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The Results of Digitizing Historical Maps: Comparison of Lithuanian Land-Use Structure in the 19th and 21st Centuries

Eglė Piškinaitė * and Darijus Veteikis

Faculty of Chemistry and Geosciences, Institute of Geosciences, Vilnius University, 03101 Vilnius, Lithuania
* Correspondence: egle.piskinaite@chgf.vu.lt

Abstract: Studies of long-term land-use changes can reveal significant results about land use in the past and lead to the main causes of these changes being revealed. We georeferenced 27 selected sheets from 1846–1872 topographical maps of the Russian Empire, covering the territory of the modern Republic of Lithuania. The georeferencing was based on using ground control points. We discuss the overall insignificant errors obtained from joining the georeferenced sheets of this historical map. Manual digitizing (vectorizing) was preferred over automated means because of the specifications of the map. All the data were merged into five land-use categories: (1) forests; (2) wetlands; (3) built-up areas; (4) water bodies; and (5) other (mostly including arable land, grassland, and pastures). The reconstructed land-use structure of the 19th century was assessed for its compatibility with the spatial data of the CORINE land cover in 2018. The results showed that forest land use increased from 26.57% to 33.52%, built-up areas increased from 4.35% to 3.23%, and water bodies increased from 2.24% to 5.78%. Meanwhile, wetlands decreased from 4.35% to 0.84%, and other land use decreased from 66.56% to 56.63%. The main LULC change trends were determined to have resulted from political and economic decisions. The reconstructed LULC situation and identified LULC changes can provide the background for land management and future studies in various academic fields.

Keywords: old maps; georeferencing; land-use changes; land-use reconstruction; Lithuania

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1. Introduction

The rapid development of technologies increases the possibilities of using geodatabases, aerial photography, satellite images, and similar digital sources in modern studies of land use/land cover (LULC) and its changes. However, for long-term retrospective and historical analyses, analogue maps remain the most important sources of information about the past's landscape situation [1,2]. Historical sources such as topographic, cadastral, and military maps represent potentially rich information resources [3] and are the only data sources that represent the landscape situation with relative spatial accuracy [4]. Historical maps have always been important in LULC change analyses of natural and anthropogenic environmental studies [5,6]. Additionally, the value of these information sources is accepted in other disciplines such as socio-hydrology [6], hydrology [5], urban development [7], cultural landscape evolution, urbanization, human-activity development [8], architecture, planning, archaeology, and demography [9].

An increasing number of historical maps are available, and their accessibility is being constantly improved [6,10,11]. The interpretation of maps is based on the map legend and is a simple and unambiguous process if the map is maintained in good condition [10]. However, visual methods are useful only for first impressions and preliminary evaluations but are less accepted in scientific analyses [12,13]. Furthermore, special knowledge and perception are needed to facilitate the high-quality interpretation of historical maps [12]. Overall, the interpretation and processing of historical maps represent a qualitative research field and are not appropriate for quantitative applications [6].

Today, the high level of technological development creates new possibilities to use historical cartographic information [9]. Modern geography is full of digital solutions, from creating maps to producing data analyses, but the situation with historical maps is different. Nevertheless, there are many historical maps that are digital (scanned) and available for users, for example, in open access sources, but only a small number of such maps are in a format allowing for analysis and interpretation by other systems and machines [10]. Scanning a map is only the first step towards creating a reliable digital map. The next step, as noted by Podobnikar and Kokalj [11], is the transformation of the scanned maps into a common spatial reference system. In general, georeferencing turns historical maps from archival documents into efficient cartographic data [9]. According to Király et al. [14], historical maps are more valuable for experts when they are available in a digital format and georeferenced. Georeferenced maps can be compared and combined with other cartographic products, such as satellite images, orthophotos, and modern digital raster and vector maps; databases, such as digital elevation models, land cover and land cadastre maps, and urban plans [11]; and, eventually, other georeferenced historical maps [15] and datasets [8].

In Europe, there are a number of researchers exploring the use of historical maps as the main source of information and analysing the methodological aspects of using old maps in LULC change studies [1,2,4,9,11,16–20]. Georeferencing methods, the period of historical map creation, and other aspects determine the quality of georeferenced maps and data. Stäuble et al. [20] also noted that the quality of the research depends on the accuracy of the historical maps and their potential for integration.

Automatic digitization/vectorization methods require expert knowledge and are not easily usable for non-expert users [21]. Automated or semi-automated georeferencing is usually used for maps with a known spatial reference system [14,22], for maps that have colourful objects and areas [23,24], and with toponyms by using text recognition tools [25]. For automated digitization, ArcGIS software [22], geocoding methods [23] and machine learning [10] can be used. There are many archives that contain millions of scanned maps that are efficiently exploited [24,26,27]. Therefore, studies that attempt to propose methods of automatic georeferencing and vectorizing have become recently relevant. Studies shows that deep learning (DL)-based methods might significantly reduce manual work when georeferencing historical maps [28,29]. DL methods can be effective only when the underlying mathematical concepts are known, and there is a requirement for software libraries, high-performance hardware to train models in a timely manner, and sufficient quantities of data [29]. The DL concept is based on extracting specific information from maps by segmenting map images by identifying which pixels belong to the feature of interest (buildings, forest, text information, etc.). Inter alia, it involves not only the visual objects of the map but also anything defined by the researcher. DL can identify granular features and bring out unique visual patterns for new analysis [30]. Nevertheless, the variety of methods, because of the map technical parameters we used, were manual georeferencing and vectorizing. Maps are uncolourful and have a lot of textual information, and there are differences in the symbols on map sheets.

A previous review showed that historical LULC change studies are scarce in Lithuania [31], with most being very local; additionally, the historical structure of land use in the Lithuanian territory has not yet been reconstructed at a national level. The aim of this article is to reveal the main changes in the LULC of Lithuania over a long-term period. We claim that these changes are the main indicators showing the results of the political and economic decisions made over 150 years. To implement this goal, we attempted to create a 19th century LULC map of Lithuania. Russian Empire maps (1846–1863) were taken as a data source for this study. Historical data were compared with the CORINE Land Cover (Coordination of Information on the Environment Land Cover) database. Since 1990, four periods of data can be used for LULC change determination. However, there are several other global/regional LULC change models. For example, the latest HYDE (History Database of the Global Environment) version is a combination of the historical population estimates and also the implementation of improved allocation algorithms with time-dependent weighting maps for cropland and grassland in the period from

10,000 BC to AD 2015 [32]. SAGE (Center for Sustainability and the Global Environment) is the result of combining satellite data and census data. The global cropland distribution from 1700 to 1992 is given in the dataset [33]. The Kaplan and Krumhardt (KK10) dataset is a reconstruction of the Europe population and deforestation from 10,000 BC to AD 1850 [34].

In the first part of the article, we present the results of processing the analogue historical maps into a digital map of land use in Lithuania from 1846 to 1872, emphasizing the advantages, difficulties, and errors of the digitization process. In the second part, we present a comparison of the LULC in Lithuania during the 19th and 21st centuries.

2. Materials and Methods

2.1. Study Area

The study area includes the territory of the Republic of Lithuania. Today, Lithuania covers 65,300 km^2 area. The country is located near the Baltic Sea and is 90.66 km off the seacoast in the west. The country's territory expands 373 km from east to west and 276 km from north to south. The country borders Latvia in the north, Belarus in the southeast, and Poland and Russia in the southwest. The Lithuanian landscape is composed of several geomorphological types: clayey plains (covering 55.2% of the territory), moraine hills (21.2%), sandy plains (17.8%), river valleys (3.6%), and coastal plains (2.2%) [35]. At present, 51.87% of the territory is covered by agricultural land, 32.93% by forests and bushes, 5.34% by roads and built-up areas, 4.11% by water bodies, and 5.75% by other types of land use [36].

The territory of Lithuania has been occupied by various powers over its history. Almost all of Lithuania's territory in 1795–1914 was occupied by the Russian Empire. At that time, the Russian Empire was divided into provinces (gubernia), counties (uezd), and districts (volost) [24]. A detailed large-scale survey was taken that covered European Russia up to the second decade of the 19th century [37]. The Vilnius and Kaunas provinces were mapped. Other parts of Lithuania (the Trans-Neman region (Lith. Užnemunė, Southwest Lithuania) and Klaipėda region) were integrated into Prussia. Later (in 1815), the Trans-Neman region (province of Suvalkai) became part of the Russian Empire. At that time, more than 50% of the land was grassland and pastures according to statistical data and other written sources [38]. The main driving forces of LULC changes were agricultural reforms.

2.2. Maps Used

Česnulevičius A. [39] divides Lithuanian cartography into four stages: (1) non-professional (16th–18th centuries), (2) professional (19th century), (3) modern topography (first half of the 20th century), and (4) modern cartography (21st century). The first cartographic works of Lithuania were created abroad by foreigners and by compatriots who studied and worked abroad. During the professional stage of cartography, astronomy, geodesy, and topography flourished at Vilnius University. In 1816, in Poland, Lithuania, Latvia, Estonia, and Finland, the mathematical basis for creating a map, a triangulation network, was created. The Russian Empire then took over works related to the cartography and topography of Lithuania. The aim of cartography was to administratively unify and statistically describe the region and occupied lands. As a result, many data from that time were recorded. Additionally, until the 19th century, maps were monochrome [40].

The map in this study had to cover the whole territory of modern Lithuania and be detailed enough to identify land cover classes. Due to differences in map purpose, territorial coverage, creation time, and scale, the historical cartographic heritage of Lithuania is diverse and inconsistent, but most maps cover only some parts of Lithuania and are too generalized. After an analysis of the cartographic data, Russian Empire maps (1846–1863) were taken as the data source for our study. The Vrublevski Library of the Lithuanian Academy of Sciences provided high-resolution copies of the map sheets. Other map sheets that cover parts of Lithuania not in the Russian Empire were downloaded from open-access sources.

The Shubert map series created in the 19th century covers the western part of European Russia. This series was named for the author Shubert Fedor Fedorovich (1789–1865), who initiated and organized a survey of the Russian Empire using topographic maps of different scales. Topographic maps were created from ten-verst maps (1:420,000) and half-verst maps (1:21,000) [41]. For this research, three-verst maps (1:126,000) were used. The maps consist of 435 sheets sized 58.5 cm × 40.8 cm. The map sheets were numbered to indicate the row number and position of the map in each row. The map was printed in Lehman's scale with a narrow range of colours. The map contains numerous symbols, features, and text information and is considered difficult to read [42]. Twenty-seven map sheets that cover the current territory of Lithuania were used and georeferenced in this study. Technical details of the scanned maps are given in Table 1.

Table 1. Technical details of the scanned Russian Empire maps.

No.	Technical Parameter	Value of Technical Parameter
1.	Date of production	1846–1863
2.	Scale	1:126,000
3.	Number of sheets	435
4.	Number of sheets used in research	27
5.	Size of sheet	58.5 cm × 40.8 cm
6.	Colour	Monochrome (black and white)
7.	Resolution of scanned map	300 dpi
8.	Pixel depth after georeferencing	8 bit
9.	Main groups of symbols	Settlements, sacral places, infrastructure of roads and railways, industrial objects, water bodies and related infrastructure, relief, physical and administrative boundaries, and other surrounding areas

2.3. Methodological Issues

Methodology is crucial when discussing how historical paper maps should be converted into digital maps because the applicability of a database and the strength of scientific inference depends on the chosen methodology [1] and involves a series of actions (Figure 1).

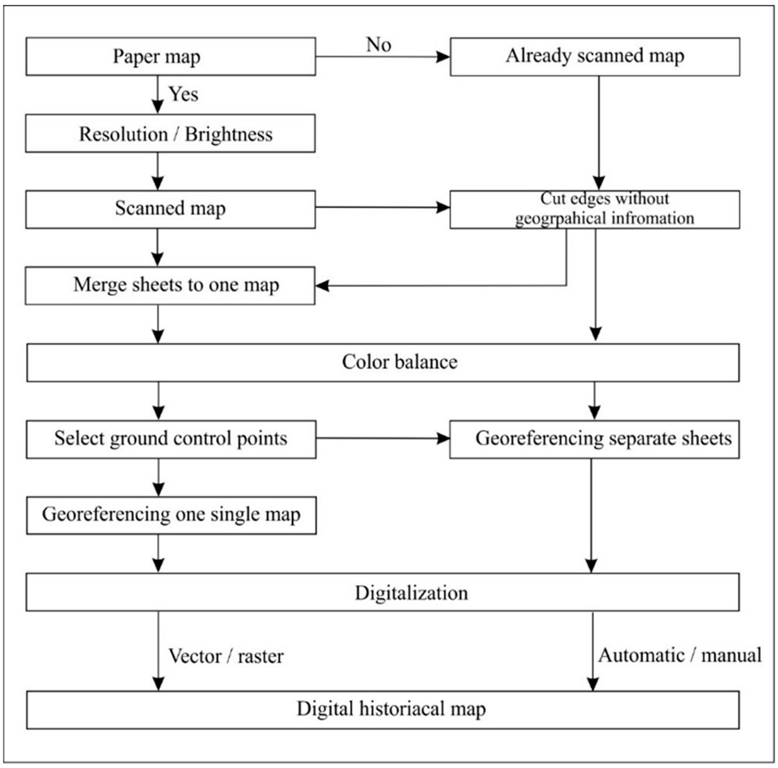

Figure 1. The process of georeferencing historical maps.

When georeferencing old maps, the first step is always to scan the paper maps [17,29]. If the researcher has the ability to do so, parameters such as geometric and radiometric resolution, contrast, and brightness should be chosen during the scanning process [17]. A lower resolution always leads to a loss of map details [43]. As mentioned earlier, the maps used in this study were already in a digital form; therefore, the scanned map parameters were unable to be modified. After the paper maps were scanned and converted from analogue to digital, the next important step was to integrate historical maps into the GIS and determine the real position of map objects [2]. The main goal of georeferencing historical maps is to transform the target spatial reference system [7].

After paper maps are scanned and converted from analogue to digital formats, the next important step is to integrate historical maps into the GIS and determine the real position of map objects. We next have to istemaenced the map [2]. There are various definitions for the term "georeferencing", but, in general, according to Hackeloeer et al. [44], georeferencing can be understood as an umbrella term for techniques that are concerned with the unique identification of geographical objects. The main goal of georeferencing historical maps is transformation to the target spatial reference system [7].

Georeferencing old maps can be challenging. The difficulty of this process correlates with the date of the map [14]. The difficulties in georeferencing are related to the lower spatial accuracy due to the topographic measurement techniques used at that time, the lack of information about map metadata (creation of time and used spatial reference system), paper distortions due to light/humidity, the quality of the scanning process, and the resolution used, which can make an impact on the georeferencing process.

Challenges can also be related to the researcher's knowledge and skills because georeferencing requires familiarity with the mathematical definitions of transformation methods, cartographic projections, and spatial reference systems [2]. There are a few commonly used methods for georeferencing. According to Havlicek, each method has its own specificities and can be used in different cases [43]. The first method is to merge all map sheets into one image (seamless map) and istemaenced that image [43,45]. The second is to istemaenced each map sheet separately [46]. The second method requires an additional process for fitting the map sheets' corners [43]. Methods for matching edges after transformation can pose difficulties [45], but the display procedure for one image may involve more complex implementation, taking into account the uneven distortion within the sheet [47].

First, we cut image edges that do not contain any geographical information. In the second step of georeferencing, we homogenize the colours and link them to the spatial reference system. Colour differences can occur as a result of the original printing or scanning process, as map sheets may have been created at different times by different cartographers who used different colours. The homogenization of colours can also become reduced due to aging [45].

After the colour balance is set, the map can be connected to the current spatial reference system. To create links from the digitized historical map to a current reference and projection system, Ground Control Points (GCP) are used. GCP are the main method for connecting historical maps to the current spatial reference system [2,9,12,14,44,48,49]. For GCP, the selected features correspond to locations that are the most stable and independent of time. The features most often used for GCP include churches, other buildings' edges, and the intersections of the main streets of villages [5,9,15,20]. In our study, we followed these provisions for GCP selection, and, for GCP, we chose permanent edges of settlements, road features, river features, or other features considered to be stable. Road features and river features are considered stable features, but some slight changes may occur over time [4]. In this work, we defined from 6 to 10 GCP per sheet on the edges and in the middle areas of the sheets. GCP were selected in the topographic map of the territory of the Republic of Lithuania (M 1:50,000) using the Lithuanian coordinate system approved in 1994 (LKS-94). In Lithuanian mapping, LKS-94 rectangular planar x, y coordinates must be used, calculated by intersecting the ellipsoid GRS-80 with a horizontal cylinder and conformally designing the territory of Lithuania so that the projection distortion scale at 24 °C prime meridian is 0.9998 [50]. After the georeferencing, the size and position of the historical map sheet were fixed manually as needed. The zero-order polynomial (only shift) transformation georeferencing procedure was applied in ArcMap using the Georeferencing tool.

After the historical map was georeferenced, digitization began. The aim of digitization is to create a vector or raster map where geographic features are reproduced from the historical map. GIS methods such as extraction, combination, and procession can be used only for a digitized map [17]. Nevertheless, visual interpretation of the maps and manual digitization are moving towards less time-consuming automated production methods [10]. In our study, we used a manual digitization method because the map specifications did not allow for automatic reading or the use of automatic object recognition tools. Historical maps include numerous symbols, lines, and textual information. Due to these difficulties, text/non-text information separation requires individual attention, which was the subject of various studies [17]. During historical map digitization, the LULC of the historical maps was divided into five categories.

The standardized processes of georeferencing involves many steps and operations. It is difficult to use a less complicated standardized process with the system of historical map sheets over a large area without losing accuracy of the map [45]. In this study, the GCP were carefully selected, while considering possible changes in the environment, and linked to the topographic map of the territory of the Republic of Lithuania (M 1:50,000) in the LKS-94 coordinate system. During the georeferencing procedure, some sheet overlaps and gaps were observed (Figure 2). Sheet-projection distortions are usually caused by miscalculations, shrinking of the paper, unknown geodetic foundations, or a lack of metadata for the map [6,24,51].

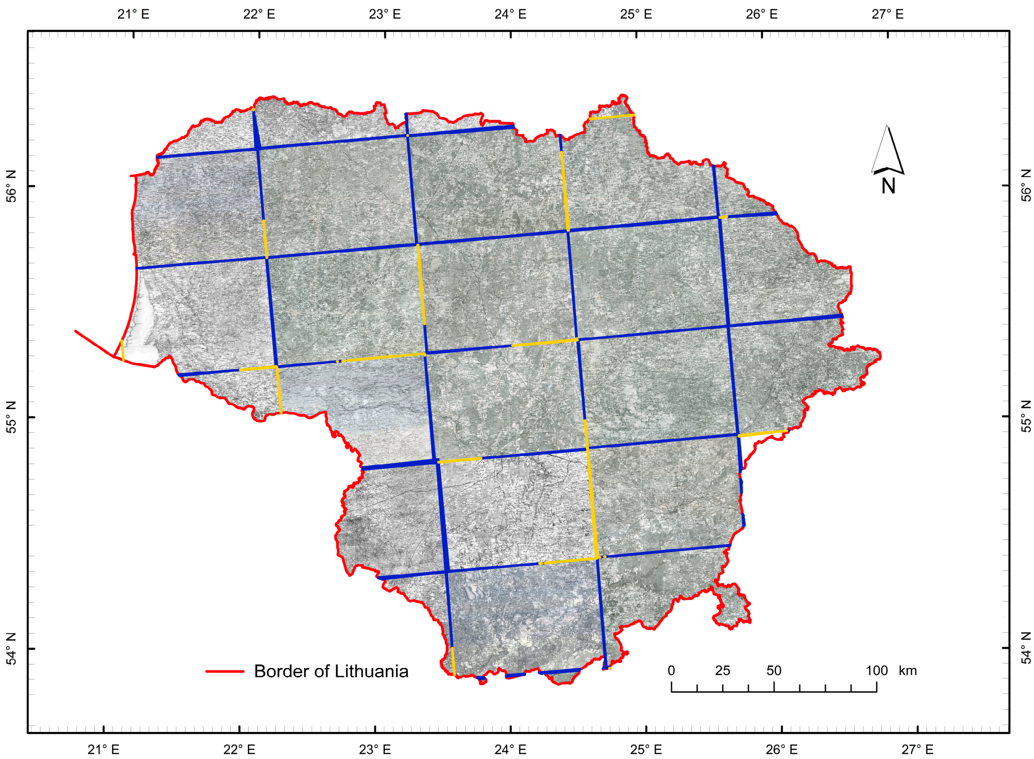

Figure 2. Lithuanian territory covered by 27 georeferenced sheets of the military topographical map of European Russia with gaps (in yellow) and overlays (in blue) marked.

Misalignment of the edges of the map sheets was previously identified as the main problem when georeferencing maps consisting of multiple sheets. Some researchers suggest combining a mosaic of map sheets into a single raster image and linking a multi-part image to a coordinate system rather than linking each map sheet individually [45]. Although this process avoids overlapping or incorrectly spacing the edges of the map, it reduces the overall accuracy of the map and increases the amount of distortion. Meanwhile, when digitizing each map sheet separately, the edges of the map sheets after the transformation do not match perfectly, but the information on the map sheets has fewer residual errors. In a combined map, errors affect not only the sheet that contains the erroneous GCP but also the neighbouring map sheets. This factor creates a larger number of gross errors in the combined result [52]. It is up to the researcher to choose whether to use digitized map sheets with fewer residual errors, which are not related to a single map, or to work with multiple errors in the map sheets using a single map. As mentioned before, in this study, each map sheet was georeferenced individually.

There were 42 edges of map sheets to match, covering approximately a 2500 km line in physical reality. In many cases, the edges of the map sheets matched perfectly, but some map sheets featured severe mismatching (Figure 3).

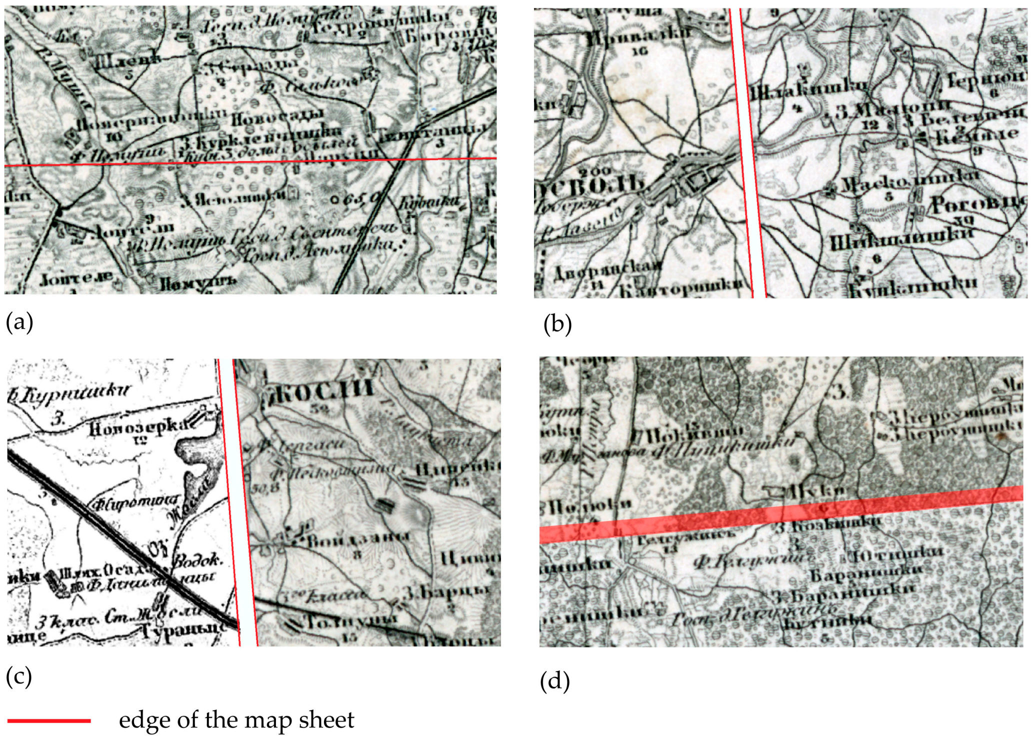

Figure 3. Results of matching edges after georeferencing each map sheet (1:25,000) individually: (**a**) good matching; (**b**) mismatch of the sheet boundaries but good matches of the corresponding map elements; (**c**) high mismatch of both sheet boundaries and corresponding map elements; (**d**) overlay area between two map sheets.

The accuracy of the GCP position in the used historical maps was evaluated next. According to the literature, in Schubert's maps, the designation and position of various objects have some errors compared with their actual positions. Depending on the objects, these errors can range from 50 to 200 m or from 100 to 500 m and sometimes even more [53]. Consequently, not all features of the map fit perfectly after georeferencing. The distance between unmatched features varies from 30 to 700 m, which is close to the described level of inaccuracy in Schubert's maps. This result could be acceptable for LULC analysis over a relatively large area such as the territory of Lithuania, which is 65,300 km^2 in size.

3. Results

3.1. Determining the 19th Century LULC Structure

During digitization of the map, five land-use classes were distinguished: (1) forests, (2) wetlands, (3) built-up areas, (4) water bodies (lakes, rivers, and estuaries), and (5) other land use (meadows, arable land, grassland and pastures, coastal sand dunes, built-up areas smaller than 25 ha, etc.).

The first edition of the map of the Russian Empire was created during 1846–1863. Later, additions to and refinements of pre-existing maps were periodically completed. In our study, most of the map sheets are from the first edition. However, some sheets from the later edition of 1872 were also used. Therefore, some sheets of the map legend varied in the map. Even in high-quality map sheet copies, it was difficult to distinguish some of the signs and boundaries.

Here, the symbol for the forest in the map legend represents the forest classes such as wet forest, dry forest, wet forest with bushes, dry forest with bushes, broad-leaved forest, coniferous forest, mixed forest, and felled forest. During the study, all classes of forest (except felled forest) were combined into two generalized classes: (1) forests and (2) wetlands. In some cases, the boundaries of the forests were clear, which did not cause major digitization problems. Problems occurred when digitizing those places where the forest boundaries were unclear and blurred because of typographical issues. Other researchers also reported problems in the accuracy of distinguishing between forest and non-forest areas as well as transitional areas [53,54]. The boundaries in such areas were guided by the previous trend where the forest boundary usually continues along natural barriers such as roads or the shores of a body of water. In places where there are no contiguities, the boundaries of the forest area were drawn according to the spread of the symbols. The most remote sign was used to establish the boundary.

Areas of wetlands were clearly visible by their signs. However, the boundaries of these areas on the map were unclear, making their digitization the most difficult. This layer included very wet forests, wet meadows, and wetlands. As mentioned before, lower-humidity forests are classified here as the forest layer. This decision was made after analysing the symbols to show the degree of humidity. Lower-humidity forests and meadows cover massive areas on the map. The land-use statistics would be distorted if all the forests and meadows marked as humid were assigned to the LULC layer, designating the groups as wet forests, wet meadows, and wetlands.

Although the built-up areas were readily distinguishable, their representation on maps varied considerably depending on the type of urban area and the characteristics of the map sheet. In one case, a built-up area was marked on the map only as a built-up area with groups of buildings separately marked. In another case, the area was defined as the whole area with land belonging to a city, village, or single farm, which together formed the built-up area. Therefore, in the land-use map covering the period of 1846–1872, urbanized areas are understood not only as built-up areas but also as areas with buildings and surrounding areas where intensive economic activities related to life in built-up areas are carried out. For later LULC comparisons with the CORINE land cover data, the smallest units had to be eliminated; only areas equal to or greater than 25 ha in size were left for further analysis. In order to generalize the georeferenced built-up areas, the units with a distance less than 100 m were aggregated. All built-up units smaller than 25 ha were merged into the background LULC areas. After aggregation, the number of georeferenced built-up class units decreased from 82,430 to 438. The layer of built-up areas was adapted for comparison with the CORINE land cover data. Considering that settlements, especially single houses, are non-scale objects in the Russian imperium map, the aggregation of units was considered to be the correct method to establish a network of settlements for the period of 1846–1872. Difficulties in spatially locating settlements over time were also encountered due to the negligible sizes of such settlements compared to other land-use types [55].

The imperial map presents detailed information on water bodies in the territory. The main rivers and lakes are marked on the map as areas, but the width of most rivers is not generally to scale. In CORINE, the rivers are represented only by the Nemunas, with the main streams in its delta and the Neris marked as areas. Therefore, to match the river data of both sources, all rivers other than the Nemunas and Neris were assigned the LULC category "Other" (Figure 4).

To compare the different LULC layers with data from the 19th century map and 21st century map, it was necessary to unify the LULC classifications. Five LULC categories (built-up areas, forests, wetlands, water bodies, and other) were used to generalize two different classifications (Table 2).

Table 2. Harmonization of LULC classes in the 19th century Russian Empire map and CORINE land cover.

LULC Elements of 1843–1864 Topographic Maps of the Russian Empire	CORINE 1 Level LULC Types Applied to 1843–1864 Topographic Maps of the Russian Empire	Corresponding CORINE Level 3 LULC Types
Settlements with surrounding areas	Built-up areas	1.1.1. Continuous urban fabric
Settlements with surrounding areas Shrines and cemeteries Walls and fences		1.1.2. Discontinuous urban fabric
Factories and industrial infrastructure		1.2.1. Industrial or commercial units
Railways and stations Highways Main roads Roads with pavements Permanent and other roads Road constructions		1.2.2. Road and rail networks and associated land
-		1.2.3. Port areas
-		1.2.4. Airports
-		1.3.1. Mineral-extraction sites
-		1.3.2. Dumpsites
-		1.3.3. Construction sites
-		1.4.1. Green urban areas
-		1.4.2. Sport and leisure facilities
Broad-leaved forests	Forests	1.3.1. Broad-leaved forests
Coniferous forest		1.3.2. Coniferous forest
Mixed forest		1.3.3. Mixed forest
Swamps Meadows Broad-leaved, coniferous, and mixed forests Swampy areas with hummocks	Wetlands and wet territories	4.1.1. Inland marshes
Peatbogs		4.1.2. Peatbogs
Rivers and water channels	Water bodies	5.1.1. Watercourses
Lakes, ponds, and basins		5.1.2. Water bodies 5.2.1. Coastal lagoons 5.2.2. Estuaries 5.2.3. Seas and oceans
-	Other	2.1.1. Non-irrigated arable land
Settlements with surrounding areas		2.2.2. Fruit trees and berry plantations
-		2.3.1. Pastures
-		2.4.1. Annual crops associated with permanent crops
-		2.4.2. Complex cultivation patterns
-		2.4.3. Land principally occupied by agriculture, with significant areas of natural vegetation
Meadows		3.2.1. Natural grassland
Shrubs, reeds and moors		3.2.2. Moors and heathland
Thin forest		3.2.4. Transitional woodland/shrubs
-		3.2.3. Beaches, dunes, and sand
Burnt forest		3.3.4. Burnt areas
Cut forest		-

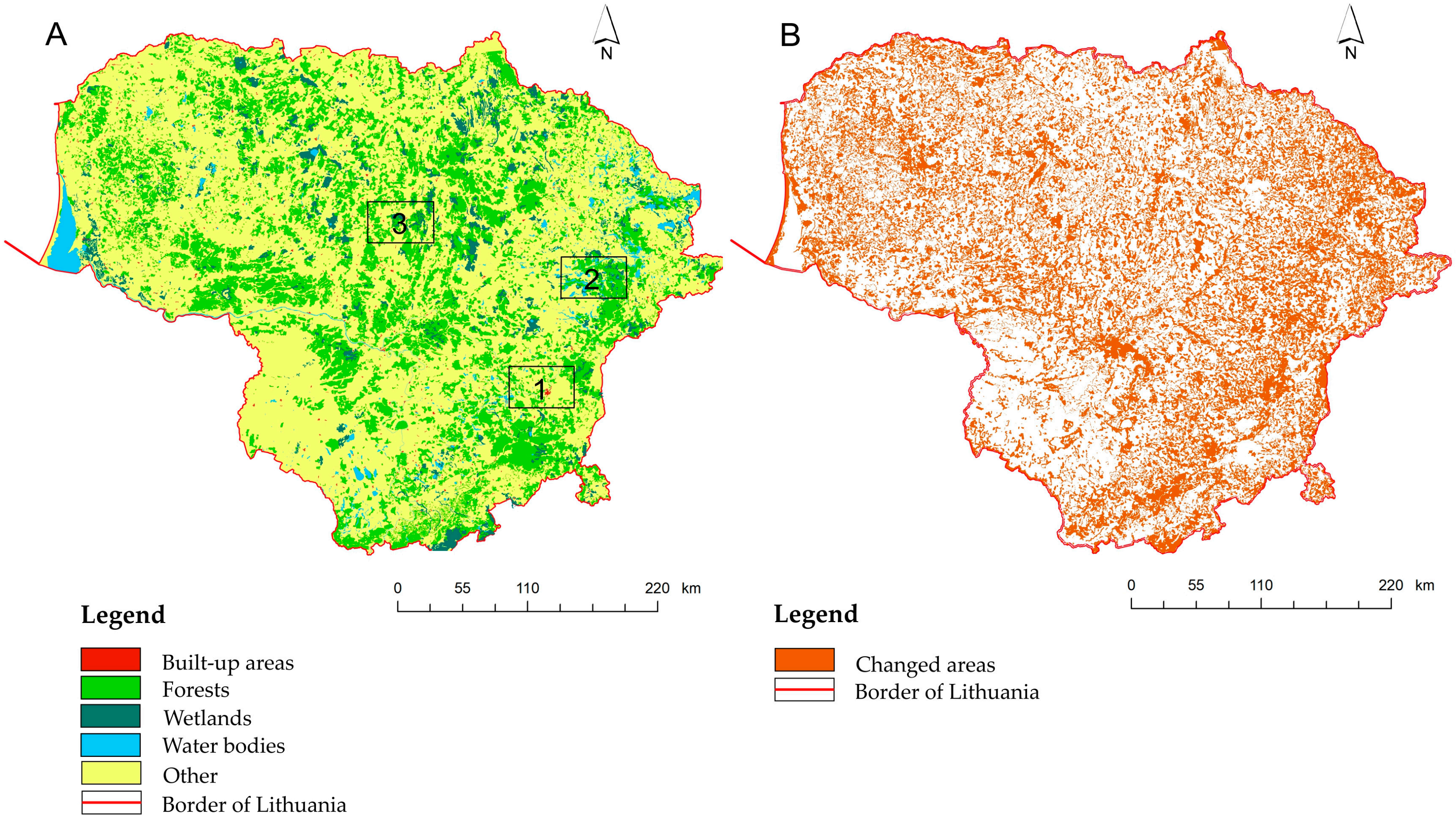

Figure 4. Land-use structure of Lithuania in 1846–1872 (**A**) and spatial distribution of changed LULC classes (**B**). Magnified clippings of 1, 2 and 3 are presented in Figure 5.

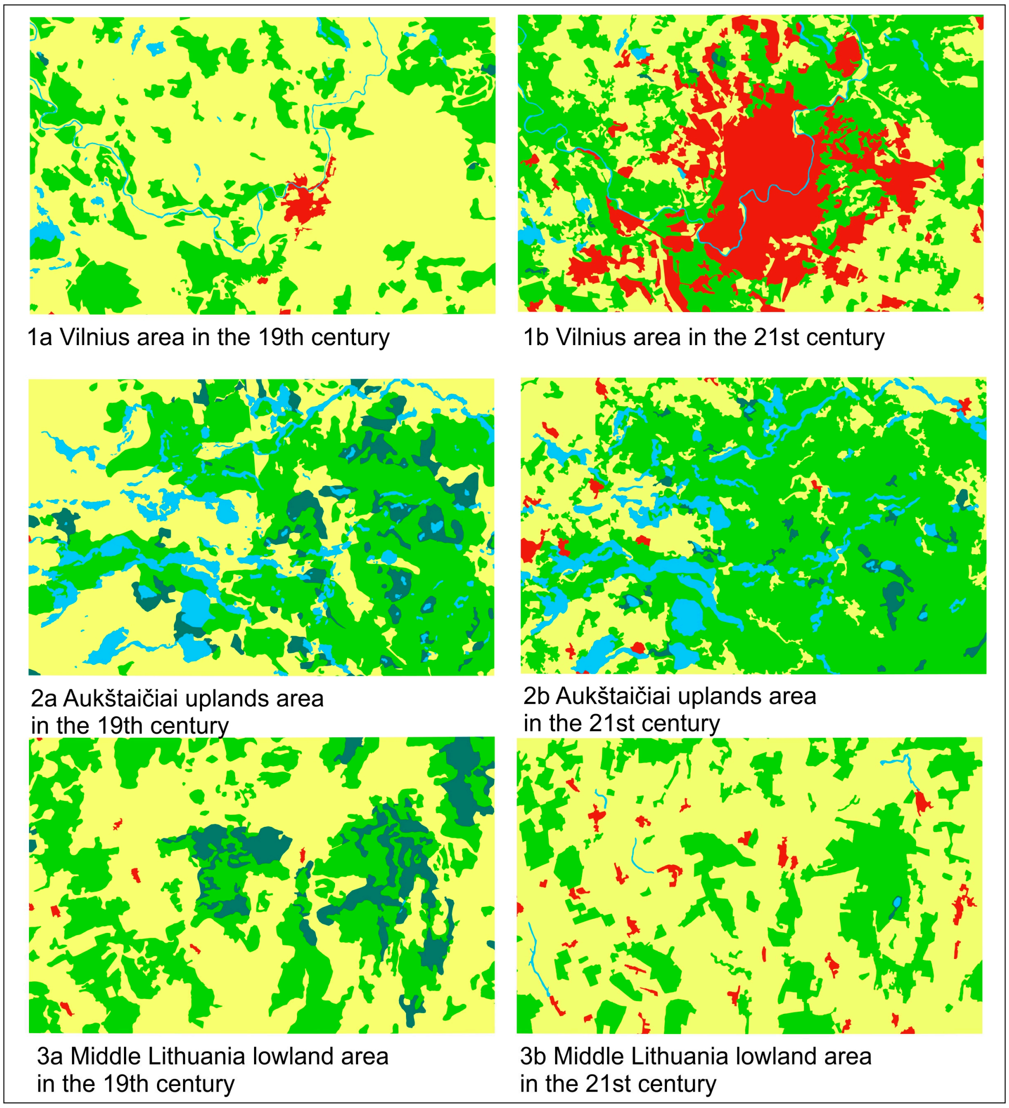

Figure 5. Visible comparison of structural LULC changes: Vilnius area in the 19th century (**1a**) and 21st century (**1b**); Aukštaičiai uplands in the 19th century (**2a**) and 21st century (**2b**); middle Lithuanian lowland in the 19th century (**3a**) and 21st century (**3b**) (1:125,000).

3.2. Land-Use Structure of Lithuania in the 19th Century

In this study, we created a product not previously available to researchers. The digitized Russian imperial map of the Lithuanian territory revealed the LULC situation in the 19th century. The 19th century map contains unique information, but the results are more relevant when compared to the modern situation.

Over more than 150 years, the changes in the land-use structure of Lithuania are obvious. However, many characteristics of the land-use structure in Lithuania and anthropogenic impacts on environmental changes since the mapping period (1846–1872) are visually recognizable, e.g., urban area development, structural patterns of the forest territories, new water bodies, etc.

In 1897, only one-sixth of the population lived in cities [56], while, in 2018, this figure was about two-thirds (Statistics Lithuania). A more accurate number of villages was determined in 1897 during the first general population census of the Russian Empire, which established that there were 26,482 villages in the territory of Lithuania. Based on the latest population and housing census in 2011, the number of villages was 16,762. During 1897–2011, 9720 villages disappeared from the Lithuanian map [57]. In open areas, the network of single farms and small villages was continuous during the 19th century. However, there were few settlements larger than 25 ha. In 1965, with the start of the Soviet Union's land reclamation campaign, the large-scale, and in most cases forced, relocation of single farms and the formation of collective farms began. Private agrarian land was collectivized, through forced land confiscation from farmers and the transformation of their individual farms into large collective farms. This process had a significant impact on the built-up/urban area network and expansion of urbanization centres. As villages decreased, urban development increased accordingly, and cities grew.

The georeferenced map shows that, during 1846–1872, forest covered 26.57% of the Lithuanian territory, while today, it encompasses 32.93% [23]. On the other hand, the two world wars and political changes in forest management that occurred between these two dates contributed to the remarkable fluctuations of the forest share (e.g., in 1937, the forest share was down to a minimum of 16.65%) [58,59]. During the occupation of the Russian Empire (1795–1915), large-scale illegal logging was carried out. Research on forest productivity and restoration began in the middle of the 20th century, and the depletion of forest resources ceased [58]. The independence of Lithuanian land reform started in 1990 and is still ongoing. The goal of the reform is to return the private land that was collectivized to its previous owners. When such land is returned (restitution) to the former owners or their successors, many private plots of land, often with a small area, are formed. Therefore, in some regions of Lithuania, agricultural activities have become unprofitable, with agricultural lands being abandoned and spontaneous renaturalization and reforestation processes being started [38]. These processes have supplemented the growth of forested areas.

In Lithuania, until 1978, about 2 million hectares of land were drained. Land drainage affected water circulation processes in forests, wetlands, and swamps. On the 19th century map, wetlands and wet territories were found to cover 4.35% of Lithuania, which is 23.51% higher than the data from 2018. To date, new reclamation systems have not yet been implemented, and old ones are not being taken care of. Reclamations that functioned 20 years ago no longer function effectively. Previously drained land is now becoming swampy and overgrown with bushes or trees [60]. The driving forces that changed the LULC are now slowly returning to the primary stage (Table 3).

To provide further examples of more visible changes, we present changes in three representative territories: Vilnius, the capital of Lithuania; the Aukštaičiai uplands; the middle Lithuanian lowland (Figure 5).

Though an increase in built-up areas was calculated, structural changes in the settlement networks are clearly visible only in the cartographic information comparison. Some structural changes, such as changes in the boundaries of forest areas and changes in the units of water bodies, are also visible on comparable maps. These comparisons of LULC between the 19th and 21st centuries are an example of the possible use of digitized 19th century maps.

Table 3. The transition matrix of LULC change in Lithuania from 1846–1872 to 2018.

1846–1872 LULC Class	2018 LULC Class Built-Up Areas		Forests		Wetlands		Water Bodies		Other	
	Area (ha)	Percentage from Class (%)	Area (ha)	Percentage from Class (%)	Area (ha)	Percentage from Class (%)	Area (ha)	Percentage from Class (%)	Area (ha)	Percentage from Class (%)
Built-up areas	8184.91	44.61	879.76	4.80	23.23	0.13	0.00	0.00	9257.81	50.46
Forests	22,891.09	1.32	1,123,960.47	64.78	10,880.65	0.63	0.05	0.00	577,342.38	33.27
Wetlands	2850.76	1.01	141,455.82	50.05	20,025.90	7.09	4071.58	1.44	114,216.33	40.41
Water bodies	2109.81	1.44	22,868.33	15.65	4305.89	2.95	94,294.66	64.53	22,542.41	15.43
Other	184,747.38	4.25	965,568.08	22.21	21,453.57	0.49	57,377.05	1.32	3,117,397.07	71.72

4. Discussion

LULC studies based on cartographic information are always accompanied by a higher or lower uncertainty [23]. Uncertainty and errors occur during the creation of maps and their transformation to digital forms. Georeferencing involves errors related to positional accuracy and digitizing. Even if georeferencing was completed as precisely as possible, cartographic imprecision and shifting can still occur [20]. Podobnikar [45] summarized that most errors come from the less precisely mapped land-use features in the original maps and positionally/thematically incorrect interpretations of the boundaries between classes. The degree of uncertainty can be reduced by using multiple methods and combinations of data. Not only LULC but also other cartographic and statistical information can be used in historical LULC studies. Other data and methods allow to determine the extent of errors. For example, Kaim et al. compared two forest cover reconstruction methods: regular point sampling and wall-to-wall historical mapping, in the same area of the Polish Carpathians. The results showed that the point-based sampling of a historical map is an efficient and accurate way to assess forest area and change trends and can be used instead of the time-consuming vectorization of a historical map [61]. It can also be used in areas where there is a lack of land-use data modelling methods that can be used. Parameters such as road network, distances to roads, relief, and population density can be used to make historical land-use reconstructions [62].

In the present study, the net changes were the main focus and were provided as a quick overview of the acquired spatial dataset of the 19th century land-use situation in Lithuania. Naturally, the next stage of research would focus on all area gains and losses (gross changes). Old maps in LULC studies can be used as additional data. Old topographic maps and land-use records are most often used in local and regional reconstructions. Meanwhile, historical LULC reconstructions of continental and global areas are based on population statistics due to the lack of LULC data. The use of statistics and maps could lead to a better certainty in LULC change studies [63]. Other sources of information were not used to check the validation of the results in this study. There is room for other studies in the future, e.g., to georeference maps from other periods between 1846–1872 and 2018 or to include other data from statistics and censuses.

Digitizing historical maps allows us to reconstruct some aspects of past landscapes and changes in certain natural and anthropogenic elements in Lithuania. In the historical past, the territory of Lithuania suffered occupation by different powers numerous times. Over more than 150 years, Lithuania has been affected by changes in political, social, and economic conditions, with corresponding consequences for the LULC structure. Quantitative analyses showed that the main changes in the Lithuanian LULC structure were decreased areas of wetlands and increased urban areas, water bodies of artificial origin (such as dams and ponds), and other territories. The new database will enable several additional analyses of intensity, connectivity, change trajectories, etc., to be performed in the future. We acknowledge the imperfections in the historical data, but we also sought to create the most reliable map of the 19th century LULC of Lithuania. We were unable, however, to mark out LULC types such as arable land, pastures, or meadows, so we merged them with the LULC class "Other". Additionally, only the largest riverbeds wider than 100 m were digitized as polygons. Despite these factors, other LULC types such as forests, wetlands, lakes, and (especially) built-up areas were marked out quite precisely. A comparative analysis of the LULC situation between the 19th and 21st centuries yielded new data that supplemented our knowledge of the development of LULC during the history of Lithuania. LULC studies can show not only the path of changes in areas but also the ability for such areas to remain unchanged. These stable landscapes are objects of interest for researchers in the landscape memory area [64].

The Russian imperial map scale is 1:126,000. Meanwhile, the scale of the CORINE land cover data is 1:100,000. However, mismatches of map scales are common in historical studies [19,20,65] and do not constitute a substantial obstacle to conducting research.

Digital historical maps are now stored in many libraries, funds, and storage locations. However, without georeferencing and adaption for use in a GIS environment, such maps have certain limits in research. Researchers constantly present methods and try to find the best, time-efficient, and most accurate historical map reconstruction and georeferencing approach for large territories [30,61,66].

The georeferenced 19th century map of Lithuania could be useful to other researchers in history, archaeology, economics, politics, ecology, and other fields. As previous studies showed, short-term, local analyses are dominant in Lithuanian LULC studies [21], and they dominate studies that cover only small areas of Lithuania. The reason can be that national level studies where historical maps are used are time-consuming [61]. Local studies could be supplemented by data from the 19th century, and more long-term studies could be completed in the future. There are still few national-level historical LULC maps in Europe. The results of our study contribute to the determination of the European LULC situation in the 19th century. Spatial data provide abundant material for data fusion. Though data fusion is more common for the digital spatial data received from satellites and remote sensing [67,68], georeferenced historical maps can also contribute to the data fusion process. Researchers are working on methods to combine historical maps and contemporary data to make LULC reconstructions and analyses. Using these, the combined historical and remote sensing data network of settlements and building density or network of roads can be reconstructed [69]. Automatic historical maps georeferencing methods are used in these studies. Our study offers the product of a manual reconstruction of 19th century land use in Lithuania, which is more accurate to use for data fusion studies.

5. Conclusions

The choice of methods depends on the technical parameters and characteristics of historical maps and the application possibilities. In this study, we successfully mapped, for the first time, the LULC situation during the 19th century at a national level. Despite certain errors and a lack of accuracy in combining the topographic model of the area divided into sheets, the historical map covering the whole territory of Lithuania is suitable for representing the LULC situation in the 19th century. This map consists of numerical data on distances as well as the areas and shapes of objects and LULC types.

Many characteristics of and changes in the Lithuania LULC are visually recognizable, such as the development of urban areas, the transformed structural patterns of the forest territories, and new water bodies. By integrating historical maps into the geographical information systems, we had the opportunity to perform spatial and statistical analyses of the LULC situation in the 19th century. Our results showed the LULC changes over more than 150 years; such changes are important for better understanding the national and regional processes of LULC change and LULC development. The main trends in land-use change between the years 1846–1872 and 2018 in Lithuania were built-up area sprawl, an increase in forest and water bodies, and wetlands reduction. Other land use also decreased.

Although this is not a unique study in general, it is the first study in Lithuania where the LULC of the Lithuanian territory was reconstructed using historical maps. Data from the 19th century and the analysis of LULC changes could support decision-making processes and help define policies to optimize the LULC structure and sustainable development. Additionally, the methods we used could be easily applied to other historical maps, and a more detailed LULC change analysis could be performed by including intermediate time intervals. This would give more detailed LULC change trajectories.

The long-term LULC study using historical maps showed that all changes could be related to political and economic decisions made in the past. The land-use reforms made mainly impact the agricultural areas and network of settlements, the changes made in industry mainly impact the built-up areas, and the planning of forest productivity and restoration and the abandonment of land made mainly impact the growth of forest areas. The assessment of these connections should be used to develop future scenarios, especially in the consolidation of sustainable management. Long-term LULC changes allow to identify the trajectories of changes and regularities and to predict possible changes in the future. One-third of Lithuanian territory has undergone changes. The biggest changes (from wetlands to other and from other to built-up areas) show the consequences of the decisions made by institutions and the government. Therefore, the results of the LULC change studies and the positive and negative effects of the decisions should be brought out and represented to decision makers and should not be limited only to discussions among scholars.

Studies where the object of the study is population, historical settlements and urbanization, natural habitats, forests, and soil, as well as other topics, may be interested in the results of LULC change over 150 years.

The results of this research improved the understanding of spatial temporal dynamics. As the main object in LULC studies usually is the changes in the LULC, an interesting extension of this study would be a comparative investigation into a stable (unchanged) LULC. The ability of such an LULC to stay unchanged and the possible reasons for this should be explored.

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