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Delineation of catchment area for the lake Kisezers for environmental sustainability

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Abstract. The study aims to develop a methodology for the delineation of a catchment area. The methodology includes the processing and analysis of LiDAR data, on-field height measurement data, bathymetric data, hydrological data. High definition catchment area maps are successfully constructed. Catchment area influencing factors such as water mass movement and changes in land use are determined. Lake Kisezers was selected as the study site because the location of the lake, the availability of data, the feasibility studies, the economic potential of the catchment area determine the topicality and significance of this study. The lake catchment area covers multiple rivers, urban and rural territories, forests, high and low terrains. In the catchment area of Lake Kisezers many hydrologic monitoring stations with continuous data are situated. In the research area, we can study how those factors interact with the possibility to perform a catchment area delineation. The final result of this study is the catchment area for Lake Kisezers. The research results are high-definition and can be used to understand locations of floodplains, territories with malfunctioning drainage systems. The repetition of this study requires extensive knowledge of cartography, experience in working with terrain and bathymetry data, wide range of GIS knowledge. The research was performed using computer software such as QGIS and GRASS GIS. The application of the methodology used in this study can serve as an example for delineation and analysis of a catchment area for other lakes and rivers. Overall, the study is a success.

Key words: catchment area, GRASS GIS, LiDAR, QGIS, lake.

INTRODUCTION

The previous extensive research on catchment area delineation in Latvia was carried out in the late 20[th] century. As a result of this historical research, the maps of catchment areas for lakes and rivers were constructed using manual work and techniques, which questions the overall precision of the maps prepared at that time. These maps can be used to compare the shapes of lakes and rivers in of 20[th]-century, their compatibility, changes in the selected basins, artificial barriers, meanders of rivers (River basin maps, 1975).

Anthropogenic impacts combine with climate change over time might lead to changes in the hydrological network of rivers, hydrological regime, surrounding terrain, depths of lakes and rivers, groundwater levels, and soil moisture conditions. As a result of anthropogenic activities and natural conditions, the characteristics of catchment areas have changed over time and it is necessary to re-identify the catchment areas and their characteristics. This exercise can help to evaluate the functional possibilities of the territory and understand how to ensure sustainable and environmentally friendly management of the territory (Gilberto et al., 2014).

Surface runoff always flows from a higher to a lower point due to gravity. As individual streams merge, converge, and gradually turn into streams, rivers, which in turn flow into the nearest lakes, larger rivers, sometimes rivers flow through the lakes (Leinerte, 1988). In order to study a lake, it is important to identify and analyze the catchment area determine the influencing factors such as morphometry, quality, water movement, and level (Gilberto et al., 2014). It is important to view and identify not only the entire catchment area but also smaller catchment areas of the water body in the entire catchment area of the main lake. The watershed can be relatively thought of as a line drawn along the highest points of the terrain around the lake (Leinerte, 1988). For coastal lakes, the boundary of the catchment area is difficult to see in nature (Melluma & Leinerte, 1992).

Chemical substances as dissolved in water enter the lake from the catchment area. (Shelton, 2009). In Latvia, we need to increase the number and details of research to analyze water quality. The identification and mapping of the catchment area are of particular importance in this type of research (Gilberto et al., 2014). Combining the results of the previous catchment studies with the possibilities provided by up-to-date technologies and geospatial data such as LiDAR, terrain models, observation stations, bathymetry data, land use data, orthophoto maps helps to delineate catchment areas in unprecedented resolution and systematically observe any changes. The areas with an understandable transport of water can be used for economic growth, for example, by identifying the economic potential of the area as agricultural land, it is possible to build irrigation systems that improve the potential for land use (Arslan et al., 2020).

Anthropogenic impacts particularly on territories with minor elevation changes make it challenging to construct the catchment areas because decomposition of the catchment areas by terrain is more time-consuming and requires the application of high cartographic skillsets (Haas et al., 2020). The territories are more suitable for economic activity and have a wide range of uses, for example, for construction, economy. Due to construction activities, felling forests, engaging in agriculture the landscape is changed, as a result of which the size and shape of the catchment area might change as well, which in turn leads to uncontrolled circulation of dissolved chemical substances with little or no control over, for example, accidental spills and pollution. Thus in-depth research is also possible to identify the effects of climate change on the site (Andri et al., 2020).

Water is one of the most important natural resources, and it is important to research its quality, movement, and impact factors (Arseni et al., 2016). Of all ecosystems, lakes are among the most sensitive to changes in the environment, therefore, research into the hydrometry of lakes needs increased attention (Agnieszka et al., 2011). The lakes contain a significant amount of the world's freshwater reserves, so it is important to take care of their water quality. The water quality of lakes affects the quality of drinking water in the area, recreation, fishing (Perivolioti et al., 2017). Lakes are an important part of the ecosystem because lakes collect all water from catchment areas (Schiefer & Klinkenberg, 2004). In the world, the study of lakes in terms of physical, chemical, and biological characteristics has developed rapidly since the beginning of the 20th century (Tundisi, 2012). Lakes are sensitive to climate change (Tan et al., 2017) as well as rising human economic activity. Identifying the physical size of a water body and the movements of water masses is important to understand how best to use water bodies (Hassen et al., 2013). Research on catchment areas of lakes is important because it is possible to understand groundwater and directional runoff flows. Research can provide a better understanding of the origin of waters and the potential risk factors that threaten water quality (Ramachandran et al., 2020). In case of accidents, it is possible to identify and localize pollution sites and act more quickly if river basin maps are available (Davraza et al., 2019). Water resources have remained under threat as a result of globalization (Ramachandran et al., 2020).

Characteristics of Lake Kisezers

The lake is located in the Seaside Lowlands in close proximity to the Gulf of Riga in the flat relief area. The lake is a part of the City of Riga, the capital of Latvia. Lake Kisezers is situated in the Daugava river basin district (Tidrikis, 1995). The lake is located in the depression of the Kisezers-Jugla lake district, in the far part of the Litorina Sea lagoon zone (Kacalova, 1988). Lake Kisezers together with Lake Jugla is located in one valley formed by the former Daugava tributary. Lake Kisezers is a continuous river-type lake (Slaucitajs, 1935; Stiebrins, 2011). Together with Lake Mazais Baltezers and Lake Lielais Baltezers, Juglas lake is interconnected and belongs to the Daugava-Gauja system, which unites 4 lakes and two rivers - Gauja and Daugava. The Daugava-Gauja system was established by the Vidzeme Waterway Improvement Society in 1901–1903 (Kacalova et al., 1962). As Lake Kisezers is located on the outskirts of the City of Riga, its catchment area has been partially reconstructed and significantly affected as a result of artificial land drainage, infrastructure development, construction, and other economic activities. In addition to natural waters, Lake Kisezers also receives storm runoff from the asphalted surfaces like streets and parking lots, quite often storm runoff is not properly treated (Stiebrins, 2011). Due to the inflow of industrial wastewater in Lake Kisezers, there have historically been problems with self-treatment (Kacalova et al., 1962). The greater the anthropogenic impact in the catchment area, the poorer the water quality will be in water bodies (Leinerte, 1988). Analyzing the topographic maps, descriptions of the lake, movement of water, it can be concluded that Lake Kisezers has a contribution from groundwater, precipitation, surface runoff, the impact of Riga Hydroelectric Power plant (HPP) activity, water also is contributed from the sea (LVM, 2020). According to Cabinet Regulation No. 418 'Regulations on risk water bodies' Lake Kisezers is defined as a water body at risk (Cabinet Regulation No. 418, 2011). A water body at risk is a water body for which there is a risk of not reaching water quality goals set by the Cabinet Regulation No. 118 'Regulations on the Quality of Surface and Groundwater' (Cabinet Regulation No. 118, 2002). Moreover, Lake Kisezers is also mentioned as a priority water for fishes, but to set appropriate ecological and chemical quality criteria for Lake Kisezers, it is necessary to identify its depths, which have been studied by the author in the previous study (Dumpis & Lagzdins, 2019). The average depth is a feature according to which lakes are classified by applying appropriate quality standards (Cabinet Regulation No. 858, 2004). As Lake Kisezers is located in the city it is an important recreational object, but at the same time, it is also subject to strong anthropogenic influences such as wastewater discharges causing increased concentrations of nutrients in the water that accelerate eutrophication processes. In its turn, Lake Kisezers is included in the flood risk area according to the flood risk management plan of the Daugava river basin district for 2016–2021 (LEGMC, 2015).

Description of the lakes in Latvia

The lakes - a very characteristic element of the Latvian landscape and an integral part of its ecological chains (Glazaceva, 2004). The lakes observed in the territory of Latvia have formed in the Holocene (Zelcs, 1995). The lakes began to form as the hydrographic network developed. As the waters gradually flowed away, the Baltic Ice Lake was formed, as the glacier melted, the first lakes formed between the hills, disappeared at the end of the Ice Age and re-emerged before the beginning of the Ice Age (Zelcs, 1995). Many of Latvia's lakes are of glacial origin. The pits of Latvian lakes have been formed in the course of complex, usually combined geological processes (Tidrikis, 1995). This can be explained by the last icing about 10 thousand years ago. A large number of lakes makes Latvia a country rich in lakes. The richness of the lakes opens up a wide range of opportunities to exploit this valuable resource. Most lakes are relatively small. There are 843 lakes with an area of more than 10 ha, but only 141 lakes with an area of more than 1,000 ha (Glazaceva, 2004). The area of many lakes is decreasing, it is related to human economic activity and eutrophication. If those lakes with an area of at least 1 ha are counted then there are 2,256 (Tidrikis, 1995). The Lake Kisezers belongs to the coastal lakes, lagoon lakes (Kacalova et al., 1962). Lake Kisezers has been formed in complicated processes. The development from the Baltic Ice Lake to the Baltic Sea has been long and can be divided into several phases, such as the Baltic Ice Lake, the Joldia Sea, the Ancilus Lake, and the Litorina Sea stages (Andrén, 2012).

The seaside lakes have formed relatively later than the lakes in the Latvian highlands and other lowlands. According to P. Sloka Lake Kisezers formed from the ancient bed of the Daugava and Lielupe rivers. The lakes formed from ancient riverbeds are deeper than other coastal lowland lakes that used to be lagoons (Sloka, 1956).

People have long been interested in the origin of the lakes, mythical explanations can be found also in Latvian legends. According to their origin, Latvian lakes can be divided into seven separate types: glacial, coastal, tributary and old-growth, hot and suffusion, moss bog lakes (Leinerte, 1988). The study examines the origin of the lakes of the Seaside Lowlands by paying special attention to the origin of Lake Kisezers.

Problem statement

The main task of this study is to delineate the catchment area for the Lake Kisezers. Delineation of lake Kisezers catchment area is crucial for further research. Further research includes an in-depth analysis of lake Kisezers. This research part focuses on delineation of catchment area and understanding of catchment area influencing factors.

This research aims to develop a methodology for the delineation of catchment areas for lakes using the example of Lake Kisezers.

The following tasks have been set:

– To develop methodology suitable for delineation of a catchment area using open-source software and tools;

– To perform high-definition delineation of the catchment area for Lake Kisezers;

– To evaluate the functionality of the methodology developed during this study and assess the possibilities of further applications.

MATERIALS AND METHODS

The research was implemented using computer software developed for processing and analysis of geospatial data such as QGIS 3.6 and GRASS GIS 7.6.1, which are free-access software. A high-definition methodology for the delineation of the catchment area was developed. After the performing delineation of the catchment area in GRASS GIS software, the quality control of the catchment area created was performed using remote sensing methods in QGIS software. To verify the accuracy of the results, the flat relief areas were inspected manually and it was checked whether the catchment area delineated represents reality. The development of the methodology was time-consuming and requires extensive cartographic knowledge, because the topography is relatively flat in Latvia, and delineation at a high degree of detail requires the processing of long-term data. Territories such as lake Kisezers catchment areas have anthropogenic influences with makes it strenuous to delineate the correct border of the catchment area.

The developed methodology is repeatable, but knowledge of cartography, geography, decoding, work with terrain data, and digitization is required. The methodology only includes open access computer software, as this makes it more accessible and more likely for someone to repeat this exercise.

The basic principles are as follows:

– Research of historical data and contours in the catchment area of interest;

– Digitization work and water connectivity analysis;

– Delineation of the catchment area using GIS tools;

– Correction of the catchment area constructed using LiDAR data, connectivity of rivers, and fieldwork measurements;

– Compilation of the results. The final design of the catchment area and reflection of the results in a map.

Planning and feasibility study

Analysis of available cartographic materials, literature analysis takes a place for understanding specifics of the study area. It has been concluded that extensive and detailed information on the catchment areas in Latvia is not available. Nowadays, the Latvian Environment, Geology, and Meteorology Centre (LEGMC) is engaged in the extraction and analysis of water bodies. Directive 2000/60 / EC of the European Parliament and the Council was adopted on 23.10.2000 to establish a comprehensive framework for the protection of inland, transitional, coastal, and groundwater. The main objective is to maintain and improve the quality of surface water and groundwater. Accordingly, each EU Member State elaborates the River Basin Management Plans. In Latvia, the River Basin District Management Plans are developed by the LEGMC as prescribed by the regulations 'Regulations on river basin district management plans and measures in the program' (Cabinet of Ministers Regulations No. 646, 2009).

When analyzing the information available in the River Basin Management Plans and 2nd cycle Flood Risk Management Plan 22.12.2021–2027. it can be concluded that the catchment areas for the water bodies are not delineated in the highest possible level of detail and for in-depth studies, it would be necessary to create more detailed catchment areas for specific rivers or lakes. It is important to mention that the main task of the LEGMC is to create the catchment areas for the water bodies of interest at a certain scale, this task does not include delineating the catchment areas for every river or lake.

Methodology for catchment area delineation

Using freely available topographic maps of Latvia's State Forests (LST) ap server orthophoto (Table 1), land reclamation, water management, and the catchment maps of the Latvian State Land Reclamation Design Institute from 1975 (scale 1:100000), LiDAR shading available on the map server (scale 1 m), LiDAR data from the Latvian Geospatial Information Agency (LGIA) to construct lake Kisezers full catchment and direct catchment area. When constructing the catchment area, the connection of watercourses and the direction of runoff were studied from orthophoto maps and the previous 1975. year research results. After the construction of the hydrological network, by studying the LiDAR data available on the LVM map server, historical information, cartographic materials, and literature, the catchment area was constructed. Based on Corine Land Cover data for 1990, 2000, 2006, 2012, an analysis of changes in land use in the catchment area was performed. The analysis is necessary to be able to characterize the factors influencing the catchment area and the lake, both natural and anthropogenic. HPPs and other dams in the catchment area have been identified, which impede the natural run-off of water and the flow of substances. Analysis of changes in Lake Kisezers bathymetry from 2017 to 2019 was performed. The mass movement of water was analyzed using the LEGMC observation station Kisezers, Milgravis.

Table 1. Orthophoto maps

Orthophoto cycle	Production yea	Catchment area territory aerial photography year
Orthophoto 1	1994	1997; 1998
Orthophoto 2	2003	2003; 2004; 2005
Orthophoto 3	2007	2007; 2008
Orthophoto 4	2010	2010; 2011
Orthophoto 5	2013	2013
Orthophoto 6	2016	2016; 2018

The study is divided into stages. **The first stage includes** the drawing of the historical catchment area from the 1975 catchment area map of the Ministry of Land Reclamation and Water Management and the Latvian State Land Reclamation Design Institute. This was followed by the construction of the shorelines of the large lakes - Kisezers, Jugla, S. Baltezers, and L. Baltezers and the shorelines of the connecting watercourses from Orthophoto maps. All Orthophoto maps were used for understanding the correct watercourse location. The shorelines of the L. Jugla and S. Jugla rivers and all their tributaries are constructed. Analyzing the cartographic materials, it can be concluded that thanks to the dense network of drainage ditches, nowadays the Kisezers catchment area merges even with the Gauja catchment area. After marking the shores, the connection of watercourses and water bodies was studied, the locations of dams were deciphered. For this step, QGIS is used.

The second stage involves the delineation of catchment area

Using the LiDAR (at leaset 1.5 point to m^2) data and the plotted water contours in the computer program GRASS GIS, the catchment area were constructed. LiDAR data were uploaded to GRASS GIS, then vector to raster function is used. After creating the raster data were inspected using QGIS. Final catchment area borders were calculated using a watershed calculating option. Data were compared with historical data, orthophotos, delineated watercourse connectivity map. Data were compared with the map server DEM model.

Catchment area construction includes relief model construction using rivers and lakes as quality control points. Digitalized river and lake contours need to match with river and lake contours from constructed relief model. After many attempts, parameter fix and work with resolution The error areas were manually edited for the catchment area and its correctness was checked using the cartography computer program QGIS. Fig. 1 reveals relief data used for the construction of lake Kisezers catchment area.

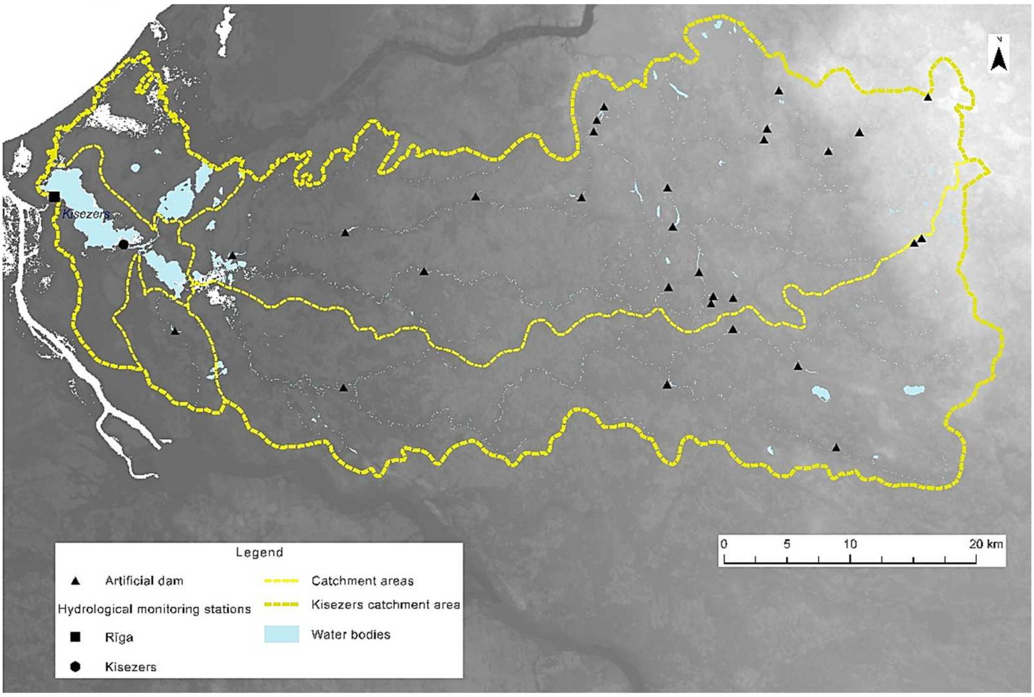

Figure 1. Catchment area shaded relief model.

Field work

In fieldwork with GPS Garmin GPSMAP 66i, obscure places, areas with flat relief, and difficult to understand water location was surveyed. Most of field work take at places with an elevation close to sea lever and places with continuous flat relief. Territories with an undetectable border of catchment area were separated and catchment areas were separated using historical maps.

Field work results are compared with the results of relief analysis data. Lake Kisezers direct catchment area, the common catchment area, the M. Jugla, and L. Jugla catchment areas have been constructed. If necessary the data are sufficient to be able to construct a catchment area for any watercourse and water body belonging to the Kisezers catchment area. For this research main focus is lake Kisezers catchment area, for understanding influencing factors and possible causes of changes in lake Kisezers not only direct catchment area maps were constructed.

The third stage is presentable data maps construction and lake Kisezers catchment area influencing factor specification for further research

The third stage includes the preparation of the catchment area maps, land use analysis based on lake Kisezers catchment area influencing factor specification using Corine Land Cover 1990, 2000, 2006, 2012 data. Water level data at LEGMC observation stations Kisezers (1948–2017), Milgravis (2014–2017), and water mass movement data at observation station Mīlgrāvis were analyzed. Depth changes in the largest water body of the catchment area lake Kisezers have been analyzed from 2017–2019. Depth changes show how the lake changes as sediments settle in it (Elsahabil et al., 2018).

RESULTS AND DISCUSSION

One of the main factors influencing the lake is the catchment area. Lake Kisezers catchment area covers 1,840 km^2 (according to A. Tidriķis data in the encyclopedia 'Latvija nature' - 1,900 km^2). The results of the study prove that lake Kisezers catchment area accurate size is 1903.26 km^2; it consists of the following water bodies:

1) watercourses: Milgravis, Jugla, L. Jugla, Suda, Mergupe, S. Jugla river;
2) lakes: L. Baltezers, S. Baltezers, Juglas, Pecoru, and Plauzu lake.

In addition to the mentioned hydrological objects, lake Kisezers catchment area also includes smaller rivers, such as Pikurga, Smerlupite, and Langa (also known as Garupe). Most of the rivers in the catchment area start in the Vidzeme highlands, flow along the Central Latvian slope and the Ropazi plain (downstream). This condition also determines the variability of the longitudinal slope of rivers in their sections (rapid descent upstream and slow-flowing sections downstream). The river Jugla and the river Langa are also slow-flowing rivers. The river Smerlupite is a typical river flowing through the city, most of which is artificially regulated and discharged underground (Tidrikis, 1995).

According to the research results, lake Kisezers catchment area is 1,903.26 km^2 (Fig. 2). The majority of the catchment area consists of the L. Jugla catchment area 941.59 km^2 and the S. Jugla catchment area 712.16 km^2. The direct catchment area of Kisezers covers 99.96 km^2. The largest bogs in the catchment area are Lielpurvs, Jūgu bog, Getliņi bog, Maltuve bog, Langa's bog, Lielais Kangaru bog, Pecora bog, Suda bog. The largest water bodies are Kisezers, lake Jugla, L. Baltezers, S. Baltezers. According to E. Apsite, Kisezers has a greater role in the regulation of runoff, because the catchment area of the lake significantly exceeds the volume of Kisezers itself and the ratio between the runoff and the area of the catchment area is 111. Usually, the ratio of runoff to basin area is between 5 and 30 (Apsite et al., 2018).

The lake is located in a lowland close to the sea, which results in water from the Gulf of Riga entering the entire catchment area W part. Brackish water from the Gult of Riga true the river Daugava can flow into lake Kisezers, lake Juglas, S. Baltezers, and L. Baltezers because of interactions between Riga HPP and Baltic sea tides. There is a high risk of pollution for Kisezers, as the water enters the lake from the Daugava, the Gulf of Riga, and the catchment area. As a result of the pollution, the consequences would be serious, because the territory is of great economic significance, part of the territory of the Latvian capital Riga is located in the catchment area. In isolated lakes located in the valley, the risk of pollution is less high and can be localized (Davraza et al., 2019), but in the case of Lake Kisezers, the solution to the problem would be an extremely difficult challenge. It is, therefore, necessary to carry out research, model potential risks, and plan measures to address them.

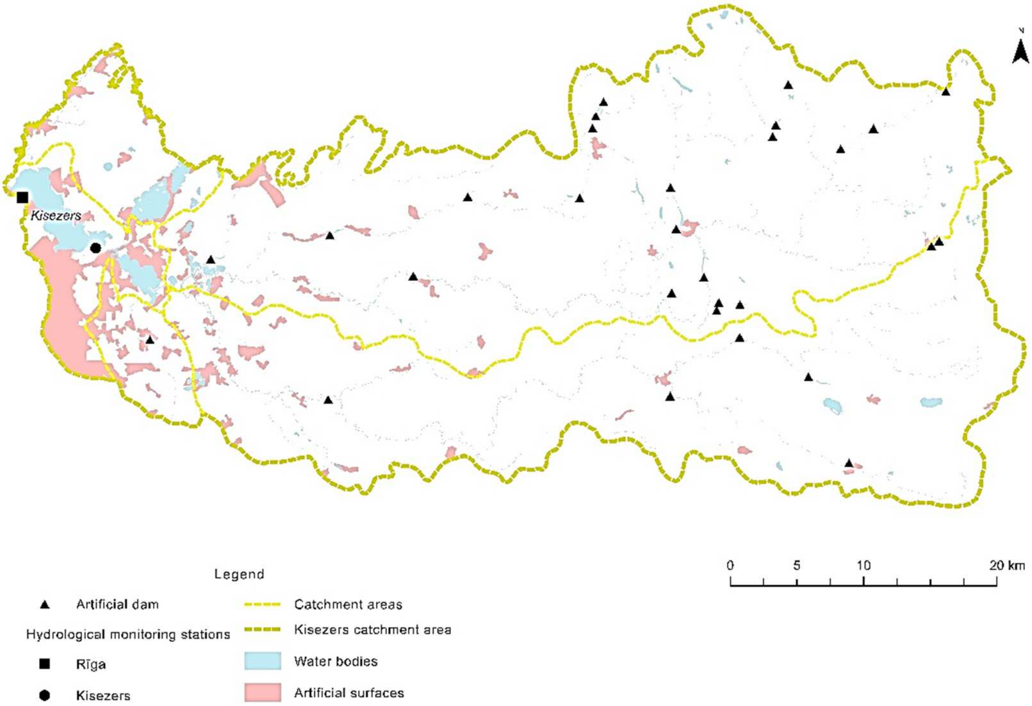

Figure 2. Catchment area map of lake Kisezers.

A total of 6 small HPPs and 20 dams were deciphered due to the construction of the catchment area. Obstacles that interfere with water movements in the catchment area were deciphered for the understanding of the transport of substances in the catchment area. Water exchange and transport between lakes and rivers, the catchment area, is one of the most important processes for maintaining a healthy ecosystem (Yang et al., 2016). By deciphering the locations of the dams, we can conclude that free mass flow of water is not possible in the catchment area. Small dams are not economically profitable in Latvia. In Latvia in general all small HPPs produce energy that is not profitable and economically advantageous for the Latvian population. Disproportionate damage is caused to nature (Timmermanis, 2001). Rapid water level changes thru-out a day is a threat to environmental sustainability in an ecosystem. In the direct catchment area of Kisezers since 1968. until 2005, 2006 in the Jugla River near Lake Jugla. there were locks built to prevent brackish water from entering lake Jugla and lake L. Baltezers (Glazaceva, 2004). Nowadays locks are dismantled.

During the floods in lake Kisezers, water flow can be observed (Kacalova et al., 1962), as a result of which the lake self-cleanses. From research, we can conclude that the lake self-cleanses frequently. Lake Kisezers can be polluted more because of water movements which bring water from Daugava and Baltic sea into lake Kisezers. Kisezers is characterized by a mixed water supply. The lake water extraction is from melting snow, rain, and groundwater, as well as diversity in terms of terrain, climate, and water regime. The long-term average precipitation layer P according to A. Pastor's 1987 study in the Kisezers catchment area varies from more than 850 mm in the NE part to 600 mm in the SW part of the catchment area. In most parts of the catchment area, the runoff layer is from 750 mm to 850 mm (Ziverts, 2004).

Land Use analysis of lake Kisezers catchment area

The land use analysis of the Kisezers catchment area has been performed (Fig. 3). Identifying land use patterns helps to understand changes in the catchment area, to identify potential problems in the future (Matsushita et al., 2006). To better understand the data, land use is divided into generalized groups which are artificial surfaces, agricultural areas, forest, and semi-natural areas, wetlands and water bodies. Areas are simplified and combine several land-use groups. The simplified breakdown is designed for a better understanding of land use in the catchment area, detailed land use data is hard to read, detailed data is used for data processing, not for visualization purposes. Detailed land use maps are not reflected in the results of the study, because research results in an analysis of catchment area impact factors not an analysis of mosaic land use where every slight difference is distributed. In the research land use is analyzed as an impact factor on large scale. Land use is one of the most important factors influencing the catchment area (Matsushita et al., 2006).

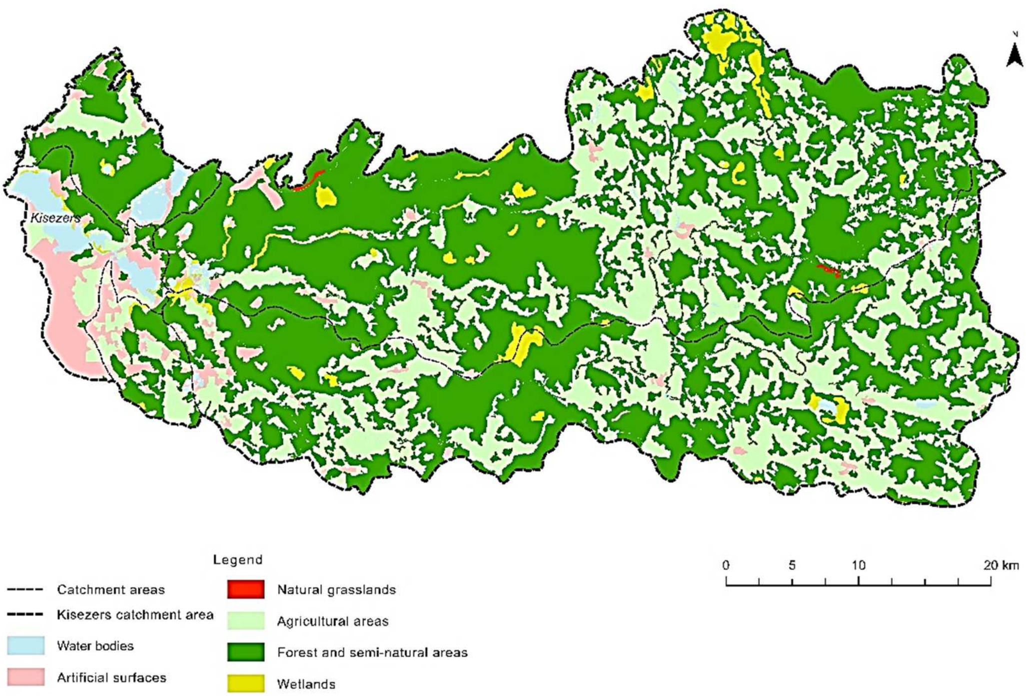

Figure 3. Catchment area land use map (Prepared by the author using Corine Land Cover 2012 data).

The main impact factors are anthropogenic land use areas (artificial surfaces). Urban fabric, industrial, commercial, and transport units, mine, dump, and construction sites, artificial, non-agricultural vegetated areas are divided into areas of anthropogenic impact (artificial surfaces). Arable land, pastures, heterogeneous agricultural areas were allocated as agricultural area covers more than 30% of the catchment area. It is observed that more areas of anthropogenic impact area in the NW part of the catchment area. Anthropogenic impact areas make it difficult to designate catchment areas and identify water mass movements (Haas et al., 2020), which in turn leads to the conclusion that areas with anthropogenic impact are areas at risk of pollution that are difficult to control and predict. Most artificial surface areas are located near Lake Kisezers, which creates an increased impact on the water body. Agricultural areas are mostly observed in part E of the catchment area. Forests, scrub and herbaceous, open spaces with little or no vegetation are combined under forests and semi-natural areas without separating forest types. Forests in the catchment area can be observed in the whole territory, coniferous forests dominate in the west part, but mixed forests in the E part. Forests and semi-natural areas are dominated land-use types covering more than half of the catchment area (Table 1). Wetlands, water bodies have been identified for understanding catchment area soil humidity. Natural grasslands are preserved on the map for understanding how endangered are natural territories in the catchment area.

The study's analysis of land use has changed between 1990 and 2012. In the period from 1990 to 2000, land use has changed relatively in large territories (Table 2). Most changes in artificial surface territories. Agricultural areas are spread. Forest territories suffer from deforesting. Wetlands are increasing in size because of beaver activities. Water bodies' territories are shrunk because of groundwater changes and small creek, melioration canal drainage.

Table 2. Land use in the Kisezers catchment area (Prepared by the author using Corine Land Cover data)

Land-use type	Area 1990 (km^2)	Area 2012 (km^2)
Artificial surfaces	65.43	98.31
Agricultural areas	558.02	633.81
Forest and semi-natural areas	1,138.73	1,088.99
Natural grassland		1.21
Wetlands	86.49	430.73
Water bodies	54.13	37.85

In total there have been changes in the area of 6,457.022 ha. Changes have taken place in the forested areas, with forests turning into shrubs, which indicates logging. Overgrazing and land reclamation have taken place. In the period from 2000 to 2006, changes took place in an area of 4,096.61 ha. According to the nature of the changes, it can be concluded that forestry is developing in the territory, the number of urban areas is increasing, and mining is taking place in quarries. In general, an increase in the anthropogenic load of the area can be observed. In the period from 2006 to 2012, changes took place in 8,388.27 ha of territory. Similar to the development of forestry from 2000 to 2006, the number of urban areas and the extraction of minerals in quarries are increasing. The trend towards anthropogenic influences continues.

Water mass movement analysis of lake Kisezers catchment area

The significant changes in the water level observed in Kisezers can be mentioned as a significant impact factor. The recording of the water level at the observation station Kisezers started on 01.04.1929, a constant data series has been available since 1948. The observation station is located at the SE end of lake Kisezers at the mouth of the river Jugla in Kisezers. Observation recording at the observation station Riga started on 01.01.2014. The station is located at the NW end of Kisezers, at the source of the Milgravija canal from Kisezers. Lake Kisezers has a runoff to the Daugava along the Milgravis canal, which was built in the 13th century. The canal functions as leakage of lake water to the Daugava, but changes in the lake level are affected by changes in the Daugava water level regime, which after 1974 is additionally determined by the Riga HPP operation regime during the day, season, and year. Another factor that can determine significant changes in the lake level from time to time is the inflow into the Gulf of Riga from the Baltic Sea through the Irbe Strait caused by the prevailing NW, N, SW, and NW winds, but water inflows - E, ENE, NE, NNE, NNW, and NW winds (Glazaceva, 2004).

Analyzing the movement of water masses, it can be concluded that Milgravis channel and Jugla river, which connect Kisezers and lake Jugla, tend to change the direction of the current in the opposite direction, as well as the Bukulti canal, which discharges the S. Baltezers and L. Baltezers waters into lake Kisezers. We can conclude that complex water mass movements are observed at the lower end of the catchment area and more water flow and level observation stations would be needed. Thus, it is difficult to correctly separate Kisezers catchment area, because as a result of complicated natural conditions and anthropogenic influence, Milgravis sometimes flows out of Kisezers, but sometimes flows into Kisezers. The movement of water masses is significant, the largest flow was observed on 06.12.2017. It has been 698.28 m^3 s. The largest negative flow was observed on 26.10.2017. it has been 1,251.34 m^3 s. Thus if the Riga HPP had been operating at a full capacity of 3,600 m^3 s. at this time (Pastors, 1990), approximately one-third of the Riga HPP runoff would end up in Kisezers. Unfortunately, there are no data available on the flow and operation schedule of the Riga HPP that would confirm this conclusion. The main factor influencing the significant flow fluctuations in 2017 is the Riga HPP. For further research is mandatory to start monitoring water levels and mass movements in canals connecting lake Juga, lake Kisezers, lake Mazais Baltezers, and lake Lielais Baltezers.

Lake Kisezers bathymetry changes

In the research bathymetric survey was performed in 2017. And in 2019. Bathymetric maps were constructed (Fig. 4). Research results are identical and lakes bathymetry has not changed. For detecting changes in bathymetry regular bathymetric survey has to be done. Lake Kisezers deepest point is 21.5 m, average depth is 1.99 m. Data were collected by the author using echosounder Lowrance HDS Carbon 9 and GNSS Trimble catalyst with a precision of 1 cm.

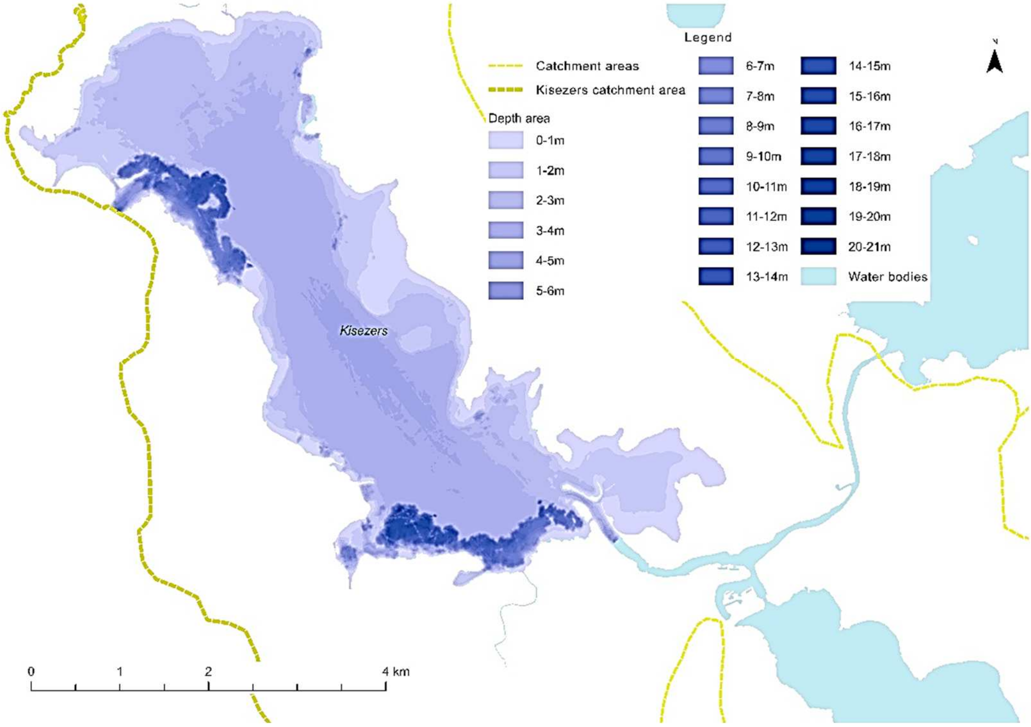

Figure 4. Lake Kisezers bathymetric map 2019. (Prepared by the author using personal field work data).

CONCLUSIONS

After successful completion of the aim and tasks of the research, a high-definition lake Kisezers catchment area map and definite influencing factors. The research was challenging and acquires special care, but its results prove that in Latvia is possible to achieve the state of the art results using open-source technologies. It would be simpler to repeat the study in another body of water because it is rare to find such a complicated situation with many influencing factors, not everywhere is that high-degree data availability. The missing water level and flow data from the Bukulti canal and the mouth of the Jugla river in Lake Jugla can be mentioned as shortcomings and collecting data for future research will improve the research result level of detail. To make the constructed catchment area even more accurate, it would be necessary to monitor groundwater flows and locate observation stations in the entire catchment area. To assess how the catchment has changed, it would be necessary to obtain LiDAR data after a few years (Elsahabi et al., 2018) and repeat the catchment design process. To assess the sediment flow, it is necessary to continue the bathymetry monitoring of Kisezers, the possibility to perform bathymetry monitoring in all large basin waters should be considered.

The prepared and described methodology can be used for the delineation of the catchment area and provides high-detail results. In order to repeat the study, the high-resolution orthophoto and LiDAR data are required.

The delineation of the catchment area for Lake Kisezers was challenging and time-consuming, as the area has a large population and is subject to anthropogenic influences, which in turn has changed the landscape and it is difficult to construct the catchment area. The methodology can be used in various hydrological, geological, chemical studies where the object of research is a lake or river because without the catchment area it is not possible to characterize water quality and quantity for a lake or river in high quality.

According to the author's observations, it can be concluded that the channels have frequent and rapidly changing water levels, current speed, and direction. In the past, the hydrographic network changed only in natural processes, but after the establishment of the city of Riga, as the city developed and expanded, changes in the hydrographic network were also facilitated by human activities.

Changes in land use in the Kisezers catchment area are mainly determined by the increase in anthropogenic load, which can be explained by the proximity of the Riga the development of the city, and its periphery. Land use analysis allows seeing in detail how rapidly territory changes. Using land cover data it is possible to determine with changes have the most significant impact. For example, if the territory is deforested and construction industrials site is built it is bad for environmental sustainability because on this landmass newer will be forest again. Thous territories from nature become polluting areas.

Factors influencing the catchment area have been analyzed, as one of the most significant are the changes in the water level and the irregularity of the movement of water masses. As well it is important to perform a high level of detailed land use analysis for the determination of potential risks in catchment areas. We need to understand the significance of anthropogenic load to the research territory and plan for solutions for making lake Kisezers catchment area environmentally sustainable.

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