EVALUATING GIS BASED WATER BUDGET COMPONENTS APPLICABILITY AND AVAILABILITY FOR THE LAGAN RIVER CATCHMENT

UTVÄRDERING AV GIS-BASERADE VATTENBUDGETSKOMPONENTER FÖR LAGANS AVRINNINGSOMRÅDE UTIFRÅN TILLÄMPLIGHET OCH TILLGÄNGLIGHET

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Abstract
Using open-access data sets on water and soil from Swedish authorities and compiling them in a QGIS-programme made it possible to present and visualise the water budget of the Lagan River Catchment. Based on the estimations of the water volume in groundwater reservoirs and lakes the total maximum available volume in the Lagan River Catchment area was determined to be 9.36 km^3. Of this 75.9% (7.10 km^3) is found within groundwater reservoirs and 24.1% (2.26 km^3) is present in lakes. This study indicates that GIS-based parameters are useful for specifying what a water budget in a catchment area looks like. The use of GIS-based parameters also allows for the development of interactive maps which can be used to visualize different conditions in the catchment area. In addition, many people who work with water management have a good habit of using GIS tools. Utilizing open data sources means that the number of additional measurements can be kept low. Furthermore, the use of open sources contributes to increased transparency in the development process.

Sammanfattning
Med hjälp av öppna datakällor från svenska myndigheter om vatten och mark vilka sammanställdes i ett QGIS-program var det möjligt att presentera och åskådliggöra vattenbudgeten i Lagans avrinningsområden. Den sammanlagda vattenmängden i avrinningsområdet kunde uppskattas till 9,36 km^3 varav 75,9 % (7,10 km^3) är grundvatten och 24,1 % (2,26 km^3) finns i sjöarna i området. Studien pekar på att GIS-baserade parametrar är användbara för att precisera hur en vattenbudget i ett avrinningsområde ser ut. Vidare möjliggör även användandet av GIS-baserade parametrar framtagandet av olika interaktiva kartor för att visualisera olika förhållanden i avrinningsområdet. Många som arbetar med vattenförvaltning har därtill en god vana vid att använda GIS-verktyg. Användandet av öppna datakällor från myndigheter innebär få eller inga kompletterande mätningar behöver göras i fält. Vidare bidrar användandet av öppna källor till en ökad transparensen när vattenbudgeten tas fram.

Key words: water balance, water budget, catchment management, GIS, Lagan River Catchment

Introduction

Problems related to high levels of freshwater scarcity have traditionally been associated with arid areas with low natural water availability (Mekonnen & Hoekstra, 2016). However, in recent years the number of high water scarcity level reports have increased from previously unaffected areas (Wada et al., 2013). One reason behind this is the rapid increase in the total global population and quality of life over the last few decades (Pereira, Cordery, & Iacovides, 2009). This is especially evident in the growing urban populations around the world, where a higher population density combined with an increased demand of goods increase the stress on water resources as well as other natural resources (Jiang, 2009).

Another important reason beside the increased stress on existing water bodies is that it is becoming impossible for the developed country to ignore the inevitable effects of climate change (Schewe et al., 2014). While extreme events such as droughts and flooding have previously been isolated incidence in the developed countries, the increased occurrence and severity of these events have highlighted the importance of water resource management, even in areas previously unaffected (Mekonnen & Hoekstra, 2016; Schewe et al., 2019).

In Sweden one of the more prominent recent drought took place in 2018, when large parts of Sweden, as well as northern and central Europe, was hit by the worst heatwave in approximately 500 years (Fennell et al., 2020; Veijalainen et al., 2019). As a result, many municipalities in Sweden were struck by high water scarcity levels and forced to implement temporary outdoor water-use restrictions and irrigation bans (Sjökvist et al., 2019). Despite this, many municipalities experienced disturbed recharge rates leading to the depletion of many groundwater reservoirs in the months following the peak of the drought (Åström et al., 2019).

Though the depletion of groundwater reservoirs underscores the extreme water stress some regions in Sweden experienced in the months following the 2018 drought, it first and foremost highlights the lack of a quantitative understanding in the current water resources management. While often driven by good intentions, most methods for the quantification of freshwater levels are heavily reliant on projections, assumptions, and interpolations (Banks et al., 2011; Krysanova & White, 2015; Ritchie, 1981) This not only makes it difficult to properly quantify individual water bodies but introduce a high level of epistemic uncertainty to any attempt to assess the total available volume (Bulygina & Gupta, 2009; Chen et al., 2011).

Beside from the difficulties associated with the current available methods for the quantification of water bodies, water resource management is further complicated by the lack of a broad approach (Heathcote, 2009). Rather than developing a management system based of the natural movement and delineation of water sources, the supervision and management of water bodies have historically been incorporated into pre-existing administrative units (Liu et al., 2020). Given that water seldom follows man-defined administrative borders water resource management, the bigger picture is often lost or diminished, as emphasis historically have been placed on pressing local matters (Pollard & du Toit, 2005). However, with water scarcity quickly becoming a wide-spread problem, there is an amplified need to improve the accuracy and reliability in the quantification of groundwater reservoirs and surface water bodies.

Research question & delimitation

In this study we aim to explore to what extent the assessment of open-source data through the application of Geographical Information Systems (GIS) based approach can be used to assess the maximum volume of available water in a catchment area.

To the limit the amount of data assessed, only groundwater reservoirs in the saturated soil and lakes were included in the final assessment. However, future assessments aim to include confined bedrock aquifers, rivers, and streams, as well as some level of uncertainty analysis to strengthen the reliability of the assessment.

Figure 1. *Map showing the delineation of the Lagan River Catchment area.*

Materials and methods

Study area description

The Lagan River catchment is located in the southwestern parts of Sweden, see figure 1. Stretching 244 km from Tahesjön in the north to Fagerhultasjön in the south before entering Kattegat at Snapparp, the Lagan River and its tributaries drain an area of 6 445 km^2.

The catchment area consists of four counties and seventeen municipalities. Of the four counties (Skåne County, Halland County, Kronoberg County, and Jönköping County) a vast majority of the catchment (86.4%) can be found within Jönköping County (53.1%) and Kronoberg County (33.3%). Of the seventeen municipalities within the catchment area the three largest Ljungby (22.5%), Värnamo (18.5%) and Vaggeryd (12.2%) make up more than half of the catchment area (53.2%), with the rest of the catchment being located within Sävsjö (9.8%), Laholm (9.4%), Markaryd (7.8%), Nässjö (3.9%), Gnosjö (3.7%), Gislaved (3.2%), Hylte (2.6%), Jönköping (1.9%), Alvesta (1.9%), Växjö (1.0%), Örkelljunga (1.0%), Halmstad (0.3%), Hässleholm (0.2%), Älmhult (0.1%). In addition, there are 50 urban areas with a population of over 200 within the catchment area, with Värnamo (19778) and Ljungby (16052) being the only two major with a population of above 10000 (SCB, 2021).

The landscape is dominated by mixed coniferous forest, although agricultural land makes up a large percentage of the southwestern parts of the catchment area. The major economic activities include forestry, agriculture, energy production, as well as light- and heavy industry.

From a water perspective, the Lagan River catchment area is one of Sweden's most important water sources, as more then 500 000 people depend on the continuous water supply from the many lakes and groundwater reservoirs located within the catchment. Out of these, the largest lake, Lake Bolmen, also happens to be the most important and largest water source, with a mean withdrawal of 1 400 l/s (Sydvatten, 2015).

Included GIS-based parameters

For this study the following nine parameters were included: main catchment area, topography, municipal borders, county borders, lakes, mean depth, groundwater reservoirs, soil composition, soil depth. As software, QGIS version 3.16.6 and 3.16.10 were used to prepare, analyse, and map the identified data components.

Geographical parameters

Geographical parameters are often used to visualize and understand the effect different physical features have on the path and delineation of the water (Liu et al., 2020). This is especially true when assessing drainage lines and sink from a catchment perspective. In addition to visualize the delineation, the use of geographical parameters such as "Main catchment area" can also be applied when analysing the movement, flow, and connectivity of surface water and groundwater (Krause & Bronstert, 2005).

In this study, the delineation of the Lagan River Catchment area was obtained from SMHI through the datafile "Haro_y_2016.shp" available through the database Vattenwebb, see "Main catchment area (HARO)" in table 1. The information was then then imported to a new QGIS library, see "A" in figure 2. For the visualization of the main catchment area was then imported to a new QGIS library, see "A" in figure 2.

Another important geographical parameter is the topography. Most commonly used in the assessment of the natural movement and flow of water (Liu et al., 2020), the parameter can also be used when assessing sediment transport (Llena et al., 2019), and effects of increased levels of organic compounds within a catchment area (Lintern et al., 2018).

In this study, information regarding the topography of the Lagan River Catchment area was determined using the "Fill Sinks xxl" module developed by Wang & Liu available within the SAGA-QGIS software (Wang & Liu, 2006). The data was then fitted to the predefined catchment delineation using the geoprocessing tool "Clip Raster by Mask Layer" available in QGIS 3.16.6, see "B" in figure 2.

Administrative borders

The delineation and visualization of administrative borders is predominately used to identify legal boundaries and the division of responsibilities between authorities (Pollard & du Toit, 2005). The parameter "Municipal borders" is especially used to assess the division on a local scale. However, the parameter can also be used when assessing issues related to land use.

Similar to municipalities, counties also play an important role in water management. Visualizing the range of county borders is a useful tool when trying to understand the legal jurisdiction within an area (Pollard & du Toit, 2005). Predominately used to identify regional authorities responsible of a specific lake or groundwater reservoir (Heathcote, 2009), the parameter can also be used to identify areas with overlapping jurisdiction and shared water bodies (Griffin, 2016).

In this study, information regarding both the parameter "Municipal borders" and "County borders" within the Lagan River Catchment was obtained from SCB through the database Digitala gränser, see "Municipal borders" and "County borders" in table 1. The data was then fitted to the predefined catchment delineation using the geoprocessing tool "Clip" available in QGIS 3.16.6, see "C" and "D" in figure 2.

Surface water bodies

The delineation of lakes is often used when assessing hydromorphological factors such as area (Krysanova & White, 2015), and connectivity of specific water columns (Eini et al., 2020).

In this study, information regarding the location and area of lakes within the Lagan River Catchment was obtained from SMHI through the datafile "Vattenytor_SVAR_2016_3.shp" available through the database Vattenwebb, see "Lakes" in table 1. The data was then fitted to the predefined

Table 1. *Table showing the nine GIS-layers used in the assessment of total maximum available volume in the Lagan River Catchment..*

Parameter	Data host	Data storage	Data source	Format
Main catchment area (HARO)	SMHI	Vattenwebb	Haro_y_2016	ESRI Shape (.shp)
Municipal borders	SCB	Digitala gränser	Kommun_Sweref99TM_region	ESRI Shape (.shp)
County borders	SCB	Digitala gränser	Lan_Sweref99TM_region	ESRI Shape (.shp)
Topography	NASA / NGA	Shuttle Radar Topography Mission (SRTM)	SRTM-Downloader 3.1.13	TIFF (8-bit)
Groundwater reservoirs	SGU	Geolagret	Grundvatten 1:1 miljon	ESRI Shape (.shp)
Soil composition	SGU	Geolagret	Jordarter 1:1 miljon	TIFF (8-bit)
Soil depth	SGU / SLU	Zeus.SLU.se	Jorddjup_10x10m	TIFF (8-bit)
Lakes	SMHI	Vattenwebb	Vattenytor_SVAR_2016_3	ESRI Shape (.shp)
Mean depth (lakes)	SMHI	Vattenwebb	sjödata_shape	ESRI Shape (.shp)

catchment delineation using the geoprocessing tool "Clip" available in QGIS 3.16.6, see "E" in figure 2.

Another parameter used in the analysis of surface water bodies is "Mean depth". Most commonly used when assessing the fixed capacity of lakes, mean depth can also be used to assess the structure of surface water bodies (Bulygina & Gupta, 2009).

In this study, information regarding the mean depth of lakes within the Lagan River Catchment was obtained from SMHI through the datafile "sjödata_shape.shp" available through the database Vattenwebb, see "Mean depth (lakes)" in table 1. The data was then fitted to the defined groundwater reservoirs using the geoprocessing tool "Clip" available in QGIS 3.16.6, see "F" in figure 2.

Geohydrological parameters

Geohydrological parameters are often used when assessing factors such as the natural delineation (Heath, 1983), and carrying capacity of groundwater reservoirs (Liu et al., 2020).

In this study, information regarding the location and area of groundwater reservoirs within the Lagan River Catchment was obtained from SGU through the datafile "Grundvatten 1:1 miljon" available through the database Geolagret, see "Groundwater reservoirs" in table 1. The data was then fitted to the predefined catchment delineation using the geoprocessing tool "Clip" available in QGIS 3.16.6, see "G" in figure 2.

Another useful geographical parameter when assessing the delineation of groundwater reservoirs is "Soil depth". By assessing the soil depth of a specific reservoirs, the height of the reservoir can be estimated (Gassman et al., 2007).

In this study, information regarding the soil depth, d, within the Lagan River Catchment was obtained from SGU through the datafile "Jorddjup_10x10m.tif" available through the database Geolagret, see "Soil depth" in table 1. The data was initially converted into an ESRI Shapefile (.shp) using the geoprocessing tool "Polygonize" and fitted to the defined groundwater reservoirs using the geoprocessing tool "Clip Raster by Mask Layer" available in QGIS 3.16.6, see "I" in figure 2.

To assess the carry capacity of groundwater reservoirs, "Soil composition" was included in the assessment (Liu et al., 2020; Ritchie, 1981). While predominately used in hydrological modelling, soil

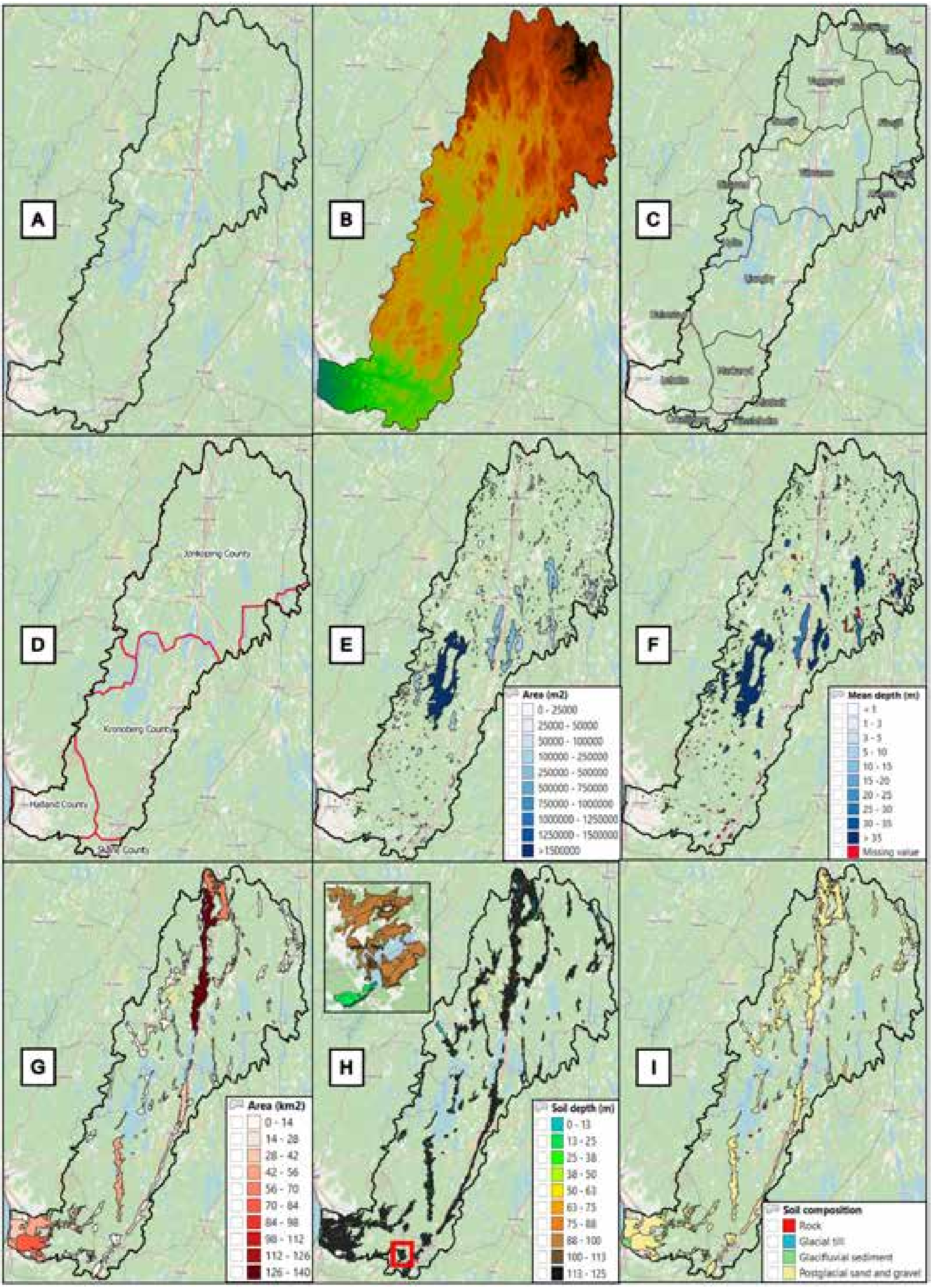

Figure 2. *The nine GIS-layers used in the assessment of total maximum available volume in the Lagan River Catchment. A) The Lagan River Catchment Area B) Topography, meter above sea level C) Municipal boundaries D) County boundaries E) Lake area (m²) F) Mean depth, lakes (m) G) Area, groundwater reservoirs (km²) H) Soil depth, groundwater reservoirs (m) I) Soil composition, groundwater reservoirs*

composition can also be used in water management to identify areas with high potential evaporation (Ji & Unger, 2001).

In this study, information regarding the soil composition within the Lagan River Catchment was obtained from SGU through the datafile "Jordarter 1:1 miljon.tif" available through the database Geolagret, see "Soil composition" in table 1. The data was then fitted to the defined groundwater reservoirs using the geoprocessing tool "Clip Raster by Mask Layer" available in QGIS 3.16.6. Next the data was converted into an ESRI Shapefile (.shp) using the geoprocessing tool "Polygonize", see "H" in figure 2.

Methods

To assess the total available water in the Lagan River Catchment the maximum volume must first be obtained for each individual lake and groundwater reservoir within the catchment area.

Starting with the lakes, the maximum available surface water, W, was determined for each individual lake, *i*, using:

$$W_i = A_i * \bar{d_\iota}$$

where A_i is the area of lake *I*, and $\bar{d_i}$ is the mean depth of the lake.

The area, *A*, was obtained for all individual lakes from *Vattenytor_SVAR_2016_3.shp.*

Next, the mean depth, $\bar{d}$, was obtained for all individual lakes from *sjödata_shape.shp.*

Finally, the total maximum available surface water in lakes, $\widehat{W}$, was then determined for the entire catchment area using:

$$\widehat{W} = \sum_{i=1}^{I} W_i$$

Once the total maximum available surface water was obtained, the maximum available water, G_q, was determined for each individual groundwater reservoir, q, using:

$$G_q = A_q * \overline{d_q} * S_q$$

where A_q is the area of groundwater reservoir *q*, $\bar{d}_q$ is the mean soil depth within the examined area expressed in km, and S_q is the estimated degree of saturation expressed in %.

First, the area of each aquifer A_q was obtained from *Grundvatten 1:1 miljon.shp.*

Next, the mean soil depth, $\bar{d}$, was determined for the area within each individual groundwater reservoir using:

$$\bar{d} = \frac{1}{N}\left(\sum_{n=1}^{N} d_n\right)$$

where d_n is the value on depth *n* where *n = 1:N.*

Finally, the degree of saturation, *S*, was set for each available soil composition. Areas dominated by postglacial sand and gravel is given a coefficient of 0,3, areas dominated by glacifluvial sediment is given a coefficient of 0,25, areas dominated by glacial till is given a coefficient of 0,1, and areas dominated by rock is given a coefficient of 0,01.

Based on the results, the total maximum available groundwater storage for the catchment area, $\widehat{G}$., was determined using:

$$\widehat{G} = \sum_{q=1}^{Q} G_q$$

Results

Of the 511 lakes within the catchment area, the maximum available volume could not be obtained for 272 due to missing value for "Mean depth (m)", see A in figure 3. While constituting 53.2 % of the total number of surface waters, the total area only account for 12.8 % of the total surface water area.

For the 239 lakes within the studied area, for which the maximum available volume could be obtained, the total maximum available volume freshwater was estimated to 2.26 km^3, or 2.26 * 10^{12} liter. Of this, 1.91 km^3, or 84.5 % of the total maximum available volume, was estimated to be located within the ten largest lakes, see table 2.

Of the 97 groundwater reservoirs assessed within the catchment area, the maximum available volume was obtained for all but one, see B in figure 3.

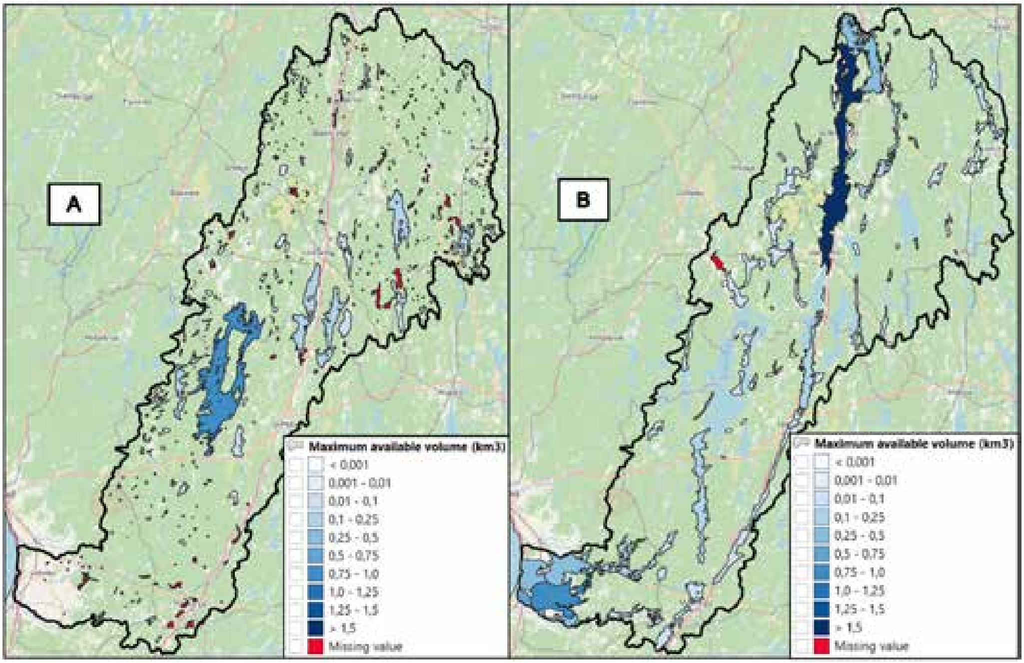

Figure 3. *Maps showing the total maximum available volume of freshwater within the Lagan River Catchment. A) Maximum available volume (km^3), groundwater reservoirs B) Maximum available volume (km^3), lake*

For the 96 groundwater reservoirs, for which the maximum available volume could be obtained, the total maximum available volume freshwater was estimated to 7.10 km^3 or 7.10 * 10^{12} l. Of this, 5.42 km^3 , or 76.5 %, of the total maximum available volume was estimated to be located within the ten largest aquifers in the studied area, see table 3.

Based on the estimations of the total maximum available volume in aquifers and lakes the total maximum available volume in the Lagan River Catchment area was determined to be 9.36 km^3. Of this 75.9% (7.10 km^3) is found within groundwater reservoirs and 24.1% (2.26 km^3) is bound in lakes. Maximum available volume (km^3), lakes.

Discussion

All data layers are available for free and as open access data sets from Swedish Authorities. The results obtained from this study indicates that the use of GIS-based approaches, such as the one suggested in this paper in, holds several promises when applied on a catchment level.

First, no, or limited, additional sampling is required (Verma et al., 2012). This has several benefits, as it not only is possible to get an adequate estimation without the need of a prolonged sampling but ensure that the overall costs of each individual assessment are kept at a minimum (Pereira et al., 2009). In addition, the use of open-access data further ensures that a high level of transparency is maintained throughout the assessment, as stakeholders and decision-makers are provided the same access as the one conducting the assessment (Martin et al., 2005).

Secondly, GIS-based approaches allow for the development of interactive maps (Martin et al., 2005). Though often overlooked, it is important to remember that the way we communicate results heavily influences how stakeholders and decision-makers perceive the information (Witcher, 1999). By utilizing a familiar medium such as maps, managers not only decrease the risk of misunderstandings, but ensure that the information is made available to the broad masses. This is especially important during periods

Table 2. *Table showing the ten lakes with the highest maximal available volume (km³) within the Lagan River Catchment.*

Name	Municipality	Volume (km³)
Bolmen	Gislaved, Hylte, Ljungby, Värnamo	0.96
Vidöstern	Ljungby, Värnamo	0.21
Flåren	Ljungby, Värnamo	0.14
Rusken	Värnamo	0.14
Unnen	Hylte, Ljungby	0.11
Allgunnen	Sävsjö, Växjö	0.11
Hindsen	Värnamo	0.07
Kösen	Ljungby	0.07
Furen	Ljungby, Värnamo	0.05
Rymmen	Alvesta, Värnamo	0.05

of water scarcity, but also in the dialogue between local authorities and water intensive industries such as agriculture (Pereira et al., 2009).

Finally, another benefit with applying GIS-based approach to the quantification of freshwater reserves is that many working within the field of water resource management are used to work within GIS-based programs and managerial tools (Gassman et al., 2007). This suggests that implementing the approach suggested in this paper should be a straightforward affair. However, and more importantly, utilizing existing structures and competences allows assessments to be coordinated and carried out remotely (Verma et al., 2012). This is particularly important in remote and low-populated areas, as the lack of specialized personnel and limited fiscal space often restrict local authorities to carry out large-scale operations (Pollard & du Toit, 2005).

Though the initial case study conducted in the Lagan River catchment area show promising results, there are still plenty areas in need of further work before any general conclusion can be drawn. This includes structural changes such as an extension of assessed parameters and the inclusion of additional waterbodies, but also an increased use of uncertainty analysis and quality assurance tools. In addition, further efforts are needed to strengthen the accuracy and reliability of the input data. This is especially evident when looking at a parameter such as mean depth from a quantitative perspective, where the inability to extract detailed information regarding the depth of 272 lakes within the catchment area meant that these had to be excluded from the overall assessment.

Table 3. *Table showing the ten largest groundwater reservoirs with the highest maximal available volume (km³) within the Lagan River Catchment.*

Name	Municipality	Volume (km³)
Värnamo-Ekeryd	Gnosjö, Vaggeryd, Värnamo	1.78
Skottorp-Ysby	Laholm	0.87
Laholmslätten	Laholm	0.65
Östra Karup-Våxtorp	Laholm	0.43
Mellbystrand	Laholm	0.43
Laholm	Laholm	0.37
Vaggeryd-Taberg	Jönköping, Vaggeryd	0.36
Hinnerydsåsen, Torpa	Ljungby, Markaryd	0.21
Bergaåsen, Trotteslöv	Ljungby	0.17
Knäred	Laholm	0.15

Conclusion

The high level of applicability combined with the low costs and potential of carrying out operations off-site suggest that the GIS-based approach proposed in this paper could provide a useful tool to water resources managers working with quantifying the total available volume of freshwater on a catchment level. However, further work is still needed to improve the accuracy and reliability of the suggested approach, including the addition of additional parameters and additional water bodies as well as the incorporation of uncertainty analysis in the assessment.

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References

Banks, E., Simmons, C., Love, A., & Shand, P. (2011) Assessing spatial and temporal connectivity between surface water and groundwater in a regional catchment: Implications for regional scale water quantity and quality. Journal of Hydrology, 404(1-2), 30-49.

Bulygina, N., & Gupta, H. (2009) Estimating the uncertain mathematical structure of a water balance model via Bayesian data assimilation. Water Resources Research, 45(12).

Chen, H., Wood, M.D., Linstead, C., & Maltby, E. (2011) Uncertainty analysis in a GIS-based multi-criteria analysis tool for river catchment management. Environmental modelling & software, 26(4), 395-405.

Eini, M.R., Javadi, S., Delavar, M., Gassman, P.W., & Jarihani, B. (2020) Development of alternative SWAT-based models for simulating water budget components and streamflow for a karstic-influenced watershed. Catena, 195, 104801.

Fennell, J., Geris, J., Wilkinson, M.E., Daalmans, R., & Soulsby, C. (2020) Lessons from the 2018 drought for management of local water supplies in upland areas: A tracer-based assessment. Hydrological Processes, 34(22), 4190-4210.

Gassman, P.W., Reyes, M.R., Green, C.H., & Arnold, J.G. (2007) The soil and water assessment tool: historical development, applications, and future research directions. Transactions of the ASABE, 50(4), 1211-1250.

Griffin, R.C. (2016) Water resource economics: The analysis of scarcity, policies, and projects: MIT press.

Heath, R.C. (1983) Basic ground-water hydrology (Vol. 2220): US Geological Survey.

Heathcote, I.W. (2009) Integrated watershed management: principles and practice: John Wiley & Sons.

Ji, S., & Unger, P.W. (2001) Soil water accumulation under different precipitation, potential evaporation, and straw mulch conditions.

Jiang, Y. (2009) China's water scarcity. Journal of environmental management, 90(11), 3185-3196.

Krysanova, V., & White, M. (2015) Advances in water resources assessment with SWAT—an overview. Hydrological Sciences Journal, 60(5), 771-783.

Lintern, A., Webb, J., Ryu, D., Liu, S., Bende Michl, U., Waters, D., Leahy, P., Wilson, P., & Western, A. (2018) Key factors influencing differences in stream water quality across space. Wiley Interdisciplinary Reviews: Water, 5(1), e1260.

Liu, Y., Wagener, T., Beck, H.E., & Hartmann, A. (2020) What is the hydrologically effective area of a catchment? Environmental Research Letters, 15(10), 104024.

Llena, M., Vericat, D., Cavalli, M., Crema, S., & Smith, M. (2019) The effects of land use and topographic changes on sediment connectivity in mountain catchments. Science of the Total Environment, 660, 899-912.

Martin, P.H., LeBoeuf, E.J., Dobbins, J.P., Daniel, E.B., & Abkowitz, M.D. (2005) Interfacing GIS With Water Resource Models: A State-Of-The-Art Review. JAWRA Journal of the American Water Resources Association, 41(6), 1471-1487.

Mekonnen, M.M., & Hoekstra, A.Y. (2016) Four billion people facing severe water scarcity. Science advances, 2(2), e1500323.

Pereira, L. S., Cordery, I., & Iacovides, I. (2009). Coping with water scarcity: Addressing the challenges: Springer Science & Business Media.

Pollard, S., & du Toit, D. (2005) Achieving Integrated Water Resource Management: the mismatch in boundaries between water resources management and water supply. Paper presented at the International workshop on 'African Water Laws: Plural Legislative Frameworks for Rural Water Management in Africa.

Ritchie, J. (1981) Soil water availability. Plant and soil, 327-338.

SCB. (2021) Statistiska tätorter 2018; befolkning, landareal, befolkningstäthet.

Schewe, J., Gosling, S. N., Reyer, C., Zhao, F., Ciais, P., Elliott, J., Francois, L., Huber, V., Lotze, H. K., & Seneviratne, S. I. (2019) State-of-the-art global models underestimate impacts from climate extremes. Nature communications, 10(1), 1-14.

Schewe, J., Heinke, J., Gerten, D., Haddeland, I., Arnell, N. W., Clark, D. B., Dankers, R., Eisner, S., Fekete, B. M., & Colón-González, F. J. (2014) Multimodel assessment of water scarcity under climate change. Proceedings of the National Academy of Sciences, 111(9), 3245-3250.

Sjökvist, E., Abdoush, D., & Axén, J. (2019) Sommaren 2018 - en glimt av framtiden? Klimatologi, 52.

Sydvatten. (2015, 2020-11-26) Bolmen. Våra råvattentäkter.

Veijalainen, N., Ahopelto, L., Marttunen, M., Jääskeläinen, J., Britschgi, R., Orvomaa, M., Belinskij, A., & Keskinen, M. (2019) Severe drought in Finland: modeling effects on water resources and assessing climate change impacts. Sustainability, 11(8), 2450.

Verma, S., Verma, R.K., Singh, A., & Naik, N.S. (2012) Web-based GIS and desktop open source GIS software: an emerging innovative approach for water resources management. In Advances in computer science, engineering & applications (pp. 1061-1074): Springer.

Wada, Y., Van Beek, L.P., Wanders, N., & Bierkens, M.F. (2013) Human water consumption intensifies hydrological drought worldwide. Environmental Research Letters, 8(3), 034036.

Wang, L., & Liu, H. (2006) An efficient method for identifying and filling surface depressions in digital elevation models for hydrologic analysis and modelling. International Journal of Geographical Information Science, 20(2), 193-213.

Witcher, R.E. (1999) GIS and landscapes of perception. In: Oxbow Books.

Åström, J., Persson, K. M., Johansson, J., Nordkvist, M., Oredsson, G., & Söderstjerna, J. (2019) Klimatsäkert vatten – hur räcker vattnet till allas behov och vem ska se till att det räcker? In (pp. 50): Sydvatten AB.