlands. Also, Uuemaa et al., (2018) carried out research on factors for wetland identification using LIDAR data.

In the case of Western Uusimaa region of Finland alternative approach is required to address the issues of deteriorating water quality which are related to historical land use changes. This study focused on the construction and restoration of wetland locations capable of serving as environmental protections and natural filters. A unique aspect of this study is its focus on the Western Uusimaa region and the use of use of both Scalgo Live and ArcGIS in providing significant information concerning the construction and restoration of wetlands within the study area.

This study addresses the suggestions and recommendations set forth in previous literature in its selection criteria. Unfortunately, the soil data were not used due to its limited representation for the study area, nevertheless, Trepel and Palmeri (2002) noted that areas with fine grained clay and peat type of soils should be prioritized as they facilitate water retention and are capable in controlling erosion. Furthermore, this study focused on stream flow and runoff risk considering the influence they have on wetland functionality as posited by Olszewska Dorota Olga, (2005), and prioritized catchments with larger proportion of risk areas.

Depression volume and slope degree selection for wetland correlates with the findings of Uuemaa et al. (2018), emphasizing the significance of natural depression and low angle slopes for effective water retention and movement. Additionally, the consideration of catchment areas linked to forest and agricultural lands reflects Qui et al.’s (2020) strategic approach of guaranteeing regular water source for wetland sustainability.

The identification of former wetland area in the Smedsedevägen as a suitable location wetland restoration is validated by several criteria, such as historical land use change, depression volume, runnoff risk proportion and catchment area composition. This is in line with the presented arguments put forward by Maleki et al., (2016) which emphasizes focusing on spatial conservation application by using satellite imagery and geographical information systems for identifying areas where special protection measures are required in several wetland development stages. The potential for wetland restoration is evident in the 1949 aerial image, with a significant depression volume, downstream runoff risk and catchment area characteristics.

Finally, the availability of land is another factor this study wants to note as a criteria that impacts wetland development. As noted by Xu et al., (2019), land availability plays an important role in wetland development. It is crucial that before any wetland development project, the ownership of land and valid laws and regulation should be taken into account.

The framework that was developed during this study incorporates a geospatial analysis and topographic assessment to provide valuable information and achieve the aim of this project in mapping suitable location for wetland development and restoration within the Western Uusimaa region of Finland. By aligning with and expanding upon previous research methodologies, this study contributes to the development of a growing set of knowledge aimed at addressing water quality problems and protecting key ecosystems for the future generations to come.

6. CONCLUSIONS AND RECOMMENDATIONS

In our pursuit of identifying potential wetland locations in the western Uusimaa region of Finland, I have applied a rigorous set of criteria to select sites that hold promise for addressing water quality issues. The geospatial analysis has unveiled several areas with favorable soil types, topographical features, and proximity to streams and runoffs, making them candidates for wetland development.

However, it is crucial to acknowledge the inherent uncertainties and limitations of such analyses. Real-world conditions may deviate from the geospatial data, the presence of streams or accumulated flow for example may be intermittent, especially outside periods of heavy rainfall, also as mentioned earlier, the soil type is an important factor when planning wetlands, but that data was omitted in our analysis due to a lack of sufficient soil data available for our study area. Therefore, recognizing the uncertainties and limitations in our analyses, particularly the omission of soil data due to insufficient information, I recommend enhancing future research. This involves conducting detailed soil surveys by employing various soil sampling techniques, engaging local expertise, and leveraging advanced technologies. This focused approach will refine wetland selection criteria, ensuring effective and sustainable development aligned with water quality improvement goals and broader environmental preservation objectives.

In conclusion, while I present these potential wetland locations as a valuable starting point, I emphasize the need for caution and thorough site-specific and land availability evaluations before proceeding with wetland construction. The effectiveness and sustainability of these wetlands hinge on the careful consideration of local realities and community involvement, ensuring that our efforts to improve water quality align with the broader goals of environmental preservation and community well-being.

References

Alikhani, S., Nummi, P. and Ojala, A., 2023. Modified, Ecologically Destructed, and Disappeared–History of Urban Wetlands in Helsinki Metropolitan Area. *Wetlands*, *43*(4), pp.33-40.

Almuktar, S. A., Abed, S. N., & Scholz, M. 2018. Wetlands for wastewater treatment and subsequent recycling of treated effluent: a review. *Environmental Science and Pollution Research*, *25*(24), 23595–23623. https://doi.org/10.1007/s11356-018-2629-3

Anderson, C.J. and Lockaby, B.G., 2011. Foliar nutrient dynamics in tidal and non-tidal freshwater forested wetlands. *Aquatic botany*, *95*(2), pp.153-160.

Craft, C., 2022. *Creating and restoring wetlands: from theory to practice*. Elsevier.

Daniel, J. and Rooney, R.C., 2021. Wetland hydroperiod predicts community structure, but not the magnitude of cross-community congruence. *Scientific Reports*, *11*(1), p.429.

Davis, C.L., Miller, D.A., Campbell Grant, E.H., Halstead, B.J., Kleeman, P.M., Walls, S.C. and Barichivich, W.J., 2019. Linking variability in climate to wetland habitat suitability: is it possible to forecast regional responses from simple climate measures?. *Wetlands Ecology and Management*, *27*, pp.39-53.

Ensign, S.H. and Noe, G.B., 2018. Tidal extension and sea-level rise: recommendations for a research agenda. *Frontiers in Ecology and the Environment*, *16*(1), pp.37-43.

European Commission, 2019. The EU Environmental Implementation Review 2019 Country Report: Finland, https://ec.europa.eu/environment/eir/pdf/report_fi_en.pdf. Accessed on 13th November, 2023.

Foti, R., del Jesus, M., Rinaldo, A. and Rodriguez-Iturbe, I., 2012. Hydroperiod regime controls the organization of plant species in wetlands. *Proceedings of the National Academy of Sciences*, *109*(48), pp.19596-19600.

Harenda, K.et.al. (2018). The Role of Peatlands and their Carbon Storage Function in the Context of Climate Change. *GeoPlanet: Earth and Planetary Sciences*.

Hammer, D.A., 2014. *Creating freshwater wetlands*. CRC Press.

Historical Aearial Photographs. Available at:

https://kartta.paikkatietoikkuna.fi/?zoomLevel=1&coord=525406_7159061&mapLayers=801+100+default,3400+100+ortokuva:indeksi&timeseries=1950&noSavedState=true&showIntro=false&lang=fi. Retrieved on 15th October 2023

Jalkanen, J., Toivonen, T. and Moilanen, A., 2020. Identification of ecological networks for land-use planning with spatial conservation prioritization. *Landscape Ecology*, *35*, pp.353-371.

Juvonen, S.K. and Kurikka, T., 2016. Finland's Ramsar Wetlands Action Plan 2016–2020.

Kalacska, M., Chmura, G.L., Lucanus, O., Bérubé, D. and Arroyo-Mora, J.P., 2017. Structure from motion will revolutionize analyses of tidal wetland landscapes. *Remote Sensing of Environment*, *199*, pp.14-24.

Knowles P., Griffin P., Davies P., 2010. A finite element approach to modeling the hydrological regime in horizontal subsurface flow constructed wetlands for wastewater treatment. ISBN 978-90-481-9585-5

Kingsford, R.T., Basset, A. and Jackson, L., 2016. Wetlands: conservation's poor cousins. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *26*(5), pp.892-916.

Kissel, A.M., Halabisky, M., Scherer, R.D., Ryan, M.E. and Hansen, E.C., 2020. Expanding wetland hydroperiod data via satellite imagery for ecological applications. *Frontiers in Ecology and the Environment*, *18*(8), pp.432-438.

Land cover Finland. Available at: https://livingatlas.arcgis.com/landcoverexplorer/#mapCenter=23.225%2C60.1%2C10&mode=step&timeExtent=2017%2C2022&year=2022&renderingRule=0. Retrieved on 12th October 2023.

Maleki, S., Soffianian, A.R., Koupaei, S.S., Saatchi, S., Pourmanafi, S. and Sheikholeslam, F., 2016. Habitat mapping as a tool for water birds conservation planning in an arid zone wetland: The case study Hamun wetland. *Ecological Engineering*, *95*, pp.594-603.

Mao, D., Wang, Z., Wu, J., Wu, B., Zeng, Y., Song, K., Yi, K. and Luo, L., 2018. China's wetlands loss to urban expansion. *Land degradation & development*, *29*(8), pp.2644-2657.

Medland, S.J., Shaker, R.R., Forsythe, K.W., Mackay, B.R. and Rybarczyk, G., 2020. A multi-criteria wetland suitability index for restoration across Ontario's mixedwood plains. *Sustainability*, *12*(23), p.9953.

Mitsch, W.J., Bernal, B., Nahlik, A.M., Mander, Ü., Zhang, L., Anderson, C.J., Jørgensen, S.E. and Brix, H., 2013. Wetlands, carbon, and climate change. *Landscape ecology*, *28*, pp.583-597.

Mitsch, W.J., Bernal, B. and Hernandez, M.E., 2015. Ecosystem services of wetlands. *International Journal of Biodiversity Science, Ecosystem Services & Management*, *11*(1), pp.1-4.

Mitsch, W.J., Gossenlink, J.G., 2000. Wetlands. *3rd edition. John Wiley*, New York.

Murray-Hudson, M., Wolski, P., Cassidy, L., Brown, M.T., Thito, K., Kashe, K. and Mosimanyana, E., 2015. Remote Sensing-derived hydroperiod as a predictor of floodplain vegetation composition. *Wetlands Ecology and Management*, *23*, pp.603-616.

Munoz, B., Lesser, V.M., Dorney, J.R. and Savage, R., 2009. A proposed methodology to determine accuracy of location and extent of geographically isolated wetlands. *Environmental monitoring and assessment*, *150*, pp.53-64.

National Land Survey of Finland. Downloadable spatial dataset. Available at: https://asiointi.maanmittauslaitos.fi/karttapaikka/?lang=en Retrieved on 15th October 2023.

Nummi, P. and Holopainen, S., 2020. Restoring wetland biodiversity using research: Whole-community facilitation by beaver as framework. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *30*(9), pp.1798-1802.

NRDC, 2023. Water Pollution: Everything You Need to Know. Report available at: https://www.nrdc.org/stories/water-pollution-everything-you-need-know#whatis. Accessed on 13th November, 2023.

Olszewska, D. 2005. Wetland planning in agricultural landscape using Geographical Information System: A case study of Lake Ringsjön basin in South Sweden. *Department and Division Department of Water and Environmental Studies 581 83 Linkoping*.

Ouyang, N.L., Lu, S.L., Wu, B.F., Zhu, J.J. and Wang, H., 2011. Wetland restoration suitability evaluation at the watershed scale-A case study in upstream of the Yongdinghe River. *Procedia Environmental Sciences*, *10*, pp.1926-1932.

Parde, D., Patwa, A., Shukla, A., Vijay, R., Killedar, D.J. and Kumar, R., 2021. A review of constructed wetland on type, treatment and technology of wastewater. *Environmental Technology & Innovation*, *21*, p.101261.

Samuelson, L., 2018. Water pollution data in the Baltic Sea basin: A local to regional approach. Article available at: https://siwi.org/publications/water-pollution-data-in-the-baltic-sea-basin-a-local-to-regional-approach/. Accessed on 13th November, 2023.

Sinha, R., Saxena, S. and Singh, M., 2017. Protocols for riverine wetland mapping and classification using remote sensing and GIS. *Current Science*, pp.1544-1552.

Sivertun Å., Prange L., 2003. Non-point source critical area analysis in the Gisselö watershed using GIS. Environmental Modelling & Software, 18(10), 887–898. https://doi.org/10.1016/S1364-8152(03)00107-5.

Snickars, M., Arnkil, A., Ekebom, J., Kurvinen, L., Nieminen, A., Norkko, A., Riihimäki, A., Taponen, T., Valanko, S., Viitasalo, M. and Westerbom, M., 2016. Assessment of the status of the zoobenthos in the coastal waters of western Uusimaa, SW Finland—a tool for management. *Nature Protection Publications of Metsähallitus Series A*, *224*, p.55.

Swan, C., 2019. The Wetlands-At-Risk Protection Tool: A five-step process to identify and protect wetland functions. Report available at: https://owl.cwp.org/mdocs-posts/the-wetlands-at-risk-protection-tool-a-five-step-process-to-identify-and-protect-wetland-functions/. Accessed on 13th November, 2023.

Syke. Finnish Environmental Institute. Available at: https://www.syke.fi/en-US/Open_information/Spatial_datasets/Downloadable_spatial_dataset. Retrieved 12th October 2023.

Trepel M., Palmeri L., 2002. Quantifying nitrogen retention in surface flow wetlands for environmental planning at the landscape scale. *Ecological Engineering 19: 127 – 140.*

Uuemaa, E., Hughes, A. O., & Tanner, C. C. 2018. Identifying feasible locations for wetland creation or restoration in catchments by suitability modelling using Light Detection and ranging (LIDAR) Digital Elevation Model (DEM). Report Avaialable at https://doi.org/10.3390/w10040464. Accessed on 15th October, 2023.

Qu, Y., Sun, G., Luo, C., Zeng, X., Zhang, H., Murray, N.J. and Xu, N., 2019. Identifying restoration priorities for wetlands based on historical distributions of biodiversity features and restoration suitability. *Journal of Environmental Management*, *231*, pp.1222-1231.

Qiu, Z., Luo, L., Mao, D., Du, B., Feng, K., Jia, M. and Wang, Z., 2020. Using Multisource Geospatial Data to Identify Potential Wetland Rehabilitation Areas: A Pilot Study in China's Sanjiang Plain. *Water*, *12*(9), p.2496.

Valk, A., 2012. *The biology of freshwater wetlands*. Oxford University Press.

Van Coppenolle, R. and Temmerman, S., 2019. A global exploration of tidal wetland creation for nature-based flood risk mitigation in coastal cities. *Estuarine, Coastal and Shelf Science*, *226*, p.106262.

Velmitskaya Maria., 2023. Risk map for the runoff of the total suspended solids and total phosphorus for Southwestern Finland. Available at https://www.theseus.fi/bitstream/handle/10024/804163/velmitskaya_maria.pdf?sequence=2&isAllowed=y. Accessed 11th December 2023.

Waly, M. M., Ahmed, T., Abunada, Z., Mickovski, S. B., & Thomson, C. (2022). Constructed Wetland for Sustainable and Low-Cost Wastewater Treatment: review article. *Land*, *11*(9), 1388. https://doi.org/10.3390/land11091388. Accessed on 15th November, 2023.

Widis, D.C., BenDor, T.K. and Deegan, M., 2015. Prioritizing wetland restoration sites: a review and application to a large-scale coastal restoration program. *Ecological Restoration*, *33*(4), pp.358-377.

Xu, T., Weng, B., Yan, D., Wang, K., Li, X., Bi, W., Li, M., Cheng, X. and Liu, Y., 2019. Wetlands of international importance: Status, threats, and future protection. *International Journal of Environmental Research and Public Health*, *16*(10), p.1818.

Xu, X., Lu, Z., Qiu, B. and Wang, H., 2019. Suitability evaluation of functional layout of National Urban Wetland Park in Jiangsu Province. *Journal of Nanjing Forestry University*, *43*(6), p.152.

Zhu, P. and Gong, P., 2014. Suitability mapping of global wetland areas and validation with remotely sensed data. *Science China Earth Sciences*, *57*, pp.2283-2292.