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Identifying and mapping the different ecosystem services around Mosvatnet from the 1930s until present day

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Introduction

The ecosystem services concept encompasses the wide array of advantages that humans gain from ecosystems, categorized into four primary types: provisioning, regulating, cultural, and supporting services (Simpson et al., 2023). These categories are crucial for sustaining life on Earth and improving human well-being. Provisioning services are the tangible resources obtained from ecosystems, such as food, water, timber, fiber, and medicinal plants, which are vital for fulfilling basic human needs and supporting sectors like agriculture, forestry, and pharmaceuticals. For instance, forests supply timber for construction and paper, while fisheries offer seafood for consumption. Regulating services are concerned with the control of ecosystem processes essential for maintaining environmental equilibrium, including climate regulation, water purification, flood control, and pollination. Forests, wetlands, and oceans play pivotal roles in regulating the Earth's climate by absorbing carbon dioxide and releasing oxygen. Wetlands act as natural filters, purifying water by trapping pollutants and excess nutrients. Ecosystems like mangroves and coral reefs serve as natural barriers, protecting coastal areas from storm surges and erosion.

Supporting services are the fundamental processes that sustain all other ecosystem services, including nutrient cycling, soil formation, and primary production (Manea et al., 2019). Nutrient cycling involves the recycling of essential elements like carbon, nitrogen, and phosphorus through biological and geological processes. Soil formation is facilitated by the decomposition of organic matter and the weathering of rocks, creating the soil necessary for plant growth. Primary production, driven by photosynthesis, forms the basis of food webs and supports the entire ecosystem (Kim & Kim, 2021). Ecosystem services are indispensable for human well-being and economic prosperity, significantly contributing to food security. Agricultural ecosystems supply most of the world's food, while natural ecosystems support wild fisheries and provide wild foods like fruits, nuts, and game. These services also play a vital role in supporting livelihoods and economies, especially in rural and coastal communities. Many people depend directly on ecosystem services for their livelihoods, including farmers, fishermen, and indigenous communities. Industries such as tourism and recreation also rely on intact ecosystems to attract visitors and generate revenue (Power, 2010)

Moreover, ecosystem services contribute to environmental sustainability by maintaining biodiversity and ecosystem resilience (Z. Li et al., 2023). Biodiversity is crucial for ecosystem functioning, as diverse ecosystems are more resilient to disturbances and better equipped to adapt to changing environmental conditions. Therefore, protecting and restoring ecosystems is essential for ensuring the long-term provision of ecosystem services and safeguarding the planet's health (Ma et al., 2024).

Table 1 showcases various ecosystem services in Norway across different categories and their respective sub-services. The diversity of services reflects the complexity of managing ecosystems and the potential for non-consensus among stakeholders. While some services, like fisheries and timber production, may have broad consensus for their importance; others, such as oil and gas production and biodiversity conservation, may elicit differing opinions and priorities. This highlights the need for interdisciplinary approaches to ecosystem management and policy development, considering diverse perspectives and trade-offs. Focusing on provisioning, regulating, and cultural services, insights can be drawn from the provided sources. The table categorizes these services into subservices (Skre, 2017).

Table 1: Various ecosystem services in Norway across different categories and their respective sub-services

Category	Subservice	Skre, 2017
Provisioning	Ecologically sustainable food production	x
Provisioning	Raw materials and fibers	x
Provisioning	Genetic resources	x
Regulating	Carbon absorption and storage	x
Regulating	Greenhouse gas absorption or emission	x
Regulating	Water flow regulation (flood control, surface water management)	x
Regulating	Erosion protection	x
Regulating	Natural disaster prevention	x
Regulating	Pest control and biological control	x
Cultural	Recreation	x
Cultural	Nature-based tourism	x
Cultural	Nature experiences	x
Cultural	Local identity and natural heritage	x
Cultural	Accessibility	x

Mosvatnet Lake, nestled in the heart of Norway is a significant ecological and cultural landmark (Figure 1) with a surface area of 0.45 square kilometers, making it the third largest lake in the city after Hålandsvatnet and Stora Stokkavatnet. This area is known for its serene beauty and biodiversity. The lake's geographical location, surrounded by a variety of landscapes including mountains, forests, and agricultural fields, makes it a unique case study for understanding the impact of human activities on ecosystems. The study also highlights the decline of vegetation cover including grazing lands, with significant fluctuations in the trends of cultivated and settlement land cover. These changes are attributed to population pressure and associated demand, which are the main causes behind the land use-land cover (LULC) changes in the study area.

The study aims to analyze the evolution of ecological services around Mosvatnet Lake from 1937 to 2023, spanning over 86 years. This period encompasses significant changes in land use, including the development of built-up areas, changes in vegetation cover, and alterations in waterbody characteristics. The years selected, 1937, 1960, 1973, 1999, 2009, 2011, 2014, 2015, 2016, 2018, and 2023, for this study are particularly noteworthy as they represent key milestones in the area's development and environmental management.

Figure 1: Mosvatnet is a lake in Stavanger, Norway – Author, 2024.

The study will utilize historical data, including aerial photographs, satellite imagery and field surveys, to identify and quantify changes in the area's land use and cover. By comparing these data sets across the selected years, the study aims to assess the impact of various factors, such as urbanization, agricultural practices, and natural processes, on the ecological services provided by Mosvatnet Lake. This analysis will contribute to a deeper understanding of the lakes and their surrounding ecological health and the effectiveness of conservation efforts in the region.

Around Mosvatnet Lake, ecosystem services such as water purification, carbon sequestration, and biodiversity support are crucial. However, the previous studies (Belle & Goedkoop, 2021; Ozersky et al., 2021; Sharma et al., 2018) have not specifically addressed Mosvatnet Lake, but focus instead on broader climate change impacts on lakes globally. These impacts include reduced ice cover, increased surface water temperatures, and altered mixing regimes, which can lead to ecological consequences like "greening" and "browning" of lakes (Finstad et al., 2016; Meyer-Jacob et al., 2019) . Climate change-induced increases in precipitation and reduced solar ultraviolet radiation inactivation of pathogens in surface waters (Williamson et al., 2017) are also noted. Factors influencing these changes include global warming, land use changes, and the feedback loop between water quality and ecosystem health. These changes highlight the importance of monitoring and managing lakes to preserve their ecosystem services and adapt to climate change (Lyche Solheim et al., 2024).

Research Questions

The study of the ecosystem services from the 1930s until the present day around Mosvatnet is guided by the following research questions:

I. What ecosystem services are present around Mosvatnet Lake?

II. How have these services changed over time?

III. What factors have influenced these changes?

Literature Review

Ecosystem services are present around Mosvatnet Lake

Deeksha & Shukla (2022) provide a foundational overview of the critical role freshwater ecosystems play in supporting human well-being and environmental sustainability. The study underscores the importance of these ecosystems in providing provisioning, regulating, supporting, and cultural services. It also highlights the future challenges and opportunities in managing and enhancing these services, particularly in the context of climate change and increasing human demands.

Booi et al. (2022) offer insights into the provisioning and cultural services of estuaries, which are closely related to the services provided by freshwater ecosystems like Mosvatnet Lake. The review discusses the significance of these services in supporting biodiversity, water quality, and recreational activities. It also identifies the threats and challenges these ecosystems face, including pollution, sedimentation, and climate change impacts, which are relevant to the context of Mosvatnet Lake.

Mengist et al. (2020) and Palomo-Campesino et al. (2018) provide a broader perspective on ecosystem services research, emphasizing the importance of integrating ecological and socio-economic considerations. These studies highlight the need for interdisciplinary approaches to address the complex challenges and opportunities associated with ecosystem services.

Himes-Cornell et al. (2018) induce valuable case studies on the valuation of specific ecosystem services, which can inform the assessment of services around Mosvatnet Lake. These studies demonstrate the importance of quantifying the value of ecosystem services for decision-making and conservation planning.

Culhane et al. (2019) underscore the critical role of aquatic ecosystems in providing essential ecosystem services and the risks they face from various environmental and human-induced factors. They highlight the need for comprehensive research, policy interventions, and community engagement to manage these risks and ensure the sustainable provision of ecosystem services in aquatic ecosystems. Also, Elmqvist et al. (2015) highlight the importance of urban green spaces in mitigating urbanization’s negative impacts, such as heat islands and greenhouse gas emissions. They discuss the environmental, social, and economic benefits of restoring ecosystem services in urban areas, advocating for their integration into urban planning for sustainable development.

Future challenges and opportunities of ecosystem services

The incorporation of ecosystem services information into quality decision-making is beneficial for solving challenges like environmental degradation, climate change and poverty (Xu & Peng, 2022). Some of the feasible ways in which the maximization and harnessing of ecosystem services benefits in the future are innumerable. One of them is green infrastructure development. Green infrastructure encompasses the steady human-modified and native forests. It entails green space for urban, rural, saltwater, and river ecosystems (Ying et al., 2022). This will help to conserve natural resources and nature itself. Furthermore, green infrastructure provides a framework for environmental, economic, and social health of the surroundings (Zabel & Häusler, 2024).

Another existing opportunity for the ecosystem services is the ecotourism and sustainable recreation. These concepts refer to sustainability in traveling. This denotes traveling while minimizing the negative impacts on the culture, local communities, and the environment (Samal & Dash, 2023). Also, ecotourism involves visiting natural areas for learning purposes or to execute environmentally friendly activities (Beall et al., 2021). It enables the local communities' social and economic development. It also boosts community development through the provision of alternative livelihood sources with better sustainability (Dinç et al., 2023).

Moreover, education and public awareness is another vital opportunity for ecosystem services. This can be done through education and outreach campaigns. This would aid in enhancing appreciation and knowledge of ecosystem services. It is a valuable tool for conservation. There, however, exist several challenges to ecosystem services. These include habitat loss and degradation, climate change, pollution, diseases and invasive species, and the overexploitation of resources (Gregory et al., 2016). The environment is highly threatened by human activities. This results in the spread of invasive species, loss of habits, and biodiversity. Habitat loss can result in the decrease of interactions and species ranges. Extinction arises due to the fragmentation of the ecosystems.

On the other hand, climate is affecting the climate variability and the mean conditions therefore altering the ecosystems. This is coupled with associated dynamics such as augmented atmospheric carbon dioxide concentrations and also the acidification of oceans (Salmond et al., 2016). The transformation of the ecosystem will eventually result in a threat to biodiversity across the globe. This will also impact the global food production. The impacts of invasive species are usually classified as social, environmental, or economic. Invasive species often represent the greatest unquantified ecosystem services threat (Giakoumi et al., 2019). Invasive species such as herbivores can consume crops or damage agricultural land. Also, they can reduce the water infiltration potential resulting in increased soil erosion and floods.

Methodology

This thesis followed a 3-step approach to map and classify the ecosystem services around Mosvatnet Lake.

1. Select LULC applicable for study area and pair to ecosystem service
2. Digitize LULC at each time step for a set of aerial images
3. Analyse results

LULC Selection and Ecosystem Service Pairing

Choosing the classes of Built-Up, Waterbody, and Vegetation/Croplands for the land use and land cover (LULC) analysis around the Mosvatnet Lake was a deliberate decision aimed at understanding the intricate dynamics of ecological services in the vicinity of this crucial waterbody. Each of these classes holds paramount significance in assessing the ecological functions and services provided by the landscape surrounding Mosvatnet Lake.

Built-Up: The Built-Up class signifies areas that have undergone development or urbanization, potentially impacting the ecosystem services around Mosvatnet Lake. Monitoring changes in built areas is vital for evaluating the extent of human encroachment into the lake's watershed, which can affect water quality, biodiversity, and the overall health of the ecosystem. By analyzing the built areas, insights can be gained into the degree of urban sprawl, land use intensification, and associated environmental implications (Dadashpoor & Salarian, 2020; Han, 2020)

Waterbody: As the main waterbody in the region, Mosvatnet Lake plays a pivotal role in providing various ecological services. Monitoring changes in the waterbody class is essential for understanding the lake's hydrological dynamics, water quality, and overall ecosystem health (Nath et al., 2023). Assessing alterations in the lake's shoreline, water volume, and surrounding wetlands can reveal the impacts of human activities and natural processes on the lake's ecological integrity (F. Li et al., 2019). Understanding these changes is crucial for effective water resource management, biodiversity conservation, and recreational opportunities associated with the lake (Chen et al., 2023)

Vegetation/Croplands: The Vegetation/Croplands class encompasses the natural vegetation and agricultural areas surrounding Mosvatnet Lake, which contribute significantly to its ecosystem services. Monitoring changes in Vegetation/Croplands provides insights into land use practices, habitat availability for wildlife, carbon sequestration, and soil conservation efforts (Almalki et al., 2022). Assessing shifts in vegetation cover, such as deforestation or afforestation, and changes in cropland extent can help evaluate the overall health and resilience of the landscape surrounding the lake (Aldiansyah et al., 2021).

By focusing on these three classes, the LULC analysis can elucidate the interconnectedness between land use changes and the provision of ecosystem services around Mosvatnet Lake. Understanding the spatial distribution and temporal dynamics of Built-Up, Waterbody, and Vegetation/Croplands facilitates informed decision-making for sustainable land management, conservation initiatives, and ecosystem restoration efforts in the lake's watershed area (Llambí et al., 2019).

LULC Digitization

LULC Digitization followed a three-step process. Eleven-time steps were selected between 1937 and 2023 based on aerial imagery availability and documented changes.

I. **Aerial Imagery:** Aerial images for the years 1937 to 2023 were collected from a national database (norgeibilder.no) and imported into ArcGIS Pro, focusing on the area surrounding Mosvatnet Lake. Aerial imageries were downloaded with a spatial resolution of 0.5 m in the UTM33 coordinate reference system.

II. **LULC Digitization:** The three LULC classes (Built-Up, Waterbody, Vegetation/Croplands) were digitized from the aerial images at each time step using ArcGIS Pro. A consistent extent around the vicinity of Mosvatnet Lake was used. Maps were produced for each time step to visualize the spatial distribution of digitized LULC features and aerial imagery.

III. **LULC Area Change:** The area of each LULC class was calculated for each time step. Bar graph charts were generated for each year to visually represent the changes in the area covered by Built-Up, Waterbody, and Vegetation/Croplands around Mosvatnet Lake. These bar graphs provided a comparative analysis of land use dynamics and their implications for ecological services provision over the study period. The changes in LULC document their significance for ecosystem services assessment.

Interpretation and Analysis

The maps, charts, and associated data were investigated to identify trends and patterns in LULC changes and their impacts on ecosystem services around Mosvatnet Lake. Insights were drawn regarding the relationship between Built-up, Waterbody, and Vegetation/Croplands dynamics and the provision of ecological services, such as water purification, habitat provisioning, and recreational opportunities.

Through this exhaustive approach, the LULC analysis provided valuable insights into the importance of ecological services around Mosvatnet Lake. By examining changes in Built-up, Waterbody, and Vegetation/Croplands over time, decision-makers can devise strategies for sustainable land management, conservation planning, and ecosystem restoration tailored to preserve and enhance the ecological integrity of the lake and its surrounding landscape. The layout maps provide a comprehensive way to analyze and visualize changes in land use, land cover, or any other temporal data, offering valuable insights into trends and patterns over time. Moreover, the chart tool was used to create a bar graph that visualizes the distribution of LULC areas across 11 different years. This is achieved by utilizing the bar chart feature, which is designed to summarize and compare categorical vectorized data using proportional bar lengths to represent values. The x-axis of the bar chart represents discrete categories, which in this case would be different years (1937 to 2023), and each bar's height corresponds to the raw or aggregated area calculated for each category, indicating the area of LULC for each year. All of the data and results are available at: https://zenodo.org/doi/10.5281/zenodo.11198747

Results

Figures 2 – 12 show the time series from 1937 to 2023 with the digitized LULC and aerial imagery. For each time step, the three LULC areas are calculated and represented by bar charts. The detected changes in area for each LULC are shown in Figures 13-15.

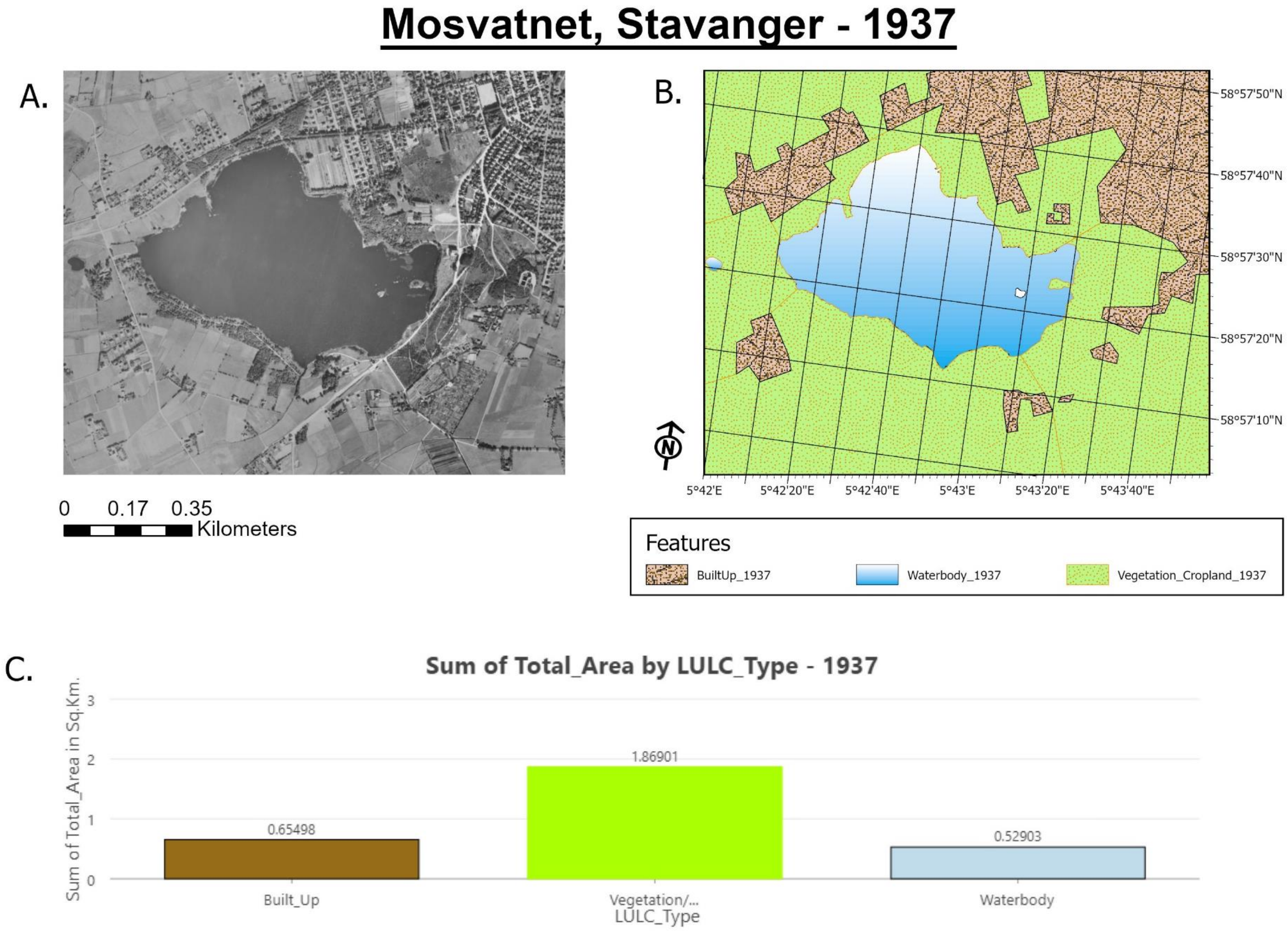

Figure 2: Mosvatnet 1937. A. Aerial photo (norgeibilder.no). B. Digitized Land-use and Land-cover – Author, 2024. C. Calculated area for each LULC – Author, 2024.

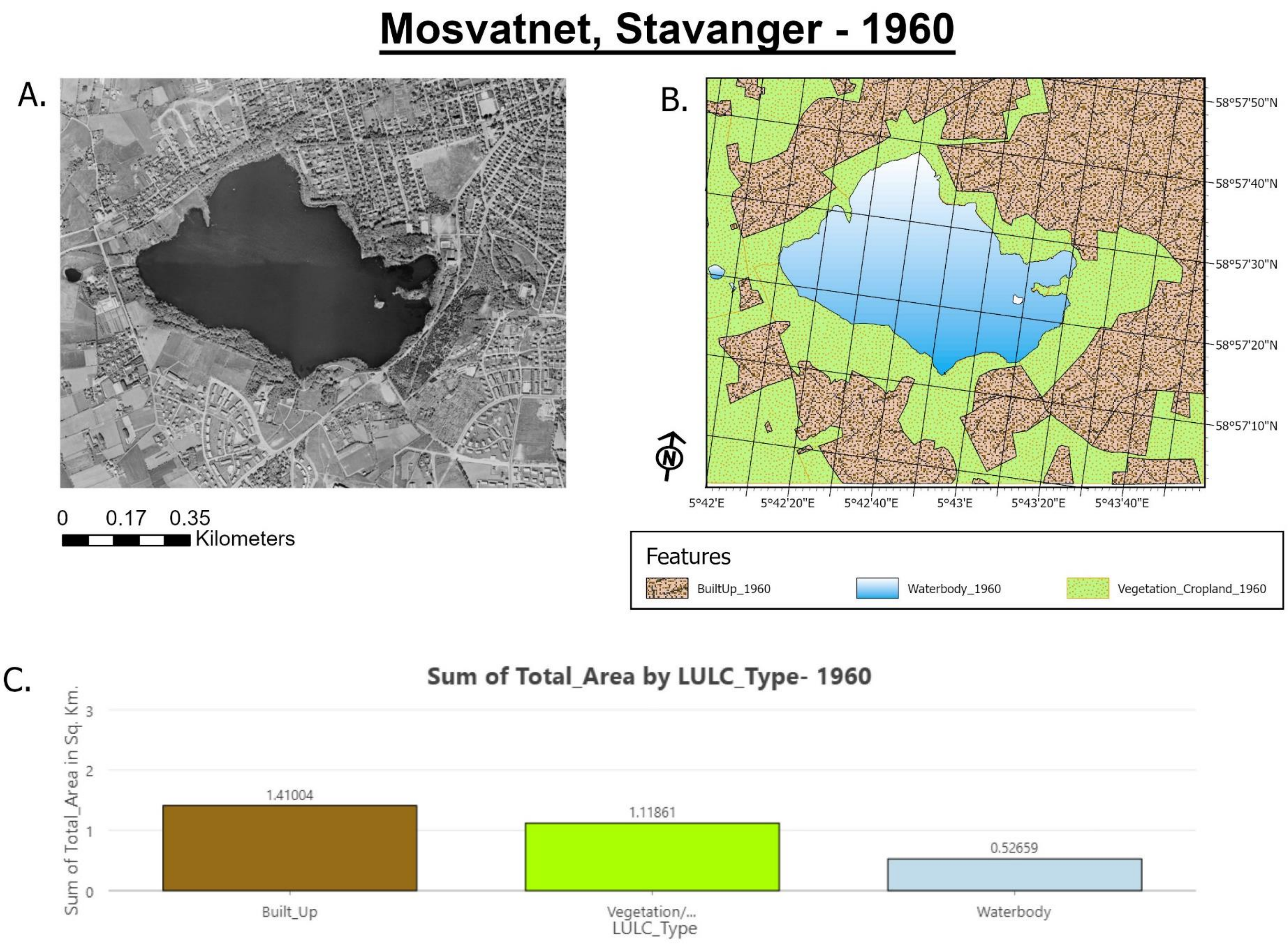

Figure 3: Mosvatnet 1960. A. Aerial photo (norgeibilder.no). B. Digitized Land-use and Land-cover – Author, 2024. C. Calculated area for each LULC – Author, 2024.

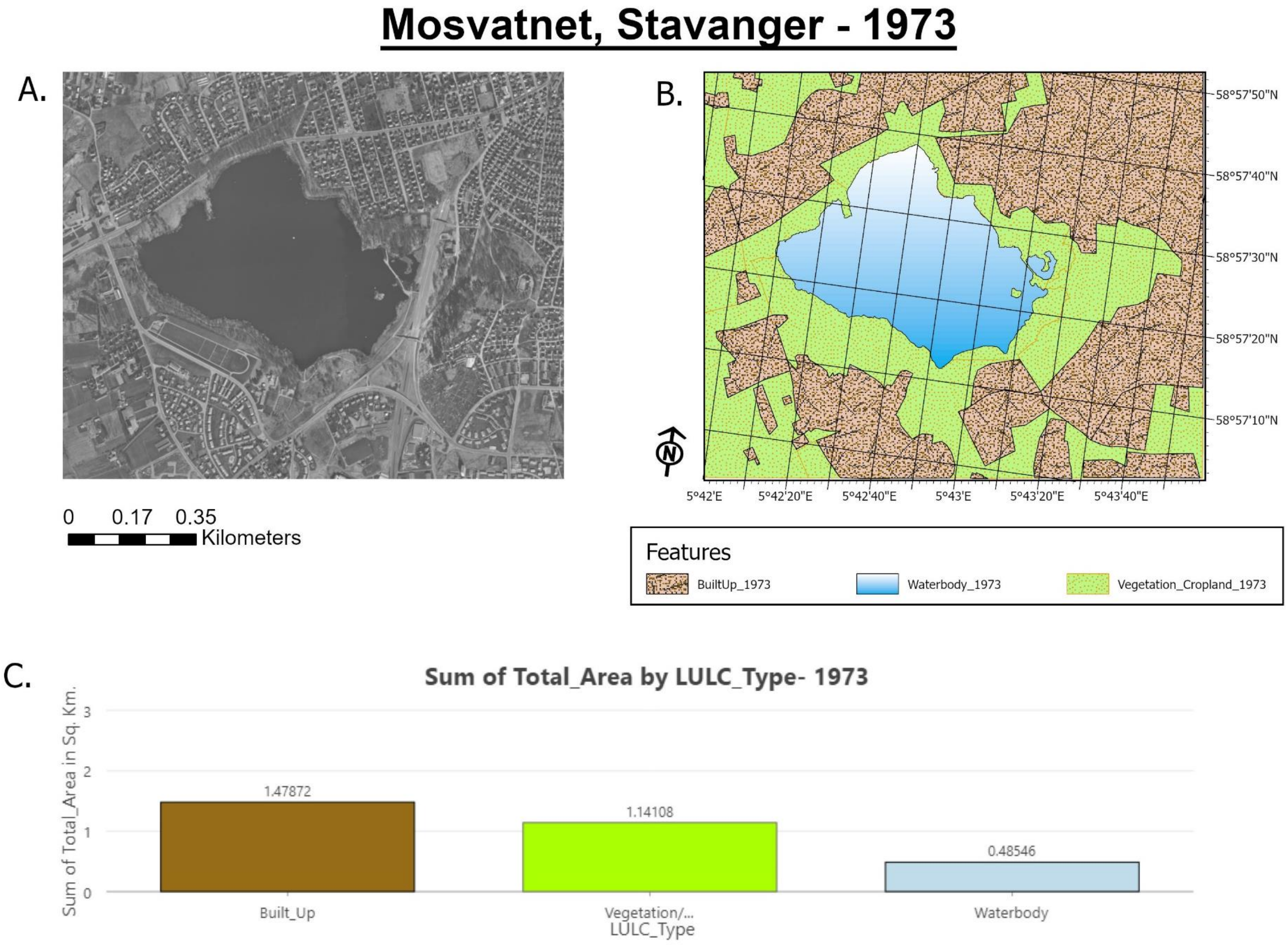

Figure 4: Mosvatnet 1973. A. Aerial photo (norgeibilder.no). B. Digitized Land-use and Land-cover – Author, 2024. C. Calculated area for each LULC – Author, 2024.

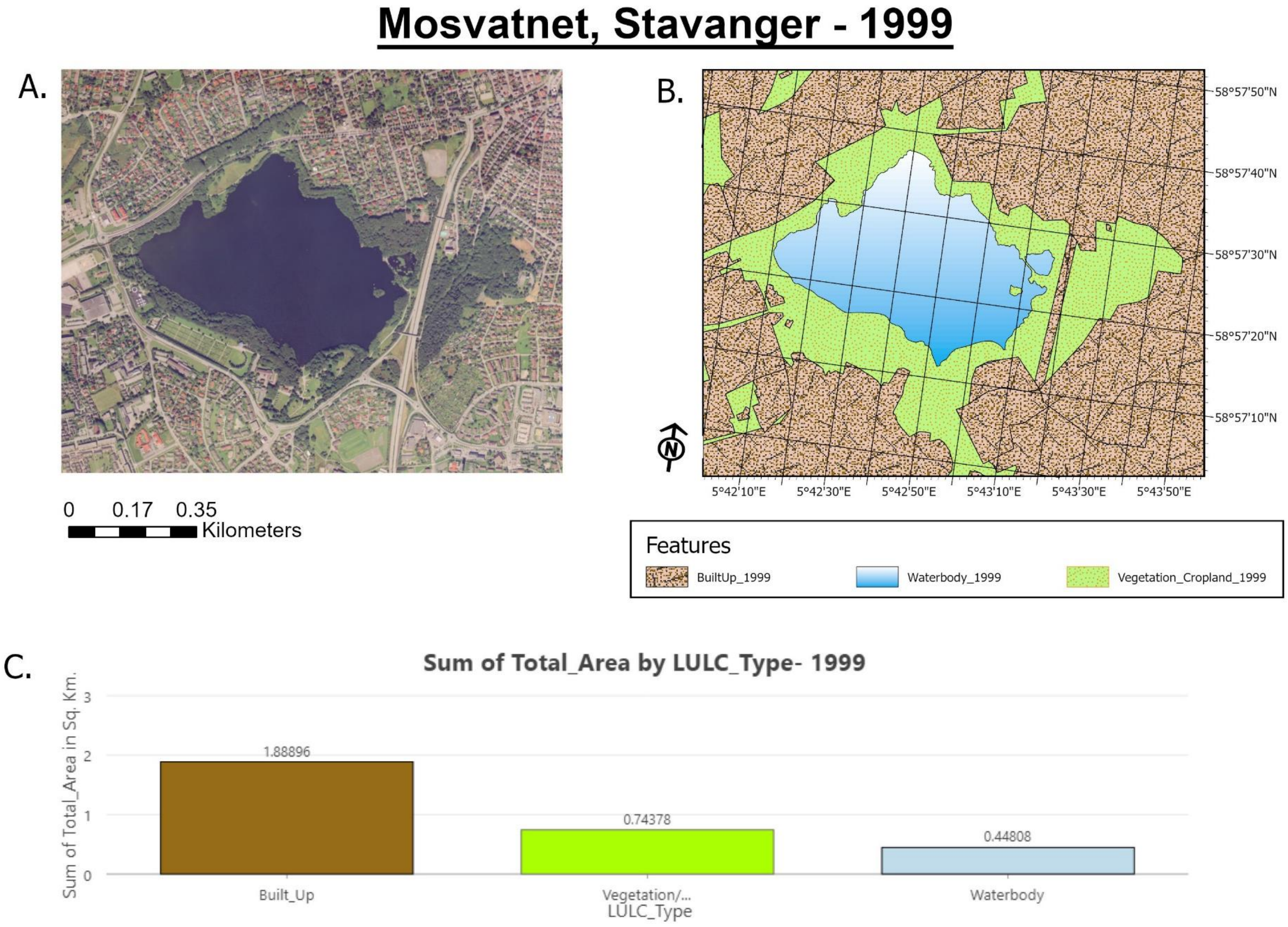

Figure 5: Mosvatnet 1999. A. Aerial photo (norgeibilder.no). B. Digitized Land-use and Land-cover – Author, 2024. C. Calculated area for each LULC – Author, 2024.

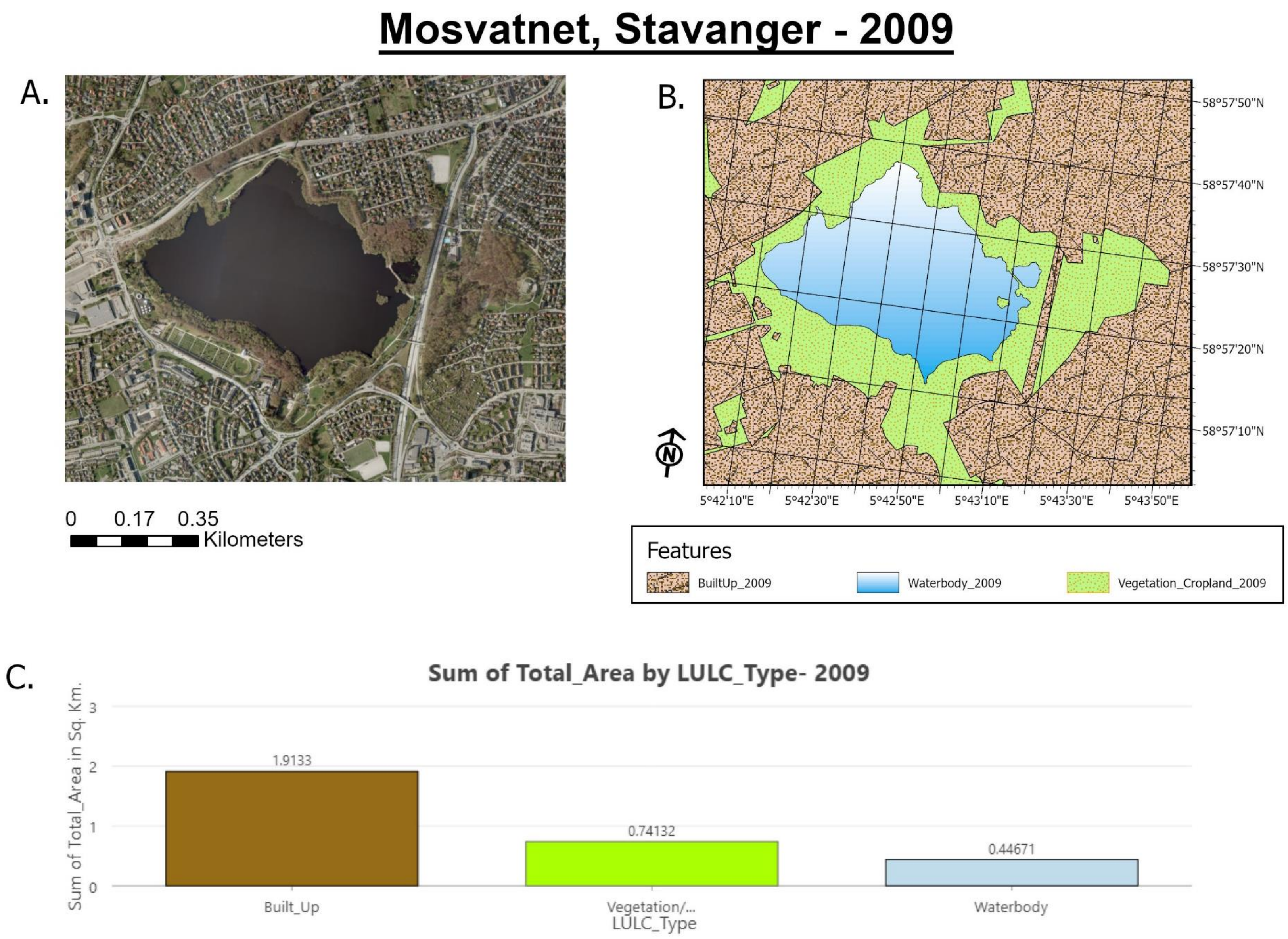

Figure 6: Mosvatnet 2009. A. Aerial photo (norgeibilder.no). B. Digitized Land-use and Land-cover – Author, 2024. C. Calculated area for each LULC – Author, 2024.

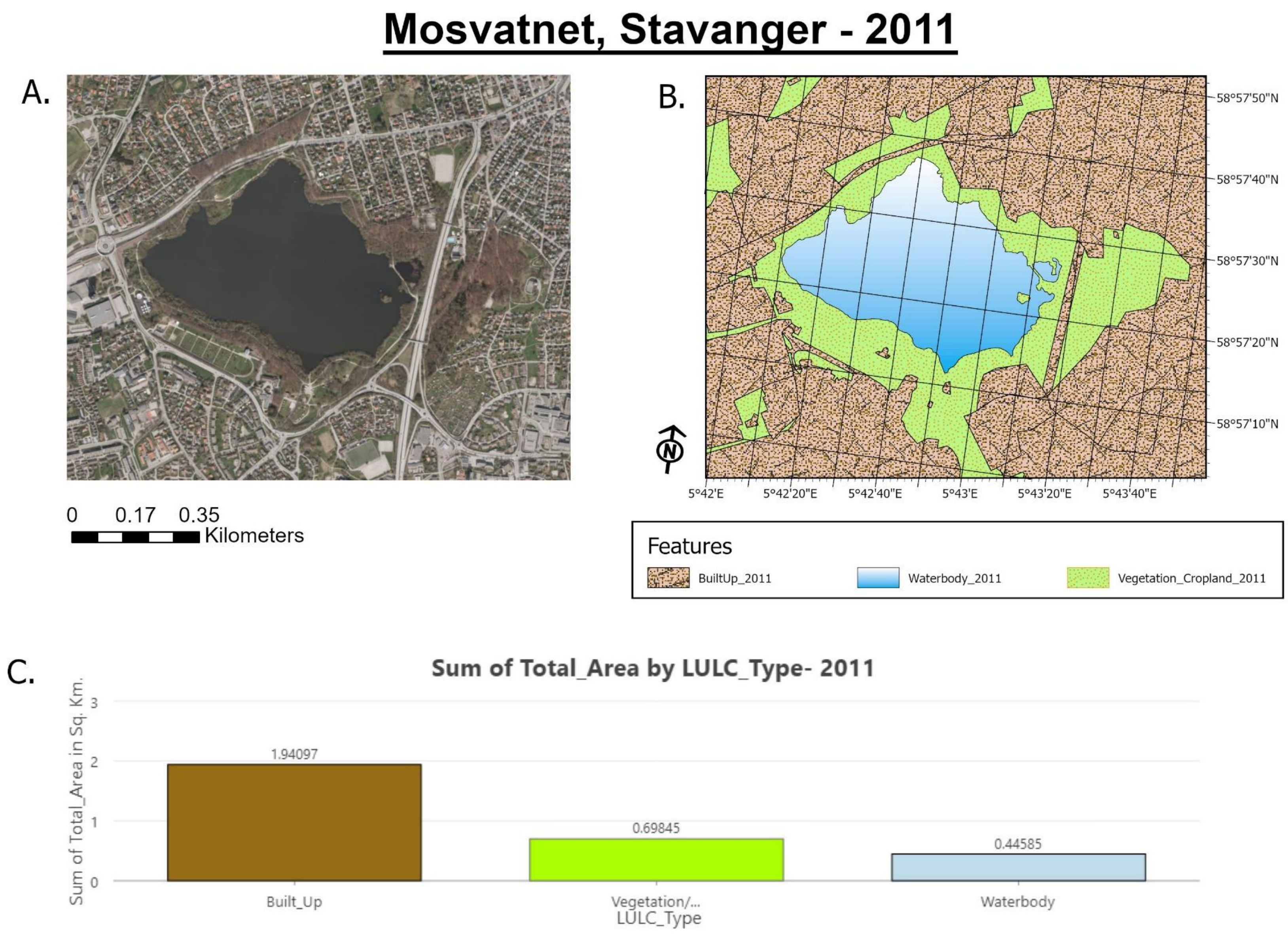

Figure 7: Mosvatnet 2011. A. Aerial photo (norgeibilder.no). B. Digitized Land-use and Land-cover – Author, 2024. C. Calculated area for each LULC – Author, 2024.

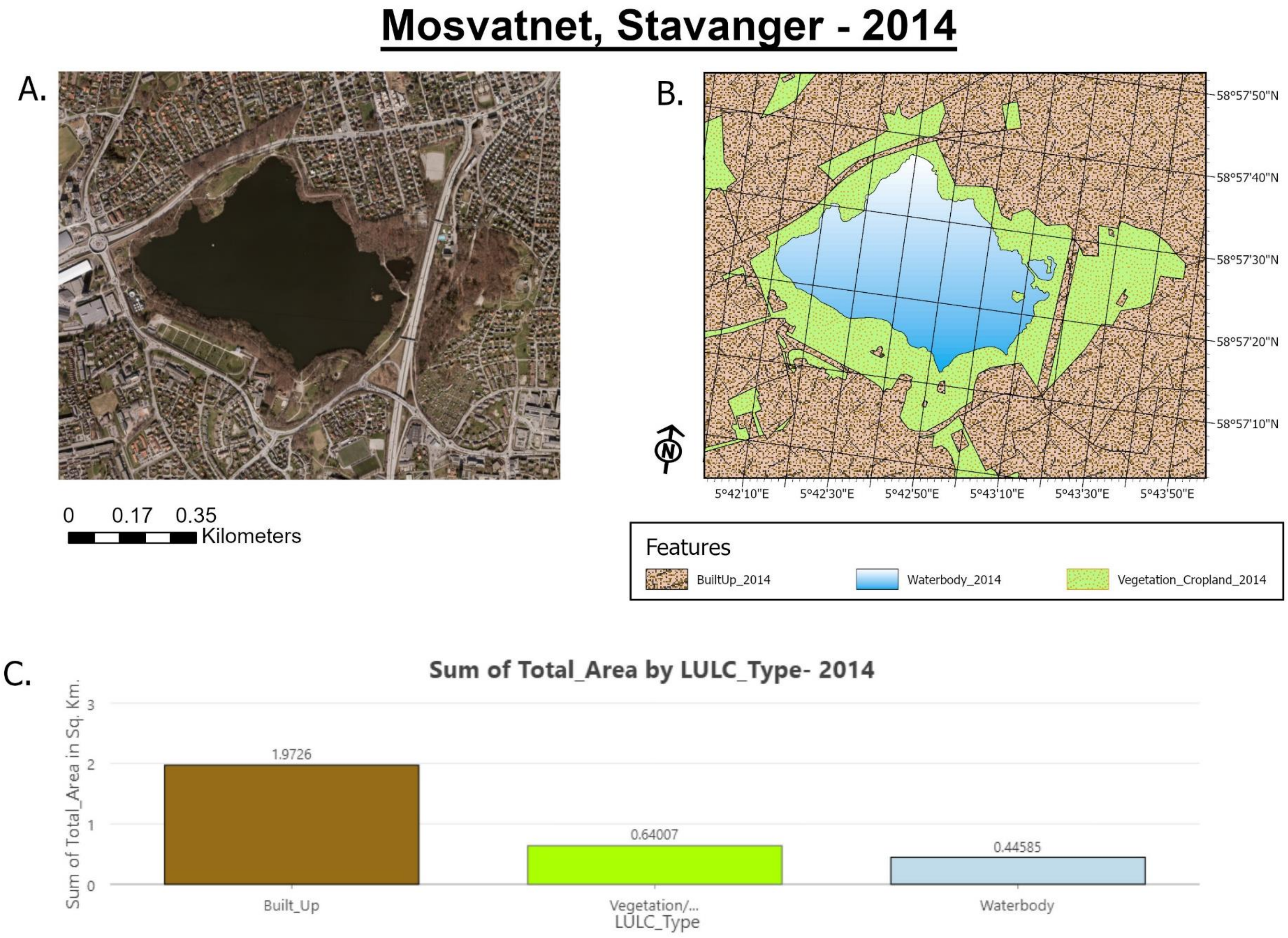

Figure 8: Mosvatnet 2014. A. Aerial photo (norgeibilder.no). B. Digitized Land-use and Land-cover – Author, 2024. C. Calculated area for each LULC – Author, 2024.

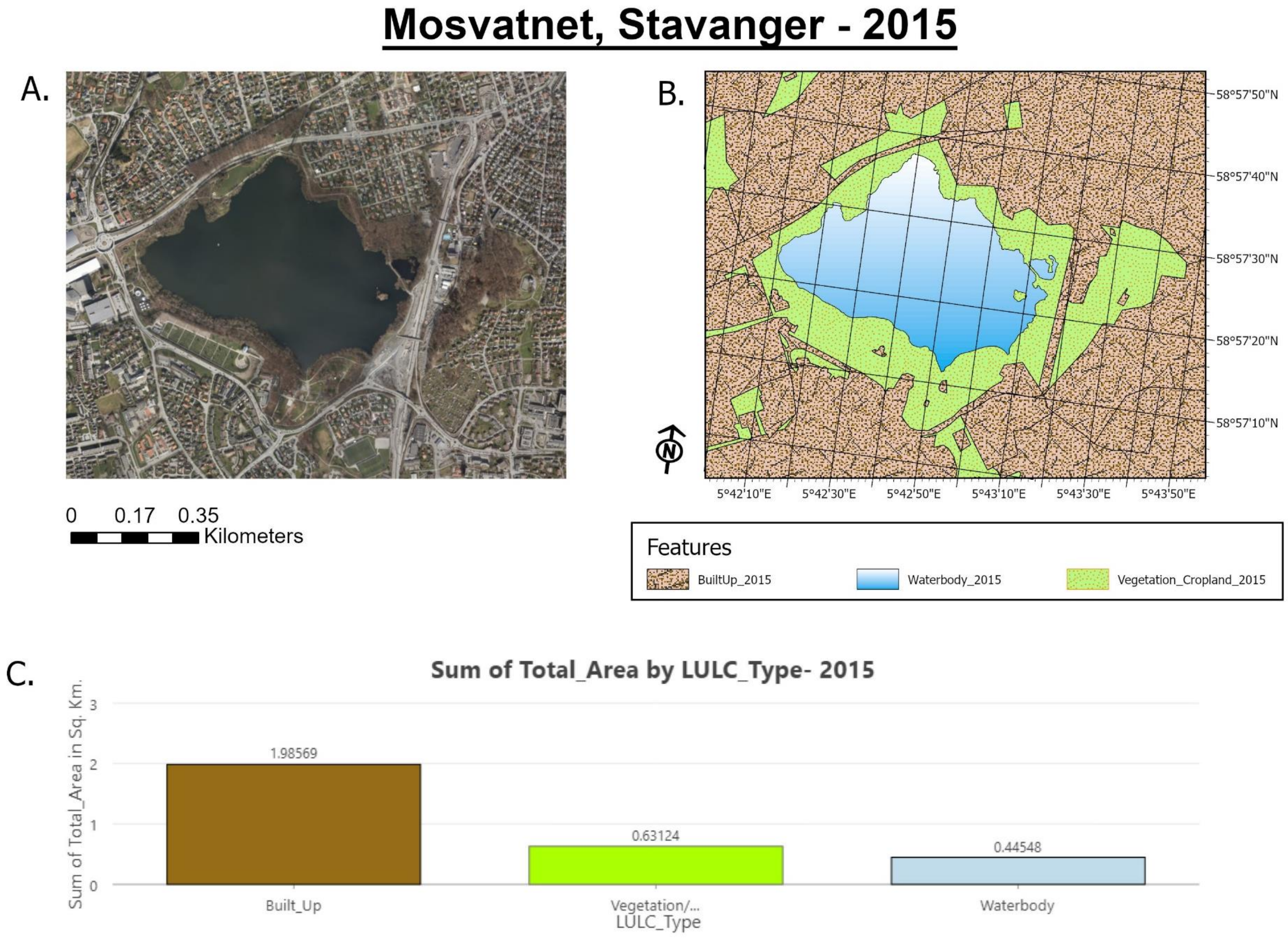

Figure 9: Mosvatnet 2015. A. Aerial photo (norgeibilder.no). B. Digitized Land-use and Land-cover – Author, 2024. C. Calculated area for each LULC – Author, 2024.

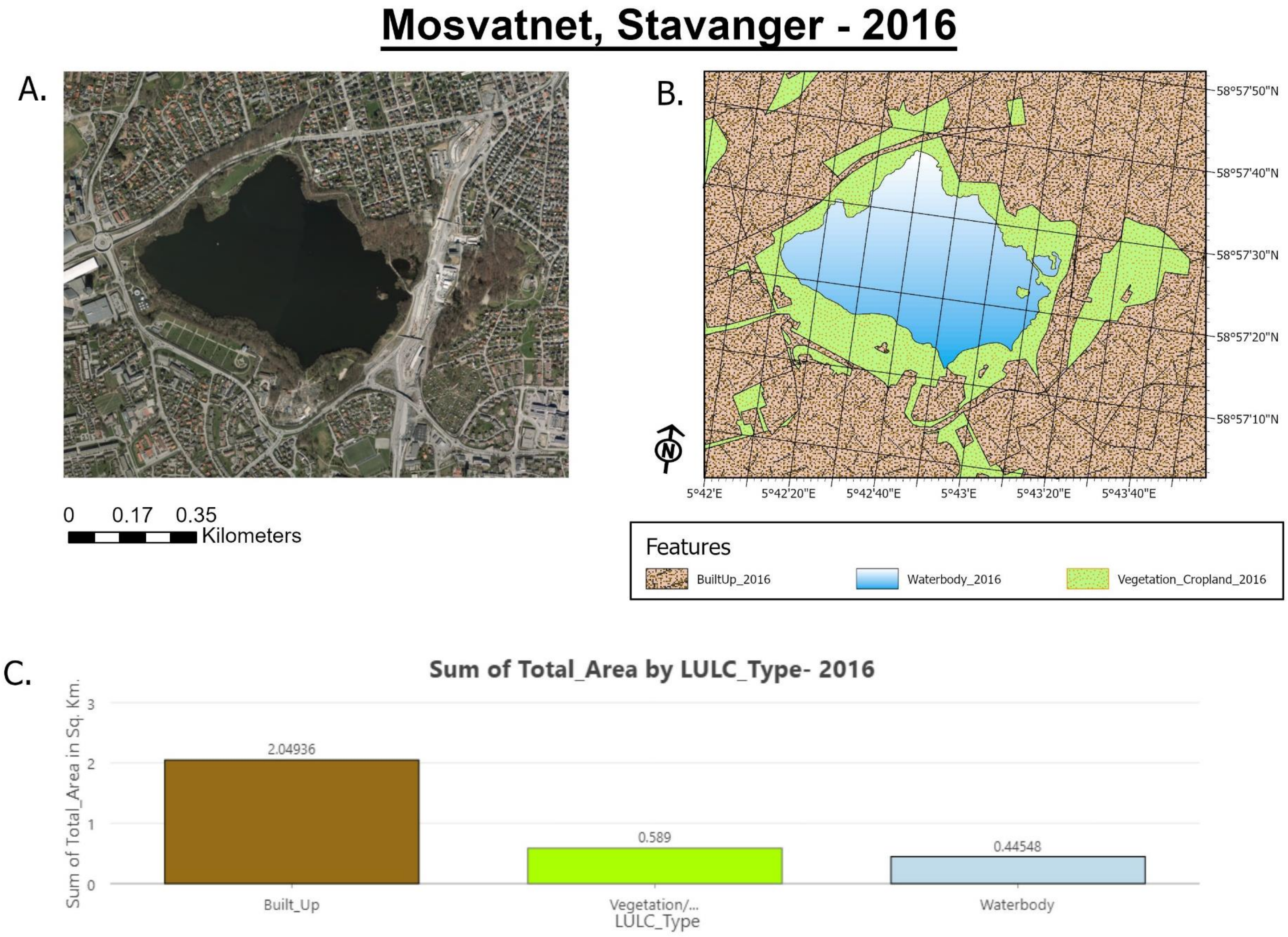

Figure 10: Mosvatnet 2016. A. Aerial photo (norgeibilder.no). B. Digitized Land-use and Land-cover – Author, 2024. C. Calculated area for each LULC – Author, 2024.

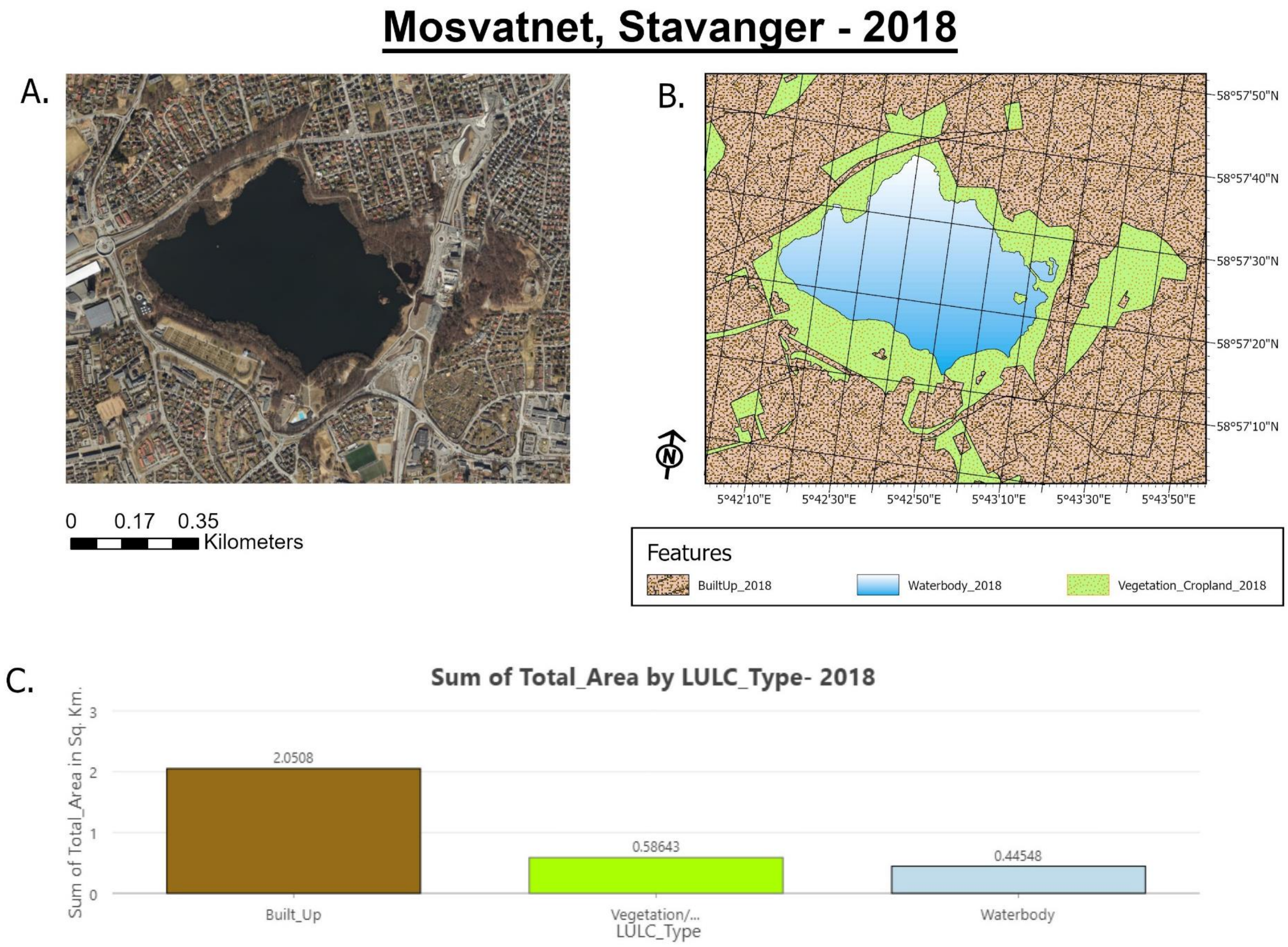

Figure 11: Mosvatnet 2018. A. Aerial photo (norgeibilder.no). B. Digitized Land-use and Land-cover – Author, 2024. C. Calculated area for each LULC – Author, 2024.

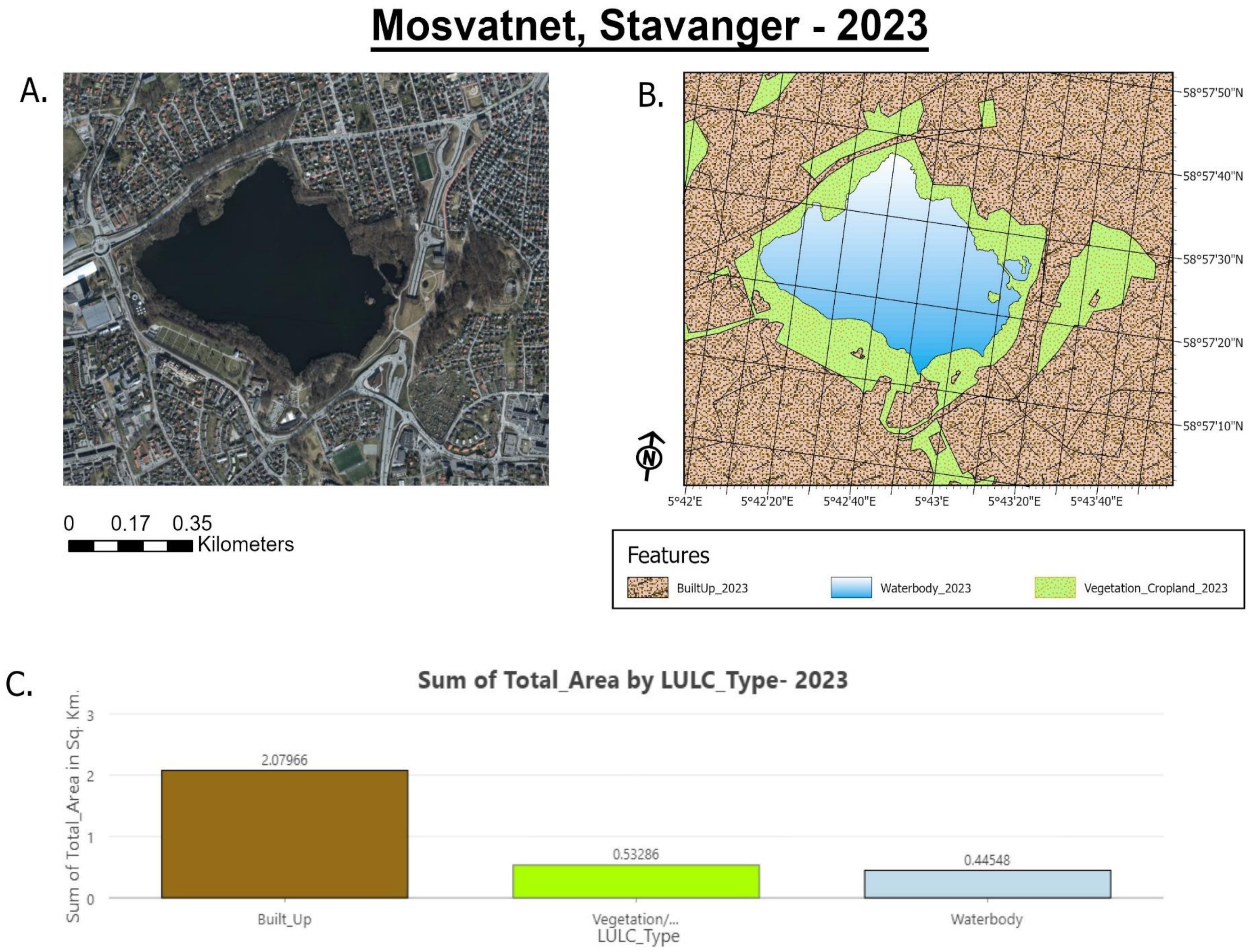

Figure 12: Mosvatnet 2023. A. Aerial photo (norgeibilder.no). B. Digitized Land-use and Land-cover – Author, 2024. C. Calculated area for each LULC – Author, 2024.

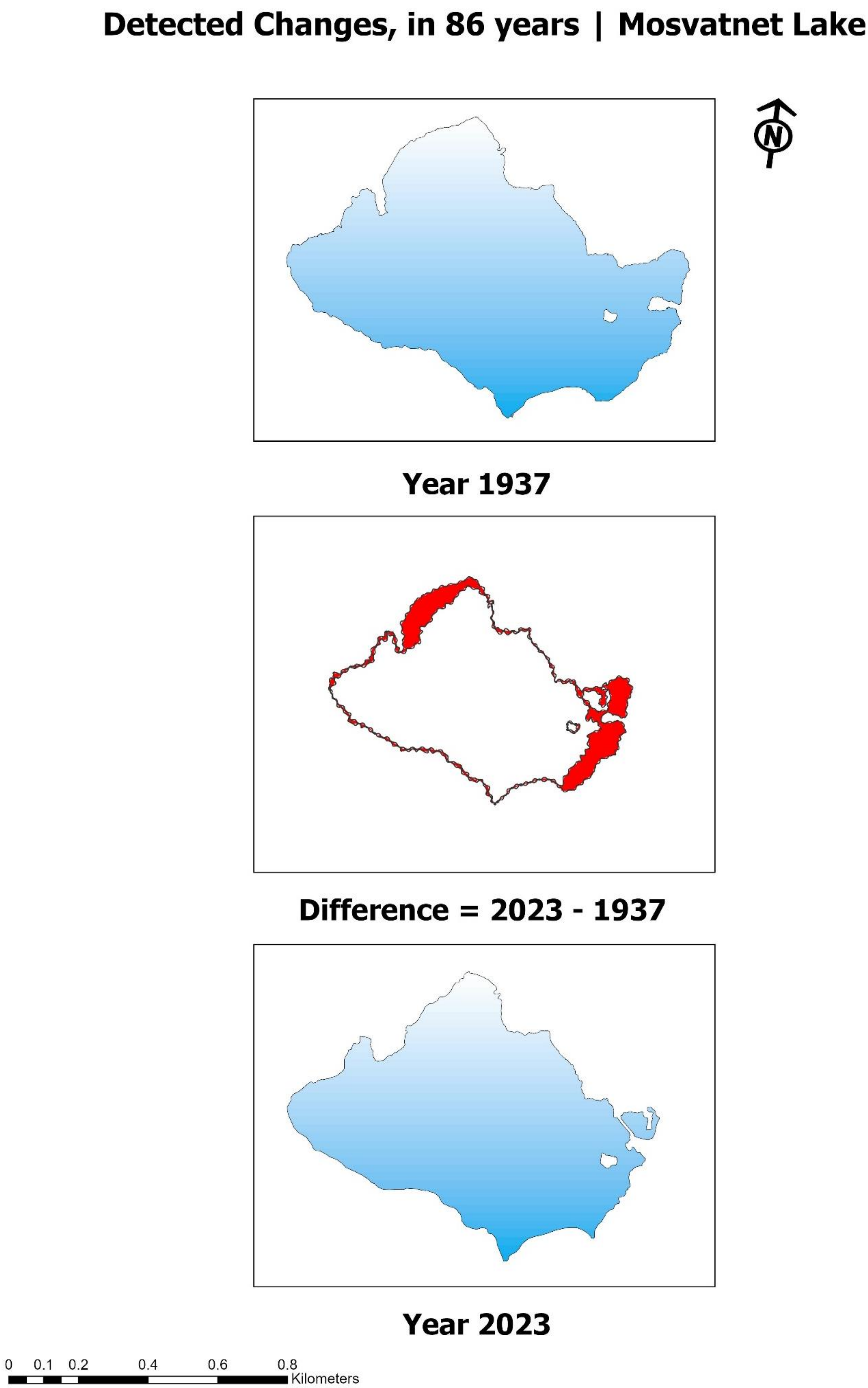

Figure 13: Mosvatnet Waterbody Detected Changes, 1937 – 2023. Red areas represent the reclaimed area.

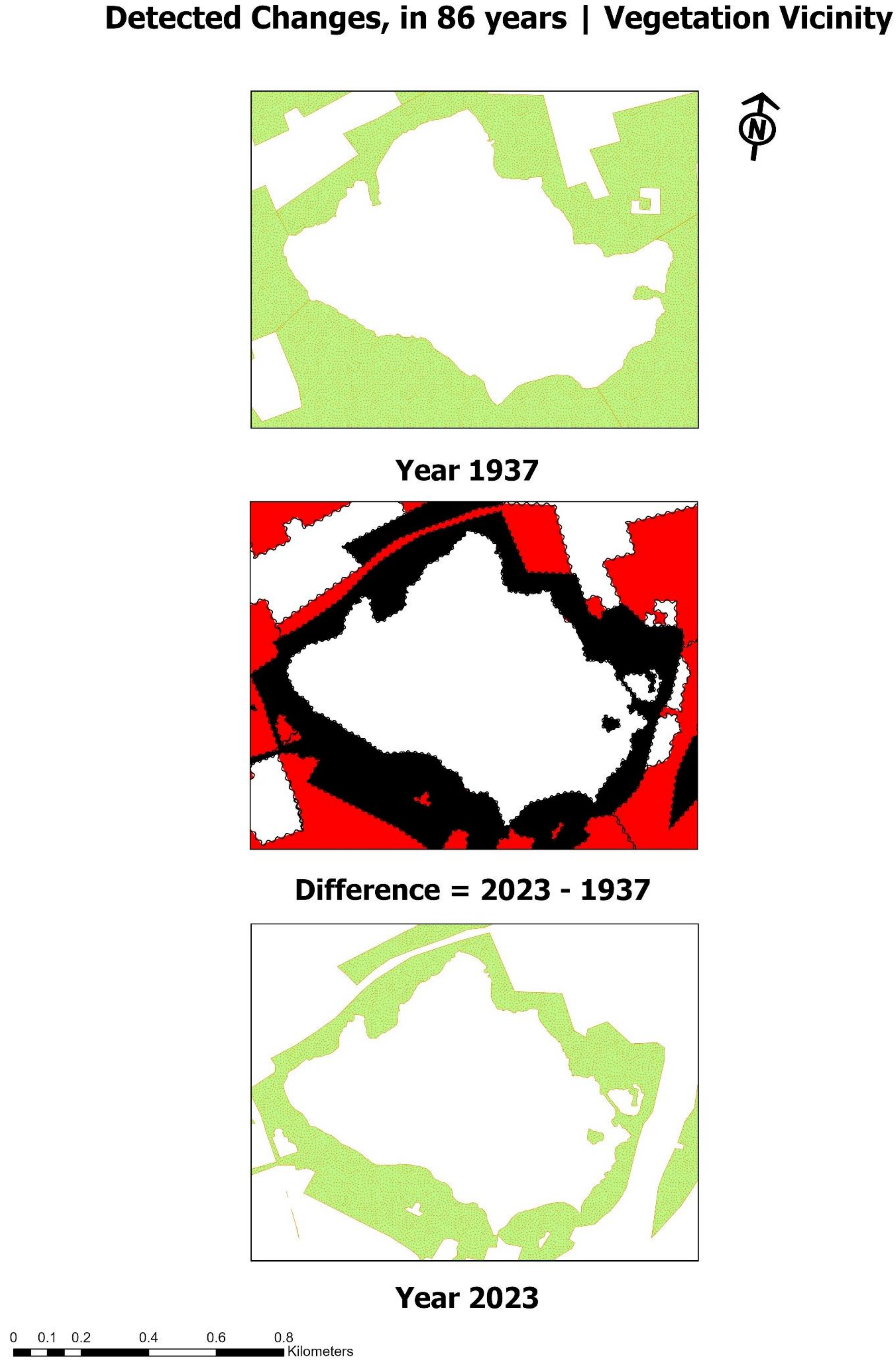

Figure 14: Mosvatnet Vegetation/Croplands Detected Changes, 1937 – 2023. Red areas represent the reclaimed area.

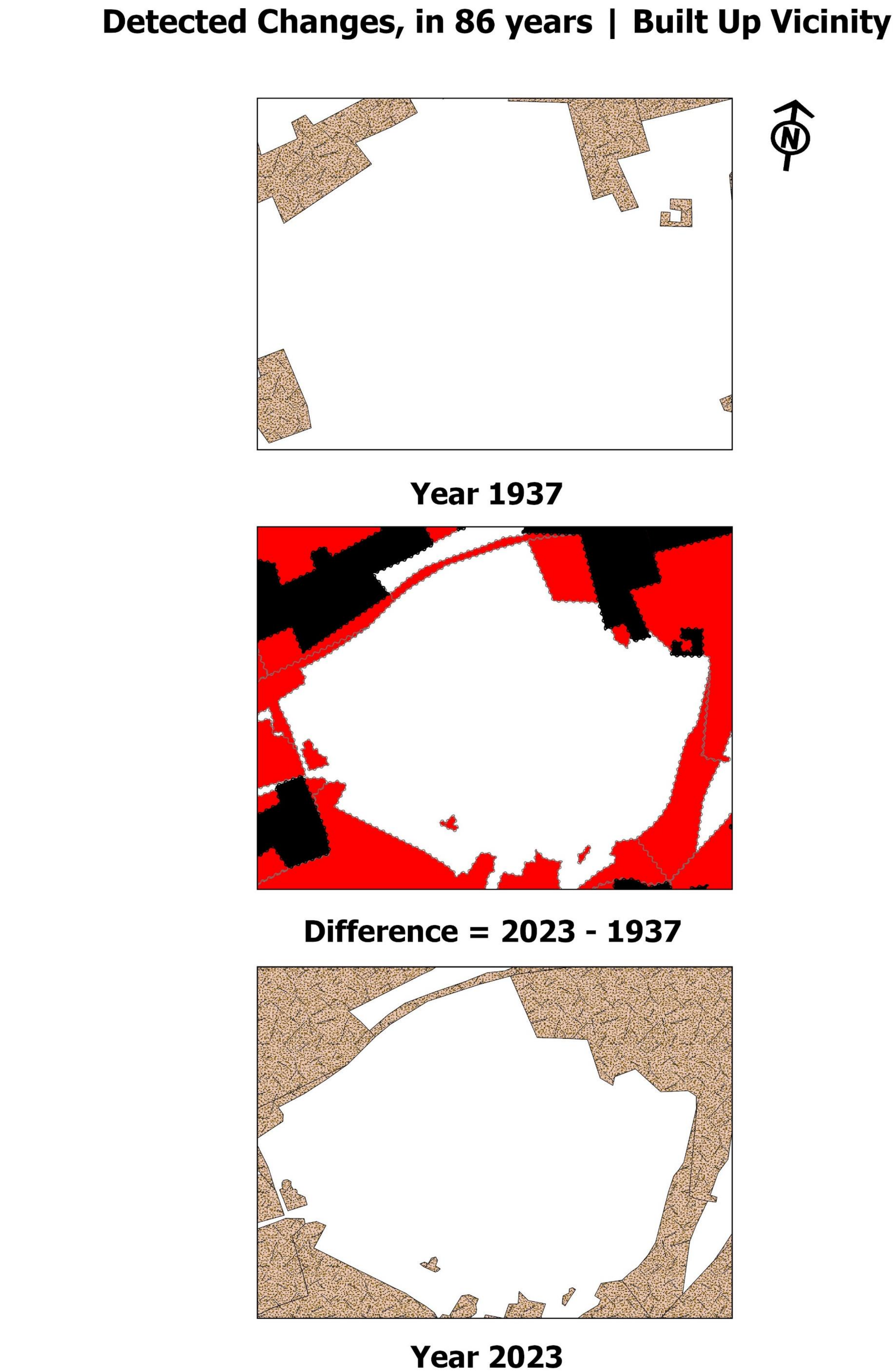

Figure 15: Mosvatnet Built-Up Detected Changes, 1937 – 2023. Red areas represent the increase in urban area.

Discussion

Norway, known for its rich biodiversity and extensive natural resources, plays a crucial role in providing ecosystem services globally (Skre, 2017). These services, which include the provision of clean water, air, and soil, the regulation of climate, and the support of human well-being, are essential for the sustainable development of the country and its people (Kaltenborn et al., 2019). However, the country faces challenges in maintaining these services, particularly in urban areas like Stavanger.

Stavanger, one of Norway's major cities, is experiencing significant environmental degradation (Kirikkaleli et al., 2022). The reduction of natural elements, such as Mosvatnet, a lake in the city, contributes to the degradation of ecological services. Mosvatnet, once a significant water body, has been reduced in size, impacting the local ecosystem and the services it provides, such as water purification and recreational opportunities. This reduction is part of a broader trend in urban development, where natural spaces are often sacrificed for infrastructure and housing.

The degradation of ecological services in Stavanger and similar urban areas is a complex issue, influenced by factors such as population growth, urbanization, and climate change (Sutton et al., 2016). Efforts to mitigate these effects include the restoration of natural areas, the implementation of green corridors, and the promotion of sustainable urban planning practices (Klaus & Kiehl, 2021). These measures aim to enhance the resilience of ecological services and ensure the well-being of both the environment and the people of Stavanger.

Relating the change of the Mosvatnet lake area from the year 1937 to the year 2023, the change detection tool was applied. It showed a reduction in the waterbody in 86 years. However, the change has not been significant in the last 50 years. The largest change happened between 1937 and 1973 when 83 550 square meters from the northern and southeastern parts were reduced and reclaimed as land (Figure 13).

The changes in the region's landscape dynamics during the last few decades are evident by the vegetation and the built-up areas. Upon the study of the shifts in vegetation, it is clear that there has been a substantial decrease in greenery since 1937. The change in difference from 1937 to 2023 is approximately 1 336 150 square meters. In this time, the vegetation has shrunk to about a third of its former size in 1937. This significant reduction of forested areas just proves the fact that the main reasons of the decrease are urbanization, deforestation and agricultural expansion that are the main causes of the destruction of the nature. The disappearance of vegetation not only changes the beauty of the place but also the worries about the species extinction, the fragment of habitats, and the imbalance of the ecology arise.

On the other hand, the built-up area has been growing astonishingly. The built-up area has almost tripled its size over the course since 1937. The change in difference from 1937 to 2023 is roughly 1 424 680 square meters, which is a clear indication of the fast urbanization, infrastructure, development, and population growth. The residential, commercial, and the industrial buildings that were built made the whole face of the land to be reshaped which led to the change of the land usage patterns, transportation networks, and the socio-economic dynamics.

The changes in ecosystem services around Mosvatnet Lake have been influenced by several factors. Environmental policies and regulations have played a crucial role in reducing pollution and promoting sustainable practices (Andersson et al., 2023). Furthermore, conservation efforts by local communities and organizations have contributed to the improvement of water quality and the recovery of biodiversity (Skre, 2017). Climate change, although not directly mentioned in the provided source, is a global factor that could potentially impact these services in the future (Pandey & Ghosh, 2023).

Conclusion

This research dwells on the necessity of ecosystem services, which include provisioning, regulating, cultural and supporting services essential for both human beings and economic welfare. These services are effective at providing food security, protecting environmental sustainability, and maintaining biodiversity and the ecosystem resilience. Moreover, the research suggests that interdisciplinary approaches are crucial for comprehensive ecosystem management and policy development aiming to cover different angles and conflicts. The research concentrates on Mosvatnet Lake in Norway, examining the transformation of ecological services around the lake for the period of 1937 to 2023 – 86 years. Using historical LULC information, including satellite imagery and field surveys, it recognizes and evaluates the amounts of changes occurred to the area by LULC. In addition, the investigation's research questions focus on the necessity of taking care of lakes in order to conserve the ecosystem services and to deal with climate change. The knowledge developed out of this investigation can be utilized for the next assessment of LULC change and how faithfully the local government enforces its land and management policies. Moreover, the scope for providing financial value to the ecosystem services mapped in the future enhances the level of our understanding and handling of such natural capital.

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