



FACULTY OF TECHNOLOGY

**CROWDICE: A CITIZEN SCIENCE REVOLUTION
FOR RIVER ICE AND ICE-RELATED FLOOD
MONITORING**

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ENVIRONMENTAL ENGINEERING

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ABSTRACT

CrowdICE: A citizen science revolution for river ice and ice-related flood monitoring

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University of Oulu, Degree Programme of Environmental Engineering

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Citizen Science revolution in cold climate hydrology aims to improve river ice monitoring in northern locations. Smartphone applications offer a means to monitor and analyse river ice conditions effectively and relatively inexpensively. The main goals were understanding what can be achieved with smartphone monitoring, assessing the extent of meaningful contribution of technologies and estimating the prospects of the use of mobile applications in hydrological monitoring. Thesis literature review focuses on river ice processes and its monitoring as well as applications of Citizen Science in hydrological monitoring. The smartphone application was developed and improvements to the application were made through an investigation of its functionality and success. Data collection for the application was carried out by a participatory approach with local community near Kiiminkijoki, as well as regional authorities and experts.

CrowdICE project was at distributed intelligence citizen science level. The total amount of observations collected was 87 observations and 221 photos. The most involved age groups were 51-60 and >70, profession retired, and gender male. Variation in answers regarding river ice cover duration now and in history was noticed. Ice-related flood effects were less significant nowadays than previously. Decrease in ice cover and small increase in damage was also foreseen. Most citizen observations correlated with in-situ cameras. Application improvements should be made to increase reachability, improve user experience and engagement. More live cameras are suggested. Future work should focus on integrated system approach, increasing the scope of citizen science and evaluating need for connections to other fields.

Keywords: Application, Citizen Science, flood, cold climate hydrology, monitoring, river ice.

TIIVISTELMÄ

CrowdICE: Kansalaistieteen kehitys jokijään ja jääpatotulvien seurannassa

Elli-Noora Törrönen

Oulun yliopisto, ympäristötekniikan tutkinto-ohjelma

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Työn ohjaajat yliopistolla: Ali Torabi Haghighi ja Epari Ritesh Patro

Kansalaistieteen kehityksellä kylmän ilmaston hydrologisessa seurannassa pyritään parantamaan jokijään ja jääpatotulvien seuranta pohjoisilla alueilla. Älypuhelinsovellukset tarjoavat keinon seurata ja analysoida jokijääolosuhteita tehokkaasti ja suhteellisen edullisesti. Tärkeimpinä tavoitteina oli ymmärtää, mitä voidaan saavuttaa älypuhelinseurannalla, arvioida teknologioiden vaikutusten laajuutta ja arvioida mobiilisovellusten käyttömahdollisuuksia hydrologisessa seurannassa. Opinnäytetyön kirjallisuuskatsaus keskittyy jokijään prosesseihin ja niiden seurantaan sekä kansalaistieteen sovelluksiin hydrologisessa seurannassa. Älypuhelinsovellus kehitettiin ja sovellukseen tehtiin parannuksia tutkimalla sen toimivuutta ja menestystä. Tiedonkeruuta tehtiin osallistavalla lähestymistavalla Kiiminkijoen lähiyhteisön sekä alueviranomaisten ja asiantuntijoiden kanssa.

CrowdICE-projekti oli hajautetun tiedustelun kansalaistieteen tasolla. Havaintojen kokonaismäärä oli 87 havaintoa ja 221 valokuvaa. Kiinnostuneimmat ikäryhmät olivat 51-60-vuotiaat ja >70-vuotiaat, eläkeläiset ja miehet. Vastauksissa huomattiin vaihtelua jokien jääpeitteen kestossa nyt ja historiassa. Jäähän liittyvät tulvavaikutukset olivat nykyään aiempaa vähäisempiä. Jääpeitteen vähenemistä ja vaurioiden vähäistä lisääntymistä odotettiin tulevaisuudessa. Useimmat kansalaishavainnot korreloivat kamerakuvien kanssa. Sovellusparannuksia tulisi tehdä saavutettavuuden lisäämiseksi, käyttökokemuksen parantamiseksi ja osallistujien sitouttamiseksi. Live-kameroita tulisi lisätä. Tulevissa töissä tulisi keskittyä integroituun järjestelmäajatteluun, kansalaistieteen ulottuvuuden kasvattamiseen sekä projektin ja muiden alojen yhteyksien tarpeen arviointiin.

Asiasanat: Kylmän ilmaston hydrologia, jokijää, kansalaistiede, seuranta, sovellus, tulva.

FOREWORD

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Elli-Noora Törrönen

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TIIVISTELMÄ

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LIST OF ABBREVIATIONS

ELY centres	Centres for Economic Development, Transport and the Environment
EO	electro-optical
GDPR	general data protection regulation
GNSS-IR	global navigation satellite system-interferometric reflectometry
GPS	global positioning system
IR	infrared
LIDAR	light detection and ranging
ML	machine learning
RPA	remotely piloted aircraft
SAR	synthetic aperture radar
SVM	support vector machine

1 INTRODUCTION

River ice jam flooding is a large-scale issue in northern rivers, including those in Finland. During wintertime, flooding caused by ice might result from ice jams, anchor ice or hanging dam (Beltaos 2008). As flood water levels during ice conditions are often higher than during ice-free conditions, structural, environmental, and ecological damage caused by ice jam flooding is significant (Beltaos 2008; Reiter & Huokuna 1989). Due to the hazardous nature of ice, it has been one of the longest monitored parameters in Finland (Korhonen 2005 p.7). Ice monitoring can be challenging, expensive, and possibly dangerous which is why technologies such as remote sensing are becoming more popular in the field (Ansari et al. 2024). Data analysis methods such as manual image interpretation, machine learning, and deep learning can be used to analyse and categorize data (Pei et al.2023; Zakharov et al. 2024).

The multifaceted importance of river ice stems from its diverse roles in hydrological processes and its significant impact on water resource management. It plays a crucial role in flood dynamics, water supply, hydropower generation, and overall water resource operations, highlighting its essential function in sustaining and regulating water-dependent ecosystems and infrastructure. (Beltaos & Prowse 2009.) Although river ice is crucial to the hydrological cycle and water resource management, systematic monitoring of it poses significant challenges such as hazardous conditions, remote locations and time consumption as well as cloud cover, spatial and temporal resolution (Ansari et al. 2024; Zakharov et al. 2024). While in situ observations are valuable, their effectiveness is limited by accessibility issues, especially in harsh winter conditions, making them insufficient for comprehensive and continuous data collection.

Challenges and possibilities created by river ice makes river ice monitoring an interesting subject to citizen. The involvement of citizen scientists gathering data and participating in research has long history but continues to grow in popularity in the field of science. Volunteer hydrological monitoring has long history in Finland, and it has included, for instance ice cover measurements. (Kettunen et al. 2016.) Use of smartphone applications in environmental monitoring enables easier participation of volunteers to data collection. Smartphone applications can utilize integrated smartphone sensors as well as add on sensors and enable additional observations from individuals. (Andrachuk et al. 2019.)

The aims in this thesis work were:

1. Developing smartphone app for environmental monitoring specifically to monitor and understand the river ice process such as start of freeze-up, duration and break-up of river ice
2. Involving citizen for river ice monitoring
3. Engaging citizen to contribute historical river ice photos
4. Understanding the citizens connection with river ice
5. Enabling smartphone tool for citizen to access live camera feed of monitored camera sites
6. Assessing using the data collected from citizens in addition with other sensors, in-situ data and remote sensing products for AI or ML tool to detect and predict river ice process in the future

This study focused on Kiiminkijoki located in Northern Ostrobothnia and Kainuu provinces, Finland. Citizen science data collection was organized through a smartphone application called CrowdICE. Stakeholders were determined to be the local communities along Kiiminkijoki as well as authorities and experts of the field. The aim of stakeholder determination was to select target groups that are interested in the subject, have access to the application and Kiiminkijoki. In addition, the goal of CrowdICE app was to offer meaningful opportunities for volunteers to contribute to scientific research. Questions in the application focused on history, current situation and future expectation of river ice. Data about river ice development and ice types, ice jams and ice jam flooding, and significance of river ice as well as changes caused by climate change were gathered.

2 LITERATURE REVIEW

2.1 River ice processes

Seasonally frozen rivers drain over one-third of Earth's landmass (Yang et al. 2020). For most of the cold region rivers there are three typical stages in wintertime river ice cycle: early winter freeze-up, mid-winter stable ice condition and late winter ice break up (Prowse & Gridley 1993; Huusko et al. 2007). Hydrometeorological parameters as well as geometric, hydraulic and thermal conditions of the river control ice-cover formation and growth (Burrell & Beltaos 2013). After the flow temperature has decreased to the freezing point, an extensive formation of river ice usually begins. Controlling factors of river-water temperature can be described as net heat flux presented in Equation (1). (Beltaos & Prowse 2009.)

$$\Phi_* = \Phi_S + \Phi_L + \Phi_H + \Phi_E + \Phi_P + \Phi_G + \Phi_B + \Phi_F \quad (1)$$

Where

- Φ_S = net heat flux of shortwave radiation
- Φ_L = net heat flux of longwave radiation
- Φ_H = sensible heat flux
- Φ_E = latent heat flux
- Φ_P = precipitation heat flux
- Φ_G = groundwater heat flux
- Φ_B = bed heat flux
- Φ_F = fluid friction heat

Various ice types are formed during freeze-up, including skim ice, border ice, frazil ice and pancake ice. One of the first types of ice to form is skim ice, a thin sheet of ice which is typically transparent and forms near riverbanks. Border ice, on the other hand, is formed as heat loss from channel banks and air cause skim ice to thermally thicken and expand. (Lindenschmidt 2020, p.11; Burrell et al. 2023.) Turbulent and supercooled waters (water temperature below 0 °C) form small ice crystals known as frazil ice (Lindenschmidt 2020, p.12; Reiter & Huokuna 1989). Frazil ice and rafted anchor ice can contribute to the formation of pancake ice, which refers to larger pans of ice formed as slush solidifies under persistent freezing conditions (Lindenschmidt 2020, p.12; Burrell et al. 2023).

Border ice can form an intact ice cover in low velocity areas of rivers, in which case thermal processes control the static ice cover formation (Beltaos 2013). Ice cover dynamic formation can happen when ice floes, slush ice, and ice pans encounter an obstruction that restricts flow and causes the floating ice to consolidate into a continuous ice sheet. Freeze-up jams occur during freezing season as ice deposits beneath the existing ice cover or as ice pans collide with the ice front, thickening the ice cover significantly (Lindenschmidt 2020, p.16; Beltaos 2013). Snowpack on top of the ice cover might also become saturated and freeze, creating snow ice which thickens the ice cover (Burrell et al. 2023).

Hanging dams refer to sizable accumulation of frazil ice, slush and ice floes beneath an intact ice cover formed during the freeze-up period (Senarathbandara 2023; Beltaos 2008). Turbulent sections creating frazil ice enable the formation of hanging dams downstream usually in deep and motionless river sections (Beltaos 2013). Similarly, anchor ice dams develop in supercooled waters before complete ice cover formation, as crystals grow locally to the riverbed or as frazil ice, floes or snow slush adhere to the riverbed (Pan et al. 2020; Huusko et al. 2007; Burrell et al. 2023). Anchor ice can also affect sediment transportation as it might lift bed material when it comes off the bottom of the river (Burrell et al. 2023). River ice formation illustrated in Figure 1.

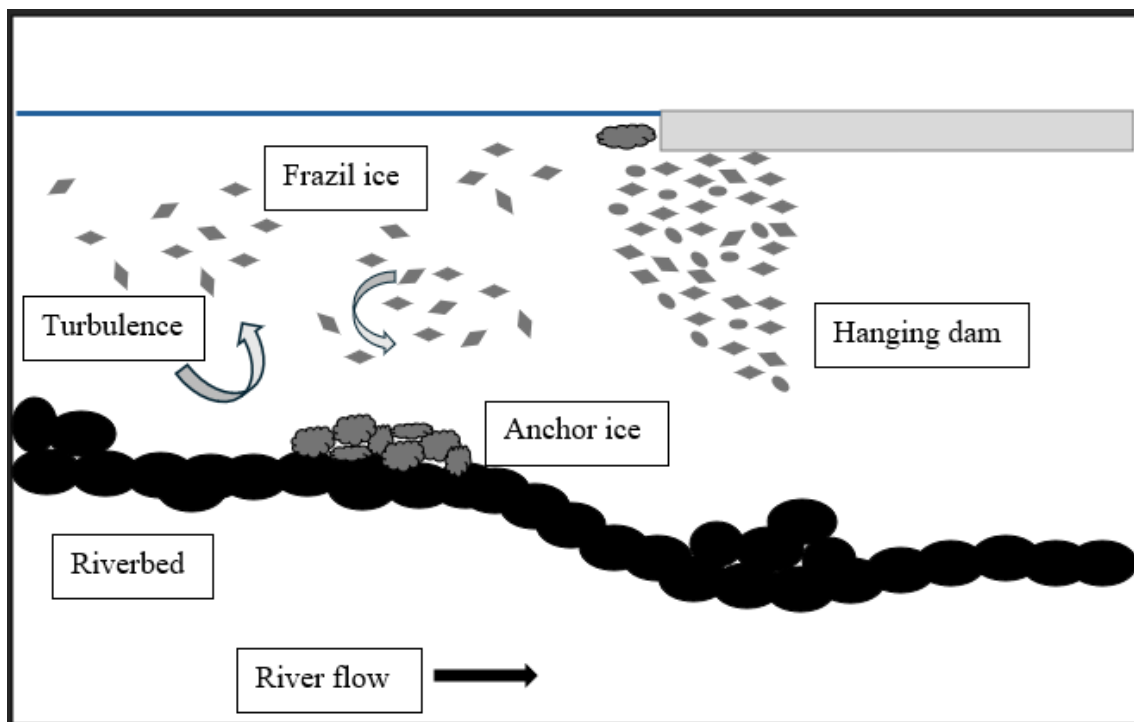


Figure 1. A schematic illustration of anchor ice and hanging dam formation (Reproduced from Huusko et al. 2007).

Ice-cover breakup, on the contrary, can be divided into two main categories: thermal and mechanical break up (Prowse & Gridley 1993). Thermal breakup typically occurs when rising temperatures melt the ice cover. During this process, water level and flow fluctuations are usually minimal. (Lindenschmidt 2020, p.79; Huusko et al. 2007.) Mechanical breakup, by contrast, is often outcome of increased flow and water level in the river, which exert mechanical forces on the ice cover causing it to fracture and breakup (Lindenschmidt 2020, p.81-83). Breakup ice jams occur as ice sheets accumulate for example at the edge of an intact ice cover obstructing water flow (Lindenschmidt 2020, p.81-83). Ice jams can cause flooding during wintertime, which because of higher water levels compared to ice free conditions, might cause significant ecological, structural and economic damages (Beltaos 2008).

River ice formation and duration variability can change flow dynamics, light availability and geomorphic or habitat structure in rivers. River ice can also rearrange material and biota through for instance scouring or anchor ice release. (Thellman et al. 2021.). Elevated sediment levels and nutrient transportation might be caused by ice jam flooding (Beltaos & Burrell 2016). River ecology during ice conditions is not that well studied due to difficulty of sampling during winter (Block et al. 2018) and most ecological studies done are focused on salmonids (Huusko et al. 2007). In addition to that, ecological studies are more common in smaller headwater streams whereas ice cover dynamics are more studied in large rivers (Turcotte & Morse 2017). Ice dynamics studies are limited as for example smaller rivers are more complicated to detect with satellites (Yang et al. 2020). However, formation of ice reduces the amount and quality of winter habitat but also creates new refugia as biotic behaviour adapts to freezing water and changes in dissolved oxygen levels (Prowse 2001).

Climate change is expected to cause hydrologic, geomorphic and habitat changes in river systems. Changes in basin response to precipitation and snowmelt events are projected in the future which also alter the timing and amount of runoff into rivers and streams. Ice formation, growth and breakup are anticipated to be influenced by changes in weather. (Burrell et al. 2023.) As winter discharges probably increase due to climate change, it might diminish ice cover periods and increase the erosion potential of the riverbed. Currently, compared to ice free conditions, thermally formed smooth ice cover decreases riverbed erosion and suspended sediment concentrations. (Kämäri et al. 2015.) Ice-related challenges in hydropower operation can appear both during freeze-up and breakup

periods (Timalsina et al. 2015). Hydropower operation is expected to have both positive and negative effects from changes in river and reservoir ice regimes caused by climate change (Gebre et al. 2014). Reduced ice cover duration and instability of river ice conditions due to climate change can lead for instance to increased frazil ice production as conditions remain freezing, but river ice cover is reducing (Gebre et al. 2014). Challenges caused by these changes include intake obstruction by frazil accumulation, water storage issues from anchor ice jams as well as ice runs and jams in bypass channels (Timalsina et al. 2015).

2.2 Available methods for river ice data collection and analysis

Monitoring river ice plays a significant role since it is helpful in making predictions about ice-cover breakup and ice jamming potential which are affected for instance by ice type, ice thickness and the amount of snow on ice-cover (Lindenschmidt 2020, p.39). Additionally, river ice monitoring can be used to better design and maintain river structures thus reducing the risk of damage. Studying river ice requires an interdisciplinary approach, incorporating remote sensing, river ice dynamics, and hydrology. It involves modeling, data processing, computer vision, machine learning, and various other technologies and research methodologies (Zakharov et al. 2024).

2.2.1 Current status of river ice observations

River ice observation technologies can be divided into satellite, aerial, and in situ (ground-based) measurements. In situ (ground-based) observation technologies consist of visual observations, photography and videos, thermal sensors, gauges and buoys, acoustic profilers, ground penetrating radar, imaging radars, seismic sensors, and global navigation satellite system-interferometric reflectometry (GNSS-IR) (Zakharov et al. 2024; Plante Lévesque et al. 2024). Gauges for example can be used to measure ice-cover thickness (Lindenschmidt 2020, p.39) whereas ground penetrating radar can be used to measure ice thickness, determine ice type and the structure of the cover (Kämäri et al. 2017; Plante Lévesque et al. 2024). However, especially through river ice freeze-up and break-up periods in situ measurements might be difficult, expensive, and potentially hazardous to implement (Ansari et al. 2024) and sometime tedious to do for entire stretch of the river.

Satellite and areal measurements are also referred to as remote sensing technologies. (Zakharov et al. 2024; Plante Lévesque et al. 2024). Multiple satellite types such as Landsat 8, Landsat 9, Sentinel-1, Sentinel-2, Sentinel-3 and NOAA-20 can be utilized to monitor river ice (Abdelkader et al. 2024). Remote sensing enables temporal and spatial monitoring of river ice patterns (Plante Lévesque et al. 2024). Sensors used in river ice satellite observations comprise electro-optical and infrared (EO/IR), synthetic aperture radar (SAR), radar altimeters, microwave radiometers and satellite gravimetry. The most used methods being electro-optical and infrared imaging as well as synthetic aperture radar technology. (Zakharov et al. 2024.) Electro-optical satellites operating with SAR systems can operate independent of weather and daylight conditions (van der Sanden et al. 2021). Synthetic aperture radar technology limitations are however uncertainties caused by incidence angle variations, speckle noise and difficulties to detect ice thickness (Zakharov et al. 2024).

Ice recognition with Sentinel-1 SAR backscatter threshold was used in two major Lithuanian rivers Nemunas and Neris Rivers. In the study three binary classification models based on VV, VH backscatter and logistic regression were analysed. Model sensitivity and specificity were managed to determine the ideal threshold between ice and water classes. To validate models in varying ice conditions, in situ observations and Sentinel-2 Sen2Cor ice mask were applied. It was noticed that Sen2Cor and SAR models precisely identified border and consolidated ice but behaved less accurately in moving ice conditions. It was recognized that in most cases, the VV polarization-based model was more precise than the VH polarization-based model. The outcome of logistic and VV models were more similar and the use of VV was more beneficial due to its easier algorithm. (Stonevicius et al. 2022.)

Remote sensing by aerial monitoring utilizes airplanes, helicopters and unmanned aerial vehicles that employ EO and IR cameras and scanners, light detection and ranging (LIDAR) technology, ground penetrating radar, synthetic aperture radar and microwave radiometers for river ice detection (Zakharov et al. 2024). Development in computer vision techniques and increasing accessibility of affordable photogrammetry devices are making close-range photogrammetry an attractive data acquisition alternative (Ansari et al. 2021). Optical imaging might be however limited due to cloudy conditions in higher altitudes whereas radar imaging might be affected by the snow cover type (Plante Lévesque et al. 2024).

Field measurements of ice jams are challenging to implement due to safety issues (Zhang et al. 2017). However, field measurements are essential in collecting data for example about water level, water temperature and flow rate (Lindenschmidt et al. 2024). Satellite remote sensing technology can be used to observe and characterize river ice behaviour. Satellite remote sensing photogrammetry enables collecting required data for enhanced understanding of river ice processes such as information about ice cover area and ice breakup series. (Zhang et al. 2017.) Ice jam photogrammetry can be also done by remotely piloted aircraft (RPA). RPA provides a greater spatial and temporal resolution than satellite imagery and it is a cost-effective and fast technique. Remotely piloted aircraft enables the formation of large-scale orthomosaics and digital elevation maps (DEMs) of ice jams. (Duguay et al. 2023.)

2.2.2 River ice analyses – status quo

The river ice data analysis is to gather knowledge about ice dynamics, processes, types and characteristics. Manual image analysis has traditionally been the primary method used for river ice examination from images; however, machine learning (ML) has become more commonly used method nowadays to process the images for automatic detection and prediction. (Pei et al.2023; Zakharov et al. 2024.) Machine learning can be used for instance ice detection, classification of ice types, prediction of ice-breakup or freeze-up dates, ice thickness estimation. Different ML algorithms used for river ice analysis are decision tree based on threshold and K-means, random forest classification and support vector machines (SVM). (Zakharov et al. 2024.)

K-means clustering is an unsupervised learning algorithm that divides a dataset into a chosen number of clusters. Whereas random forest algorithm is a learning technique that links various decision tree classifiers to develop predictive precision and decrease overfitting. (Purnell et al. 2024.) Support vector machine (SVM) is a two-group classifier that can be taught to recognize two distinctive types of information occurring in pictures (Kalke & Loewen 2018). Machine learning techniques can be utilized in river ice classification for instance in separating ice-free conditions and river ice from images (Purnell et al. 2024; Kalke & Loewen 2018). Through deep learning algorithms image classification, restoration, segmentation and extraction of river ice properties is possible and thus enables calculation of surface ice concentrations as well as ice pan dimension and structure properties (Pei et al.2023).

Effective forecasting of spring breakup or freeze-up ice jam floods requires a profound understanding of local hydrology, atmospheric dynamics, and ice cover behaviour. Additionally, the integration of multiple data sources and modeling techniques is required. Simulating ice jam behaviour under varying meteorological, hydrological, and hydraulic conditions requires the use of numerical models. (Lindenschmidt et al. 2024.) The user must specify ice jam locations in numerical models, as those do not automatically predict the location. For instance, commonly used HEC-RAS models in operational forecasting mode are primarily used to assess flooding potential in specified location over the next few days. (Beltaos et al. 2012.)

2.3 River ice significance in Finland

Significance of ice cover in Finland results from both the challenges and possibilities it creates. While ice cover obstructs transportation and shipments, it also allows for example construction of ice roads and ice rinks which allow transportation on ice. River ice makes various forms of recreational use possible. Ice cover enables activities such as Ice-fishing, skiing, ice-skating, snowmobiling and as mean for animals (such as moose and reindeers) to cross the rivers. (Korhonen 2005 p.7.) Even though stable river ice provides an essential platform for winter recreation, accessing a river during ice formation is particularly dangerous. River stretches that remain ice-free or develop only a thin ice layer pose significant risks for the users. Additionally, hydropower operations impact ice cover formation and stability throughout the winter season. (Krause 2023.)

2.3.1 River ice monitoring

Ice cover is one of the longest monitored environmental parameters in Finland (Korhonen 2005 p.7). The longest continuous presentation of ice cover degradation series in Finland is from Tornio River since 1693 (Kajander 1995). Ice monitoring is in an important role since structural, environmental and economic damages caused by river ice jamming are major, even though damages are minimized with various water management and flood prevention measures (Reiter & Huokuna 1989). Ice cover monitoring sites in Finland have reduced during the years since at best there has been 150 ice cover monitoring sites from which 50 are still at use (Finnish Environment Institute 2017).

The most common method for ice thickness measurement have been ground based. Historically ice thickness measurements have been done at 15th and 30th day of each winter month with bearing ice cover. Since the 1980s, ice thickness measurements have been made on the 10th, 20th and 30th of each month. (Korhonen 2005 p.8.) Before the 1970s, only the total thickness of the ice and the snow thickness on the ice were measured. After the 1970s also the thickness of the ice crust layer, the water level from beneath of the ice and the reading of the ice crust rod have been measured from each measuring point. Nowadays, at each measurement, three holes are drilled into new points and the average of these is used as the official value. (Korhonen 2005 p.9.) Nevertheless, monitoring is limited to some rivers at limited locations and not on the entire stretch of rivers. At present, citizen science observations are also collected through waterinfo map service (Waterinfo 2025).

2.3.2 Ice jamming

There are several examples of ice jamming in Finland, the earliest flood observation from Tornio River is from 1615 when river flood destroyed the church of Ylitorio. Floods caused by ice jams in Tornio and Muonio Rivers have also been observed in years 1677, 1968, 1934, 1971, 1984, 1985, 1986, 1990 and 2023. (Kajander 1995; Waterinfo 2024a.) Ice jam floods in Lapland have occurred in Kemijoki, Paatsjoki, Simojoki and Tenojoki river basins (Waterinfo 2024b). Northern Ostrobothnia is another major region of ice jams in Finland. For example, Kalajoki, Pyhäjoki, Siikajoki, Temmesjoki, Oulujoki, Kiiminkijoki and Iijoki river basins are prone to ice jam flooding. In some of the river basins flood embankments have reduced the impact of floods. (Waterinfo, 2024c.)

In 2013 ice jam flooding at Ylikiiminki prevented the use of the road from Oulu (Yle 2013). Similarly, in 2016 ice-related flooding occurred in Kiiminkijoki causing multiple water damages to buildings along the river. At that time the Finnish Environment Institute Syke warned the residents of northern Finland about ice-related flooding also in the Simo and Ii Rivers. (Yle 2016.) Recently, in 2024 a large ice jam at Alavieska that was hundreds of meters long and over hundred meters wide caused water levels to rise at foundation of few houses before it was released (Yle 2024a). An ice jam that was about five kilometres long was also formed to Tornio River in November 2024 causing some damage to structures near the river and it was estimated to influence ice durability throughout the entire winter (Yle 2024b).

In Finland, 18 significant flood risk areas have been defined. In these areas, significant flood damage can be caused by rising water or sea levels. Flood hazard and flood risk maps as well as estimates of future flood risks have been prepared for all significant flood risk areas. Risks posed for each area are relatively well presented by flood maps and other spatial datasets. (Syke 2021.) Ice jam prevention methods used are water barriers, ice thickness measurements, ice sawing, and previously also sanding. Water barriers can be used to slow down the surface flow of water which accelerates the formation of ice cover. Ice thickness measurement data are needed for planning of advance measures for the ice jam prevention. Ice sawing is used to prevent an ice jam formation in a place where rising water levels would cause flood damage to buildings in the area or for other structures. In the past, ice softening by sand was used at some sites prone to ice jamming but has now been largely replaced by ice sawing. (Ministry of the Environment 2006.)

Implementation of ice jam prevention can be done by excavation or explosion. Excavation can be executed from the river shore in small rivers, narrow areas of the river and next to bridges. If excavation from shore is not possible, it can be done on ice or from a surface constructed of ice and frazil. Blasting activities need to be carried out in compliance with the relevant Act, Decrees, and Government Decisions. According to the Explosives Regulation the police authority should be notified at least seven days prior to the beginning of the work except for minor blasting processes. After the explosion, the blaster must ensure that all charges have exploded and carefully consider the length of the waiting time after which it is safe to go to the blast site. (Ministry of the Environment 2006.)

2.4 Citizen science in environmental monitoring

Citizen science projects have grown more common in the last decade however, engagement of non-scientists to data gathering and research is not a new phenomenon (Kettunen et al. 2016). Citizen science can be described in numerous different ways but common points in citizen science are involvement of public into research, and scientific benefit from citizen science monitoring (Pocok et al. 2014). Citizen science related environmental monitoring includes broad range of activities engaging volunteers to observe, record and share data (Bonney 2021). Terms crowdsourcing, public participation, volunteer geographic monitoring and community-based monitoring are also used in many publications (Njue et al. 2019; Andrachuck et al. 2019).

Citizen science descriptions are often based on varying levels of involvement by volunteers (Nardi et al. 2022). These could be divided to three main categories: contributory projects, collaborative projects and co-created projects. Contributory projects are often designed by scientists and allow volunteers to primarily contribute data. In collaborative projects, designed by scientists, the public may also help to refine project design, analyse data, or disseminate findings in addition to data collection. The most involving type, co-created projects, refer to projects designed by scientists and members of the public working together and in which participants can be involved in most or all steps of the scientific process. (Bonney et al. 2009.) Issues of regional concerns are often at focus in community-based projects driven by participants themselves (Bonney 2021).

Opportunities of citizen science come from the cost-effectiveness of data collection, enhanced understanding of the public about scientific processes, as well as straightforward promotion and data collection through the use of technology (Pocok et al. 2014; Svahn et al. 2022). Citizen science can enhance public knowledge and present scientific evidence to support natural resource management and governance. It enables lowering costs, improving data coverage, building social connections, and empowering better decision-making while complementing traditional observing techniques. (Bonney et al. 2009; Haklay 2015.) Participatory science improves making environmental decisions more transparent and offers an opportunity to increase the trust of citizen in the decisions of experts (Haklay 2015).

Challenges of citizen science on the other hand are often related to organizational, data collection or data use issues (Conrad & Hilchey 2011). A great number of resources are needed to provide feedback and support to volunteers as well as to validate data to ensure trustworthiness and suitability (Pocok et al. 2014). Volunteers typically collect data when convenient for them, which may result in more observations of externalities rather than a comprehensive overview. Essential points among privacy concerns in citizen science is the possession, transmission and storage of the data. (Andrachuk et al. 2019.) Citizen science monitoring projects can also possibly endanger participants if risks are not well assessed, and crucial safety procedures are not employed (Haklay 2015).

Complexity, expenses, technological demands and requirements for spatially and temporally distributed measurements makes implementation of volunteer hydrological monitoring challenging (Paul et al. 2018). One of the earliest documented citizen science studies related to hydrology are reported to be drift bottle studies in 1960's and 1970's examining surface water patterns in the Caribbean Sea (Njue et al. 2019). Areas of citizen science implementation in hydrological monitoring include for instance, water quality, precipitation and soil moisture measurements (Njue et al. 2019). In Finland national hydrological service started in the beginning of the 20th century and citizen volunteers were actively engaged into hydrological monitoring (Kettunen et al. 2016). Volunteer hydrological monitoring in Finland has involved among others water level, ice cover and snow thickness measurements (Kettunen et al. 2016).

2.5 Smartphone applications in citizen science

Nowadays citizen science data collection can be implemented through smartphone applications that can be used by the public in environmental monitoring. Smartphone sensors such as camera, GPS (Global Positioning System), and microphone enable easier data collection by the public. Smartphone applications made for environmental data collection enable the use of add on sensors and entry of individual observations in addition to the use of integrated smartphone sensors. Smartphone use limitation may result from lack of participant interest, not involving participants to app development as well as battery life and connectivity limitations. (Andrachuk et al. 2019.)

Common features of application success in citizen science projects are known to be motivation of the volunteers to participate through pre-existing interest or concern of the matter, time and access of partakers to technology as well as possibility of participants to recognize meaningful opportunities to contribute to scientific research and society. In addition, gamification and symbolic rewards are known to increase participants interest to data collection. (Baruch et al. 2016; Newman et al. 2012.) Some studies have shown that participants might be more interested to if they have possibility to learn and to tech others as well as to be outdoors and stay active (Etter et al. 2023). It has been noticed that smartphone costs and volunteer time costs are not included in discussion at many studies which might distort the results of application costs (Andrachuk et al. 2019).

Citizen science environmental monitoring projects by smartphone applications include a wide range of monitored parameters. Ecodatos electronic form used in eastern region of Bolivia enabled wildfire, deforestation, mining, unplanned settlement, commercial hunting, road opening, water bodies and wildlife monitoring as well as category for other variables monitoring. Project website includes for example information on app use, publications, maps and warnings (FCBC 2020). In case of Ecodatos citizen science project it was noticed that challenges for research participants were damaged devices, obtaining internet coverage, economical costs caused by having internet connection and availability of the application only for Android. These problems were at some level sorted by providing equipment and internet connection packages for the participants. Organizers had held 16 training courses between 2021 and 2023 which resulted in total of 379 records during the project. (Maillard et al. 2024.)

Citizen science data from a community-based project The Fresh Eyes on Ice implemented in Alaska was used to support remote sensing data to evaluate snow and ice conditions by the University of Alaska Fairbanks (UAF 2025). As most municipalities in Alaska are not connected to road system, river ice has an important role in navigational purposes. In The Fresh Eyes on Ice project volunteer participants can gather photo observations as well as ice and snow thickness data (Abdelkader et al. 2024). In the project participants can share observations through programme website or GLOBE Observer app (UAF 2025). When combining citizen science data with remote sensing data it was noticed that ground-based observations enrich the analysis. It was however noticed that more extensive image handling resources within the Google Earth Engine platform would be needed and that there were limitations in data pre-processing. (Abdelkader et al. 2024.)

2.6 General data protection regulation

When implement citizen science-based monitoring app in Europe, it is necessary to follow the European general data protection regulation (GDPR) guidelines to ensure appropriate data collection, management and protection. The general data protection regulation safeguards individuals when their data is being handled by the private sector and the majority of the public sector. It is part of the European Union (EU) data protection reorganization, along with the data protection law enforcement directive and Regulation (EU) 2018/1725 on the protection of natural persons regarding the processing of personal

data by the EU institutions, bodies, offices and agencies. The GDPR enables individuals to have more control over personal data. It updates and unifies rules, allowing companies to reduce bureaucracy and to benefit from greater user trust. Additionally, GDPR establishes a system of separate managing authorities in control of supervising and enforcing agreement. (EUR-Lex 2022.)

The general data protection regulation improves existing rights, offers new rights and grants people more control over their private data and simpler access to an individual's own data. Individual's control over personal data contains supplying more information on how data is treated and ensuring that material is accessible in an apparent and understandable way. A newfound right to data transferability allows an easier transmission of personal information between service providers. More evident right to be forgotten when a person no longer wishes their data to be handled and there is no lawful reason to retain it, the data will be erased. Additionally, GDPR allows individual's the right to know when their personal data has been breached which means that relevant data protection supervisory authority and, in cases of serious data breaches, also the individuals affected need to be notified. (EUR-Lex 2022.)

3 MATERIALS AND METHODS

3.1 Case: Kiiminkijoki

Kiiminkijoki basin locates in Northern Ostrobothnia and Kainuu provinces (Finland) mainly at region of municipalities of Oulu, Pudasjärvi, Puolanka and Utajärvi (Räsänen et al. 2024). The catchment area of Kiiminkijoki basin is 3814 km² (Figure 1). The main channel of the river is 178 km long starting from Iso-Puutio Lake and ending in the Bay of Bothnia and the largest side channel of Kiiminkijoki is Nuorittajoki. (Waterinfo 2024d.) Kiiminkijoki belongs to the waters requiring special protection and is protected from power-efficient construction by the act on the protection of rapids. Kiiminkijoki is part of International Water Research Program Project Aqua which means that the river is among the water bodies reserved for scientific research. As Kiiminkijoki is relatively natural i.e. non-regulated it is scientifically valuable research site. (ELY centres 2023.)

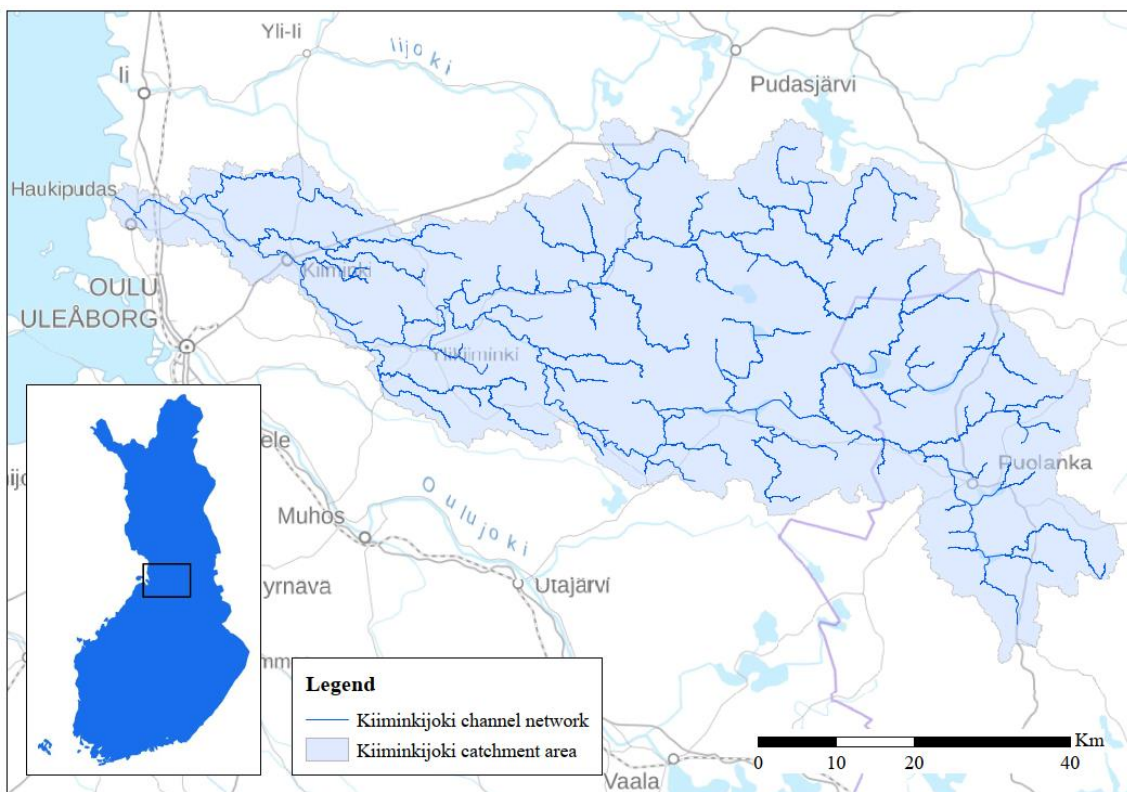


Figure 2. Kiiminkijoki basin (Maanmittauslaitos 2/2025, background map CC BY 4.0; Syke 5/2023, catchment division CC BY 4.0; Syke 3/2024, river channel network CC BY 4.0).

The catchment area of the Kiiminkijoki is a reasonably sparsely populated area dominated by agriculture and forestry. High content of humus causes the Kiiminkijoki to be naturally brown-watered. Swamps located in the catchment area leach humus to waters, but forest drainage and peat production also contribute significantly. There are multiple sites belonging to the Natura network and national conservation programmes that are in the catchment area of the Kiiminkijoki. (ELY centres 2023.) There are five nationally significant built cultural heritage sites in the river basin which are Haukipudas Church with its surroundings, Kiiminki Church with its surroundings, Ylikiiminki church area, Askanmäki village and Tiainen crown forest croft (Waterinfo 2024d).

The river landscape includes spectacular rapids, rolling rivers and rocky beaches (ELY centres 2023). Kiiminkijoki is a risk area for ice-related flooding and has multiple known locations prone to ice jamming. As Kiiminkijoki riverbanks are mainly in a natural state and hardly any flood protection embankments have been built, the flood spreads widely beyond the main riverbank in many places. Properties located near the riverbanks are at risk in case of ice jam flooding. (Waterinfo 2024d.) Ice jams have caused flooding in Kiiminkijoki in years 2012, 2013, 2014 and 2016. The worst points of flooding in Kiiminkijoki are in residential areas near the middle and lower part of the main channel. Ice jam flood in 2013 caused one fatality and damages to infrastructure. (Waterinfo 2024c.)

Kiiminkijoki was selected as a study site due to its northern location which enabled river ice studies. Additionally, Kiiminkijoki has already been studied about river ice which enables using data collected in this study with data from previous studies. Citizen science data was aimed to be collected, which could later be used for further studies to support remote sensing data. Kiiminkijoki is an unregulated river which enabled studying river ice and ice jamming when hydropower operation doesn't alter water levels. There is also a lot of housing along the river that is affected by ice jam flooding and would benefit from ice jam flood prevention. Significance of the further study of Kiiminkijoki to locals and possibility to use the collected data for ice jam prevention was also one of the contributing matters when selecting the study site.

3.2 Development of CrowdICE application

Citizen science project to collect hydrological monitoring data regarding river ice and flooding was implemented in Kiiminkijoki, Finland. Smartphone application CrowdICE (<https://crowdice.fi/user>) was developed as a citizen science project to collect hydrological data from Kiiminkijoki. The development of CrowdICE website and application was done in cooperation with information technology student Mahmood Sharifzemeidani. Hydrological monitoring aspect of the application development included investigation of app functionality and success, determination of data collection purpose and content creation for the application. On the other hand, application development part done by the application developer included website creation, application creation, testing of the app, ensuring availability of the application as well as publication of the app.

3.2.1 Investigation of app functionality and success

Application functionality was aimed to be achieved through material availability, consideration of languages and different age groups. Both the website and application were made available in iOS and android platforms. Project related material was made accessible through these channels. Application functionality was evaluated with multiple devices before publication to ensure functionality. During the project English and Finnish were the applied languages of the application to reach majority of people living in the area. More languages such as Swedish were considered but due to lack of time it was not employed. Functionality for different age groups was aimed to be achieved by utilizing simple and intuitive user interface by employing simple visual elements such as colours, logos and texts as well as using logical naming. Feedback feature was added into the online interface to support further improvement of the website and application as well as the questionnaire. Application outlook is presented in Appendix 1.

Participant motivation was considered when aiming for application success. According to literature it was concluded that the most relevant points were motivation of participants through pre-existing interest or concern of the matter, volunteers time and access to technology as well as opportunity of participants to distinguish meaningful occasions to contribute to scientific research and society. In this study the aspects mentioned above were aimed to be achieved by stakeholder determination, providing information about the

project and minimizing participants time consumption. Stakeholder determination was used to enhance interaction with interested parties. Providing information about the project and river ice as well as by discussing the matter with participants that wish to know more was provided in the blog material for increasing the interest and awareness among participants. Volunteers time need for research was minimized by trying to optimize the questionnaire and simplify the user interface. It was however assumed that in this research area most of the targeted volunteers would have access to technology. Feedback regarding the questionnaire and website was collected from experts of the area before the publication of the website and application. Questions were modified multiple times prior to the publication based on feedback.

3.2.2 Purpose of data collection

Purpose of the data collection was to gather information about river ice conditions and ice-related flooding in Kiiminkijoki through smartphone application CrowdICE. Aims of the data collection were to collect more information about temporal duration of ice in river during winter, the occurrence of ice types, ice dam flooding and the uses of ice, and their effects in history, today and in the future. Through citizen science data collection wider range of data from different times was expected. Kiiminkijoki was selected as a case study due to ongoing research at the area. Smartphone application was implemented in a manner that allowed the use of application on a larger geographic area. Data was collected to understand what can be achieved with smartphone environmental monitoring, assess the extent of meaningful contribution of technologies to monitoring and estimate prospects of the use of mobile applications in cold climate hydrological monitoring.

Historical and current river ice data was collected to validate remote sensing data on the area and to further identify critical locations of ice jamming in Kiiminkijoki in the past. Remote sensing data validation was noted as one of the important factors as satellite imagery might be limited on cloudy days. Additionally, ground-based observations can be used for model education and ice type determination purposes. Possibility of using historical and current photographs for flood forecasting in the future was also considered. Future expectation regarding river ice were collected to determine what kind of ideas participants have about river ice future and what type of action they would see appropriate. Through data collection from different times climate change effect can also be considered.

Possible challenges determined beforehand were participants difficulty to access riverside, lack of motivation and difficulty to use technical devices. Additionally, limited language selection was noted to be a possibly restricting factor on data collection. Access to river was noted to be reduced for instance due to snow, housing and steep riverbanks as well as lack of nature trails at some parts of the river. Lack of motivation to data collection could result for example from difficulty to use or find the application, limited language selection or not having a personal connection to the matter. One of the main challenges noticed in citizen science is lack of data accuracy which was also considered while forming the questions and analysing the data.

3.2.3 Content development for the app

Content for the application and advertisement purposes included material for the online interface, the questionnaire and fliers (Appendix 2) describing the project. Material released on the website and application included blog post material, feedback function, Kiiminkijoki live cameras and the questionnaire. All the material was formed both in English and in Finnish. The login function was not added at the testing phase as more personal information should have been collected. Data protection and privacy was considered by only collecting necessary information for research purposes. Access to Kiiminkijoki live camera feed, giving feedback and reading blog posts was made accessible for users without having to give any personal information.

Available material published as blog posts on the project website and on the application described the project, contained a small educational material package (Appendix 3) and useful links to other websites that provide more information about river ice. Educational material was formed based on thesis literature review and it included information about Kiiminkijoki, citizen science and river ice processes as well as ice-related flooding. After publication feedback was collected through website and application about the online user interface and the questionnaire. Kiiminkijoki live cameras used for research were made available through the online interface. Two of the cameras located in Kiiminki and one of them located downstream in Haukipudas area.

Questionnaire development was started by dividing river ice timeline to three different sections: current situation of river ice, history of river ice and future expectations. Photo answer additions were made possible at river ice current situation and river ice history

sections along with multiple choice and open answer options while future expectations part only contained multiple choice and open answer options. Total of six versions of the questionnaire were created with improvements of the questions, answer formats and specifying texts based on feedback from experts of the subject as well as the application users. All questionnaire versions were formed both in English and in Finnish to be able to further develop the translations and to find appropriate forms for words. Online interface functionality of the created questionnaire was also tested during the process using both android and iOS operating systems. The final version of the questionnaire (Appendix 4) implemented during the thesis was formed for further use.

Separate questionnaire (Appendix 5) for experts was created to gain perspective and to improve knowledge of river ice in Finland. Privacy Notice was drafted as the questionnaire development was started, and it was updated and improved as the questionnaire was changed. Privacy Notice (Appendix 6) was implemented to the beginning of the questionnaire as the fourth version was drafted. Participant name and email address were collected for photo publication purposes to ensure rights holders permission to publish photographs if participants wanted to keep their rights for photos. Other personal information collected for data analysis purposes were age group, gender and occupation. Information needed for filling the questionnaire were camera or gallery, location, time and text data about river ice. Minimizing collecting personal information and safety of participants was considered while forming the questions. Participants were notified not to enter river ice to make observations if the conditions were not appropriate.

3.3 Stakeholder determination and data collection

Two different target groups: local community and regional authorities and experts were determined for testing the app functionality. The aim in collecting data from different type of groups was to increase data amount and variety through altering life stages, professions and genders. It was assumed that for example age and role in society might influence the ability of participants to collect data and that volunteers would have pre-existing interest or concern regarding the matter as ice jamming and ice jam flooding has occurred in the area. Common features of stakeholders were determined to be access to the river and knowledge of the area.

Contacting stakeholders was done by sending emails or calling to target groups, by sharing fliers in the target area, posting about the project in LinkedIn and by attending to meetings. Contacting stakeholders was mainly organized by sending emails to possible participant groups or associations. A total of 128 emails, texts, or calls were made to reach potential volunteers. During the thesis project six meetings were organized, from which two were with professionals of the subject and four with research participants. In addition to emails and meetings three social media posts were made to further encourage larger group of people to participate. Twenty (20) fliers describing the project and directing to project website were distributed along Kiiminkijoki. Larger datasets were collected by email or by meeting with participants. Some questionnaires were filled based on interviews if it was the most suitable way of sharing data for participant.

3.3.1 Local community

Citizen living by the Rivers in Finland were contacted about the project but most focus was placed on contacting Citizen by Kiiminkijoki as it was the case study. Emails and calls were used to contact Pensioner's Associations, hunting clubs, fishing communities, river associations and businesses as well as Schools and Parents of Students. Additionally, to contact participants from a wider area, village associations from Northern Ostrobothnia and Lapland were contacted. One meeting with village association and some face-to-face meetings with locals were organized to present the subject and to assist participants to answer the questionnaire. Fliers about the project were distributed to shops, libraries, campfire sites and other notice boards, as well as to some mailboxes in Kiiminkijoki area.

Stakeholders were selected as they have possible interest towards river ice and ice jam flooding, firsthand knowledge of river processes and changes in river ice during the years, as well as knowledge of flood damages and access to river. Especially more aged participants were assumed to have knowledge of river ice use in the past. Participants from various age groups, professional status and genders were aimed to be contacted through the stakeholder group selection. The aim of forming emails and fliers was to present information in an informative matter while maintaining appealing outlook. Receivers were encouraged to participate and contact the data collector in case of feedback or need for further assistance.

3.3.2 Regional authorities and experts

Regional authorities and experts were contacted through email or by phone to participate in the research and to give feedback regarding the application. Separate questionnaire developed for experts of the subject was sent to 23 Finnish experts. Contacted stakeholders were Finnish Environment Institute, The Flood Centre, Centres for Economic Development, Transport and the Environment (ELY centres) in Northern Ostrobothnia and Lapland, City of Oulu Environmental Services Department, Northern Ostrobothnia fire and rescue department as well as experts from University of Oulu. One (1) meeting was organized with Lapland ELY centre to discuss application functionality, improvement possibilities and future uses of the application. In addition, a request to get to know the project and give feedback was sent by email to some international experts.

Regional authorities and experts were selected as stakeholders due to their expert knowledge regarding ice processes and ice jam flooding, awareness of flooded areas and possible interest groups as well as knowledge of legislation and resources. Additionally, authorities have archives containing information from ice jams and ice jam floods as well as data from hydrological monitoring sites that was considered significant to research. It was noticed that possibility to cooperate with local and regional authorities could benefit the development of river ice modelling and ice jam flood warning systems. Development of the application was aimed through feedback received from authorities and experts.

3.4 Data analysis

Data analysis was separated to five main sections: citizen science level determination, analysis of observations, citizen engagement, participant's perception and citizen science comparison with in-situ cameras. Citizen science level determination as well as the spatial analysis of observations were done at project level. Citizen engagement and participant perceptions parts focused on volunteer observations at Case: Kiiminkijoki. Lastly, the comparison of citizen science with in-situ cameras part focused on all observations (public and thesis worker) from Kiiminkijoki and the in-situ cameras from the case area.

3.4.1 Citizen science level

Levels of participation and engagement were determined to be crowdsourcing, distributed intelligence, participatory science, and extreme citizen science based on Haklay (2013). Each level from crowdsourcing (level 1) to extreme citizen science (level 4) has a higher standard of participation and engagement (Table 1). CrowdICE project level was defined according to the definitions of each level’s participation and engagement by comparing project requirements from participants with citizen science level descriptions.

Table 1. Levels of participation and engagement in citizen science projects (Haklay 2013).

Term	Description	Level
Crowdsourcing	Citizens contribute data with minimal understanding of research – simple tasks requiring little or no training	1
Distributed intelligence	Participants also help interpret or analyse data in addition to data collection – some training or guidance needed	2
Participatory science	Collaboration between citizen and scientist in defining research questions and collecting or analysing data	3
Extreme citizen science	Communities guide the research process from start to finish – Research grounded in local needs, scientist act as advisors	4

The most basic level, crowdsourcing (level 1), involves participants contributing data actively or passively, while participants often have minimal understanding of the research objectives. Tasks at this level are typically simple, repetitive, and require little or no training. At the second level, distributed intelligence, participants do not only contribute data but also assist with basic interpretation or analysis. Participants are often provided with some level of training or guidance. At the third level, participatory science, more collaboration between citizens and scientists is present as they work together to distinguish the problem and collect or analyse data. Participants are more intensely involved in the research process than in the previous levels. At the highest level of engagement, extreme citizen science (level 4), communities or groups lead the research process from beginning to end. Scientists may be involved in advisory role, but the study is grounded in local requirements and experience. (Haklay 2013.)

3.4.2 Analysis of observations

Analysis of observations was performed for all data gathered during the data collection period from 1st of April to 9th of June 2025. The overview of all the results included calculation of total observations and photos, the percentages of public observations and photos, as well as observations and photos from Kiiminkijoki. Additionally, answers were categorized into only photo, only answer, or both answer and photo observations to calculate the percentages of each type of addition. Spatial distribution of observations could be estimated based on photo coordinates or river name in cases where no photos were added with the answer.

Current and historical observations were categorized more precisely based on observation location, observation timing, observer, and observation type. Observation location was added to the map based on coordinates provided with photo observation. Observation timing was simply divided into current and historical according to the section that participant had selected when submitting an answer. Possible observers in this case were determined to be the public (volunteer) and the thesis worker. Observations were divided to only photo or answer and photo observation types determined by the amount of information given. Additionally, number of observations as well as number of historical and current photos were calculated for similar inputs (location, timing, observer and observation type). A map of these more precise calculations was created for Kiiminkijoki.

3.4.3 Citizen engagement

Citizen spatial engagement was evaluated by visual inspection of most answered locations at Kiiminkijoki based on analysis of observations map. Comparison of current and historical observations and observations type (only photo or photo and answer) spatial distribution was also assessed. Additionally, citizen engagement was evaluated based on answers of each personal information group (age range, profession, and gender) to the questionnaire in total and in comparison, to each questionnaire section (current, historical and future). Percentages of answers by each personal information group to different sections were calculated to understand the engagement of each group better and to see the differences among the sections.

Photos obtained from participants were divided to four different photo categories: river ice or no ice and camera or drone images. In this work “river ice” photos refer to photos taken during winter season with varying amounts of ice and “No ice” photos refer to ice-free season where as “camera” images includes all ground-based photos and “drone” category refers to low altitude aerial images. The contribution of answers by different personal information groups to photo observations was computed. Moreover, the involvement to each photo category was calculated to determine differences in photo observations in river ice current and historical sections.

3.4.4 Participant perceptions

Analysing participants perceptions was done by determining the connection between personal information (age group, profession and gender) and different questionnaire sections (river ice current situation, river ice history and future expectations) as well as individual questions within the three different sections of the questionnaire (Figure 3). Three questions of each section were selected as those were connected to the relationships and ideas that participants have concerning river ice. Questions related to river ice condition and ice types were excluded from this part as river ice conditions were analysed at citizen science vs. in-situ cameras part. After calculating the number of answers by for example age groups at each section per specific question’s answer options, the percentages from total number of answers to that question were calculated. This procedure was performed for all questions and then comparison of answers was done based on these percentages. Lastly, expert answer was briefly discussed in relation to citizen science observations.

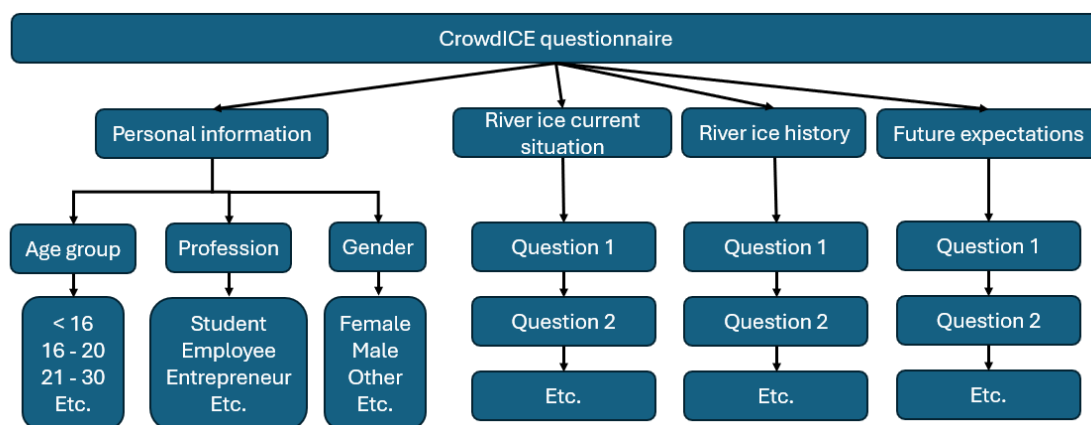


Figure 3. CrowdICE questionnaire structure.

The selected questions from river ice current situation section were: “For what purposes do you use river ice nowadays?”, “How does river ice flooding affect your life?” and “What advice would you give to younger generations regarding river ice?”. Similarly, for river ice history sections the questions were: “How would you describe the duration of the winter ice cover in history of the river?”, “For what purposes have you used the river ice in the past?” and “Has River ice flooding affected your life?”. Lastly, future expectations questions were: “How would you imagine the duration of the winter ice cover in the river is in the future?”, “How do you think river ice jam flooding will affect your life in future?” and “In what ways do you think that the situation with river ice can be improved?”.

3.4.5 Citizen science versus in-situ cameras

Comparison of citizen science observation and in-situ camera observations was done for all observations (public and thesis workers) from case Kiiminkijoki. There are 3 in-situ live cameras by Kiiminkijoki that take an image of the river at every half an hour period. Two of the cameras photograph river upstream and downstream at Kiiminki (Figure 4) and one of the cameras takes pictures of the river at Haukipudas (upstream direction).

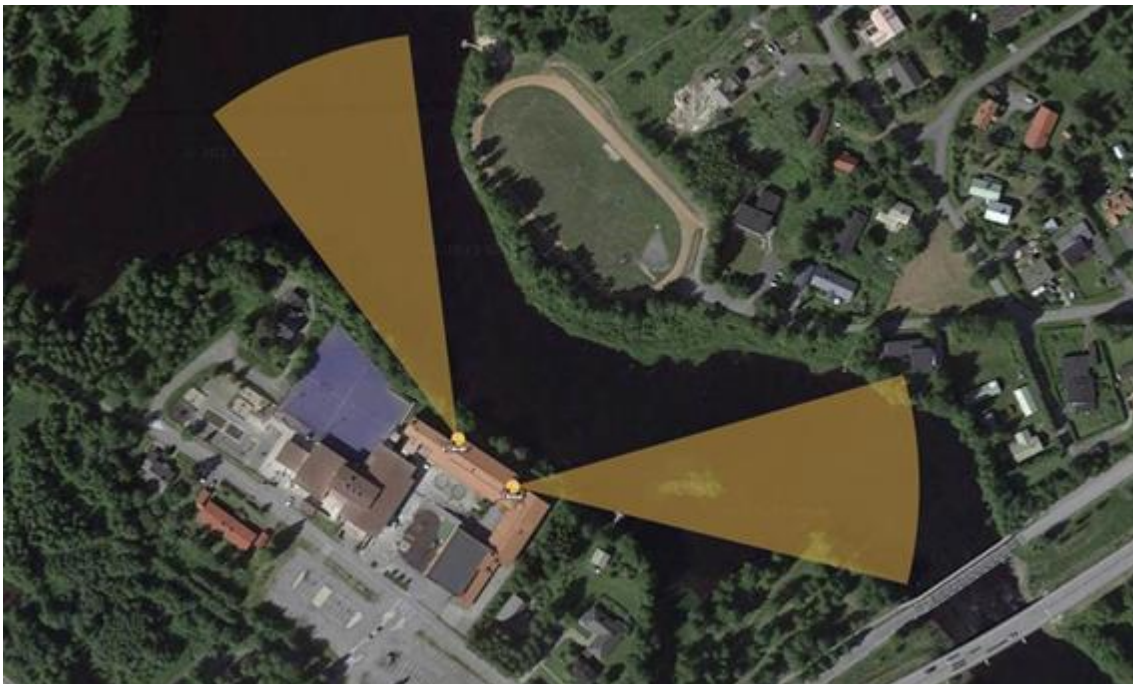


Figure 4. Kiiminkijoki upstream and downstream live cameras located at Kiiminki (Photo credit: Abolfazl Jalali Shahrood 2025).

Data analysis time was determined to be from 1st of January to 30th of April 2025 as participant observations and camera images could be compared from that time. However, addition of participant observations to river ice current situation was only possible from 1st of April to 30th of April 2025 during that time. Images from all three live cameras were downloaded every day at 12:00 from the determined timeframe (1 January to 30 April 2025). Visual determination of ice condition by simply dividing photos to three different categories entirely frozen, partially frozen and no ice was done for both camera images and citizen science observations. Images were then organized spatially, so that river ice conditions could be compared between citizen science observations and in-situ camera images. If citizen science observations included multiple photos from same location at the same date, conditions in all the photos were detected after which only one observation was used if conditions were similar in all photos.

4 RESULTS

The results were divided into the determination of citizen science level, analysis of all the gathered observations, examination of citizen engagement, and participants' perceptions as well as comparison of citizen science observations with in-situ camera images. Citizen science level determination as well as the general analysis of results were done on project level. Examination of citizen engagement and participant's perceptions as well as comparison of citizen observations with in-situ cameras were narrowed to the case study.

4.1 Citizen science level

CrowdICE project was determined to be at citizen science level 2 (distributed intelligence) as citizen do not only contribute data to the system but also help with data analysis. When citizen add observations to CrowdICE system (river ice current situation and river ice history) they are also asked to determine the ice condition and if possible, the ice type. Because of the simple analysis tasks, some guidance is needed to answer the questionnaire. Some informative material is provided at CrowdICE website to demonstrate for example river ice types. In addition to that, when volunteer observers add photos to the questionnaire they are asked to determine the date, time and location of the photo. The guiding texts of the questionnaire help participants to respond as desired.

The current aim with the CrowdICE project is to reach citizen science level 3, participatory science which would mean collaboration between citizens and scientists in defining research questions and collecting or analysing data. To reach level 3, more profound connections with participants should be created to be able to define the research questions in collaboration. Additionally, need for outreach and education should be determined to improve collaboration regarding data collection and analysis. Determination of ice types should be evaluated to determine the level of trust in the visual observations. Challenges to reaching participatory science level 3 were, a) identifying citizens with continuous interest to contribute, b) organizations and societies with higher outreach to the larger community and different regions for uptake and deployment of the app at wider scale, c) continuous improvement of the app based on the feedback of participants and d) real time visualization of all the data collected following the privacy guidelines in a meaningful way to retain the citizen participations actively.

4.2 Analysis of observations

The total number of observations collected during the data collection period (1st of April to 9th of June 2025) was 87 observations and 221 photos collected including answers to all questionnaire sections: river ice current situation, river iced history and future expectations. Observations were added along various rivers in Finland as overall, 12 different rivers were presented, the most southern being Kyrönjoki and the northernmost Tenojoki while the easternmost was Koitajoki and the most western was Kiiminkijoki. The number of public observations was 67 observations (77 %), and 160 photos (72.4 %). Public observations consisted of only photo (41.8 %), only answer (20.9 %) and with both photo and answer (37.3 %) observations.

All observations from the study area, Kiiminkijoki, consisted of 68 observations and 184 photos, from which 48 observations (70.6 %) and 123 photos (66.8 %) were made by the public. In Kiiminkijoki area 54.2 % of the observations were with photo, whereas 27.1 % were only answers to the questionnaire, and 18.8% were both photo and answer observations when considering all questionnaire sections. All current and historical observations from Kiiminkijoki (Figure 5), including thesis worker observations, were added on a map.

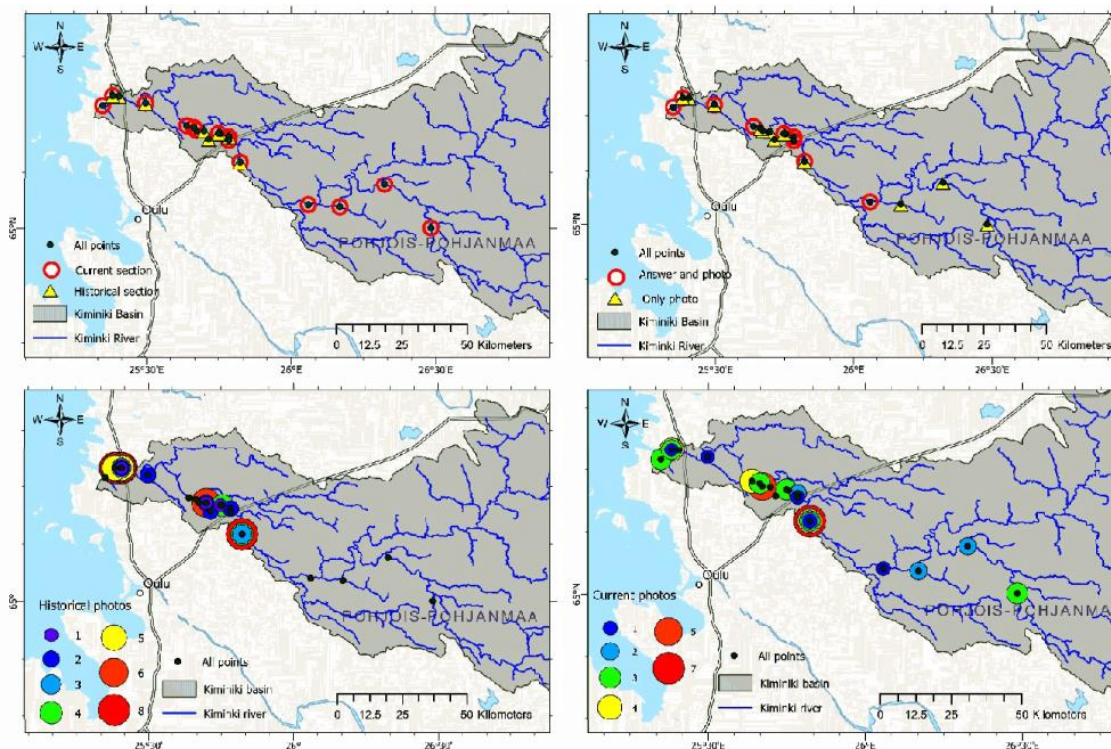


Figure 5. All observations collected from Kiiminkijoki (Photo credit: Alireza Sharifi).

The Kiiminkijoki observations were divided according to photo timing (historical or current photo), answer type (only photo or photo and answer) and number of observations from one location for both historical and current photos. The number and distribution of historical and current observations were presented on one map (Figure 5, upper left) while division of observations to only photos or photo and answer was presented separately (Figure 5, upper right). The number of photos from one location was also presented separately for river ice historical (Figure 5, down left) and current situation (Figure 5, down right). From all Kiiminkijoki photos 111 were historical and 73 current photos. In river ice current situation and river ice history sections there were 41 observations that only contained photos and 14 observations that included both answer and photo.

4.3 Citizen engagement

Citizen engagement was evaluated in Kiiminkijoki area from all public observations. Spatial distribution at Figure 5 shows that most of the observations were from the most populated areas along the river. There were only few observations from less populated areas and no observations from Utajärvi, Puolanka and Pudasjärvi areas. It was noticed that all historical photos were from relatively small area close to Kiiminki and Haukipudas. While most of the current photos were also from that same small area, there were also some observations further along the river. Additionally, the largest amounts of photos in both current and historical sections are from few locations. The observations from further upstream only contained photos but other than that “only photo” and “photo and answer” observations were spatially distributed quite similarly.

The contribution of various age groups, professions and genders to different sections in the questionnaire indicates that the least active were participants from ≤ 15 and 16-20 age groups, since there were no additions from these groups. Additionally, there were no answer to something else, and I don't want to specify at professions section as well as to other and I don't want to specify at gender section. At river ice current situation and river ice history sections there were also no answers to age group 31-40 as well as profession group unemployed. At future expectation's part there were no answers from age group 51-60 and the profession group employee.

The highest engagement in river ice current situation section were noticed from age groups 21-30 and >70 both with 28.6 % of the answers. In regards of profession, retired were the most engaged with 35.7 % of answers and the most active gender was male with 64.3 % of the answers to this section. The most contested age group in river ice history part was from 51 to 60 by 39.5 % of the answers whereas the most active profession was employee (36.8 %) and gender male (78.9 %). Future expectation's part had most engaged participants from age group >70 (30 %) and profession retired (50 %). Future expectation's part was equal, in regards of men and women.

When looking at average engagement in different sections (river ice current situation, river ice history and future expectations) the most involved age groups were 51-60 and >70, most active profession was retired and gender male. However, it was noticed that there was quite a lot of variation in engagement especially by age groups (Figure 6) and professions to different sections. The engagement of men and women did not vary that significantly but contribution from men was overall higher. Age groups 41-50, 51-60, 61-70 and >70 provided more answers to river ice history section than to river ice current or future expectations part. This was also noticed with professions employee, entrepreneur and retired. Meanwhile age group 21-30 and profession student provided more answers to river ice current situation section.

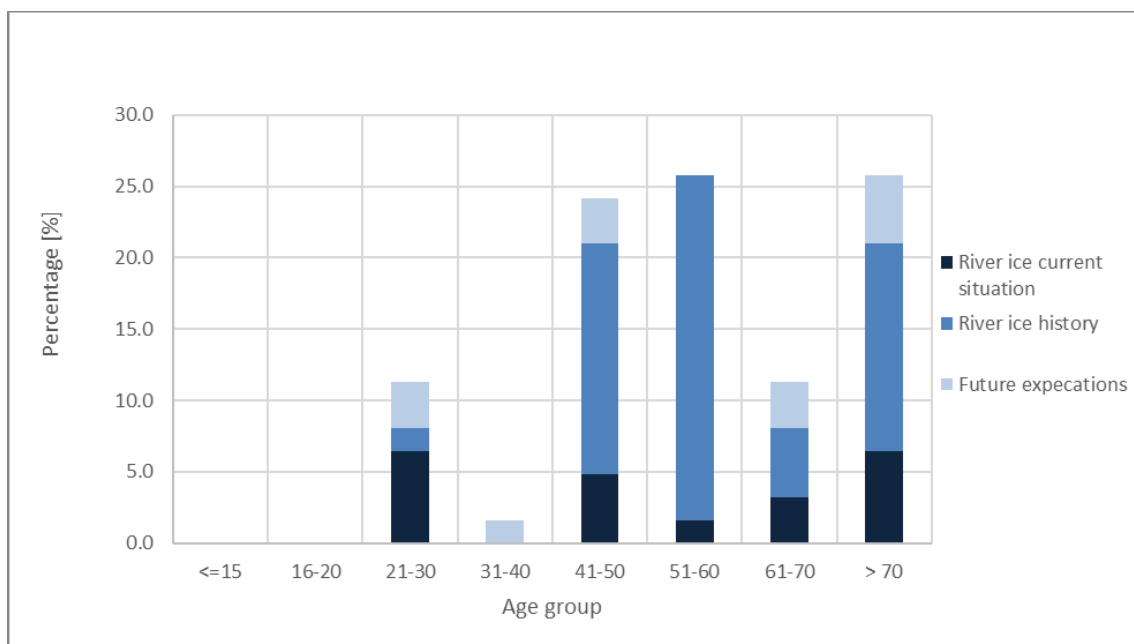


Figure 6. Age groups' engagement with different sections of the questionnaire.

When focusing only to observations that also include photos, in river ice current situation and river ice history sections, it was noted that there were no answers from age group 61-70 and profession unemployed in addition to those non-active groups mentioned before. In river ice current situation part there were also no answers to age group > 70 and profession retired in regard of photo observations. While focusing on observations that include photos, there seems to be less overall engagement as for example only half of the age groups (21-30, 41-50, 51-60 and >70) have added observations with photos. However, those groups that have added photos, have contributed with multiple observations.

Overall, river ice current situation section received 19 photos from Kiiminkijoki that had all been taken with camera. The most engaged age group was 21-30, profession student and gender female, all groups with 68.4 % contribution to the answers. River ice history part consisted of 104 photos from which 78 (75 %) were with river ice and 26 (25 %) with no ice whereas 30 (28.8 %) of the photos had been taken with camera and 68 (71.2 %) with drone. The highest percentage of participants were from age group 51-60 (73.1 %), profession employee (65.4 %) and gender male (79.8 %).

4.4 Participant's perception

Participants' perceptions were evaluated with a focus on Kiiminkijoki public observations. Three questions from each section were selected for closer analysis to include the different perspectives from all the sections. The first question selected from the river ice current situation part was "For what purposes do you use river ice nowadays?" (Figure 7). Overall, it was noticed that skiing was the most selected answer for river ice uses nowadays and the second highest were snowmobiling and fishing. Age group 41-50 provided most answers to this question. Age group 21-30 had more variety among answers compared to other age groups but also quite many said to use river ice for nothing. Entrepreneur was the profession group with highest number of answers and the uses of river ice were skiing, snowmobiling, fishing, skating and use of an ice road. There were less answers from women than men and the difference between men and women was that women had added cycling whereas men had answered snowmobiling as use of river ice.

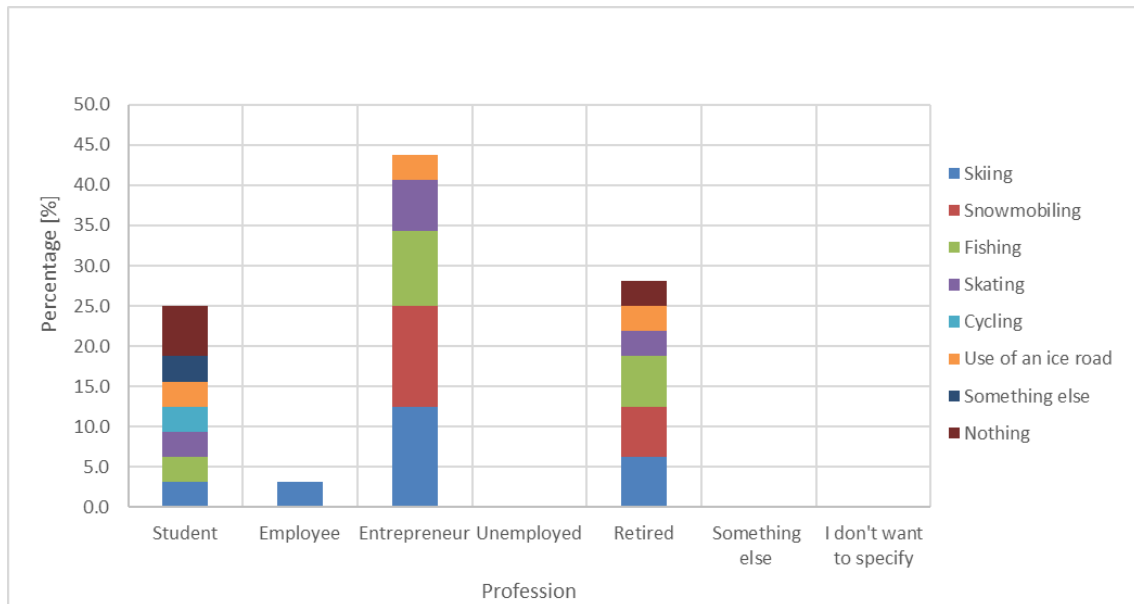


Figure 7. River ice current situation question “For what purposes do you use river ice nowadays?” as percentages per professional group.

The second question selected from the river ice current situation section was “How does river ice flooding affect your life?” (Figure 8). Most participants had not identified as being affected by ice-related flooding nowadays. However, all effects, need for adaptation, structural and environmental damages, had been noticed in age group 41-50 while participants from the age groups 21-30 and 61-70 had only noticed environmental effects or no effects at all. Participants from the age group 51-60 had identified environmental effects and participants from age group >70 had mostly not seen any effects or had seen some other effects than the ones listed. The most affected professional group seems to be entrepreneurs, while students, employees and retired had only detected environmental effects or no effects at all. Men had noted more effects from ice-related flooding than women as women had only noted environmental effect or no effects at all while men had noticed all types of effects.

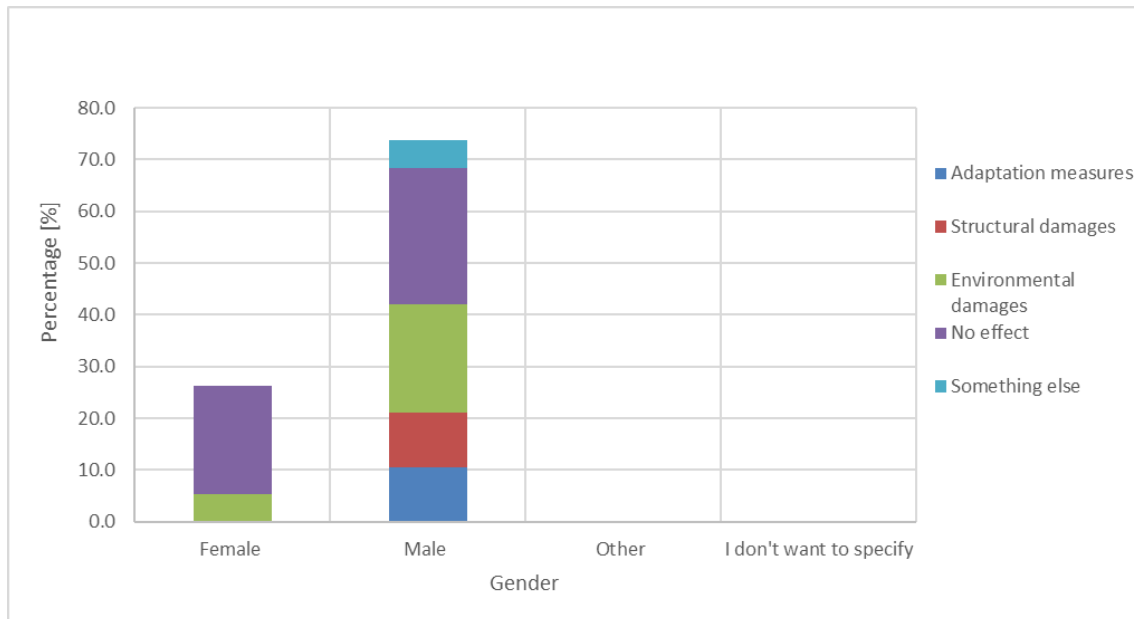


Figure 8. River ice current situation question “How does river ice flooding affect your life?” as percentages per gender.

The final question from river ice current situation section was “What advice would you give to younger generations regarding river ice?”. The most common advice had been definition of hazardous river ice conditions (46.2 %). Contributors from age group 21-30 had not given any advice at all or had given advice for younger generations to check the thickness of the ice while participants from age group > 70 had more often selected to tell a cautionary tale. Professionally the same trend can be noticed as student and retired answers. All men had selected to give some advice a cautionary tale, definition of hazardous ice conditions or check the thickness of ice while women had either decided to tell younger generation to check the thickness of ice or had not given any advice at all.

The first selected question from river ice history part was “How would you describe the duration of the winter ice cover in history of the river?” (Figure 9). The most common answer had been “shorter than nowadays” with 58.3 % of the answers. Participants from age group 21-30 had answered that river ice cover has been longer in history than nowadays while 51-60-year-olds had said that it has been shorter than nowadays and volunteers from age group 41-50 had thought that the duration is like today. Meanwhile participants from age groups 61-70 and >70 have answered both longer and shorter than nowadays. Professionally the presented groups had been student, entrepreneur and retired. Women had more often answered that the river ice cover duration has been longer in history than nowadays compared to men.

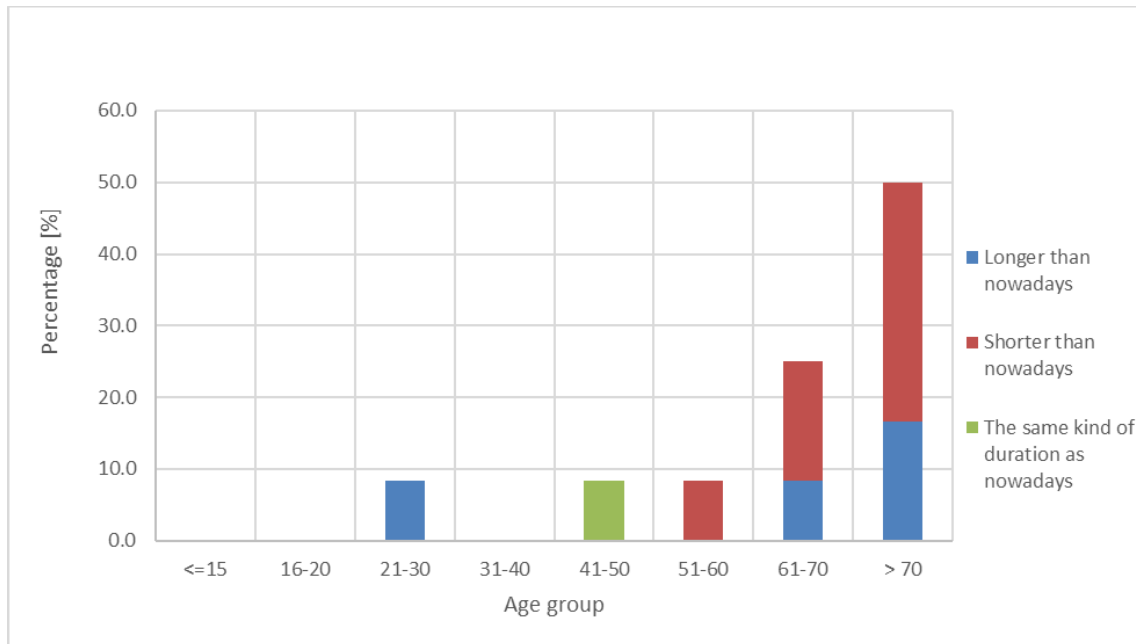


Figure 9. River ice history question “How would you describe the duration of the winter ice cover in history of the river?” as percentages per age group.

The second selected question from river ice history part was “For what purposes have you used the river ice in the past?”. Similarly to current uses of river ice skiing has been the most selected option in past uses of river ice following with fishing. Participants from age group > 70 had been the most active when answering this question and had more activities selected compared to other age groups. Retired had noted having used the river ice as an ice road while entrepreneurs had not selected that option. Student had not used river ice for any purposes in the past. Men and women had mostly used the same answer options, but women had also selected the option of not having used river ice in some cases.

The last selected question from the river ice history section was “Has River ice flooding affected your life?” (Figure 10). Overall, the most common answer was environmental damage by 41.2 % of the answers. Participants from age group 21-30 had not detected any effects from ice-related flooding in the past. Retired and entrepreneurs had taken some adaptation measures or had structural or environmental effects. Some retired had also noted some other effects in addition to those listed or hadn’t noted any effects at all. Women had noticed more environmental effects while men had noticed more structural effects in the past.

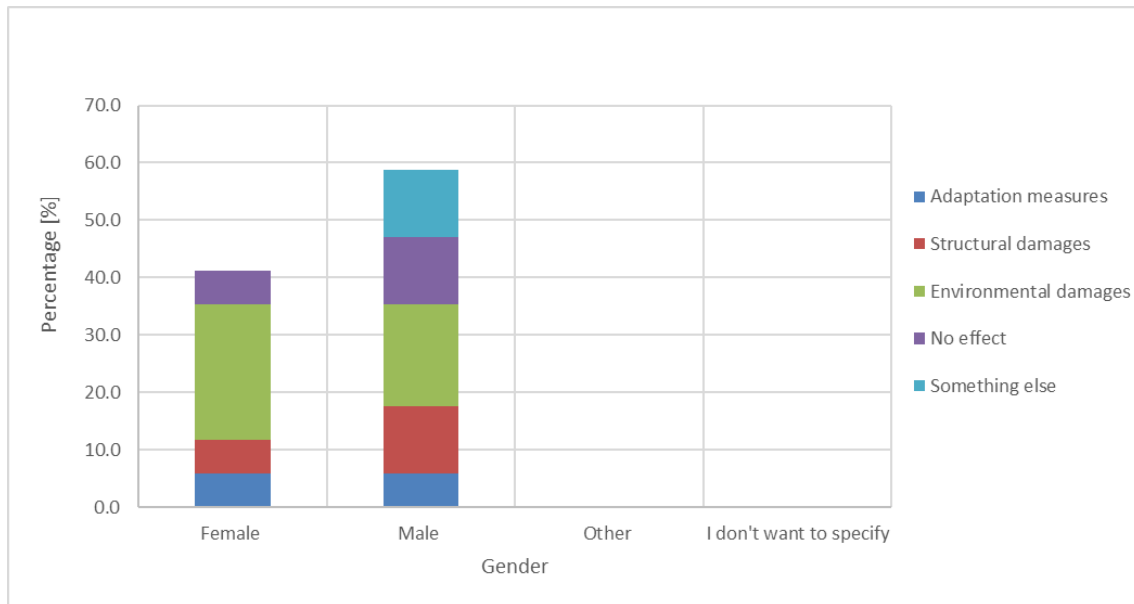


Figure 10. River ice history question “Has River ice flooding affected your life?” as percentages per gender.

The first question part was “How would you imagine the duration of the winter ice cover in the river is in the future?”. Most of the participants (90 %) had thought that the ice cover duration would be shorter than nowadays. Participants from the age group > 70 had provided most answers while volunteers from age groups 21-30, 41-50 and 61-70 had contributed equally and participants from age group 31-40 slightly less. Men and women had engaged equally. All answers stating that winter ice cover will be the same as now had been added by participants from age group >70, profession group retired and gender male. None of the participants had thought that winter ice cover would be longer than nowadays.

The second question selected from future expectations section was “How do you think river ice jam flooding will affect your life in future?”. All participants from age groups 21-30, 31-40 and >70 had estimated that ice related flooding will not affect their lives at all. Meanwhile, volunteers from age group 41-50 had predicted all types of effects and participants from age group 61-70 had estimated either environmental or structural damages in the future. Entrepreneurs had projected to have to adapt or to have structural, environmental or some other kinds of effects. Retired have assessed either structural and environmental damages or no effects. Meanwhile student and unemployed have not foreseen any effects from river ice-related flooding in the future. Men had predicted more effects in the future compared to women.

The final question chosen from the future expectations part was “In what ways do you think that the situation with river ice can be improved?” (Figure 11). The most common answer had been “I don’t know” with 55.6 % contribution to the question. Other than that, volunteers from age groups 21-30 and 41-50 had stated that there is a need for action regarding river ice while participants from age groups 61-70 and >70 had not seen need for improvements. Professionally the groups that had stated need for action are students and entrepreneurs whilst retired had not identified require for actions. Both men and women had answered all the options “No need for action”, “Need for action” and “I don’t know” quite similarly but there were more answers from men.

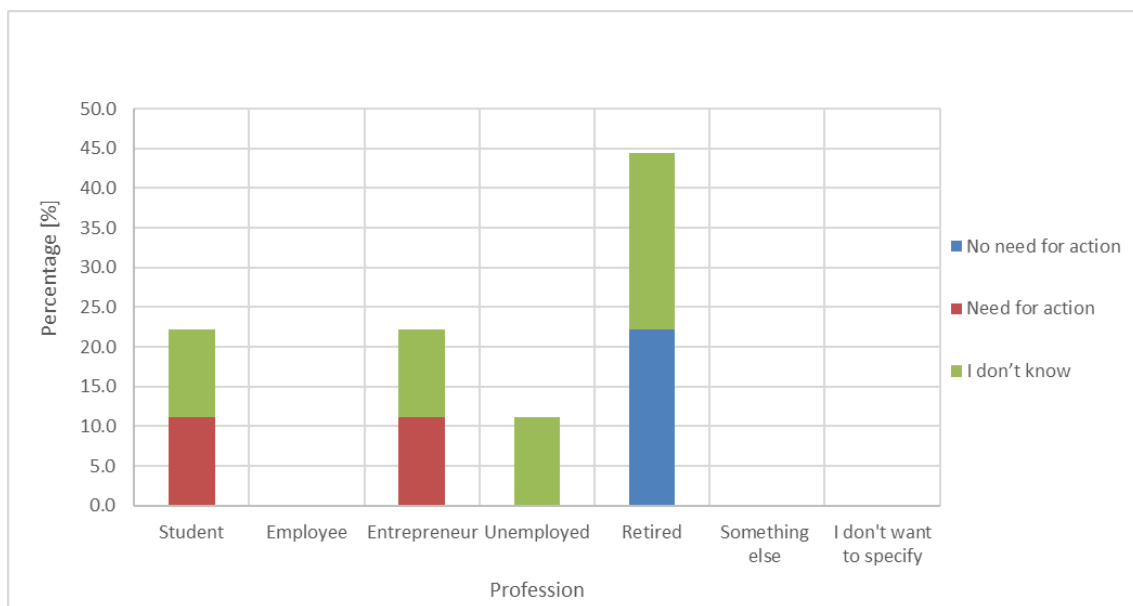


Figure 11. Future expectations question “In what ways do you think that the situation with river ice can be improved?” as percentages per profession.

Expert’s answers to the separate questionnaire identified river ice effects such as enabling recreational activities, changing river morphology and potentially causing damages for example through flooding. These subjects were also noted in application questions related to river ice uses and effects of ice-related flooding. In expert answers it was stated that river ice types are somewhat visually identifiable, but more specific ice cover structure determination is difficult. The CrowdICE questionnaire also had a question related to ice types present in the added photo, however no measures have yet taken to determine the applicability of that question. Experts predict that citizen science observations especially photos and videos could be helpful in predicting ice-related flooding.

Regarding climate change effects on river ice in history it is known by experts that ice cover duration has decreased from previous. In CrowdICE questionnaire there was a lot of variation in answers regarding this subject, as large portion of participants had said that river ice cover used to be shorter even though in many discussions with participants the opposite was suggested. Experts have noticed that nowadays there is some freeze-thaw cycle visible and not so many ice jams anymore. The same kind of trend was noticed in the questionnaire responses as ice-related flood effects nowadays seemed to be less significant than previously. Experts predict that in the future, winters might get even warmer and decrease the formation of stable ice cover but on the other hand frazil ice production might increase and cause ice-related flooding. Citizen answers suggest that most participants believe that winter ice cover will decrease and predict small increase in structural damages as well as in some other effects.

4.5 Citizen science versus in-situ cameras

Total number of Kiiminkijoki camera observation images used in analysis was 360 images (120 images from each location). Ice condition for each day from 1 January to 30 April was determined by visual examination of the photos (Figure 12). There was one short period from 1st to 5th of March during which ice cover melted at Haukipudas camera location. Similarly, there was some melting at Kiiminki upstream camera location. Ice melting started at all the camera locations 31st of March or 1st of April. The river was partially frozen at Kiiminki upstream and at Haukipudas camera locations until 18th of April. However, river froze again at Kiiminki downstream location at 7th of April and started melting again at 17th of April. River was completely free of ice at Kiiminki downstream camera setting at 23rd of April.

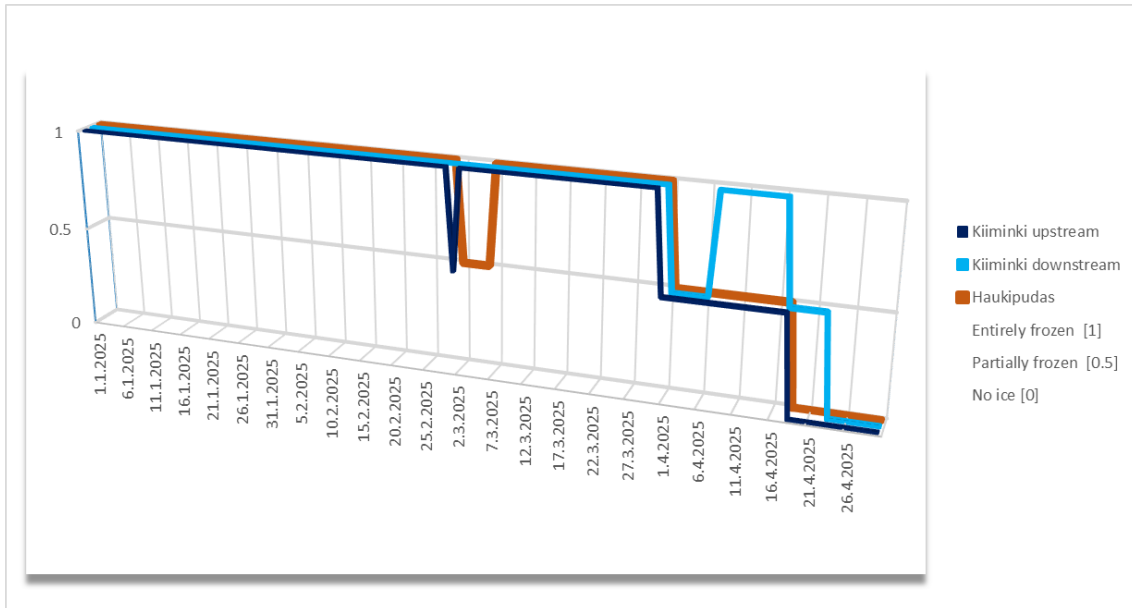


Figure 12. Ice conditions at camera locations from 1 January to 30 April 2025.

All citizen science observations were examined visually to determine ice condition in those locations and ice condition from the same date was examined from in-situ cameras to compare observations. Additionally, citizen’s estimates of ice condition were considered to examine the ability of citizen to categorize photos (Table 2). There were 16 citizen science observations after narrowing remarks to one photo per day and location as ice conditions were similar in all the photos provided from specific date and location. There were two locations (location 1 and 2) that were compared with Kiiminki upstream camera, five locations (location 3-7) that were compared with Kiiminki downstream camera and three locations (location 8-10) that were compared with Haukipudas camera.

Table 2. Citizen science observation locations (upstream to downstream), dates and ice conditions as well as ice conditions from in-situ camera observations for the same dates.

Location	Date	Ice condition observation		Camera ice condition		
		Thesis worker	Participant	Kiiminki upstream	Kiiminki downstream	Haukipudas
1	3.4.2025	Partially frozen	Partially frozen	Partially frozen	Partially frozen	Partially frozen
2	12.4.2025	Partially frozen	Partially frozen	Partially frozen	Entirely frozen	Partially frozen
Kiiminki upstream camera						
Kiiminki downstream camera						
3	4.4.2025	Partially frozen	Partially frozen	Partially frozen	Partially frozen	Partially frozen

4	1.2.2025	Partially frozen	-	Entirely frozen	Entirely frozen	Entirely frozen
5	12.1.2025	Entirely frozen	-	Entirely frozen	Entirely frozen	Entirely frozen
	13.1.2025	Entirely frozen	-	Entirely frozen	Entirely frozen	Entirely frozen
	31.1.2025	Entirely frozen	-	Entirely frozen	Entirely frozen	Entirely frozen
	1.2.2025	Entirely frozen	-	Entirely frozen	Entirely frozen	Entirely frozen
	12.3.2025	Entirely frozen	-	Entirely frozen	Entirely frozen	Entirely frozen
	1.4.2025	Partially frozen	Partially frozen	Partially frozen	Partially frozen	Partially frozen
	2.4.2025	Partially frozen	-	Partially frozen	Partially frozen	Partially frozen
	6	22.2.2025	Partially frozen	-	Entirely frozen	Entirely frozen
7	12.4.2025	Partially frozen	Partially frozen	Partially frozen	Entirely frozen	Partially frozen
8	2.4.2025	Partially frozen	Partially frozen	Partially frozen	Partially frozen	Partially frozen
9	17.4.2025	Partially frozen	-	Partially frozen	Partially frozen	Partially frozen
10	13.4.2025	Partially frozen	Partially frozen	Partially frozen	Entirely frozen	Partially frozen
Haukipudas camera						

Participants had added ice condition to the questionnaire in seven cases out of sixteen (7/16), and in all those cases thesis worker estimation of the ice condition was identical to the ice condition determined by citizen. When comparing citizen observations and in-situ camera images with Kiiminki upstream camera, ice condition was determined to be the same. Most of the citizen observations were compared with Kiiminki downstream camera as that was the closest one to those observations. There were three singular observations from locations 4, 6 and 7 that disagreed with ice condition at in-situ camera location. In all the citizen observations river was partially frozen whereas it was completely frozen at Kiiminki downstream camera location. Locations from 8 to 10 were compared with Haukipudas in-situ camera observations and those observations were in line with the ice conditions observed from the camera.

5 DISCUSSION

The discussion section includes discussion on questionnaire development and challenges as well as application challenges and their connection to the obtained results. Lastly, discussion on the possible future work related to CrowdICE is being discussed.

5.1 Questionnaire development and challenges

The questionnaire developed started from trying to obtain information from three perspectives from Kiiminkijoki: river ice currently, river ice in the past and river ice in the future. The aim was to develop a questionnaire that suits participants from various backgrounds. The first version of the questionnaire related to Kiiminkijoki was created by asking about river ice effects on life, challenges, and possibilities that it creates and river ice conditions in current situation part. The historical part consisted of questions related to river ice conditions, possible memories and photos related to river ice, and witnessing river ice jamming or ice jam flooding. The future expectations' part was focused on climate change challenges, possible loss of river ice, and ideas about the future of river ice.

After the first draft of questions, a meeting with water resources experts was organised to improve the relevance and understandability of the questionnaire. The main points that were discussed in the meeting were related to specifying the questions, for example including questions related to practical uses and effects of ice. Additionally, question related to transferring information to younger generation was added. Because of these comments the second version of the questionnaire asked about recreational use and professional interest to river in the river ice current situation part. Additionally, guessing the date when river ice leaves was included. In the future expectations section, recommendations regarding river ice situation were asked. Other than that, the questions were the same as before but with more answer options.

The second version of the questionnaire then went for another round of improvements suggested by the water resources experts. At that point, it was noticed that the study site description, as well as the improvement of the words used, would probably clarify the questionnaire. The study site description was then added to the third version of the

questionnaire, and the questions were modified significantly. In the river ice current situation and river ice history sections river ice duration, ice types and ice jam flooding as well as recreational use of river ice were asked. Additionally, question asking advice for younger generations regarding river ice was included in the river ice current situation section. Ideas about the duration of ice cover, occurrence of ice types, ice jam flooding and improvement of river ice situation were questioned in the future expectations part.

Once the third version of the questionnaire was ready, it was discovered that this type of questionnaire would not probably work in the application, and due to that, the questionnaire format was changed. Moreover, the spatial area for adding observations was decided to increase to be able to gather more information but questionnaire was not yet changes in this regard. In addition to those mentioned, fourth version of the questionnaire included privacy notice, personal information part, questionnaire description and more guiding texts on how to fill the questionnaire. Location, date and time were asked in relation to added river ice photos, but less open answer boxes were made available to shorten the questionnaire. The fourth version of the questionnaire was then made public on the application.

In the fifth version of the questionnaire, mentions of Kiiminkijoki were removed to gather more information and to encourage the use of the application in a more spatially distributed area. Due to that change a question about the name of the river was implemented to all the sections. During the spring, feedback from users was received that the questionnaire sentences were somewhat confusing when there was no longer ice at river. Considering this feedback some of the questions such ice river ice type determination at river ice history section were changed to the sixth version of the questionnaire to only focus on the added photos.

The main challenges in questionnaire development were implementing the European general data protection regulation (GDPR) and forming the questions so that they are relevant, understandable and specific but keeping the questionnaire relatively short at the same time. The GDPR was considered simultaneously when creating a privacy notice for the questionnaire. The European GDPR is quite strict regarding the collection, storing and uses of the data which made determination of allowed data collection, storing and uses somewhat difficult. At the same time European GDPR also encouraged consideration of ways to enable users to have as much control over their data as possible.

Questions relevancy, understandability and specificity was challenging due to variety in participant age, gender, profession, language and overall background. There is not yet a separate site in Finland for informing citizen specifically regarding river ice. This creates challenges in involving citizen into river ice monitoring as river ice word definitions, monitoring methods and ice jam prevention methods are not clearly listed in one place. In the CrowdICE project, these challenges were addressed by having multiple improvement rounds for the questionnaire as well as adding a small educational material part regarding river ice at the application.

Two questions seemed to either have some unclarity or participant perceptions were not in line with scientific knowledge. In river ice history section, the question regarding river ice duration in history probably had some unclarity to participants as overall, the results had a lot of variation and quite many participants had stated that river ice cover duration was previously shorter than nowadays. However, scientifically the river ice cover duration has been known to decrease in Finland. Another question in which some participants disagreed with the scientific prediction that climate change will further decrease the duration of stable winter ice cover in the future. In this question it was noticed that those who had expected the same kind of conditions in the future as now were from older age groups, retired and men. Though, none of the participants expected longer ice cover duration compared to nowadays.

Comparison of citizen science observations and in-situ cameras revealed that there were three singular citizen observations that disagreed with ice condition at in-situ camera location. Considering Kiiminkijoki conditions it quite possible that there has been a higher flow rate at those areas where camera images and citizen observations do not agree. These results would indicate that most of the observations agree but the amount of data now is quite limited, and more verification methods might be necessary for comprehensive river ice condition analysis. Alternatively, feedback from volunteer could be asked about the clarity of the question and if needed further explanation could be added.

5.2 Application challenges

Practical challenges encountered during the application development were connected to developing the app so that it is clear and understandable for users and admin has possibility to modify the app without coding. Time limitations were one of the greatest challenges during the development and with the time of having the questionnaire online. A lot of changes were made to the app during the development process, either due to internal feedback or due to feedback from users. Users noted for example that minimal text box size made it difficult to add longer responses to the questionnaire as the participant could not see what they were writing. This was then fixed by adding larger text boxes to all open answer questions.

The format for sending the questionnaire was one of the parts that was modified multiple times during the project. Initially, at the end of each questionnaire section there were “back” and “submit” buttons. Pressing the back button would take the user back to the latter section where they could select another section that they wanted to answer, while the submit button would just send one part of the questionnaire. This format led to participants sending the questionnaire too early and having to start filling it out from the beginning. Based on feedback gotten regarding this the buttons were changed to “save” and “send”. However, since there was no registration for the users, none of the answers could be saved. This then resulted in some observations not being sent as participants just left the site after pressing save, mostly likely thinking that the results had already been sent. Lastly, the buttons were changed to “fill other parts” and “send” options to describe the functions better.

One of the issues that was not solved during the application development was having the possibility to give multiple responses to one section. This would have been useful if some users had multiple observations from different locations. However, it could have caused some misunderstandings regarding the analysis of the data. Currently, users can only add one answer per section for example if they have two historical observations from either different location or from the same location but from different times, they can only add both by filling the questionnaire twice. This might have led to fewer observations from some of the users and could maybe be fixed by adding registration functionality. Registration would also allow users to see their previous observations. However, at this point of the project registration was not included to maintain the app simple for testing.

Not having the possibility to modify the questionnaire without coding was one of the most significant challenges, as it delayed the modification and improvement of the questionnaire. However, it is noticeable that other aspects, such as getting feedback from experts and participants, always take some time. Due to the challenges related to the application, the release of the app was first done on the 1st of April 2025. This was too late in spring to collect a comprehensive amount of current river ice observations from the 2024-2025 winter season. The late app release date could be one of the reasons for only receiving photo observations from populated areas along Kiiminkijoki. Overall, the involvement of the public was, however, moderate as 67 observations and 160 photos were received.

Engagement analysis suggested that on average the most involved age groups were 51-60 and >70 while most active profession was retired, and the most engaged gender was male. Meanwhile the least active citizens were from age groups ≤ 15 and 16-20 with no observations. Lack of answers from these age groups could be explained by not having direct contact to younger participants due to school policies as well as possible caution of parents for allowing younger participants to add personal information. All the determined professions had some contribution to the questionnaire and the only empty options in that group were something else, and I don't want to specify. Lastly, there were no answers to other questions, and I don't want to specify in the gender section, but the small sample size most probably caused the lack of other genders. However, noticeable was that not all observations were made directly to the application which increased the number of observations as they did not have to learn how to use the application.

Application reachability could be improved by further introducing the application and its use to locals for example by attending to village associations meetings or having more social media appearances. Additionally, application use could be improved by adding more guidance on app use for instance through videos or illustrations. Analysed data could be made available at the app as it would probably increase citizen participation as they would also gain more information. More approachable app outlook would also improve the user experience and thus increase the app use. As discussed, a lot of the changes were done based on participant feedback which is why encouraging volunteers to give feedback of the system could also be used for further development.

Improving engagement in more rural areas and further along the river could be achieved through multiple announcements of the project on a larger area, increasing local notifications, such as adding posters to campfire sites, and increasing the available time for participants to add observations. Furthermore, citizen engagement could be improved by providing participants with the possibility of adding more observations at once and being able to see their previous observations. Live camera feed available at the application probably increased interest in the topic while also providing essential information about the river. For future use more cameras from different rivers could be added to the website to increase interest in a larger area. However, possible damages to the system should be considered as camera locations are revealed.

5.3 The future work

The future work related to CrowdICE application could include increasing the scope of the work to determine ice types automatically using images and responses from citizen by integrating citizen science into larger river ice monitoring system (Figure 13).

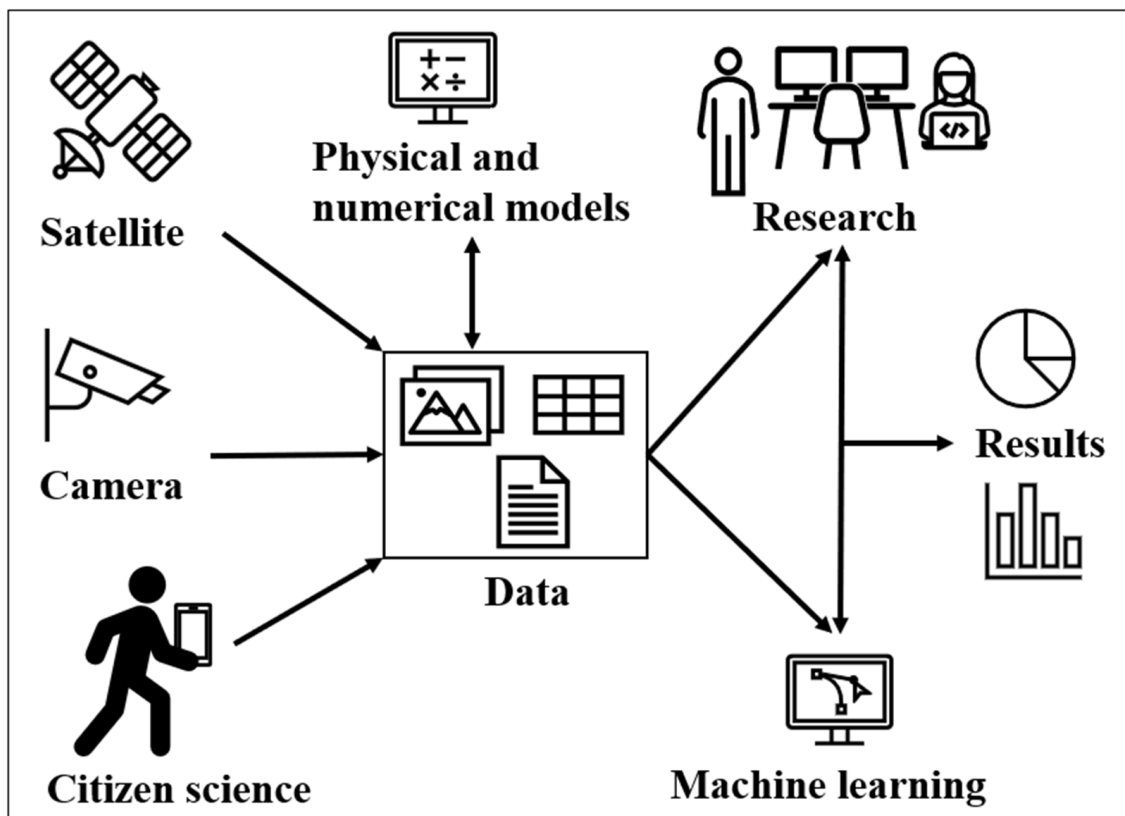


Figure 13. Citizen science app implementation into river ice monitoring system.

Reliable automatic ice type determination would in addition to observations require integration of sensors as well as simultaneous use of satellites, in-situ cameras and physical models for river ice determination. River ice prediction would also require the use of machine learning and researcher input. This kind of system development would need increasing the project's citizen science level to participatory science as well as having more connections to various fields of expertise. Challenges related to the integrated system approach would most likely be related to simultaneous handling of the data as well as increasing the spatial disruption of the system.

Other directions of the future work could include increasing the scope of citizen science for example by data collection from newspapers. Once the application is at satisfactory level, connections to other fields could be considered. Data collection from newspapers could enable discovery of large data sets usually provided with required information such as location, date and even time of the occurrence. Challenges related to this kind of data collection are likely related to the large amount of data and the way that newspapers provide information. However, digital copies of the original papers from multiple years could provide comprehensive informative data for river ice monitoring. Need for connecting CrowdICE to other fields of science should be more thoroughly examined once necessary improvements to the system have been made. Connecting multiple fields to one project could create great opportunities for interaction but might also confuse and complicate citizen science implementation.

6 CONCLUSIONS AND RECOMMENDATIONS

CrowdICE smartphone application was developed for river ice monitoring to understand river ice processes better. Information regarding river ice cover duration and ice break-up was received from 12 rivers in Finland but only some data regarding the start of freeze-up was obtained due to the delayed app release date. Overall, smartphone application was noticed to be applicable solution for river ice data collection. However, the extend of data collected during the thesis is not yet enough for comprehensive analysis of river ice processes. Smartphone application could be improved by increasing the amount of information provided by the application, considering more approachable app outlook and allowing easier addition of multiple observations as well as giving participants access to available analysis results.

Citizen involvement in river ice monitoring was moderate considering the timeframe for informing about the project and adding observations. The total number of public observations during 1st of April to 9th of June 2025 was 67 observations and 160 photos and the spatial extent of observations was from the middle of Finland to the very northern part. However, citizen involvement appeared to be more active along Kiiminkijoki, in the areas where the app was most advertised. Application reachability and citizen involvement could be improved by further introducing the application and its use to locals and by providing more guidance on app use at the application site for instance through videos or illustrations.

Engaging citizens to contribute historical river ice photos from the case study Kiiminkijoki was quite successful with a total of 104 past river ice photos received during the testing. Most of the received photos were taken during the winter season (75 %), and the rest were taken during ice-free conditions. Majority of Kiiminkijoki historical river ice photos were taken with drone (71.2%) which enabled a wider view of the river but did not provide ground-based perspective. Citizen engagement especially regarding photo observations could be improved by the possibility of adding more observations at once. Additionally, allowing participants to see their previous observations could improve engagement. Unclear questions should be modified to have more reliable answers from the participants.

Citizens' connection with river ice was evaluated through questions related to river ice uses, ice-related flooding effects and participants' perceptions about need for improvements regarding river ice. According to the results it was noticed that the most common uses of river had remained the same in history and today. Ice-related flooding effects, on the other hand had decreased nowadays compared to past but small increase in structural damages and in some other effects was predicted in the future. Need for improvements regarding river ice divided different generations as participants from age groups 21-30 and 41-50 had specified that there is need for action while participants from age groups 61-70 and >70 had not perceived need for improvements.

CrowdICE application enabled citizens to access live camera feeds of monitored camera sites at Kiiminkijoki. Two of the live cameras were located at Kiiminki and one at Haukipudas. Cameras provided data for the comparison of in-situ camera images and citizen observations, while also providing an interesting aspect for participants. According to the analysis quite good correlation was noticed. There were however some observations that disagreed which is why more data would be need for more reliable analysis. For future work more cameras along different rivers could be added to the system to provide information for participants from more spatially distributed area. As live feeds reveal the camera locations it would be beneficial to consider system safety and possible damages.

Discussion on using the data collected from citizens in addition to other sensors, in-situ data, and remote sensing products for an AI or ML tool to detect and predict river ice processes in the future was performed. It was concluded that this type of system development would require enhancing the project's citizen science level at least to participatory science. Additionally, more connections to various fields of expertise would be need. Thorough planning of simultaneous handling of the data, as well as preparation on how to increase the spatial disruption of the system, should be done to be able to use an integrated system approach.

7 SUMMARY

River ice jam flooding causes issues in northern rivers, including Kiiminkijoki, Finland. Ice-related flooding might result from ice jams, anchor ice, or a hanging dam (Beltaos 2008). Usually there are three typical stages in the wintertime river ice cycle for cold region rivers: early winter freeze-up, mid-winter stable ice condition, and late winter ice breakup (Prowse & Gridley 1993; Huusko et al. 2007). River ice can alter flow dynamics, light availability and geomorphic or habitat structure in rivers (Thellman et al. 2021). Additionally, climate change is anticipated to cause hydrologic, geomorphic and habitat changes in river systems (Burrell et al. 2023). Monitoring river ice is important as it is effective in making predictions about ice-cover breakup and ice jamming potential which are influenced for instance by ice type, ice thickness and the amount of snow on ice-cover (Lindenschmidt 2020, p.39). Citizen science data collection can be employed through smartphone applications (Andrachuk et al. 2019). When implementing a citizen science-based monitoring app in Europe, it is necessary to follow the European General Data Protection Regulation (GDPR) guidelines.

Kiiminkijoki was selected as case study due to its northern location and non-regulated nature. Smartphone application CrowdICE was developed regarding citizen science project to collect hydrological data from Kiiminkijoki. Different type of stakeholder groups was selected to increase data amount and variety through altering life stages of participants. The selected stakeholder groups were local community and regional authorities and experts. Data analysis was divided into five main sections: citizen science level determination, analysis of observations, citizen engagement, participant's perception, and comparison of citizen science with in-situ cameras.

As a result of citizen science level analysis, the CrowdICE project was determined to be at a distributed intelligence level, as in addition to data collection, citizens also contribute to data analysis. The future aim of the project is to reach citizen science level 3, participatory science. This would require more profound connections with participants so that defining the research questions in collaboration would be possible. Observations analysis showed that the total amount of observations collected (1st of April to 9th of June 2025) was 87 observations and 221 photos while observations from case area Kiiminkijoki consisted of 68 observations and 184 photos. Participants' perceptions

analysis revealed a lot of variation in answers regarding river ice cover duration now and in history. Large number of participants answered that river ice cover used to be shorter even though in discussions with participants the opposite was suggested. This might indicate that there is still some unclarity in the questions. Volunteers had also stated that ice-related flood effects nowadays are less significant than previously which is supported by expert observations. Most participants believe that winter ice cover will decrease in the future. Small increase in structural damages as well as in some other effects was also foreseen. According to comparison of in-situ camera images and citizen observations most citizen observations correlated with in-situ cameras. There were only three observations that disagreed on the ice condition. This could be caused by the variations in river flow along Kiiminkijoki.

Project challenges included challenges in application improvements, implementation of European GDPR and limited information provided about river ice to citizens. Practical challenges in application improvements included for example, participants not having the option to give multiple responses to one section and not being able to modify the questionnaire without coding. Nevertheless, the involvement of citizens in the project was moderate, as 67 observations and 160 photos were received from the public. Engagement analysis for Kiiminkijoki observations suggested that the most involved age groups were 51-60 and >70 while most active profession was retired, and the most engaged gender was male.

It was concluded that application reachability would be improved by further introducing the application and its use to locals. Application use could be improved by adding more guidance on app use, making analysed data available at the app and creating a more approachable app outlook. Furthermore, citizen engagement could be improved by providing participants with the possibility of adding more observations at once and being able to see their previous observations. For future use, more cameras from different rivers could be added to the website, and possible damages to the system should be considered as camera locations are revealed. The future work related to the CrowdICE application could include enhancing the scope of the work to determine ice types automatically using images and responses from citizens by integrating citizen science into a larger river ice monitoring system. Other future work aspects could include increasing the scope of citizen science, for instance, by data collection from newspapers. After having applied at a satisfactory level, connections to other fields could be considered.

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APPENDIX 1: APPLICATION OUTLOOK

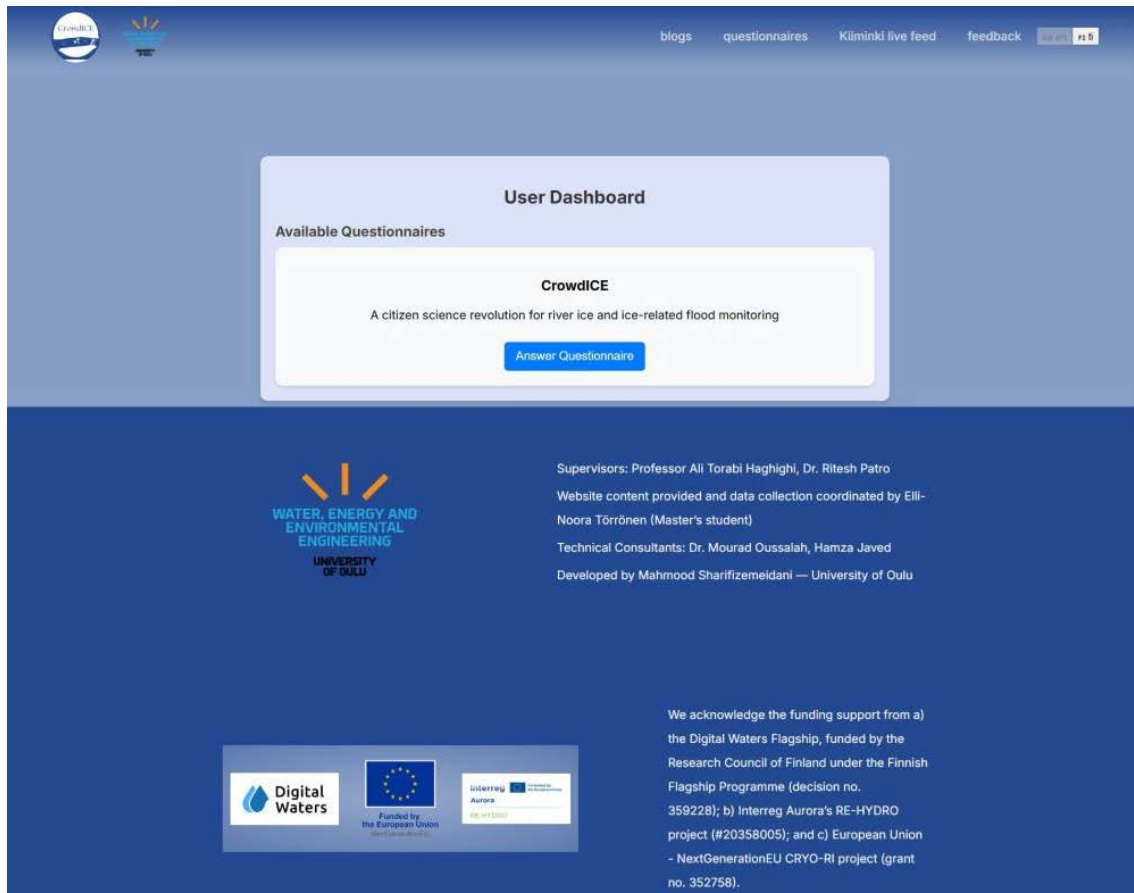


Figure A.1.1. CrowdICE application frontpage.

APPENDIX 2: CROWDICE FLIER

Master's thesis

CrowdICE: A citizen science revolution for river ice and ice-related flood monitoring

Purpose of the study

- Citizen science project to collect hydrological monitoring data with smartphone application
- Extended knowledge of river ice history
- Ice development during winter
- Determination of ice types
- Detection of ice jams and ice jam floods
- Ideas about the future of river ice
- Meaning of river ice to people

CrowdICE app
QR-Code to website



<https://crowdice.fi>

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Figure A.2.1. CrowdICE project flier in English.

APPENDIX 3: EDUCATIONAL MATERIAL

CrowdICE project

Kiiminkijoki

Kiiminkijoki basin locates in Northern Ostrobothnia and Kainuu provinces (Finland) mainly at region of municipalities of Oulu, Pudasjärvi, Puolanka and Utajärvi. The catchment area of Kiiminkijoki basin is 3814 km². As Kiiminkijoki is relatively natural it is a scientifically valuable research object. Kiiminkijoki is a risk area for ice-related flooding and has multiple known locations prone to ice jamming. As Kiiminkijoki riverbanks are mainly in natural state and hardly any flood protection embankments have been built, the flood spreads widely beyond the main riverbank in many places.

Citizen science in environmental monitoring

Citizen science: can be defined in various ways but two common points in citizen science are involvement of non-scientist into research and scientific benefit from monitoring

Environmental monitoring: citizen science related environmental monitoring includes a lot of different kind of activities engaging volunteers to observe, record and share data.



Figure 1. Sharing data between generations. Photo: Created with AI.

River ice processes

River ice winter cycle

Early winter: freeze-up

- Various ice types are formed

Mid-winter: ice cover

- Forms when river flow is restricted, and thus floating ice consolidates into a continuous ice sheet

Late winter: ice break-up

- Thermal break-up: ice melt due to rising temperatures
- Mechanical break-up: mechanical forces such as forces caused by water level rise make ice sheet to break

Ice types

Skim ice: A thin sheet of ice which is typically transparent and forms near riverbanks.

Border ice: formed as cooling temperatures thermally thicken skim ice.

Frazil ice: small ice crystals formed in turbulent and supercooled waters (water temperature below 0 °C)

Pancake ice: larger pans of ice formed as slush solidifies under persistent freezing conditions



Figure 2. River ice types: skim ice.



Figure 3. River ice types: border ice and frazil ice. Photo: Knut Alfredsen, NTNU.



Figure 4. River ice types: border ice and frazil ice. Photo: Knut Alfredsen, NTNU.



Figure 5. River ice types: pancake ice. Photo: Knut Alfredsen, NTNU.

Ice-related flooding

Typical characteristics of ice-related flooding:

- Higher water levels compared to flooding in ice free conditions
- Damages caused by ice-related flooding are major
- Occurs due to ice jamming

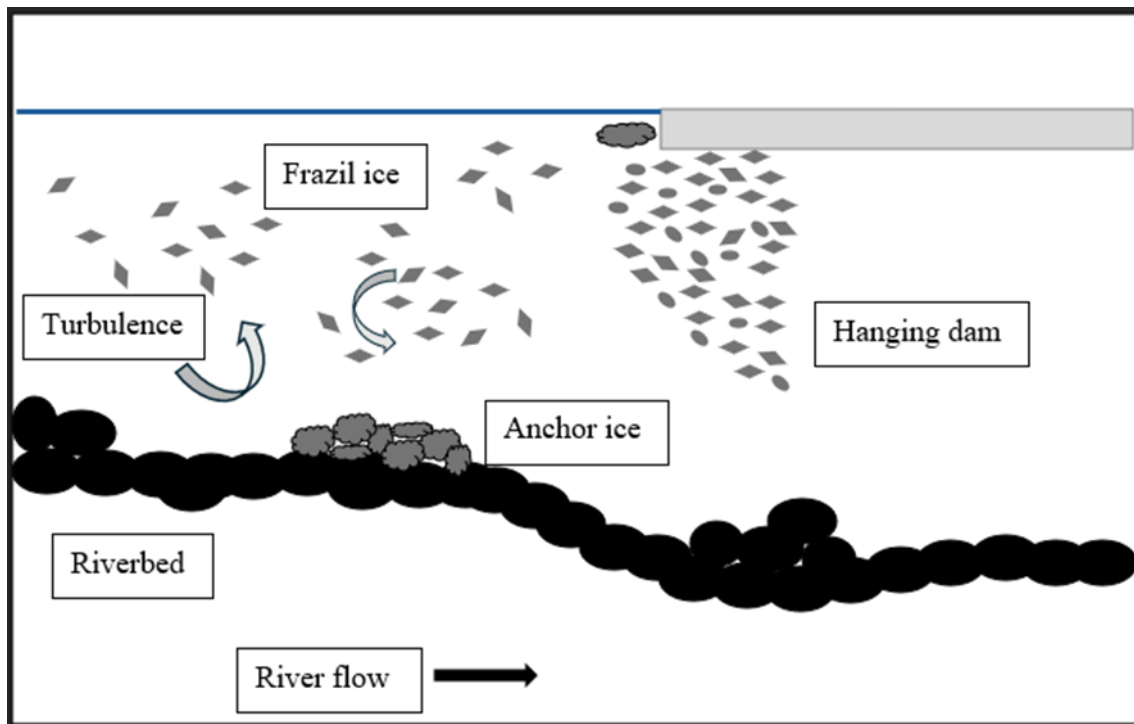


Figure 6. Formation of anchor ice and hanging dam (Reproduced from Huusko et al. 2007).

Hanging dams: accumulation of frazil ice beneath an intact ice cover.

Anchor ice dam: frazil ice adheres to the riverbed.

Ice jam: ice sheets accumulate for example at the edge of an intact ice cover obstructing water flow



Figure 7. Anchor ice. Photo: Knut Alfredsen, NTNU.



Figure 8. Ice jam. Photo: Knut Alfredsen, NTNU.

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APPENDIX 4: CROWDICE QUESTIONNAIRE

CrowdICE: A citizen science revolution for river ice and ice-related flood monitoring

The purpose of this project is to collect data about temporal duration of ice in river during winter, the occurrence of ice types, ice dam flooding and the uses of ice, and their effects in history, today and in the future.

Personal information

Name: _____

E-mail: _____

Age group*

- ≤ 15
- 16 – 20
- 21 – 30
- 31 – 40
- 41 – 50
- 51 – 60
- 61 – 70
- > 70

Profession*

- Student
- Employee
- Entrepreneur
- Unemployed
- Retired
- Something else
- I don't want to specify

Gender*

- Female
- Male
- Other
- I don't want to specify

Appendix 4

The questionnaire has been separated to three sections: current situation of river ice, history of river ice and future expectations. In current situation of river ice and history of river ice sections it is possible to take or upload photos and to answer questionnaires. In future expectations part ideas and options of river ice future are asked through questionnaire. You can answer any of the sections or all of them.

Current situation of river ice (photos and questionnaire)

Take photos / upload images

Date of the photo _____

Time of the photo _____

Location (mark the location where photo was taken on the map or alternatively write the location to text box below): _____

Street address (you can mark the location here if you didn't mark it on the map)

- Name of the river _____
- How would you describe the river now?
 - Partially frozen _____
 - Entirely frozen _____
 - No ice _____
- What river ice types are present in the river currently? (multiple answers allowed)
 - Skim ice
 - Border ice
 - Frazil ice
 - Pancake ice
 - Something else _____
 - I can't specify / None
- What time would you assume the river ice leaves this year?
 - Add your guess (date) _____
- For what purposes do you use river ice nowadays? (you can choose more than one option)
 - Skiing
 - Snowmobiling
 - Fishing
 - Skating
 - Cycling
 - Use of an ice road
 - Something else _____
 - Nothing

Appendix 4

- How does river ice flooding affect your life? (you can choose more than one option)
 - Adaptation measures (flood barrier, plinth protection etc.)
 - Structural damages (building, pier etc.)
 - Environmental damages (forest, farmland, yard etc.)
 - No effect
 - Something else _____
- What advice would you give to younger generations regarding river ice?
 - A cautionary tale (of what kind?) _____
 - Definition of hazardous river ice conditions (how?) _____
 - Check the thickness of the ice (when are conditions safe?) _____
 - Something else _____
 - Nothing

River ice history (photos and questionnaire)

Take / images photos

Date of the photo _____

Time of the photo _____

Location (mark the location where photo was taken on the map or alternatively write the location to text box below): _____

Street address (you can mark the location here if you didn't mark it on the map)

- Name of the river _____
- How would you describe the incidence of ice in the uploaded photo?
 - Partially frozen _____
 - Entirely frozen _____
 - No ice _____
- What are the river ice types on the uploaded photo? (multiple answers allowed)
 - Skim ice
 - Border ice
 - Frazil ice
 - Pancake ice
 - Something else _____
 - I can't specify / None
- How would you describe the duration of the winter ice cover in history of the river?
 - Longer than nowadays _____
 - Shorter than nowadays _____
 - The same kind of duration as nowadays

Appendix 4

- For what purposes have you used the river ice in the past? (you can choose more than one option)
 - Skiing
 - Snowmobiling
 - Fishing
 - Skating
 - Cycling
 - Use of an ice road
 - Something else _____
 - Nothing
- Has river ice flooding affected your life? (you can choose more than one option)
 - Adaptation measures (flood barrier, plinth protection etc.)
 - Structural damages (building, doc etc.)
 - Environmental damages (forest, farmland, yard etc.)
 - No effect
 - Something else _____

Future expectations

- Name of the river _____
- How would you imagine the duration of the winter ice cover in the river is in the future?
 - Longer than nowadays _____
 - Shorter than nowadays _____
 - The same kind of duration as nowadays
- What types of river ice would you imagine in the river in future? (multiple answers allowed)
 - Skim ice
 - Border ice
 - Frazil ice
 - Pancake ice
 - Something else _____
 - I can't specify / None
- How do you think river ice jam flooding will affect your life in future? (you can choose more than one option)
 - Adaptation measures (flood barrier, plinth protection etc.)
 - Structural damages (building, doc etc.)
 - Environmental damages (forest, farmland, yard etc.)
 - No effect
 - Something else _____
- In what ways do you think that the situation with river ice can be improved?
 - No need for action
 - Need for action _____
 - I don't know

APPENDIX 5: EXPERTS QUESTIONNAIRE

CrowdICE: A citizen science revolution for river ice and ice-related flood monitoring

Could you tell when was your first memory or interaction with river ice?

For what purposes do you use river ice nowadays? (you can choose more than one option)

- Skiing
- Snowmobiling
- Fishing
- Skating
- Cycling
- Use of an ice road
- Something else

- Nothing

Could you explain the role of river ice in river corridors and hydrological processes?

Are you able to identify type of river ice by visuals/plain sight?

What is your opinion on the past and future of river ice in Finland in this era of climate change?

Appendix 5

Do you get information about river ice conditions or warnings about related hazards, such as ice jam floods? If so, could you specify the sources?

In your opinion, what is currently lacking in monitoring and modelling river ice?

Do you think it is a good idea to involve citizen in collecting information about river ice?

APPENDIX 6: PRIVACY NOTICE

Introduction

The CrowdICE tool is designed to help volunteer observers record information related to river ice. Such information helps assess risks from disasters like floods, understand change over time, and address many other scientific questions.

The data collected by this app are used for research at the University of Oulu. By using this app, you are contributing to our understanding of river ice formation and the effects of climate change on river-ice processes. You will also provide information that will help the research community in advancing the understanding of river ice processes.

What Do I Do?

CrowdICE guides you through documenting and identifying river ice. Even just taking photos is valuable since researchers and scientists may lack observations for certain areas.

When to Observe?

Although observations at any time are valuable, it is preferable to take observations during daylight. This helps with the interpretation of your photos.

Privacy and Terms of Use

Safety

1) CrowdICE encourages you to make scientific measurements which help characterize the area you are in. When making these measurements, use caution - stay safe.

2) Before you begin, familiarize yourself with your environment and always collect data in a safe location and a safe manner. Do not take pictures outside if there are currently issues in your environment that are unsafe (e.g., thunder, lightning etc.)

3) Always follow the law of the area in which you are making measurements. Do not take pictures on private land without permission where it is unlawful to do so, and do not trespass.

Appendix 6

- 4) Avoid taking pictures with people in the field of view.
- 5) Be careful with your device - do not take a picture in a way that you risk damaging your device such as by dropping it
- 6) Do not attempt to take photographs or measurements while operating a vehicle.

Communication

CrowdICE may use your email address to contact you to take your permission to publish your uploaded photo and name for research publication purposes.

Data Handling and Management

By uploading pictures using this app, I confirm that I have rights to all images, and I permit the University of Oulu to use these images for scientific and research publication and communication.

In addition, I confirm that the images, captions, and associated field notes do NOT contain the following:

- inappropriate or offensive language
- identifiable people, children, or inappropriate/offensive images

I understand the measurement data that is sent to CrowdICE includes the location of that measurement. The location information, along with measurement data and photos, are stored in the CrowdICE database. Any scientist, researcher, or person utilizing the CrowdICE database from the University of Oulu shall credit the CrowdICE program collectively as appropriate. Detailed user information (for example your email address) is protected and is not displayed on the website.

Extended Privacy notice is available here: [Privacy Notice](#)

I have read the *Privacy Notice and accept it*



PRIVACY NOTICE FOR SCIENTIFIC RESEARCH PARTICIPANTS

EU General Data Protection Regulation Art. 12-14

Date: 26.3.2025

Information for Research Participants

You are taking part in a thesis study organized by the thesis worker Elli-Noora Törrönen. This notice describes how your personal data will be processed in the study.

Participation in the study is voluntary. There will be no negative consequences for you if you choose not to participate in the study or if you withdraw from the study. However, if you withdraw from the study, data collected prior to your withdrawal may still be used in the study. For more information on your rights and how you can affect the processing of your personal data, please see section 13 of this notice.

1. Name and duration of the study

Name of the study: CrowdICE: A citizen science revolution for river ice and ice-related flood monitoring

Duration of the study (how long personal data is processed): Thesis will last until 6/2025

2. Data Controller

Data Controller: University of Oulu

Address: Pentti Kaiteran katu 1, Linnanmaa

Tel.: 0294 480 000

E-mail: oulun.yliopisto@oulu.fi

Contact person for research-related questions:

Name: Elli-Noora Törrönen

E-mail: elli-noora.torronen@oulu.fi

Contact details of the Data Protection Officer

You can contact the Data Protection Officer of the University at dpo@oulu.fi.

3. Description of the thesis / research project and the purpose of the processing of personal data

Master's thesis CrowdICE: A Citizen science revolution for River Ice and ice-related flood monitoring. The work aims to engage citizens into collecting information on the history, current situation and future expectations of river ice with the help of a smartphone application. The data collected is used to monitor river ice during winter, the type of river ice formation and issues like ice jam flooding, in addition to identifying the effects of climate change on river ice as well. We also collect information to help us understand and identify the significance of river ice to citizens.

The main goals of the thesis are understanding what can be achieved with smartphone environmental monitoring, assessing the extent of meaningful contribution of technologies to monitoring and estimating the prospects of the use of mobile applications in cold climate hydrological monitoring.

All information related to this research project (thesis, publication of images and use of the application) is processed based on the research participant's consent. The retention period for personal data is stated in parentheses after the data group.

Data to be collected to enable the study of the thesis:

- Age Group (6/2030)
- Gender (6/2030)
- Dictation function audio recordings (deleted during analysis or no later than 6/2030)
- River ice related images (location, date, time) (6/2030)
- Written text (6/2030)
- Multiple choice questions (6/2030)

Images related to river ice may be published in connection with the research study, and for scientific publication and communication purposes. If you leave your contact information, you may be contacted separately regarding the rights to the images. Name and email are necessary information for giving credit of photos and by not providing this information rights for images will be lost. Data to be collected for the publication of images:

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- Name (to be deleted during analysis or no later than 6/2030)
- Email (will be deleted during the analysis or no later than 6/2030)

Data collected to ensure and improve the functionality of the application:

- Open feedback to improve the functionality of the application (6/2030)

Principal Investigator

Name: Ali Torabi Haghghi

Address: Erkki Koiso-Kanttilan katu 5, Linnanmaa

Tel: +358404492894

E-mail: ali.torabihaghghi@oulu.fi

Persons processing personal data in the study

Researchers and research assistants in the Department of Water, Energy and Environmental Engineering at the Faculty of Engineering.

4. Lawful basis of processing

Personal data is processed on the following basis, which is based on Article 6(1) of the General Data Protection Regulation:

- participant's consent
- performance of a task carried out in the public interest: scientific or historical research purposes or statistical purposes
- legitimate interests pursued by the controller or by a third-party

Description of the legitimate interest:

5. Types of personal data processed in the study

Research data includes the following types of personal data:

- Name (deleted in analysis step or at latest at 6/2030)
- E-mail (deleted in analysis step or at latest at 6/2030)
- Audio recordings (deleted in analysis step or at latest at 6/2030)

6. Sensitive personal data

No sensitive personal data will be processed in the study.

7. How and from what sources personal data is collected

Personal data is collected by a questionnaire through a smartphone application.

8. Transfer or disclosure of the personal data outside the research team

Personal data will be stored in the CSC data management service. Images collected during the study may be published with a separate consent of the rightsholder, in which case the name of the rightsholder will also be published in connection with the published image.

9. Transfer or disclosure of personal data to countries outside the EU/European Economic Area

Personal data is not transferred outside the EU or the European Economic Area.

10. Automated decisions

No automated decisions are made.

11. Safeguards to protect the personal data

The data is confidential.

Protection of manual material: No manual material is collected

Protection of personal data processed in IT systems:

username password logging access control

other:

Processing of direct identifiers:

Personal data will be anonymised

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- Direct identifiers will be removed in the analysis phase
- The material to be analysed includes direct identifiers. Reason: Images related to river ice may be published in connection with the study. If you leave your contact information to publish the images, you may be contacted separately regarding the rights to use the images.

12. Processing of personal data after the completion of the study

- The research material will be deleted
- The research material will be archived:
 - without identifiers
 - with identifiers

Where will the material be archived and for how long: The material is stored in the CSC data management system for 5 years after completion of the study (until 06/2030). The material can be used for research during the retention period.

13. Your rights as a data subject, and exceptions to these rights

Data protection legislation guarantees the data subject certain rights that enable them to ensure the fundamental right of the protection of privacy. If you wish to exercise the rights mentioned in this section 13, please contact the contact person of the study mentioned in section 2 of this notice.

Withdrawing consent (GDPR Article 7)

You have the right to withdraw your consent, provided that the processing of the personal data is based on consent. The withdrawal of consent will not affect the lawfulness of processing based on consent before its withdrawal.

Right of access (GDPR Article 15)

You have the right to obtain information on whether or not personal data concerning you are being processed in the project, as well as the data being processed. You can also request a copy of the personal data undergoing processing.

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Right to rectification (GDPR Article 16)

If there are inaccuracies or errors in your personal data being processed, you have the right to request rectification or supplementation of the data.

Right to erasure, right to restriction of processing, right to object, right to data portability (GDPR Articles 17, 18, 20, 21)

You may request the erasure of your personal data that are processed in the research. You may also request the restriction of processing your personal data, object the processing, or request the transmission of your personal data from one system to another.

Derogating from rights

In certain individual cases, derogating from the rights described above in this section 13 Your rights as a data subject and exceptions to these rights may be made on the basis of the GDPR and the Finnish Data Protection Act, insofar as the rights render impossible or seriously impair the achievement of scientific or historical research purposes or statistical purposes. The need for derogations will always be assessed on a case-by-case basis.

14. Right to lodge a complaint

You have the right to lodge a complaint with the Data Protection Ombudsman's Office if you think your personal data has been processed in violation of applicable data protection laws.

Contact details:

Office of the Data Protection Ombudsman (Tietosuojavaltuutetun toimisto)

Street address: Lintulahdenkuja 4, 00530 Helsinki

Postal address: PL 800, 00531 Helsinki, Finland

Tel. (switchboard): 029 56 66700

Fax: 029 56 66735

E-mail: tietosuoja@om.fi