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RISK ASSESSMENT OF SURFACE AND GROUNDWATER INTERACTION

2022

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ABBREVIATIONS

ArcGIS	Family of client software, server software, and online geographic information system (GIS) services
FyrisNP	Tool for catchment-scale modelling of source apportioned gross and net transport of nitrogen and phosphorus in rivers and lakes
GIS	Geographic information system
N, Ntot	Nitrogen, total nitrogen
P, Ptot	Phosphorus, total phosphorus
SIA	Limited Liability Company (in Latvian)
U.S.	United States of America
USEPA	Environmental Protection Agency of the United States of America

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I INTRODUCTION

The intense anthropogenic load, or human activity (agricultural activity, urban development, etc.) in the catchment area of the Ilzu (Garais)/ Ilge Lake, poses a risk of contamination for both surface water and groundwater. Potentially, pollutants can migrate from one water body to another along hydraulic roads, especially when significant interactions between surface and groundwaters are noted.

In order to assess the risk of surface water - groundwater interaction, various factors that may affect the ecological status of the Ilzu (Garais)/ Ilge Lake are discussed in this report. A concept of the pollution' retention or residence time in the lake is provided in this work. Risk of groundwater pollution to affect the chemical quality of the lake and the risk of existing groundwater abstraction to affect the water quantity of the lake is analyzed in this report, as well. The analysis of the data has been carried out on the basis of the existing knowledge and available information as well as on the results of field works. This is an initial assessment, which might be clarified after obtaining more recent data. Within the TRANSWAT LLI-533 project, a survey of pilot areas was carried out on 9th August 2021 with the aim to visually assess potentially large pressure sources (e.g. cattle locations) and assess the extent and type of future studies needed to evaluate groundwater balance into the lake.

II PRESSURES AND IMPACTS ANALYSIS

2.1. Estimation of the lakes residual time

The Ilzu (Garais) /Ilge is a running-water lake with small inflow from the drainage channel in Latvian territory as well as from the Apvalasai Lake in Lithuanian territory and outflow to Lithuanian territory - Minava River. Specific water discharge in a lake basin is about 7 l/sec*km^2.
According to Zilani Meteorological station (hereinafter MS) data, the annual air temperature in the vicinity of Garais/Ilge Lake is +6.6°C, annual amount of precipitation – 670 mm (climate normal data for the period 1991-2020).

A widely used expression to estimate the residence time **T** in reservoirs (Foy, 1992; Sivadier et al., 1994; Straskraba et al., 1995) consists of dividing the volume of water **V** stored in the reservoir by the volumetric flow-rate **Q**:

$$Tf\,(t) = V\,/\,Q(t) \ ,$$

where Q might be as the total inflow volume (tributary inflow and precipitation), or as the total outflow (water runoff from a reservoir and evaporation from surface).

Meteorological data (amount of precipitation, relative humidity, air temperature) were used that represent an average for the period 1991-2020 (the climatic norm). Taking into account lack of inflow amount data, the results of outflow measurements obtained during the project were used for the residence time calculations. For the calculation of the evaporation volume, the method of Konstantinov (Konstantinov A, 1968) was applied. According to this method, the evaporation volume is calculated using the reference evaporation data (the evaporation pond with surface area 20 m^2), relative humidity and air temperature data (from Zilani MS). Initial data for the Ilzu (Garais)/Ilge Lake residence time calculation is shown in Table 2.1.1.

Table 2.1.1. Meteorological, hydrological and lake morphological data (1991-2020)

Name	**Lake volume, km^3**	**Lake surface area, km^2**	**Outflow annual, m^3/sec**	**Outflow annual, km^3**	**Evaporation annual, mm**	**Evaporation annual, km^3**
Ilzu(Garais)/Ilge	0.00208	0.83	0.074	0.002	673	0.00056

On average, the residence time of the Ilzu (Garais)/Ilge Lake is 0.72 years or <u>262</u> days. It differs from season to season. In spring water runoff increases and water mass motion becomes more active. During the low flow period the water particles transport is almost stopped as well as in winter time, when the outflowing creek completely freezes.

This quantification of the lake residence time is approximate. A number of factors such as the timing of stratification, the depth of the thermocline and the variability of the inflows that limnologists usually take into consideration, is missing out in this calculation.

In spite of uncertainties, the result can be used for describing the pollution load in the lakes' water and especially in sediments.

2.2. Lakes inflow and outflow discharge measurements

Lake inflow and outflow were mentioned above:

- Inflow includes water of the drainage channel in Latvian territory and water of creek between the lzu (Garais)/Ilge Lake and the Apvalasai Lake in Lithuanian territory;
- outflow occurs through the Minava River.

During the project the Minava River water discharge was measured several time and then the daily water flow was calculated using water level data from measurements on the lake and Water level - water runoff rating curve (Fig. 2.2.1).

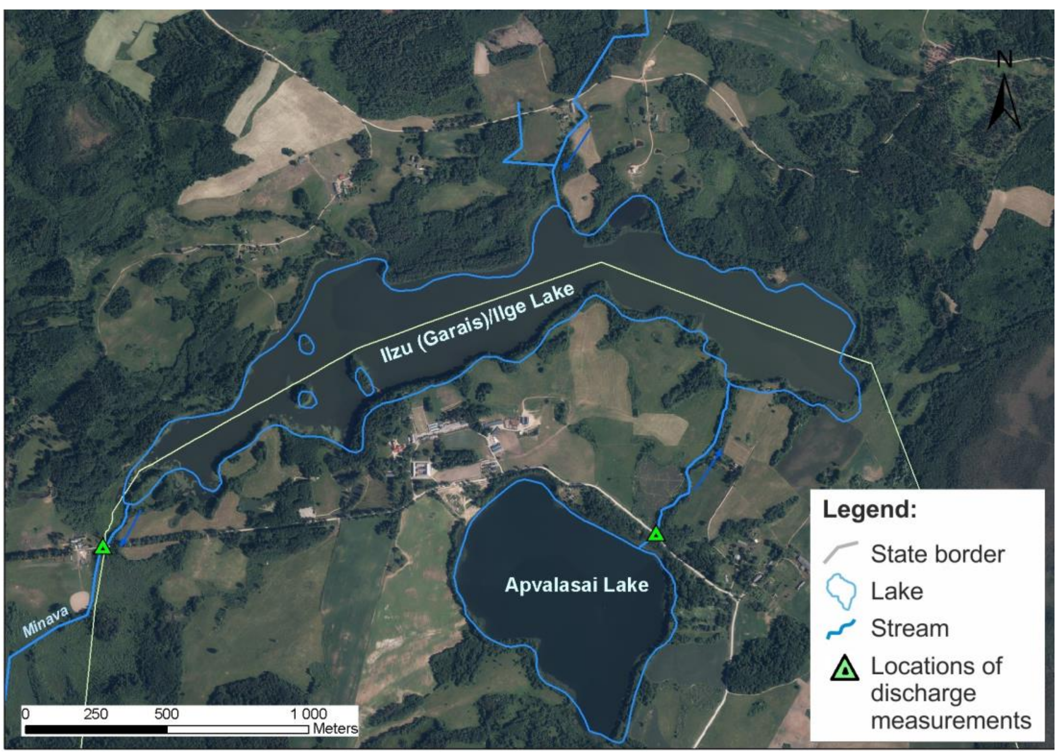

Figure 2.2.1. Ilzu (Garais)/Ilge Lake hydrography sketch map

According to the Minava River water runoff calculation the annual water discharge or Ilzu (Garais)/Ilge Lake outflow is 0.074 m3/s (268 mm). The inflow from the Apvalasai Lake is around 0.017 m3/s and from the drainage chanel about 0.0024 m3/s, total inflow to the Ilzu (Garais)/Ilge Lake is 0.019 m3/s (281 mm).
The main inflow to the Lake is precipitation - 670 mm per year in average. The volume of evaporation (673 mm per year) is almost equal to the volume of precipitation.

2.3. Groundwater vulnerability assessment and impacts of land use

Ecological quality of lakes that are fully or partly dependent on groundwater input are more vulnerable to various risks associated with changes in quantity or quality of inflowing groundwater (Jakeman et al. 2016). Status of groundwater can be threatened by many human activities like agricultural practice, urbanization and industrialization, extraction of natural resources and forestry (mainly clearcuts). All these threats can significantly influence the ecological quality of lakes and, depending on the severity of the action, the influence can be short term or long term, as well as of local or even regional importance.

To evaluate the risk of surface-groundwater interaction on ecological quality of the lake, the major attention should be given to the assessment of potential pollution migration in groundwater environment. It is known that chemical composition of inflowing groundwater can be of high importance for associated aquatic ecosystems. This is because of nutrients and electron acceptors (e.g. sulfate) that groundwater transports into the ecosystem and thus creates unique physico-chemical conditions in the lake itself (Jakeman et al. 2016).

The risk assessment for groundwater pollution must be carried out evaluating natural aquifer vulnerability in combination with the pressures from human activities (land cover changes) that are present or might occur in the future (Fig. 2.3.1). The areas with the highest vulnerability to pollution and intensive anthropogenic pressures (e.g. agricultural activity) pose the highest risk to pollution migration from surface to groundwater, and consequently, to associated aquatic ecosystems (e.g. lake).

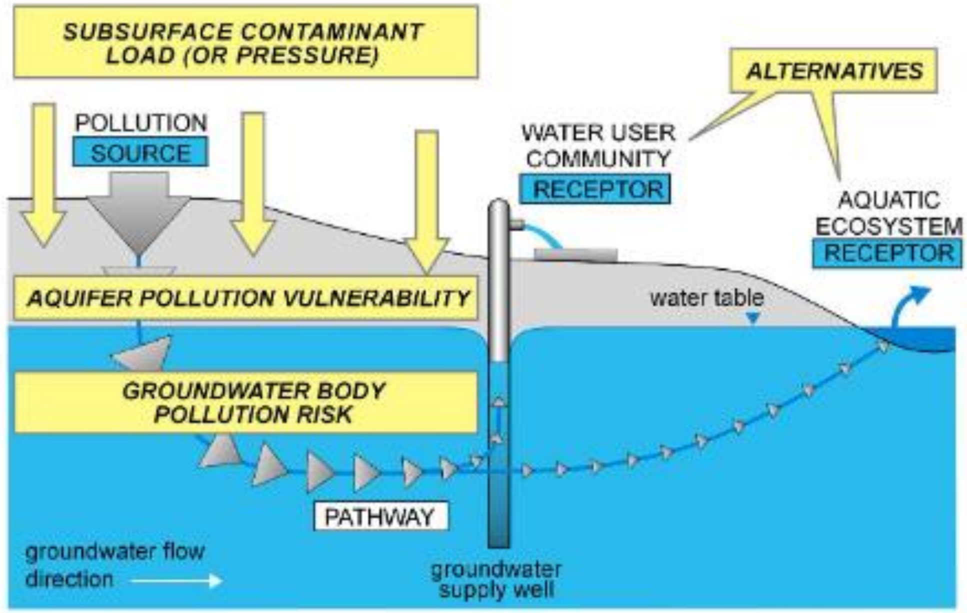

Figure 2.3.1. Conceptual Schemes of Groundwater Pollution Risk Assessment (European Commission, 2004)

According to the initial assessment of Ilzu (Garais)/Ilge Lake' catchment, the area is dominated by forests (mixed forests, broad-leaved forests and transitional woodlands/ shrub), water bodies and agricultural lands with significant areas of natural vegetation. While agricultural areas like pastures and non-irrigated arable land, which typically pose a high risk for groundwater pollution with nutrients, form only a small part of the catchment ~9%. The proportion of such land use areas increases to ~10% if the area of Ilzu (Garais)/Ilge Lake itself is excluded (TRANSWAT Project report, 2022).

Land use	Area, ha	Area, %
Pastures	58.1	6.6
Non-irrigated arable land	20.6	2.4
Mixed forest	210.1	24.1
Broad-leaved forest	24.3	2.8
Transitional woodlands shrub	103.4	11.9
Water body	131.0	15.0
Agriculture lands with significant areas of natural vegetation	324.1	37.2
Total	**871.6**	**100**

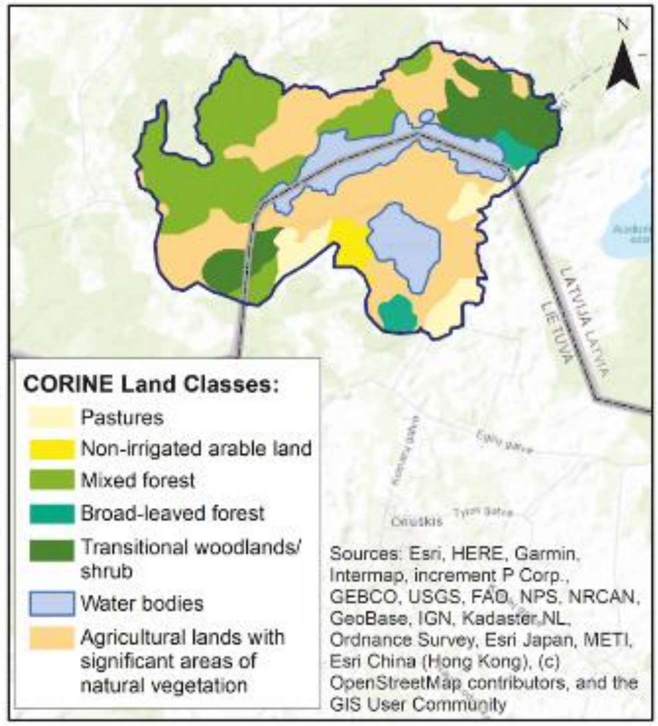

Figure 2.3.2. Land use types in the catchment of Ilzu (Garais)/Ilge Lake (TRANSWAT report, 2022).

To assess the potential risk to groundwater pollution or groundwater vulnerability to pollution we used the DRASTIC method developed by the U.S. Environmental Protection Agency (USEPA), and GIS software. DRASTIC index or vulnerability assessment was calculated using seven hydrogeological parameters (depth to groundwater (D), net recharge (R), aquifer media (A), soil media (S), topography (T), the impact of vadose zone (I) and hydraulic conductivity (C)) that were developed as spatial layers using the existing knowledge base and available information about the study area. DRASTIC index was calculated according to the following formula:

DRASTIC index (vulnerability rating) = DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw, where w is weight and r is rank.

For a defined area being investigated, each criterion is assigned a typical range and a rating relative value scale (r, Rating) from 1 to 10. In this scale, the higher values represent more sensitive areas for contamination. These index criteria further are combined in an additive equation. Moreover, each criterion is decided a weight factor (w), from 1 to 5, reveal the relative importance of each factor. Hydrogeological parameters used to calculate DRASTIC index for the lake’s Ilzes (Garais)/Ilzu catchment are presented in Table 2.3.1.

Table 2.3.1. Hydrogeological parameters used to calculate DRASTIC index

Parameter	Weight (w)	Range	Rating (r)
Depth to groundwater in meter **(D)**	5	<2 2-5 >5	10 9 7
Net recharge in mm/year **(R)**	4	80 34	5 9
Aquifer media **(A)**	3	Sand and gravel	8
Soil media **(S)**	2	Clay	3
Topography, %Slope **(T)**	1	<3 3-5 5-10 10-15 >15	10 9 5 3 1
Vadose zone **(I)**	5	Sand and gravel Till	8 1
Hydraulic conductivity in meter/day **(C)**	3	<5	1

Depth of groundwater (D): Depth to water is considered an important variable with respect to groundwater sensitivity, because it represents the distance a contaminant must travel through the unsaturated zone before reaching the water table. Depth to groundwater was assumed from existing hydrogeological modeling results of a regional scale. It is worth mentioning that deeper groundwater (low water table) is less vulnerable than higher water table aquifers. In the study area the depth to groundwater table varies from 1 to >5 meters, therefore in DRASTIC calculations the rating was set from 7 (representing deep groundwater) to 10 (representing shallow groundwater).

Net recharge (R): Yet an important factor for groundwater vulnerability, as the contaminant moves with the rainfall water as infiltration and goes down deep into the aquifer saturated layer. In the study area precipitation is the major source of groundwater recharge. Net recharge criterion of this study is taken from literature, where net recharge for sand and gravel sediments is set as 340 mm/year, but for till sediments - 80 mm/year (Prols J., Dēliņa A., 1997). Distribution is presented in Figure 2.3.3.

Aquifer media (A). The aquifer layer acts as a main function over the pathway and leaching of contaminants. Normally, the larger the particle size distribution or the more permeable rock within the aquifer - the higher the permeability and the lower the attenuation capacity. For this study we assumed that the aquifer material within the whole study area is sand and gravel (Fig. 2.3.3). Therefore, only one DRASTIC rating (8) was set for the parameter “aquifer media”.

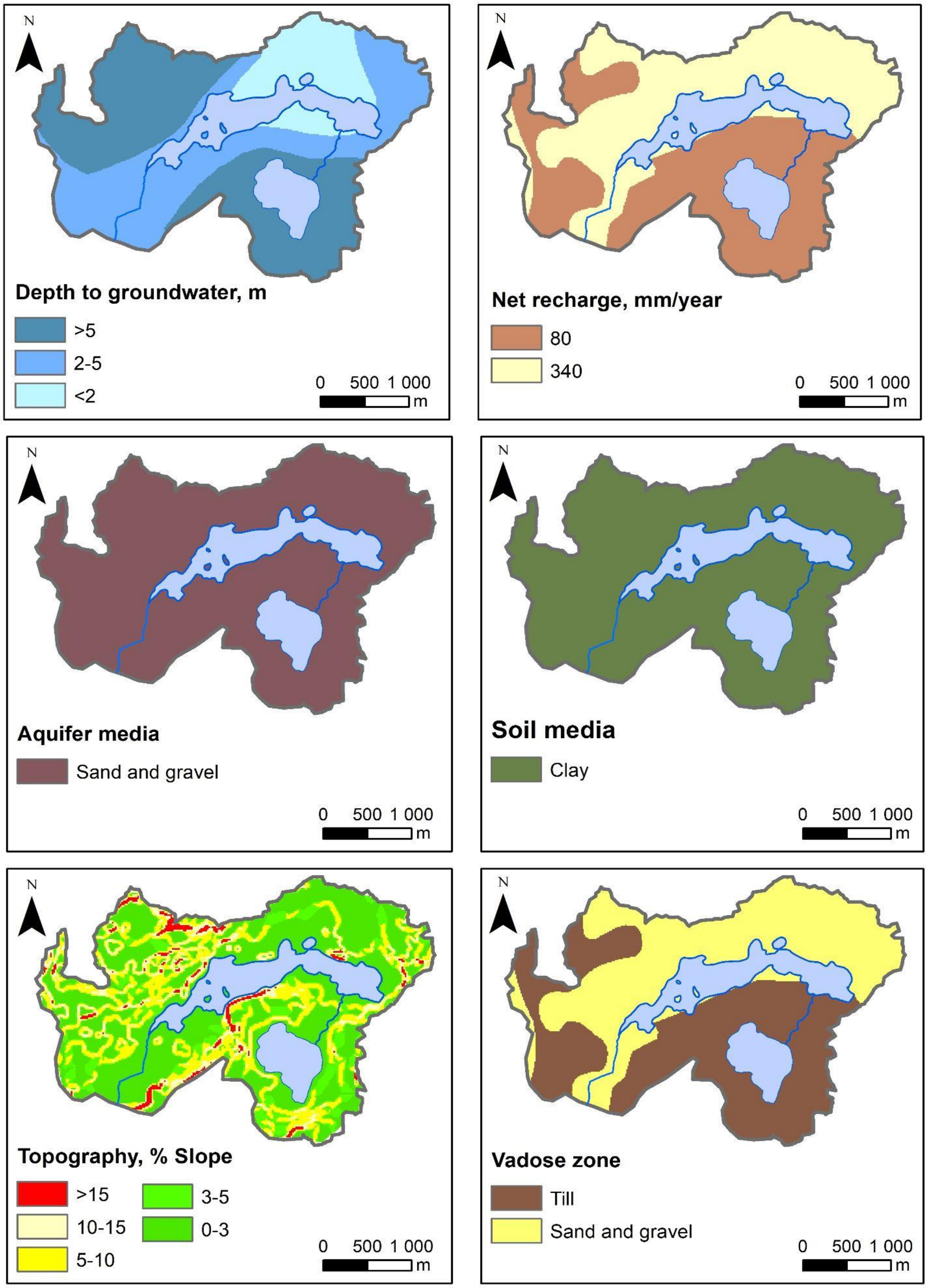

Figure 2.3.3. Used parameters (Depth to groundwater, Net recharge, Aquifer media, Soil media, Topography and Vadose zone) for calculation of DRASTIC vulnerability index for Ilzu (Garais)/Ilge Lake catchment.

Soil media (S): The soil layer is the upper part of the vadose zone which averages to a depth of 2 m or less from the ground surface. Soil properties affect groundwater pollution migration potential as they control the movement of contaminants. The soil media map is given in Figure 2.3.3.

Topography (T): Slope can be defined as the measure of steepness of an area. The area having low slope leads to storage of water that gives more time to water to percolate as compared to areas having large slope. The areas of low slope have greater potential for contamination infiltration and are more vulnerable to groundwater pollution. The slope was determined from the Digital Elevation Model, using ArcGIS. The slope map is given in the (Fig. 2.3.3). Slope variation in the study area is divided into five classes, namely, <3%, 3-5%, 5-10%, 10-15% and >15%. Topography ratings, according to standard DRASTIC for this area study are 1 to 10.

Impact of the vadose zone (I): The vadose zone is an unsaturated layer above the water table. The impact of vadose zone on groundwater potential contamination is in principle identical to that of characteristic soil cover. The impact of vadose zone is a difficult phenomenon, depending on aquifer layers and topographic characteristics. A higher impact of vadose zone is, if it is composed of porous soils. The data for impact of vadose zone was retrieved from identification and classification of the quaternary geology map. For the parameter “impact of the vadose zone” rating values from 1 to 8 were assigned (Fig. 2.3.3). Higher rating value means higher vulnerability.

Hydraulic Conductivity (C): Hydraulic conductivity represents the capacity of the aquifer materials to transmit water enabling to control the rate at which groundwater will flow under a specified hydraulic gradient. With increment in hydraulic conductivity, groundwater velocity along with the speed at which pollutants are transported also increases resulting in the rise in aquifer vulnerability. Hydraulic conductivity was taken from the previous literature and was assumed to be relatively small for sand and gravel sediments, reaching a maximum 5 meters per day.

Using the previously described seven layers of hydrogeological parameters (descriptors) and by using the Spatial Analyst tool, the vulnerability map for groundwater pollution was created for the study area with three vulnerability classes: low, moderate and high (Fig. 2.3.4. A). The range of DRASTIC vulnerability index in the study area varies from 94 to 169. As it can be observed, in large part of the catchment the areas with high vulnerability to pollution dominate and they coincide with fluvioglacial sediments (sand and gravel, fQ_3*ltv*) distribution in the territory. Then follow areas with moderate vulnerability, while only in small portion of the catchment there are areas that can be assumed as protected from potential pollution migration into groundwater, namely, low vulnerability areas.

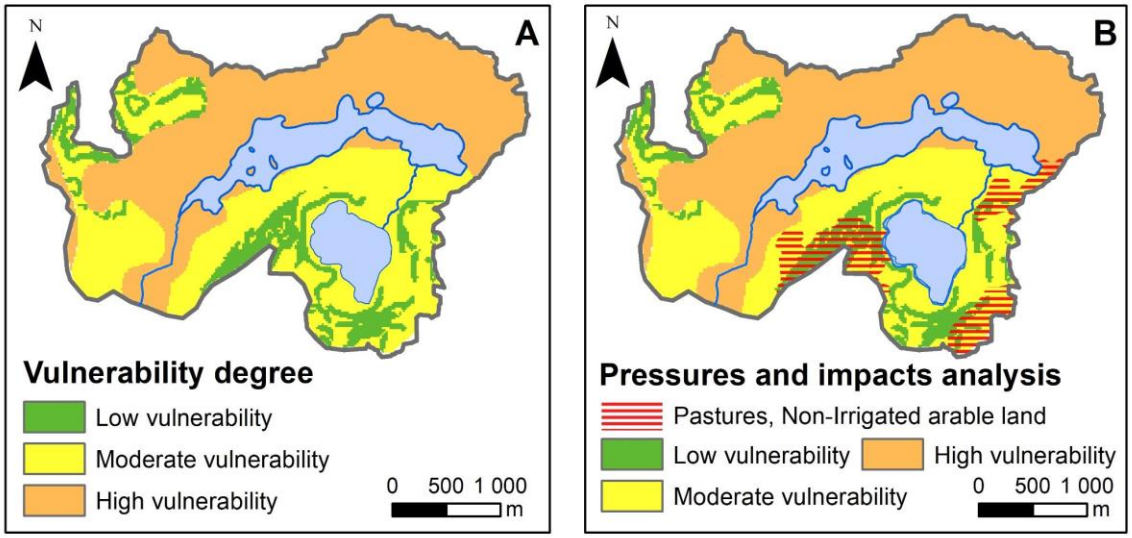

Figure 2.3.4. A . DRASTIC vulnerability map, B - Pressures and impacts analysis

Agricultural areas (pastures and non-irrigated arable land) that might put a high risk to groundwater pollution with e.g. nutrients in the Ilzu (Garais)/Ilge Lake's catchment, are mainly located in territories assessed as low and moderate vulnerability. This allows us to assume that groundwater is less exposed to such type of pollution in the study area and the main source of nutrients in the lake could be surface runoff, rather than groundwater input.

It should be highlighted that more detailed assessment of the catchment area is necessary to assess all ecological risks associated with surface-groundwater interaction with high confidence. New hydrological and hydrogeological data should be gathered (by installation of monitoring wells and seasonal groundwater quality sampling) to develop up-to-date understanding of processes and pathways in the study area, especially in the context of climate change. In this research such new data were not planned to be obtained and gathered, therefore the assessment was theoretical, with low confidence and based on regionally available datasets. New studies in the future would allow us to gather missing and up-to-date datasets to update developed DRASTIC vulnerability map. Moreover, data gathered on site could be used to calibrate and validate the developed vulnerability map and adapt (if necessary) the assessment procedure.

2.4. Nutrient source apportionment

To evaluate the nitrogen and phosphorus loads in the Lake FyrisNP tool for catchment-scale modeling of nutrients was used. Modeling was carried out for a period of 22 years (2000-2021). The year 2021 was analyzed deeply due to the availability of additional Ntot and Ptot concentration and water level data. Hence the model results for 2021 are more reliable (TRANSWAT Project report, 2022).

The modeling results show that the greatest share of nitrogen loads within the catchment originate from arable lands and forests - 54 % and 34 % respectively.

The graphs below (Fig. 2.4.1 and Fig. 2.4.2) show nitrogen (N) and phosphorus (P) load distributions by sectors in Ilzu (Garais)/Ilge Lake catchment for 2021.

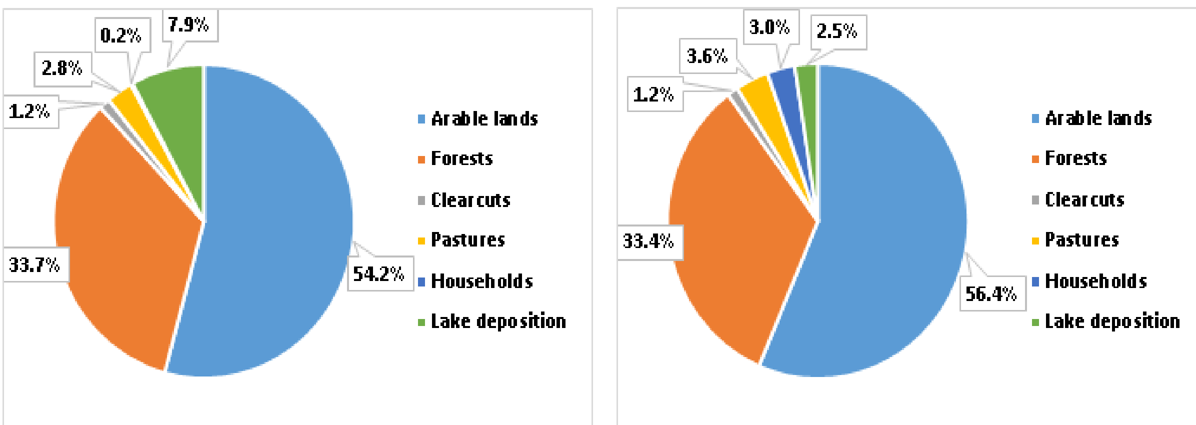

Figure 2.4.1. N source (left graph) and P source (right graph) apportionment in Ilzu(Garais)/Ilge Lake catchment

Loads are also calculated by months, not just by years. The largest N runoff occurs in spring but it increasing is also observed in winter. Large P runoff occurs in both spring and summer. Figures 2.4.2. illustrate the N and P load volumes by months in Ilzu (Garais)/Ilge Lake catchment in 2021.

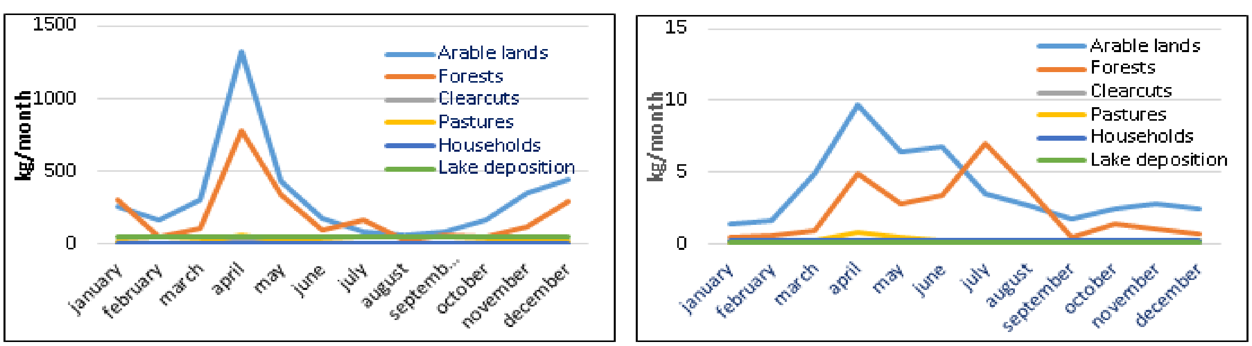

Figure 2.4.2. N load volumes (left graph) and P load volume (right graph) by months in Ilzu (Garais)/Ilge Lake catchment

Table 2.4.1. shows the amounts of N and P from different sources in the year 2021 for the Ilzu (Garais)/Ilge Lake catchment. It should be noted that not all arable lands and pastures runoff is considered to be an anthropogenic load, because arable lands and pastures also have a so-called *background* - natural N and P runoff. Therefore, it can be concluded that in general the largest N and P load is caused by natural sources.

Table 2.4.1. N and P loads from different sources in Ilzu (Garais)/Ilge Lake catchment

Nutrient	Arable lands	Forests	Clearcuts	Pastures	Households	Lake deposition
N, kg	3835,8	2386,7	83,6	198,7	14,1	558,0
P, kg	46,4	27,5	1	2,9	2,5	2

According to Latvian 3rd cycle River basin management plans 2022-2027, the most significant pressure on the lake is the risk of transboundary pollution from Lithuanian side. Diffuse pressure from forests and agricultural lands are considered insignificant.

In Lithuania, Lake Ilzu (Garais)/Ilge has not been previously identified as a water body, and has therefore not been monitored. The lake shore is subject to quite intensive economic activity, but there are no known point sources of pollution (no wastewater treatment plants that exceed the volume of wastewater discharged, which triggers the obligation to register the treatment plants and to monitor the quality of the wastewater.
Taking into account the most intensive agriculture in 70s - 80s of the last century, can assume that pollutants might be accumulated in the bottom sediments of lake and lead the secondary water pollution. Therefore, diffuse pollution on Lithuanian side and secondary pollution from the bottom sediments are the main sources of the Lake Ilzu (Garais)/Ilge’ medium ecological quality.

2.5. Groundwater abstraction

To initially assess if groundwater abstraction can influence Ilzu (Garais)/ Ilge lake’s quantitative status, the available data from Latvian Environment, Geology and Meteorology Centre’s database “Wells” and “2-Water” system were gathered. There are no registered water supply wells in the catchment area, but the nearest wells are located 0.7-1.2 km far from the study area and concern the deeper Gauja-Amata (D3gj+am) aquifer (with interval 70-90 m from the surface). It is worth to mention that there is almost no hydraulic connection with deeper located confined aquifers (D3gj+am), therefore it is presumed that the only groundwater input into the lake comes from shallow groundwater recharged within the watershed area.

Considering that Ilzu (Garais)/ Ilge Lake is a shallow lake and mostly connected only with shallow quaternary sediments, old topographic maps were analyzed additionally to look for potential dug wells in the catchment area. As a result, eight dug wells were identified with depth varying from 3 to 8 meters that might be currently used to supply household needs in the catchment area. But the water abstraction from such dug wells is usually small and we did not verify their locations in the nature. Visually identified potential locations of dug wells are represented in Figure 2.5.1.

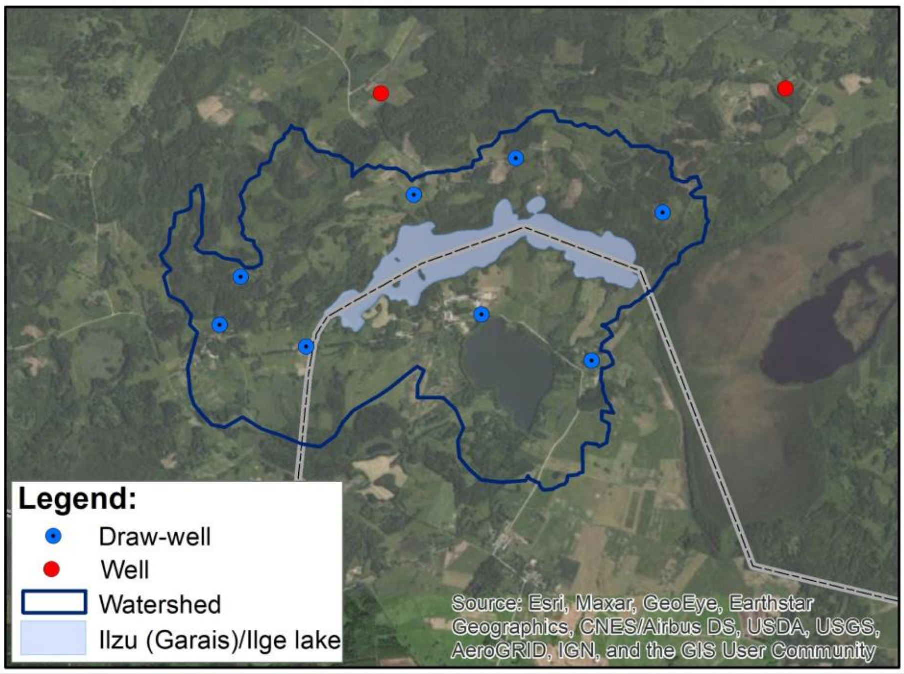

***Figure 2.5.1. Location of water supply wells and dug wells in the catchment area*.**

Officially there is no information in the register about groundwater abstraction amounts in the catchment area. Therefore, it is impossible to assess if groundwater abstraction takes place in significant amounts in the area or if the current abstraction influences the lake's Ilzes (Garais)/ Ilzu quantitative status. First, the identification of all water abstraction sites should be carried out (including potential water abstraction from the lake itself). Second, the abstraction amounts should be gathered, if possible, including their changes during the seasons. Third, groundwater level measurements should be obtained to identify if there are local depression cones formed as a result of intensive abstraction. Currently, we assume that only dug wells are exploited in the catchment area with typically low abstraction rates that cannot influence the lake's ecological status. But this assessment is theoretical and with low confidence.

III RESULTS AND RECOMMENDATIONS

It is evident that the Ilzu (Garais)/Ilge Lake has zero water mass balance, when total inflow and precipitation are equal to total outflow and evaporation.

The average length of time water remains within the boundaries of an aquatic system (residence time) is one of the key parameters controlling the system's biogeochemical behavior. An approximate residence time of Lake is more than 260 days. This quite a long period for accumulation of pollutants in sediments. For the very reason contaminated sediments might lead the moderate quality of Lake' water.

Data analysis results shows that under current anthropogenic load the groundwater cannot affect the ecological status of the Ilzu (Garais)/Ilge Lake and consequently to worsen its chemical quality, as well as affect the hydromorphological status of the Lake. At present, significant groundwater abstraction has been identified in the Lake' catchment area. However the groundwater cannot be considered as the main source of pollution. Taking into account the agricultural areas (pastures and non-irrigated arable land) that usually increase the pollution risk of groundwater with e.g. nutrients, might be concluded that the Ilzu (Garais)/Ilge Lake's catchment is located in territories assessed as low and moderate vulnerability.
As this initial assessment is theoretical and of low reliability, it is recommended to collect more actual data on the abstraction of groundwater within the catchment area of the Lake. It is also necessary to obtain the new hydrological and hydrogeological data (by installing monitoring wells and seasonal groundwater quality sampling) in order to understand the actual processes and pathways in the study area, especially in the context of climate change. The data will allow to update and to refine the vulnerability map that was currently created.

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