

Sustainable risk management of trouble spots caused by heavy rainfall events: Regional Citizen and Community Science app and dataprototype for flood risk analytics in the Ahr Valley with global applicability for residents and authorities

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10 **Abstract.** ~~To address the~~ The increasing threat frequency and intensity of heavy extreme rainfall events ~~the FloReST (Urban~~
~~Flood Resilience – Smart Tools) project focuses on the identification and prediction of emergency flow paths in present a~~
~~critical global challenge for urban areas and enhancing.~~ While flood risk management and communication. The project
~~developed a~~ has historically prioritised fluvial hazards, pluvial flooding and urban overland runoff pathways require local
15 and global attention and scalable, community-inclusive solutions. This proof-of-concept paper presents the local-scale
development and implementation of a prototype Citizen and Community Science app ~~mobile application, designed within a~~
municipal extreme rainfall context, where both the app’s testing environment and current operational scale are spatially
limited to neighbourhood and city level in the Ahr valley. The prototype enables residents to document, classify, and report
pluvial flood risks in urban areas due to the fact that conventional flood protection has so far focused mainly on fluvial hazards.
~~The population is involved in sustainable, while supporting community-based~~ risk minimisation through the active use of the
20 app and local risk-enhanced awareness. Additionally, the app includes and embedded educational functions through a user
guidance on categorizing pluvial hazards and taking hazard categorisation and preventive measures. The app is complemented
by a actions. Crowdsourced observations are transferred to a Geo Data Warehouse, which enables providing local authorities
to analyse and visualise the data transmitted by users via with customisable dashboards- for analysis, visualisation, and
decision support. Although there are still some technical limitations, such as limited constraints remain—particularly
25 restricted offline functionality and inaccuracies/variability in the use of Global Navigation Satellite Systems, these may be
addressed in future research. Thanks to its open source design, the system remains scalable and can be adapted to other
regions worldwide. Overall, the Citizen Science app and Geo Data Warehouse form an innovative, System accuracy—the
system architecture was intentionally designed to support iterative refinement. Despite its present local application, the
prototype is based on a fully open-source, modular, and scalable design, allowing international transferability and future
30 expansion to regional, national, or global datasets and governance frameworks. This proof-of-concept thus demonstrates the
global scaling potential of combining citizen-generated flood risk data with centralised geospatial infrastructure as a pathway

toward more climate-resilient and participatory tool that improves the resilience of cities to climate change through inclusive, data-driven urban pluvial flood risk management worldwide.

35 1 Introduction

Heavy rainfall events and flood disasters have increased in frequency and intensity in recent years (Deumlich and Gericke, 2020). Because of climate change this trend will continue to intensify in the coming years and decades, causing numerous material and human losses.

40 In Europe, extreme weather events are increasing frequently, leading to severe damage in some areas due to pressure systems such as the low-pressure system 'Bernd' in July 2021. 'Bernd' caused flooding that was characterised by particularly high flow velocities, rapid progression of the flood event and high water levels, especially in the Ahr Valley (Rhein and Kreibich, 2025). In 72 hours, more than 150 mm of precipitation fell on already saturated soil, leading to particularly high runoff (Mohr et al., 2023). The flood led to the loss of 135 lives in the Ahr Valley (Heidbreder, 2023). Floods, such as those in the Ahr Valley in 2021, have shown that warning the population in time is a crucial factor, especially in pluvial events: (Rhein and
45 Kreibich, 2025). To mitigate this factor, continuous research is being conducted on better forecasting methods and the communication of various alert chains is being improved.

~~The Water Extreme Events (WaX) program of the German Federal Ministry of Research, Technology and Space (BMFT) is also dedicated to these tasks. The funding line includes 12 projects focusing on water-related topics. One of these projects is the "Urban Flood Resilience – Smart Tools (FloReST)" project. As part of this project, various smart tools are being developed to improve risk management in heavy rainfall events. The focus is on identifying and predicting. An important part of risk management in flood protection is the identification and communication of flow paths in urban areas and the resulting risk management. (Agonafir et al., 2023; Schmitt and Scheid, 2020).~~

50 ~~Risk management includes a wide range of measures aimed at mitigating problematic areas within these flow paths that may pose dangers during heavy rainfall events. These include, for example, clogged drains, grates, and sieves that can no longer absorb water masses during a strong runoff, causing the water to flow elsewhere.~~

55 Risk management includes a wide range of measures aimed at mitigating problematic areas within these flow paths that may pose dangers during heavy rainfall events (Schmitt and Scheid, 2020). These include, for example, clogged drains, grates, and sieves that can no longer absorb water masses during strong runoff, causing the water to flow elsewhere (Agonafir et al., 2023).

Identifying such problematic areas requires a high level of local knowledge. Many citizens are familiar with how their
60 neighbourhood behaves during heavy rainfall events and possess detailed knowledge about runoff behaviour on their own property and in adjacent public spaces. This valuable knowledge often resides with residents who have observed and even documented their surroundings during past events. Since responsibility for public spaces lies with the respective municipalities, (in Germany), establishing a communication chain between these knowledgeable locals and decision-makers is essential.

65 This knowledge is particularly valuable for researchers and municipalities in preventing heavy rainfall events. The involvement of citizens in research projects through Citizen ~~Science (CS) has been established for several years and is increasingly being used in civil projects.~~

~~and Community Science has been established for several years and is increasingly being used in civil projects (Bonney, 1996; Conrad and Hilchey, 2011; Irwin, 1995).~~ The goal is to provide local knowledge to researchers and municipalities to enable efficient and effective risk management. Communication with citizens also plays a crucial role in this process- ~~(Denda and Fujikane, 2024).~~ Participation fosters greater tolerance and acceptance of implemented measures among those affected- ~~(Ueberham, 2016).~~

This participatory process shall be implemented in the form of a mobile application (app) for Android smartphones. The app should allow citizens to report problematic areas directly, including both the exact location and a description of the issue. ~~At its current stage, the app represents a functional prototype that has been specifically developed and tested for the local extreme rainfall risk context of the Ahr Valley (Germany).~~ Researchers or municipalities can analyse the data according to their risk management strategies and use it for implementing measures. ~~Due to its modular open-source architecture, the prototype was intentionally designed to support future scalability and global transferability, enabling adaptation and deployment in other regions worldwide, beyond the original local use case.~~ With this tool we aim to investigate how the citizen ~~and community science method in heavy rainfall prevention can be technically implemented and tested as a contribution to sustainable flood~~ management.

The paper begins with a literature review on the topics of risk management in flood scenarios, citizen ~~and community science~~, and appropriate technical solutions (Section 2). This is followed by a description of the methods (Section 3) used and a detailed presentation of the results (Section 4). The discussion section explains the advantages of the citizen ~~and community science method regarding the management of emergency drainage routes, as well as the challenges and limitations of the method~~ (Section 5). Section 6 concludes with a summary of the work.

2 Literature Review

2.1 ~~Risk~~Flood risk management ~~for floods-~~ local and global relevance of heavy rainfall and pluvial hazards

~~Flood events are not unusual on rivers and larger water bodies in Germany. People live with the regular rise and fall of water levels and are usually able to deal with occasional moderate floods with confidence and resilience. Floods that originate from watercourses are the result of long term rainfall or the occurrence of melting snow are referred to as fluvial phenomena. Unlike fluvial events, which are usually easy to predict, so-called pluvial events usually occur spontaneously and without sufficiently long predictions or annual intervals. Pluvial floods are characterised by the fact that they can occur independently of a watercourse and are usually caused by heavy rainfall in a short period of time and in a small area (Kutschker and Glade,~~

95 ~~2016).~~

The poor predictability and short warning times of these events make good prevention and risk management even more important.

One of the most important findings in risk management is that people are more likely to implement measures if they are personally (directly or indirectly) affected by an event. Affectedness is primarily controlled by the occurrence of emotions in those affected. The stronger the emotion the higher the likelihood of a reaction (Netzel et al., 2021).

How people perceive their personal risk is also crucial. A distinction should be made between global and personal risk perception. If people perceive a global risk, such as climate change itself, this only rarely leads to them taking protective measures. However, if people are personally affected and experience the associated emotions, such as in the case of a heavy rainfall event as a result of climate change, they are more likely to take precautionary measures (Netzel et al., 2021).

This realisation brings risk management to a small scale level that must take local conditions into account (Rosenzweig et al., 2018). The probability of measures being implemented is only high if people are addressed directly. The level of education and knowledge of the people targeted are crucial here. People with a higher level of education and a higher level of knowledge about heavy rainfall and runoff processes are more likely to implement appropriate measures (Netzel et al., 2021).

Risk management therefore has both an educational task and an obligation to address people's emotions to implement the best possible precautionary measures.

Due to the so far poor spatial predictability and the non-periodic occurrence of pluvial events, permanently installed flood protection measures are only practicable to a limited extent. Widely used methods for flood protection (from fluvial floods), such as permanently installed systems for the on-demand construction of flood defence walls, are only partially applicable or not applicable at all during pluvial events. It is therefore crucial that more precise forecasting systems are developed and risk assessment is improved. The latter makes it possible to implement preventive measures and flood warnings in a more targeted and effective manner (Falconer et al., 2009). In order to maximise the integration of risk management, the involvement of citizens and authorities is essential (Ueberham, 2016). Participatory approaches can promote the development of risk awareness and thus increase the population's awareness of e.g. problematic areas in urban runoff events (Rollason et al., 2018). Personal precautions, both in the form of measures at private homes and networking with each other (e.g. by setting up warning chains), but also increasing knowledge about heavy rainfall and its dangers can make people more resilient to pluvial flood events (Gallmetzer et al., 2021). Currently there is often a gap between people recognising the risks and the implementation of measures due to a lack of communication. In order to close this gap, it is necessary to share people's findings with the responsible authorities as easily as possible in order to improve communication and data accessibility (Rosenzweig et al., 2018). Methods from the field of CS are suitable for this purpose.

2.2 — Citizen Science in Environmental Monitoring

Citizen Science refers to the involvement of citizens in research projects and scientific data collection (Bonn et al., 2021). Citizens collect data independently, which is then analysed by researchers. In this way, large quantities of small scale and diverse data sets can be generated (Abecker et al., 2012a, 2012b; Bonn et al., 2021).

CS in the environmental sciences was first used in ornithological monitoring projects for which it is still very well known today (Bonney, 1996).

The CS approach is a win-win situation for everyone involved (Bonn et al., 2021). In this way, science obtains a large amount of data that is collected by independent persons so that the bias of the scientists themselves can be minimised. At the same time it offers the opportunity to make science accessible and understandable for people and thus gain a greater insight into science and its topics among the population. Science itself benefits, among other things, from the opportunity to release innovation potential at an individual and social level (Bonn et al., 2021).

According to surveys conducted by the Science Barometer (Wissenschaftsbarometer), well over half of citizens are interested in science and research (Ziegler, 2022). An interest that has increased even further in recent years, e.g. due to the coronavirus pandemic (Ziegler, 2022). But also, movements such as 'Fridays for Future' and other climate campaigns clearly show that society is increasingly interested in scientific issues and wants to be involved in them. Environmental issues are often turned into strategic decisions by the existing political and administrative structures, which often do not involve people and leave them as silent observers (Liu et al., 2014). It is precisely these silent observers who are increasingly becoming active participants in political and socially relevant decisions and could be actively involved in research through CS. This form of participation can fulfil citizens' expectations of co-determination and at the same time give them the opportunity to better understand the limits of scientific methods (Bonn et al., 2021; Liu et al., 2014).

In line with the saying 'tell me and I'll forget, show me and I may remember, involve me and I'll understand', this can strengthen society's trust in science and achieve a more positive attitude towards science and the implementation of the resulting measures (Bonn et al., 2021; Liu et al., 2014).

2.3 — Technological Solutions for Data Collection and Analysis

In CS projects, data should be collected by participants and sent for example to authorities or researchers. This process can be realised using different apps. These include computer apps that are installed on the device, online apps that can be accessed via a browser or apps that can be used on mobile devices (mD) (Lemmens et al., 2021). The potential of CS has grown immensely since mD has been used across the board. Thanks to the integrated sensors of the Global Navigation Satellite Systems (GNSS), the exact position (within the limits of the inaccuracy of the respective GNSS) can be determined in addition to the data entered manually by the participants, so that the data can be supplemented by an important geo-component. These applications are particularly valuable in the field of environmental sciences. The apps are usually installed under the two common operating systems iOS (Apple) or Android (Google) (Lemmens et al., 2021).

Mobile apps offer many functions that are particularly interesting for CS. The most common method of CS is the questionnaire. This can be used on a website or in a local app. Participants answer questions on one or more topics. It is possible to depict different types of questions and thus do better justice to the diverse content (e.g. multiple choice, drop-down menus or free text fields). If the location of data collection is important, questionnaires can be supplemented with this information. Since

GNSS sensors are now installed in mD as standard, the apps can automatically determine the position of the device and send it as additional information (Lemmens et al., 2021).

In addition to GNSS sensors, mD also often offer other sensors that can be used to record data. For example, image or sound recordings can be made, compass data can be read out or the brightness and ambient volume can be determined (Odenwald, 2020a). External sensors can also be connected to the mD or used independently of it. Their data can then also be entered via a questionnaire (Lemmens et al., 2021; Odenwald, 2020b). CS games are particularly popular among younger participants. Here, data is generated in a playful way that follows a competitive approach and thus encourages participants to use the app as long and intensively as possible (Lemmens et al., 2021).

Flood events occur periodically during both winter and summer in rivers and larger water bodies within Germany's low mountain regions (Bronstert et al., 2023). These fluvial floods are well-documented hydrological phenomena to which residents are generally accustomed, enabling them to cope with moderate events with a considerable degree of confidence and resilience (Thieken et al., 2007). Floods that originate from watercourses are the result of long-term rainfall or melting snow and are referred to as fluvial phenomena (Bronstert et al., 2023). To understand these processes, it is essential to distinguish clearly between fluvial and pluvial flood types and their differing hydrological characteristics. Unlike fluvial events, which are usually easier to predict, pluvial floods often occur suddenly and without sufficiently long warning periods or identifiable recurrence intervals (Schmitt and Scheid, 2020). Pluvial floods are characterised by the fact that they can occur independently of a watercourse and are usually caused by heavy rainfall in a short period of time and within a small area (Kutschker and Glade, 2016). The poor predictability and short warning times of these events make good prevention and risk management even more important (Bronstert et al., 2023). Local prevention and individual flood risk adaptation are therefore crucial for enabling households in Germany to better cope with recurrent flood events and to reduce potential damages (Dillenardt and Thieken, 2025).

One of the most important findings in risk management is that people are more likely to implement measures if they are personally (directly or indirectly) affected by an event. Affectedness is primarily shaped by the emotional responses of those concerned. The stronger the emotion the higher the likelihood of a reaction (Netzel et al., 2021). How people perceive their personal risk is also crucial. A distinction should be made between global and personal risk perception. If people perceive a global risk, such as climate change itself, this only rarely leads to preventive action (Netzel et al., 2021). However, if people are personally affected and experience the associated emotions, such as in the case of a heavy rainfall event linked to climate change, they are more likely to take precautionary measures (Netzel et al., 2021). This realisation brings risk management to a small-scale level that must take local conditions into account (Rosenzweig et al., 2018). The probability of measures being implemented is only high if people are addressed directly (Rosenzweig et al., 2018). The level of education and knowledge of the targeted people is crucial here. People with a higher level of education and a higher level of knowledge about heavy rainfall and runoff processes are more likely to implement appropriate measures (Netzel et al., 2021). Risk management therefore has both an educational task and an obligation to address people's emotions to implement the best possible precautionary measures.

195 Effective flood risk management thus depends not only on individual preparedness but also on close cooperation between
residents and local authorities (Schmitt and Scheid, 2020). Due to limited spatial predictability and the irregular occurrence of
pluvial events, permanently installed flood protection measures are only practicable to a limited extent. Widely used methods
for flood protection (from fluvial floods), such as permanently installed systems for the on-demand construction of flood
defence walls, are only partially applicable or not applicable at all during pluvial events (Rosenzweig et al., 2018). It is
200 therefore crucial that more precise forecasting systems be developed and risk assessments be improved. Such improvements
allow preventive measures and flood warnings to be implemented in a more targeted and effective manner (Falconer et al.,
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205 Personal precautions, both in the form of measures at private homes and networking with each other (e.g. by setting up warning
chains), but also increasing knowledge about heavy rainfall and its dangers can make people more resilient to pluvial flood
events (Gallmetzer et al., 2021). Currently there is often a gap between people recognising the risks and the implementation
of measures due to a lack of communication. In order to close this gap, it is necessary to share people's findings with the
responsible authorities as easily as possible in order to improve communication and data accessibility (Rosenzweig et al.,
210 2018). Against this background, participatory approaches such as Citizen and Community Science offer valuable opportunities
to integrate local knowledge systematically into environmental monitoring and flood risk management.

2.2 Public participation in environmental risk monitoring – Citizen and Community Science

Public participation has become an increasingly important component of environmental monitoring, as citizen-generated
observations can significantly enhance the spatial and temporal coverage of conventional measurement networks (Cohn, 2008).
215 In this context, a distinction is made between Citizen Science, Community Science, and their hybrid forms. Citizen Science
refers to the involvement of citizens in research projects and scientific data collection (Bonney, 1996; Irwin, 1995). Citizens
collect data independently, which is then analysed by researchers. In this way, large quantities of small-scale and diverse data
sets can be generated (Abecker et al., 2012a, 2012b; Bonney, 1996; Conrad and Hilchey, 2011). Citizen Science in the
environmental sciences was first used in ornithological monitoring projects for which it is still very well known today (Bonney,
220 1996). Citizen science projects are typically characterised by being initiated predominantly by researchers (scientist-led), who
also take primary responsibility for data analysis, while citizens are, in most cases, involved mainly in the collection of data
(Ballard et al., 2024; Lin Hunter et al., 2023). In this way, science obtains a large amount of data that is collected by independent
persons so that the bias of the scientists themselves can (potentially) be minimised. At the same time, it offers the opportunity
to make science accessible and understandable for people and thus gain a greater insight into science and its topics among the
225 population (Ballard et al., 2024). Science itself benefits from the opportunity to unlock innovation potential at both individual
and societal levels (Bonn et al., 2021). In contrast, Community science refers to research approaches that are driven by local
priorities and perspectives, with the initiating ideas, decision-making authority, and responsibility for the research process

residing within the community itself (community-led) (Ballard et al., 2024; Cooper et al., 2021). Furthermore, there are frequent hybrid forms that incorporate characteristics of both citizen science and community science. In the context of this work, this hybrid approach is referred to as Citizen and Community Science (CCS). CCS may, for example, involve researchers providing methodological frameworks and digital tools, while local communities independently initiate data collection on issues they consider locally relevant. In such a model, scientific actors support quality assurance and analysis, whereas communities retain agency in defining priorities and applying the results within their local decision-making processes (Ballard et al., 2024).

According to surveys conducted by the German Science Barometer (Wissenschaftsbarometer), well over half of citizens are interested in science and research (Ziegler, 2022). An interest that has increased even further in recent years, e.g. due to the coronavirus pandemic (Ziegler, 2022). But also, movements such as ‘Fridays for Future’ and other climate campaigns clearly show that society is increasingly interested in scientific issues and wants to be involved in them. Environmental issues are often turned into strategic decisions by the existing political and administrative structures, which often do not involve people and leave them as silent observers (Liu et al., 2014). It is precisely these silent observers who are increasingly becoming active participants in political and socially relevant decisions and could be actively involved in research through CCS. This form of participation can fulfil citizens' expectations of co-determination and at the same time give them the opportunity to better understand the limits of scientific methods (Bonn et al., 2021; Liu et al., 2014).

More broadly, CCS aligns with principles of polycentric risk governance, in which responsibility and decision-making are distributed across multiple actors rather than centralised within formal institutions. Such distributed approaches represent one possible form of polycentric governance, enhancing adaptive capacity, legitimacy and responsiveness by integrating scientific expertise, local experiential knowledge and institutional decision-making (Baldwin et al., 2024). In this way, CCS can strengthen public trust in scientific processes, deepen societal understanding of environmental risks, and foster a more positive attitude towards both scientific findings and the implementation of resulting measures (Bonn et al., 2021; Liu et al., 2014). Building on the growing relevance of participatory risk observation and the distinct but increasingly interconnected paradigms of Citizen and Community Science, digital platforms have emerged as key enablers for scalable environmental monitoring and authority-facing data analytics (Johnson et al., 2021).

2.3 Digital platforms and open-source tools for participatory flood monitoring

In modern CCS projects, data can, for example, be collected by participants and sent to authorities or researchers. This process can be realised using different apps. These include computer apps that are installed on the device, online apps that can be accessed via a browser or apps that can be used on mobile devices (Lemmens et al., 2021). The potential of CCS has grown immensely since mobile devices have been used across the board (Paul et al., 2021). Thanks to the integrated sensors of the Global Navigation Satellite Systems (GNSS), the exact position (within the limits of the inaccuracy of the respective GNSS) can be determined in addition to the data entered manually by the participants, so that the data can be supplemented by an

260 important geo-component. These applications are particularly valuable in the field of environmental sciences. The apps are usually installed under the two common operating systems iOS (Apple) or Android (Google) (Lemmens et al., 2021). Mobile apps offer many functions that are particularly interesting for CCS (See, 2019). One method of CCS can be questionnaires. They can be used on a website or in a local app. Participants answer questions on one or more topics. It is possible to depict different types of questions and thus do better justice to the diverse content (e.g. multiple choice, drop-down

265 menus or free text fields). If the location of data collection is important, questionnaires can be supplemented with this information. Since GNSS sensors are now installed in mobile devices as standard, the apps can automatically determine the position of the device and send it as additional information (Lemmens et al., 2021). In addition to GNSS sensors, mobile devices also often offer other sensors that can be used to record data. For example, image or sound recordings can be made, compass data can be read out or the brightness and ambient volume can be determined (Odenwald, 2020a). External sensors

270 can also be connected to the mobile devices or used independently of it. Their data can then also be entered via a questionnaire (Lemmens et al., 2021; Odenwald, 2020b).

To increase motivation for the actual use of such apps, CCS games are popular, especially among the younger population. Here, data is generated in a playful way that follows a competitive approach and thus encourages participants to use the app as long and intensively as possible (Lemmens et al., 2021). This approach represents a form of gamification, that is, the

275 incorporation of game-like elements and mechanisms into non-game contexts with the aim of influencing user behaviour and enhancing motivation. Typical gamification components include goal descriptions, defined roles and rules, points, rewards, and comparative metrics, and an increasing number of digital applications - particularly mobile apps - integrate such elements to promote sustained user engagement (Lexa, 2021).

The major advantage of using ~~mobile devices~~ in ~~CS~~ also brings challenges. By using ~~mobile devices~~, more people

280 can generate data more quickly and thus contribute to research. At the same time, this data must be stored and processed accordingly to be able to evaluate and analyse it later. It therefore requires both an app specifically tailored to the needs and data management software that takes over the analysis and visualisation- (Lemmens et al., 2021).

In principle, it is possible for ~~CS projects to access existing platforms that already offer some functionalities and can be customised to a limited extent. Another option is to programme new software, which is then generally used by a single project~~

285 ~~(Lemmens et al., 2021).~~ CCS projects to access existing platforms that already offer some functionalities and can be customised to a limited extent. Another option is to programme new software or applications, which is then generally used by a single project (Lemmens et al., 2021). An established example of a Citizen and Community Science project in the field of hydrological observations is the CrowdWater initiative. It enables citizens to record hydrologically relevant information (such as water levels, soil moisture, or potential inundation areas) using a smartphone app (Seibert et al., 2019). Observations are

290 generated predominantly in a qualitative manner via so-called “virtual staff gauges”, in which users estimate water levels using reference images. These data are subsequently compiled centrally in a database, validated, and made available for research purposes. CrowdWater is therefore primarily oriented towards improving hydrological models and forecasts by complementing conventional monitoring data with fine-scale, temporally detailed citizen observations (Seibert et al., 2019). However,

295 [CrowdWater does not address specific, spatially localised risk points in urban environments that may arise during pluvial flood events, such as blocked drains, constrictions in surface runoff pathways, or inadequately dimensioned structural elements. Nor is the application designed to integrate municipal actors directly into operational risk management processes or to make citizen observations immediately usable for decision support or the planning of mitigation measures. Against this background, the application developed in the present study adopts a different focus and expands the spectrum of CCS approaches by introducing a more practice-oriented and municipally actionable dimension.](#)

300 ~~In this project, a new software will be programmed~~[The application \(as ~~CS~~ projecta prototype\) is initiated and set up by researchers, but its application and subsequent management can, in one of the potential use cases, remain entirely within a local community, with citizens collecting data and municipalities analysing and acting upon it. Using open-source components so that it is-, the prototype app is designed to be reusable for interested parties and thus to enable, for example, opens the possibility for various municipalities to use/adapt the project for system to their specific locations and thus sustainably organise their local contexts, thereby supporting a more sustainable and locally responsive form of heavy rainfall risk management-in heavy rainfall.](#)

305

3. Methodology

The methodology describes the development of the [ESCCS](#) app on the technical side and addresses design and functionality. It shows the connections between the mobile application and the Geo Data Warehouse (GDW) and explains the methods for analysing data in the latter.

310

3.1 Development of the CS app

The development of [ESCCS](#) apps is strongly influenced by the expectations of future user groups. Lemmens et al. (2021) lists some criteria specifically for [ESCCS](#) apps, which are used to guide the development of the [FloReST-ESCCS](#) app:

- 315
- *Usability: the ease of use for the participants*
 - *Look and feel: the visual quality of the app*
 - *Performance: the speed with which an app opens and operates*
 - *Security: the level of technical security an encryption of sensitive data*
 - *Compatibility: the range of operating systems and devices supported*
- 320
- *User privacy: compliance with the EU General Data Protection Regulation (GDPR)*
- “ (Lemmens et al., 2021)

In the following, the various aspects of the design and implementation of a [ESCCS](#) app, data collection and subsequent data visualisation are listed and explained.

3.1.1 Technical structure

325 When developing mobile apps, a distinction is made between web, native and hybrid apps. The FloReST-CSCCS app was developed as a hybrid app. This means that it is designed/created using web technologies but is ultimately output in/operates within a native format/app framework. Hybrid apps combine the advantages/strength of two technologies/both web and are therefore particularly/native systems thereby supporting efficient development and broad device compatibility (Schilling, 2016). The actual FloReST-CSCCS application is implemented within JavaScript (JS) and displayed as a web view and is therefore nothing more than a standard website, functioning like embedded web content within the app. Figure 1 shows that in a hybrid app, this classically programmed website is converted into a native format using AngularJS (a single-page application framework from Google) provides the structural basis for integrating the web content into the native environment (Weiße, 2016). The Ionic framework is an important building block that makes it possible to implement the CS app on different mobile devices without having to make manual adjustments. If you want to run the CS app on different devices with different screen sizes, for example, Ionic is responsible for automatically adapting the components of the CS app to the respective conditionsThe Ionic framework supports cross-platform deployment and automatically adjusts the interface to different screen sizes (Weiße, 2016). As a runtime environment, Capacitor, just like Ionic, also enables implementation on different mobile devices. In contrast to Ionic, however, it multi-platform deployment but additionally provides access to the various hardware elements such as the camera or speakers. Both Capacitor and Ionic are part of the AngularJS framework, which in turn depends/relies on the Node.JS runtime environment. As a software development kit, NodeJS is the basis for development, as it makes web technologies such as and builds. NodeJS provides the environment needed to run JavaScript executable outside of the browser and thus enables programming/supports development in editors such as Visual Studio Code (Weiße, 2016). Overall, the FloReST-CSCCS app achieves a high level of platform compatibility with these components and enables implementation/ensures stable performance across a wide/broad range of devices. It also offers a fluid application for the

345 user.

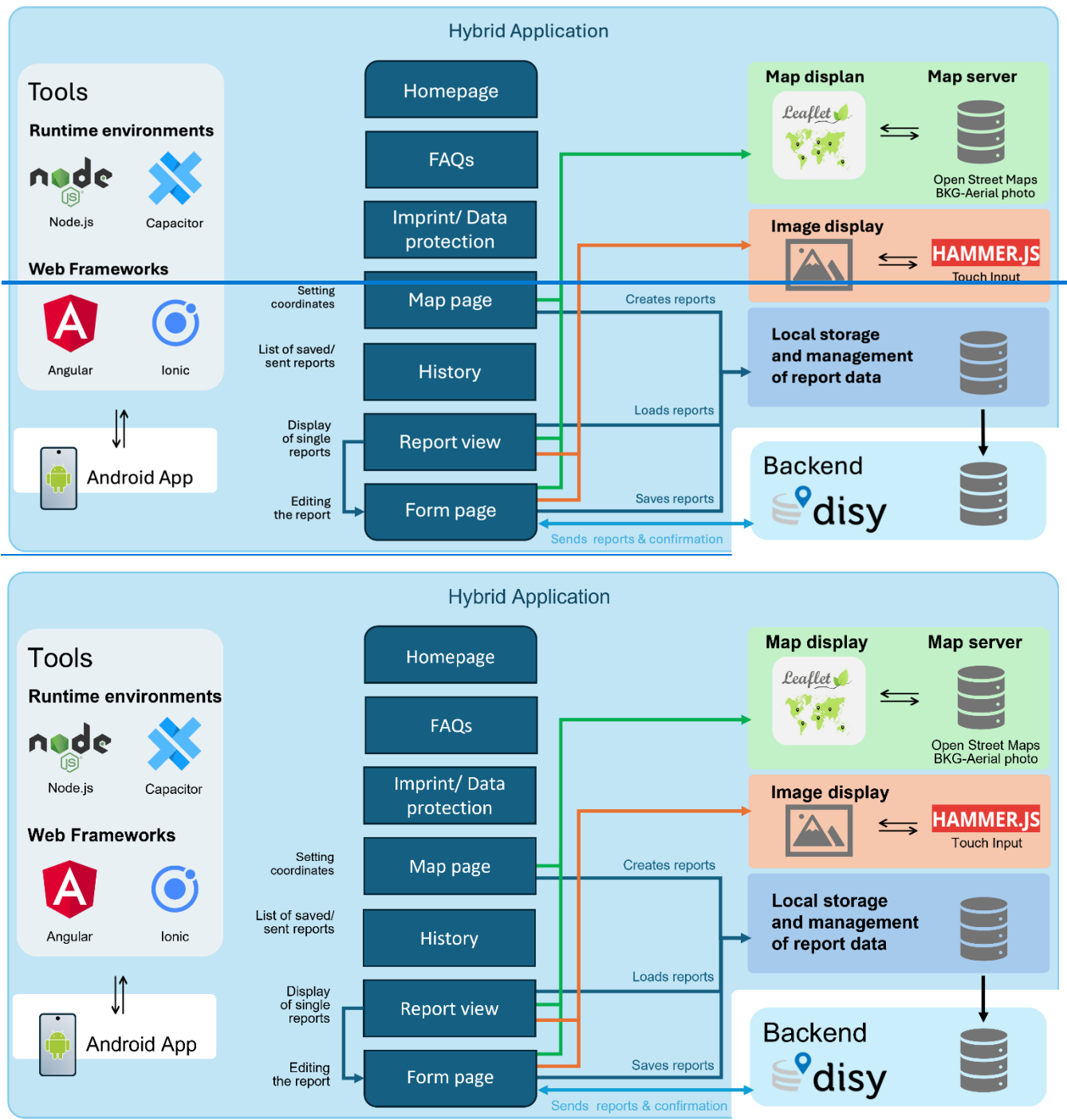


Figure 1: Structure and components of the hybrid [FloReST-CSCCS](#) app with functional relationships within the application.

3.1.1 Design and functionality

350 The design and functionality of the [ESCCS](#) app play a central role in user-friendliness. The aim is therefore to ensure intuitive operation and, at the same time, to guarantee an appearance that is as barrier-free as possible. Intuitive navigation and operation are achieved through clear structures, easily recognisable interaction elements and a consistent design.

The system functionality was defined as part of a requirements workshop at the start of the research work and is described successively below.

355 A style guide defines the design and layout of the [ESCCS](#) app. Among other things, identical visual elements for the same function were provided in the associated layout specifications. The use of prefabricated components from the Ionic library supports a uniform look. Overall, this creates a coherent overall picture for the user, directing the focus to the essential content. The colour scheme has been deliberately reduced to create a clear and uncluttered user interface. A broad colour palette has been avoided in favour of high contrasts, which facilitate readability and orientation and thus make the [ESCCS](#) app more
360 accessible. Interactive elements, such as blue buttons, are highlighted to clearly signal their functionality.

Typography also makes a decisive contribution to user-friendliness and appearance. The use of the system's internal font, such as Roboto on Android, preserves a native look and ensures a familiar user experience. The focus here is on a low-barrier appearance by adopting the user's global settings. Different font sizes and thicknesses are used to clearly present the structure of the [ESCCS](#) app and promote readability.

365 Icons are an integral part of the design and user guidance. Common symbols that users are familiar with from other applications are used in a targeted manner. They are designed to be platform-independent to ensure a uniform appearance on different devices. Icons serve as navigation and menu elements as well as contextual support. Their intuitive recognisability ensures quick orientation and improves usability.

The combination of all these elements creates an [ESCCS](#) app with a simple design that emphasises functionality and barrier-free use. The evaluation of the user-friendliness of the [ESCCS](#) app for different target groups in the risk communication of heavy [rainrainfall](#) management has already been carried out on one group but still needs to be carried out for the other target groups and analysed as a whole.

3.2 Geo Data Warehouse and data analytics platform

The captured data is transmitted by the [FloReST-ESCCS](#) app to a backend where the reports are stored and processed. This
375 backend is designed and prototypically implemented as a part of the “FloReST water extremes data platform” (Janßen and Abecker, 2025). For data storage, a GDW (Schrauth et al., 2017) is ~~realized~~[realised](#). For data analysis and ~~visualization~~[visualisation](#) for specific target groups, the “disy Cadenza platform for business and location intelligence” is employed (Abecker et al., 2024). [The web-based application disy Cadenza is used for data discovery and analytics of the CCS report data. disy Cadenza is in daily use in many federal and state authorities in Germany and has already proven its value to
380 the public sector, especially when dealing with geo and environmental data. disy Cadenza allows the user to link the data with](#)

one another and it provides a user-friendly Graphical User Interface (GUI) to combine data visualisations with data-analytics capabilities to create data dashboards. A variety of possible data representations, including tables, bar charts, pie charts, maps, heat maps, etc. can be utilised for this purpose.

385 During the design of the system a conscious effort was made to ensure the openness of the solution created. The selected components are loosely coupled so they can be used independently of each other. To ensure interoperability, also with other possible software solutions, an Application Programming Interface (API) for communication between the [E5CCS](#) app and the datastore has been defined. An OpenAPI specification of the interface was created for implementation and documentation purposes¹.

390 Another design criterion for the selection of the individual software components was their scalability. This is important to ensure operation in larger-scale load scenarios.

The data analytics application requires an easy access to the datapoints as well as a powerful tool to fit subject-matter experts' needs. A user ~~customizable~~[customisable](#) web application as the analytics platform meets these requirements.

395 Figure 2 provides a partial overview of those actual components of the water extremes data platform which deal with the [E5CCS](#) reports. The API is used to transmit the data recorded by the [E5CCS](#) app. A python-based Extract-Transform-Load (ETL) component transforms the received data into the specific target formats. ETL processes ~~realize~~[realise](#) the basic steps for integrating heterogeneous input data into a homogeneous data warehouse. Structured data of a report, including its metadata, is then stored in a PostgreSQL database. PostgreSQL is the world's most successful open-source
400 database management system – which can also be extended for efficient management of geospatial data. Transmitted photos are stored in an S3-compatible object storage. The S3 (Simple Storage Service) principle has been introduced by Amazon for a massively scalable, typically cloud-based, storage system for arbitrary data objects. Additional media files like videos or audio files could also be stored here. Finally, the data can be viewed and analysed using the [disy Cadenza](#) as the data analytics software.

405 To ensure data protection and secure data handling throughout the workflow, a rights-and-roles concept, encrypted data transmission, and anonymised user identifiers were implemented as part of the system architecture. These measures, together with token-based authentication and support for established identity-management protocols, form the methodological foundation for safeguarding user privacy and controlling authorised access to the analytics environment.

¹ <https://www.openapis.org/>

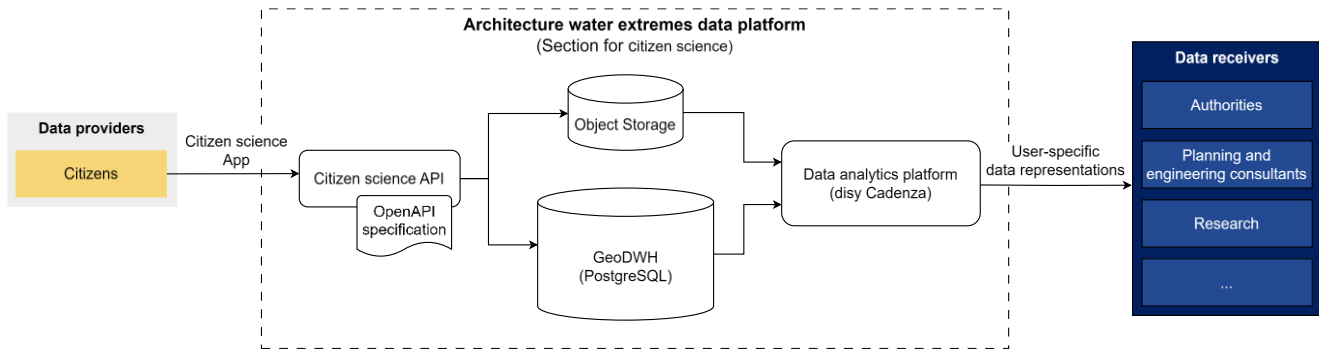


Figure 2: Components used for data processing and analytics of the [ESCCS](#) app data

3.3 App-prototype test-procedure

The CCS app was tested in three distinct contexts. The first test run was conducted with internal university staff, the second took place during a municipal event on heavy rainfall and flooding in an affected area of the Ahr Valley and involved local residents, and the third was carried out with a group of students of various age groups as part of a university course. For all test settings, participants received flyers containing a QR code for downloading the app and two additional QR codes linking to the respective questionnaires. Before beginning the prototype test, participants were asked to complete an initial questionnaire that primarily assessed their prior knowledge and level of engagement with the topic.

For the app test itself, participants were instructed to download and install the application independently from the app store. They were then asked to identify problem areas relevant to heavy rainfall within their surroundings and to document and submit these using the app. After completing the test, participants were invited to fill in a second questionnaire to capture any changes in the previously measured indicators. All questionnaires were completed anonymously. To allow later matching of responses from both questionnaires, participants were asked at the start of each survey to create an individual code.

The pre-test questionnaire collected demographic information, expectations regarding the app, participants' existing knowledge of heavy rainfall and flood preparedness, and their personal engagement with these topics. Following the test, participants evaluated their experience with the app, and changes in their knowledge and engagement were recorded. As the prototype was developed for use in German-speaking regions, the questionnaires were also administered in German. The original questionnaire is available as supplementary material.

4. Results

The [ESCCS](#) app for sustainable risk management in [managing the impacts of heavy rain prevention/rainfall](#) has a simple design. The [ESCCS](#) app has currently been developed in German. The start page provides a brief introduction to the topic and invites you to start an initial site survey. The main menu provides information on frequently asked questions.

4.1 Data Collection

The data is recorded by the user via a form within the [eSCCS](#) app. Only data that is relevant for the assessment of the problem area was selected for recording. The precise data collection process and the exact structure of the captured data are explained below.

4.1.1 Process of data submission by citizens

Data collection should be intuitive and efficient for the user. The first step for the user is to identify a problem area in their immediate surroundings. The [eSCCS](#) app can then be opened, and the localisation of the problem area can be started using the map function in the [eSCCS](#) app. This is done either by using localisation services, so that the user's currently determined location is used as the location of the problem area, or the user can select any location on the map themselves. A topographical map and an aerial map are provided for better orientation. The user then assigns one of the four possible categories to the problem area. The following categories are available: 'Accumulation of floating debris / driftwood' (Ansammlung von Treibgut / Treibholz), 'Bottleneck' (Engstelle), 'Deflection of water' (Ablenkung des Wassers) and 'Constructed buildings / structures' (Errichtete Gebäude / Bauwerke). The categories are provided with pop-up help so that the user can view a descriptive text and sample images for each category to make the best possible assignment. The user then describes the problem area in detail and has the option of adding images to this description. These images can either be taken directly using the [eSCCS](#) app's camera function or added from the [mDmobile devices](#)' gallery. If the user can assess the responsibility of the respective location, it can be indicated whether the problem area is located on private property or on public land. Figure 3 provides an overview of the start screen- [\(a\)](#), the location selection on an aerial map [\(b\)](#) and a section of the entry page- [\(c\)](#).

Once all the information has been entered, the report can be sent via the [eSCCS](#) app. The sending process ends with a success or error message informing the user about the status of the submission.

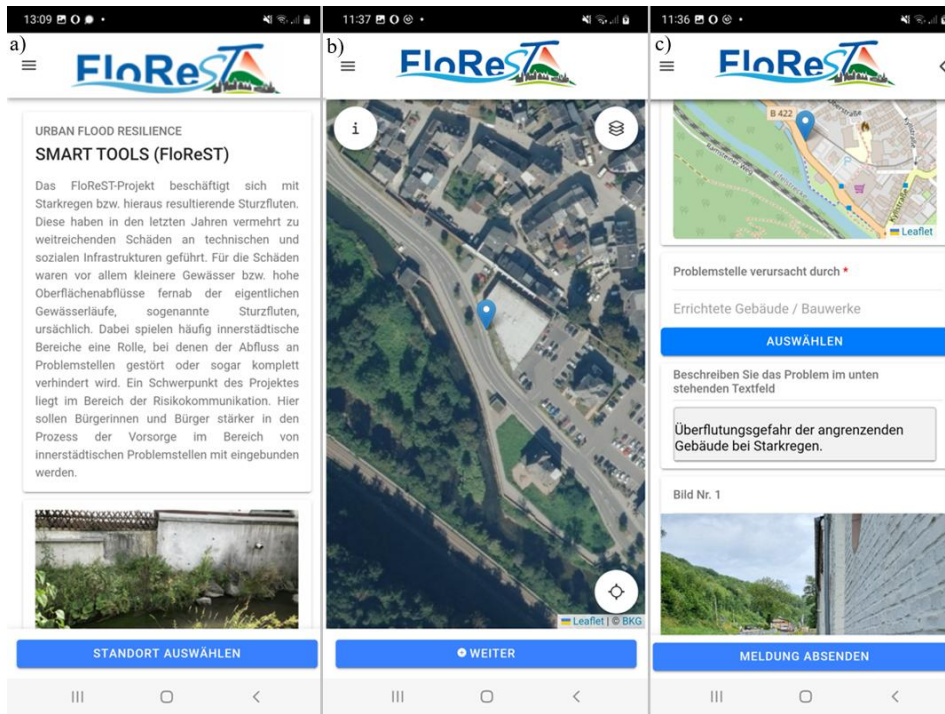


Figure 3: Overview of the [eSCCS](#) app with start page (a), location selection (b) and survey page (c).

4.1.2 Types of data collected (e.g., location, description, photos)

The *user ID* (*userId*) is randomly generated when the [eSCCS](#) app is started for the first time so that messages can be clearly assigned to a user without collecting personal data. This guarantees maximum anonymity and minimises data protection risks.

The *report ID* (*reportId*) is an internal identifier (ID) that is primarily used to control the [eSCCS](#) app processes. This ID is also transmitted to the server, where it is supplemented by an external ID.

460 The *recording date and time* (*timestamp*) document the time at which the report was created (not the time of submission), derived from the system time of the end device. This data is initially stored unformatted (specification of elapsed milliseconds since 1 January 1970, 0:00, *Coordinated Universal Time*, UTC) and converted if necessary.

The *latitude and longitude* (*latitude*, *longitude*) define the location of the problem area. They are output in the World Geodetic System 1984 coordinate system (WGS 84, European Petroleum Survey Group, EPSG 4326) in decimal degrees and are
465 therefore compatible with the map service used. The data is then projected in EPSG 3857 for visualisation.

The *problem area is caused by* (*deficiencyType*) a cause of the problem, such as accumulations of floating debris, bottlenecks or deflections of the water. This categorisation can be carried out by the user themselves and makes it easier for the authorities to assign and prioritise the problem subsequently.

The *type of spatial utilisation* (*onPublicProperty*) indicates whether the problem area is located on private or public land. This
470 information can be legally and organisationally relevant.

Under *further information* (*additionalInformation*), users can enter specific information and notes on the problem area in a text field.

All *images* (*Report__<No.>.jpg*) are used for visual documentation of the problem area. The images can be added using the camera function or from the gallery.

475

The collection data listed has been selected to ensure that it covers the relevant information on the problem area while complying with data protection standards. The anonymised user ID ensures that no personal data is collected. The focus is on the technical data required to precisely describe the problem areas during heavy rainfall events and derive recommendations for action. The combination of location data, categorisation, detailed description and photo documentation ensures a
480 comprehensive representation of the problem area. At the same time, the requirement to minimise data storage is met so that recording remains quick and uncomplicated for the user. After the message has been sent, the user receives confirmation of the result of the sending process. [In the current prototype of the app, users do not receive additional information when their submitted data are processed by researchers or local authorities. In future versions, however, communication back to citizens is intended. Such bidirectional communication requires a separate data protection assessment and has therefore not yet been](#)

485 [implemented. Users currently receive direct feedback only when the respective municipality takes action based on the submitted data and resolves identified problem areas.](#)

490

Figure 4 summarises the end-to-end workflow of the CCS app, illustrating how reported data move from the citizen-facing mobile interface through the backend infrastructure, data transformation processes, and ultimately into the analytics environment accessible to public authorities.

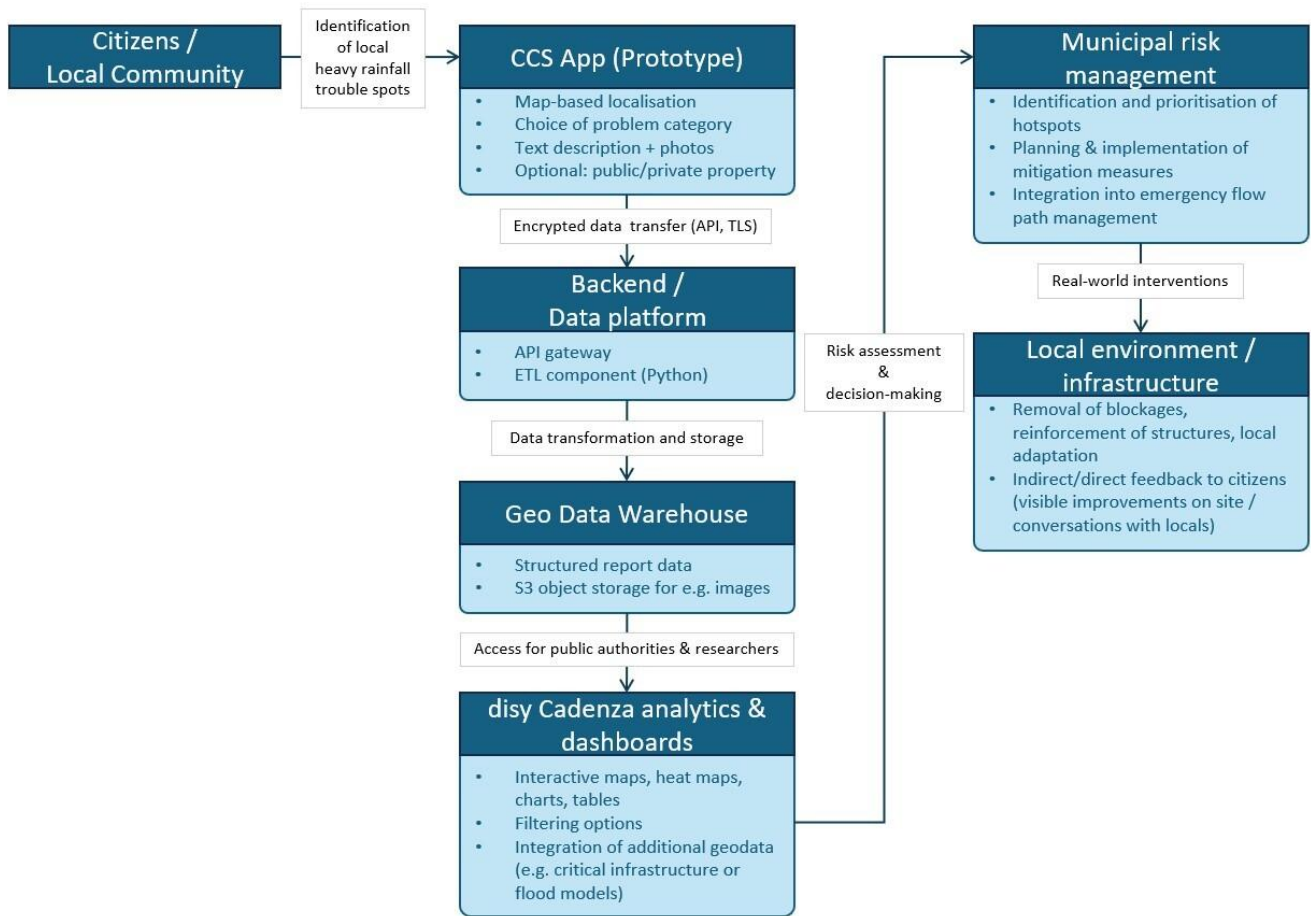


Figure 4: Schematic use-case diagram of the functional relationships within the CCS app.

4.2 Data analytics and data visualization for public authorities

495

To support systematic analysis of the CCS report data, the web-based application platform disy Cadenza is used offers a robust environment for data discovery and analytics of the CS report data. Disy Cadenza is in daily use in many federal, exploration, integration, and state authorities in Germany and has already proven its value to the public sector, especially when dealing with geo and environmental data. Disy Cadenza allows the user to link the data with one another and it provides a visualisation. Its user-friendly Graphical User Interface (GUI) to combine data visualizations with data analytics capabilities to interface enables public authorities to link datasets, perform analytical operations, and create data customised dashboards. A

500 ~~variety of possible data representations, including using diverse visualisation formats such as~~ tables, ~~bar charts, pie charts,~~
maps, ~~and heat maps, etc. can be utilized for this purpose.~~

For recurring tasks, the user has the option to access predefined curated workbooks to fulfil the analytics requirements. A user-defined customisation of the data view allows the completion of individual inquiries. On all dashboards, the data can be restricted by filtering the considered data points geographically, temporally, or by other attributes of the data. Using these
505 capabilities, the [ESCCS](#) reports can be selected by the attributes recorded with the [ESCCS](#) app, such as the ~~eategorization~~[categorisation](#) of problem area, but also spatially, restricting the area of consideration on the map. A fully integrated Web Geographic Information System (GIS) completes the spatial analytics capabilities. This enables the user, for example, to measure distances in the map (e.g., between an observation and a watercourse) or to add geodata layers such as
510 Points-of-Interest (where are vulnerable buildings, facilities, or infrastructures) or task-specific maps (e.g. about critical infrastructures, land survey register, other cadastre data etc.) and additional cartographic information (like aerial pictures or even flood simulations) to the result view. In addition to that, activating the Cadenza live mode will result in a periodic update of the data shown.

In Figure 5 one of the predefined curated workbooks is displayed. As an entry point for the users, an overview dashboard [\(a\)](#)
515 was created. It shows the [ESCCS](#) report data on different aggregation levels. A map shows the spatial distribution of the reports- [\(b\)](#). The ~~color~~[colour](#)-coded dots each represent a single report, coloured according to the ~~eategorization~~[categorisation](#) of problem area. By selecting a point, further details of the report can be observed.

~~On the right-hand side, the report data is presented in tabular form-~~ [\(c\)](#), sorted by the submission date. A pie chart provides an overview of the distribution of the reported problem area types- [\(d\)](#). The total number of reports displayed is shown by an
520 indicator- [\(e\)](#). By default, the submitted reports of the last three month are selected. The data can be further expanded or restricted using the filters on the left-hand side- [\(f\)](#). The type of the problem area as well as the period in which reports were received, can be adjusted, in absolute and relative terms.

~~Weblinks at the bottom right offer an option to jump to a detailed view of the reports or a heat-map representation of the data-~~
525 [\(g\)](#). By using these links, the state of the applied filters is transmitted to the corresponding page.

~~The detailed report view~~ [utilized](#)~~utilised~~ a table component to show all available details of a report. Attached images can be selected and viewed here. A spatial summarisation of the reports can be created by a heat-map representation of the data. It can be used to determine focus points of reported problem areas. By zooming in and out, the heat map is recalculated and adjusted accordingly to the zoom level.

530

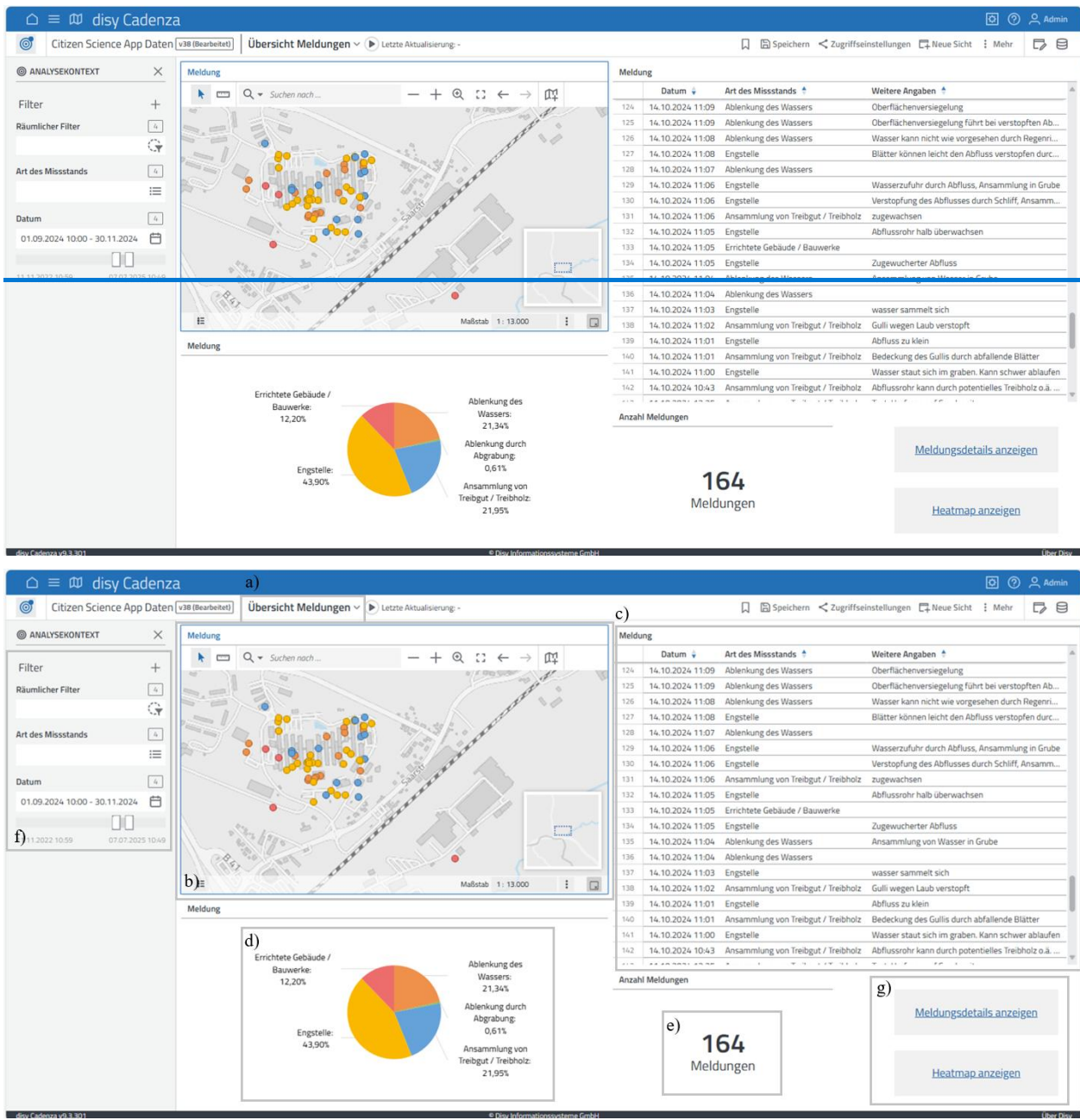


Figure 5: Selected dashboard of the analytics application, with different functions (a-g).

Using disy Cadenza it is possible to implement a fine-grained rights-and-roles concept. This allows to restrict the access to the data, the created dashboards and the analytics views to ~~authorized~~authorised personal only. A state-of-the-art identity provider can be used for authentication of the users. For example, the widely adopted OpenID Connect protocol is supported.

540 Only the data related to a report is recorded. No user-related data is stored in the database. Just a randomly generated user id is attached to a report which enables a grouping of the individual messages related to a specific ESCCS report. It is therefore not possible to draw conclusions about a specific person.

The transmission of data from the ESCCS app is secured by a transport encryption via Transport Layer Security (TLS, an internet communication protocol for safe data transport). Authentication of the ESCCS app at the API-Gateway is implemented using token authentication.

545

4.4 Performance analysis

The app was evaluated by conducting a performance analysis. This involved using and evaluating the application in test groups consisting of participants from different ages ranges. Bugs identified during these tests were documented and ~~fixed~~resolved in several subsequent releases of the app. Remaining technical issues are described in section 5.2.1. In total, 38 individuals participated in the prototype testing phase and answered the evaluation questionnaire.

550

A comprehensive practical evaluation of the app's impact on flood risk management requires further investigation with a broad~~broader~~ user base. Conducting such evaluations was challenging because the topic is highly politicised. Several participation appointments were cancelled at short notice, making it impossible to ~~conduct~~carry out a large-scale survey. In addition, some local authorities ~~were cautious because reporting problem areas expressed caution, as reports submitted through the app could potentially highlight problem areas that might require additional action that might be required, which could entail, potentially resulting in~~ administrative ~~and~~ financial obligations.

555

However, the ~~non-representative~~ results of an evaluation of participants from different test groups show that people are particularly willing to engage with flood protection when they ~~themselves~~ have an emotional ~~ties~~connection to the topic and feel personally affected by it or have been affected ~~by it~~ in the past. In the evaluation, participants completed a questionnaire before and after testing the app. It is important to note that the findings presented here do not hold statistical significance due to the limited number of participants.

560

The responses to the questionnaires were originally provided in German and were translated into English for inclusion in this paper. Exemplary responses illustrate the range of perceptions and behavioural tendencies observed. For example, one male participant aged between 21 and 28 years, who lives in rented accommodation, has completed vocational training, and reported no previous experience with the topic, expressed the emotions “fear and concern, frustration and anger” prior to using the app. After testing the app, however, he reported feeling “relief, hope, motivation and engagement.” He assessed the risk of a drainage-related problem occurring on his property during a heavy rainfall event as 2 on a scale from 1 (very low) to 10 (very high) before using the app, and as 3 after the test. Furthermore, he indicated that participating in the app test might encourage him to implement measures for flood preparedness in the future.

565

570 5. Discussion

Targeted risk communication always includes the perspective of the affected citizens. Therefore, a survey was conducted in five different pilot municipalities in Rhineland-Palatinate, Germany, as part of the preparatory work for this project. One of the aims of this survey was to identify target groups for certain risk communication tools based on socio-economic data. The survey revealed that accessibility through the chosen media has a significant influence on the under-35s and on the under-20s.

575 For this reason, the [ESCCS](#) app was chosen as the preferred citizen [and community](#) science method. In the following the different components (sustainable risk management, heavy rainfall, citizen [and community](#) science) of the initial question are analysed and evaluated in relation to the chosen method of the [ESCCS](#) app.

5.1 Advantages of the Citizen [and Community](#) Science approach in emergency flood path management

Sustainable risk management requires that the affected persons can apply realistic benchmarks when differentiating between
580 global and personal risk perception (Netzel et al., 2021). If the risk is assessed as a personal risk, the personal involvement of the affected individuals increases. This usually leads to people associating stronger emotions with the situation and consequently increases the likelihood of a reaction, in this case the implementation of protective measures (Netzel et al., 2021). By using the [ESCCS](#) app, the affected persons learn directly that there are potential sources of danger in their personal environment. This increases the likelihood of protective measures being implemented after using the [ESCCS](#) app. It is also
585 important to consider the different scale levels for successful risk management. As heavy rainfall events are often very localised events and even small-scale changes can lead to major differences in runoff behaviour, it is particularly important to record the small-scale conditions and get as detailed information as possible (Rosenzweig et al., 2018). This is made possible by using the [ESCCS](#) app, as it is primarily designed for small-scale problem areas in private and public spaces.

Furthermore, the individual level of knowledge and education of the people involved should be considered. These two factors
590 are essential for the likelihood of measures being implemented. Accordingly, the [ESCCS](#) app should not only be intuitively designed and usable but also fulfil an educational function by providing information on the topic of heavy rainfall and flooding, as well as providing information on further education both within the [ESCCS](#) app and beyond. This is provided in the [ESCCS](#) app as info buttons (

Figure 6) and as additional links. The [ESCCS](#) app ~~provides additional~~[offers contextual](#) information on ~~for example, different~~
595 [various](#) categories of problem areas and ~~makes people aware~~[raises awareness](#) of ~~possible potential~~ drainage ~~blockages in their~~
~~neighbourhood. The CS app~~[obstructions within the local environment. It also](#) ~~links~~[provides direct access](#) to the Rhineland-Palatinate flood management website, which ~~provides comprehensive information~~[supplies extensive guidance](#) on ~~flood-related~~
~~issues. In this way, the~~ ~~topic. The CS app~~ ~~thus~~ fulfils ~~its an~~ important educational ~~mission regarding~~[function in supporting](#)
sustainable ~~heavy rainfall~~ risk management ~~for heavy rainfall~~.

600 The development of more precise forecasting methods is crucial in the prevention of heavy rainfall events. Today, these forecasting methods are often implemented using trained machine learning / deep learning models; ([Agonafir et al., 2023](#)),

which require a large amount of training data. The requirement for this training data is the highest possible spatial, temporal and thematic coverage. The amount of data needed for this cannot be collected by the scientists themselves, which is why models are often only reliable for certain regions with temporal and/or thematic restrictions. For improving these models, it is essential to have a more comprehensive database. The [ESCCS](#) app offers the opportunity to collect such data with the help of local stakeholders and then make it available to the scientific community. In this way, a unique data set with high variability in the observed parameters can be created. It is also very important for citizens to be able to carry out a realistic risk assessment in the event of heavy rainfall. This is the only way they and their neighbours can react in time and protect themselves. The [ESCCS app's](#) participatory approach and the information [provided](#) enable users to make such an estimation. ~~At the same time, these skills increase users' topic of pluvial flood risk. This increased awareness, fostered through accessible guidance and contextual knowledge, enhances users' ability to recognise potential dangers and to react earlier and more appropriately during heavy rainfall events~~ (Gallmetzer et al., 2021; Rollason et al., 2018), ~~allowing them to react earlier in the event of heavy rainfall.~~

Another gap exists between people recognising risks and the implementation of measures by the authorities. The [ESCCS](#) app provides the opportunity to precisely close this gap by giving people a direct link to the relevant authorities and allowing them to report their findings directly. The evaluation of the data and, if necessary, the implementation of a measure is then at the decision of the public authorities, depending on their responsibilities.

Wie ändere ich die Standardkarte?

Die App bietet die Möglichkeit, zwischen einer Straßenkarte und einer Luftbildkarte zu wählen. Eine Umschaltfunktion für diese Karten besteht innerhalb der Kartenansicht.

Was soll ich tun, wenn die Karten nicht richtig/vollständig geladen werden?

Wenn Probleme bei der Darstellung der Karten auftreten, liegt dies oft an einer langsamen Internetverbindung, z. B. bei starker Auslastung des Mobilfunknetzes oder an technischen Problemen des jeweiligen Kartendienstes. Gegebenenfalls versuchen Sie es später erneut.

Kann ich meinen aktuellen Standort manuell anpassen?

Ja, dies ist möglich. Darüber hinaus kann die App den aktuellen Standort über die Funktion „Aktueller Standort“ automatisch erfassen. Es kann jedoch auch hierbei notwendig sein, diesen manuell an den tatsächlichen Standort des Missstandes anzupassen, um genaue Daten zu gewährleisten.

Welche Maßnahmen kann ich bei Starkregen ergreifen?

Informationen über Starkregen und mögliche Maßnahmen im privaten Bereich sind auf einer eigenen Infoseite verlinkt:
<https://hochwassermanagement.rlp.de/>

Ablenkung des Wassers

(z.B. durch Straßenführung, Topographie, Aufschüttung / Abgrabung)

Hier wird das Wasser bspw. durch eine besondere Hanglage oder eine Straßenführung so abgelenkt, dass es bei Starkregen Schaden anrichten kann.



Beispiel: Überflutungsgefahr der Straße, bei starkem Regen, durch den steilen Hang.

Foto: Ingenieurgesellschaft Dr. Siekmann + Partner mbH

Errichtete Gebäude / Bauwerke

(z.B. Mauern)

Hierunter fallen sämtliche vom Menschen errichtete Bauwerke, die den Abfluss negativ verändern. Ist beispielsweise eine Mauer, eine

Ansammlung von Treibgut / Treibholz

(Verstopfung / Versperrung)

Hierunter fallen sowohl aufgestaute oder versperrte Gewässer (bspw. durch Holz / Pflanzenmaterial, etc.), aber auch angesammelte Materialien auf einer Straße, einem Graben oder an anderen Stellen, an denen Wasser bei Starkregen ungehindert abfließen soll.



Beispiel: Mögliches Problem durch das verstopfte Gitter bei der Ansammlung von Ästen und Laub.

Foto: Ingenieurgesellschaft Dr. Siekmann + Partner mbH

Errichtete Gebäude / Bauwerke

(z.B. Mauern)

Hierunter fallen sämtliche vom Menschen errichtete Bauwerke, die den Abfluss negativ verändern. Ist beispielsweise eine Mauer, eine Einfahrt oder ein Objekt in einem privaten Garten / einer öffentlichen Parkanlage so errichtet, dass der Abfluss eines Starkregenereignisses zur Gefahr wird, zählen sie in diese Kategorie.



Beispiel: Gefahr für das angrenzende Gebäude durch den künstlich errichteten Graben.

OK

OK

OK

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Beispiel: Überflutungsgefahr der Straße, bei starkem Regen, durch den steilen Hang.

Foto: Ingenieurgesellschaft Dr. Siekmann + Partner mbH

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(z.B. Mauern)

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Beispiel: Mögliches Problem durch das verstopfte Gitter bei der Ansammlung von Ästen und Laub.

Foto: Ingenieurgesellschaft Dr. Siekmann + Partner mbH

Errichtete Gebäude / Bauwerke

(z.B. Mauern)

Hierunter fallen sämtliche vom Menschen errichtete Bauwerke, die den Abfluss negativ verändern. Ist beispielsweise eine Mauer, eine Einfahrt oder ein Objekt in einem privaten Garten / einer öffentlichen Parkanlage so errichtet, dass der Abfluss eines Starkregenereignisses zur Gefahr wird, zählen sie in diese Kategorie.



Beispiel: Gefahr für das angrenzende Gebäude durch den künstlich errichteten Graben.

OK

OK

OK

620 **Figure 6: Information on heavy rainfall (a, b, c and d) and links to information pages of the state of Rhineland-Palatinate (a, bottom) in the [€SCCS](#) app.**

Individual problem areas are usually not responsible for large amounts of damage in the case of a heavy rainfall event. It often involves several problem areas that add up to considerable damage (Wang et al., 2019). As the authorities do not have the staff to identify and record the large number of problem areas, the [€SCCS](#) method offers a major advantage over conventional mapping options. The [€SCCS](#) app can be used to record large amounts of data in equally large spatial distributions without having to increase staffing levels. Only the evaluation of the data requires the attention of the authorities.

When measures are implemented, they can achieve a higher level of acceptance than without the use of the [€SCCS](#) app. Due to the greater knowledge base of the affected persons and residents, they can relate to the measures and are more willing to contribute to them because their risk assessment is improved.

630 An [€SCCS](#) app offers the possibility of quick and large-scale distribution without requiring too many resources. It can collect thematic data (like a questionnaire) and at the same time offers data such as the exact location and image material, which would have meant a great deal of effort for the surveyors using the conservative method. The report can be submitted in less than two minutes and can be used by many people thanks to its high level of compatibility with all standard Android devices on the market. The [€SCCS](#) app is basically aimed at citizens of all ages, but also specifically addresses the younger generation-
635 [The CS, due to the more intuitive use of smartphones. The CCS](#) app thus provides an answer to the low level of knowledge of the younger generation about heavy rain and flooding. Users do not need any prior knowledge of citizen [and community](#) science or flooding and are guided intuitively through the [€SCCS](#) app. The categorisations can be made as accurately as possible using example images and descriptions.

In the application test, it became clear that the topic of flooding and heavy rainfall evokes strong emotions in many of the affected people-, [both positive and negative](#). Those affected often feel anxious and worried because they feel unable to act in a flood situation. The [€SCCS](#) app offers the opportunity to regain the ability to act and to name and report the problems specifically for their own property or the neighbouring public space. This returns autonomy to users that many have lost to the water. While the accompanying emotions before using the [€SCCS](#) app were predominantly fear and concern, this changed to trust and security after using the [€SCCS](#) app. Many of the respondents were also motivated and felt a sense of commitment.
645 The results of the application test confirm the assumptions that the [€SCCS](#) app is a suitable tool for sustainable risk management in the context of heavy rainfall.

5.2 Challenges and Limitations

When using the [€SCCS](#) app and the GDW, there may be challenges and restrictions during development and use. Both technical as well as thematic and data-related aspects can influence functionality, user-friendliness and data quality. The main
650 problems are identified, and potential solutions are presented to increase the effectiveness of the application afterwards.

5.2.1 Technical challenges

Technical difficulties can occur both on the [ESCCS](#) app side and on the GDW side. The problems were recognised but could not be fully resolved within the scope of the project. Solution approaches are provided that could point the way for further development of the application.

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The problem with many mobile applications is that they are dependent on the use of mobile data connections. In principle, messages can also be sent later with the [ESCCS](#) app when mobile data is available again. However, it is not possible to send a message without an active mobile data connection. In addition, the map services are not available if there is a lack of connection, which makes manual localisation on the map impossible. This is particularly problematic in rural areas.

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Inaccuracies can also occur if there are not enough satellites available for positioning by the [mDmobile device](#) used. As the number of available satellites decreases, the accuracy of the positioning also decreases and may lead to incorrect markings of the problem area. To minimise this problem as far as possible, images of the problem area can be supplied from different perspectives. This makes it possible to correct or reposition the problem area during data analysis.

665

It is also possible that the spatial resolution of the maps provided (digital orthophoto, spatial resolution 20 cm and Open Street Map) may make it difficult for users to correctly locate the problem areas, making it harder to allocate and find them again later.

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The validity of uploaded data has also not yet been checked. The date and time are automatically recorded from the [mDmobile devices'](#) internal data. All other data can be customised by the user and is not compared with data such as the coordinates of a captured image (should corresponding data be collected by the [mDmobile devices](#)). Such a comparison would further increase the accuracy of the data and could eliminate possible sources of error. However, the inaccuracies of the data automatically collected by the [mDmobile devices](#) must also be considered here.

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The current implementation of the data processing after receiving a report via the API gateway, includes only a minimal form of data validation. On the server-side the data fields are just validated on the data type level. A domain specific plausibility check, if still possible at the backend level, has not been implemented yet. For example, a cross-check of the media metadata and the location could prevent the misuse of the [ESCCS](#) app backend. Thinking further, using Artificial Intelligence for the analysis of the picture content and the submitted additional textual information, could enhance the validation and therefore the data quality. For privacy protection, mechanisms to automatically review the picture content or to remove personal identification information, could be implemented as well, e. g., for removing faces of people on photos, or for removing license

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plates of cars.

5.2.2 Thematical and data quality limitations

Users can have a significant influence on data quality. Although appealing to emotions is important to encourage participation and the implementation of measures by those involved, this appeal can also lead to emotional behaviour that can impair data quality. For example, users may submit false reports or deliberately make false statements in the report. It is therefore particularly important that the data is subsequently evaluated by experts to generate objective drain problems from subjectively viewed problem areas.

One of the biggest problems of citizen [and community](#) science projects and the data collected is the motivation of citizens to use the [ESC](#) app. If the [ESC](#) app is not used or not used regularly and extensively, it is not possible to generate sufficient data with corresponding spatial, temporal and thematic coverage. This is where incentive systems such as gamification (for younger users) or feedback systems (for older users) can be useful. ~~Feedback can consist of a direct message within the CS app stating what happens to the data or regular messages in the CS app when measures have been implemented because of messages. Feedback may take the form of direct messages within the CCS app indicating how submitted data are being processed, or periodic notifications informing users when measures have been implemented as a result of their reports. However, introducing a direct feedback function also creates an expectation among participants that their concerns will be~~ [addressed promptly. This expectation often conflicts with the operational reality in many municipalities, where incoming data must first be analysed, prioritised, and followed by on-site assessments before any measures can be taken. Consequently, direct user feedback mechanisms are viewed critically from a political and administrative perspective, as they may generate obligations that cannot be fulfilled within the available resources or timeframes.](#)

~~A~~Another fundamental problem is that some people do not consider it necessary to use the [ESC](#) app. Even if they are aware of the existence of the [ESC](#) app, basic knowledge about the problems of heavy rainfall is helpful to increase motivation to use it. Pluvial events often occur in areas where ~~people would otherwise flooding is not experience floodings and typically experienced, meaning that local residents are therefore unlikely less likely~~ to be sensitised to the ~~issue-associated risks~~. In addition, the use of ~~mD~~ [mobile devices](#) can exclude people from participating who do not have ~~an mD: a mobile device~~. This often affects elderly people, who either do not have ~~an mD a mobile device~~ or are technically unable to download or use the [ESC](#) app. The user group is restricted here, which is a clear disadvantage compared to other options for data collection such as physical questionnaires.

5.3 ~~Potential for scaling~~ [Scalability, future development](#) and ~~replication~~ [integration potential](#) in other regions

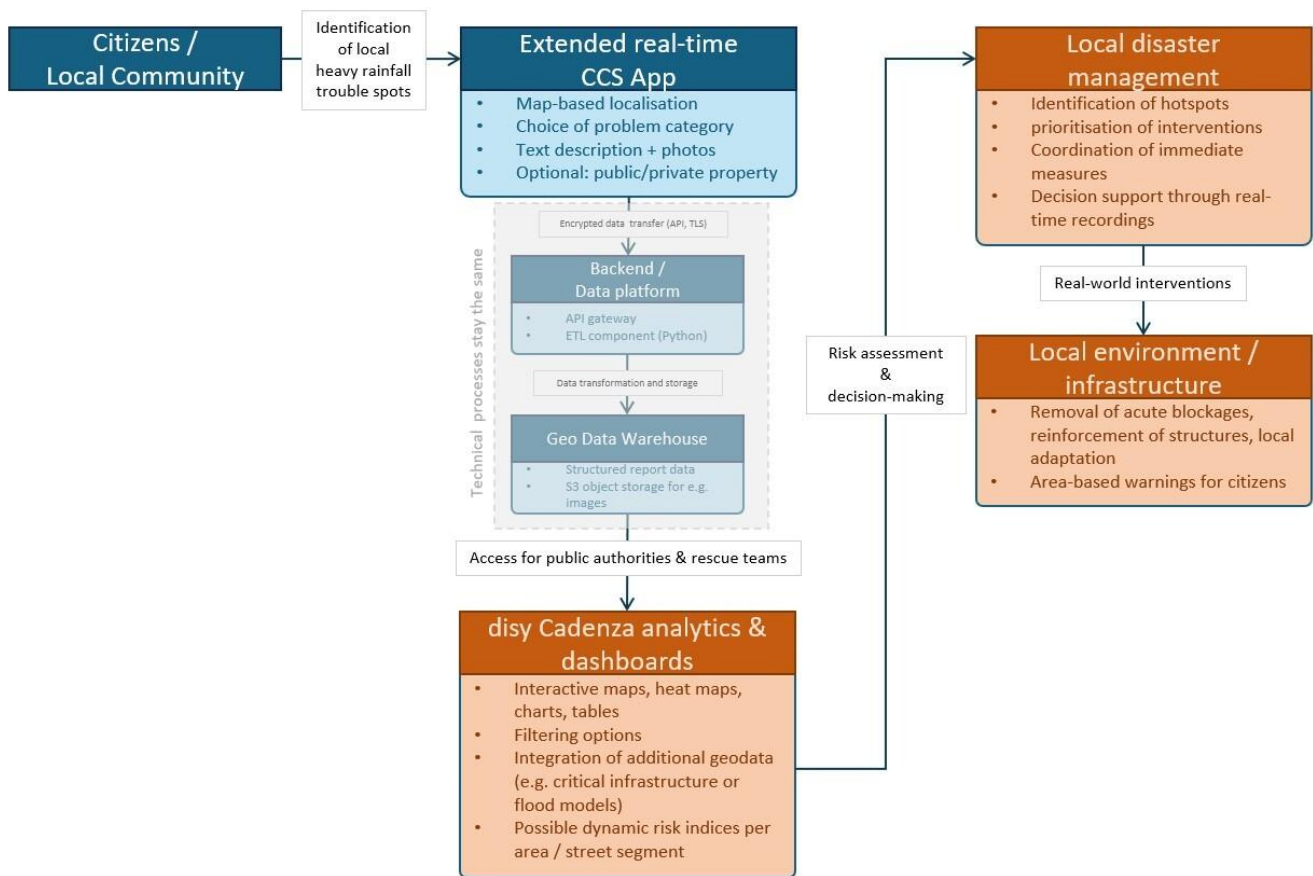
The [ESC](#) app was developed under open-source standards so that it can be set up and ~~installed~~ [deployed](#) in any location. The ~~instructions~~ [implementation guidelines](#) are ~~made~~ publicly available at the end of the project. This ~~means that enables~~ the [ESC](#) app ~~can to~~ be used [not only](#) throughout Germany ~~and but also~~ internationally. For ~~international use~~ [implementation in other countries](#), both the language [settings](#) and the integrated ~~maps~~ [map services](#) would ~~have need~~ to be adapted, as ~~these services are currently only available for Germany. For location~~ [the current configuration only provides access to German web](#)

map services and has only German language settings. Location-specific categories that used to describe problem areas, these can also be adapted accordingly.

715 For some adjusted to reflect regional conditions. For regions that cannot guarantee a without reliable mobile data connection, the coverage, relevant map sections should be integrated directly into the CS-app (offline map function) and not rather than accessed as a via web map service. This means that although services. Although this increases the CS-app uses more memory on the mD, it can be used independently storage requirements on end devices, it ensures full functionality independent of mobile data connections-connectivity. A correspondingsuitable geodatabase with-infrastructure using, for example, Geoserver is
720 required for data transfer,the storage, evaluation and processing, visualisation and analysis of the collected data. This Depending on local resources, this infrastructure can either be set up and hosted in-house or purchasedprocured externally. This decision depends on the available resources.

At the current stage, the application is a functional prototype that has undergone technical testing but has not yet been integrated or deployed by any municipality for operational use. The open-source modular design allows municipalities worldwide to
725 adopt, customise and deploy the system according to their specific environmental, administrative and infrastructural needs. Future development paths include the integration of real-time support functions during active heavy rainfall events, enabling dynamic hazard communication, operational decision support and potentially automated alerting workflows. These perspectives highlight that the existing prototype represents a foundation for a wider, globally applicable system that can evolve into a comprehensive operational tool for municipal risk management.

730 Figure 7 illustrates how the prototype can be expanded into a real-time operational system. Building upon the app's modular and open-source architecture, the diagram outlines potential extensions for integrating real-time data sources and decision-support functionalities. These components would enable dynamic risk communication with citizens and support municipal authorities during active heavy rainfall events. The conceptual model visualises how the current local prototype can evolve into a scalable, regionally adaptable platform for operational pluvial flood risk management.



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Figure 7: Schematic use-case diagram of the potential extended functions as a real-time risk communication and decision support tool. The grey box shows technical processes that do not change (see Figure 4).

6. Conclusion

740 The focus of the FloReST project is on the identification and prediction of emergency flow paths caused by heavy rainfall events and the resulting risk management and communication. As climate change is expected to lead to an increase in such extreme events in the coming decades and conventional flood protection measures largely ~~cover~~ address fluvial hazards, rather than pluvial ones, the aim of this work was to develop and test a citizen ~~and community~~ science app that can be used by the public to identify and report problem areas during heavy rainfall events. One focus was the app's contribution to sustainable risk minimisation and early warning ~~in the event of a~~ heavy rainfall ~~event~~ event in an urban context.

745 With its intuitive and user-friendly design, the app offers the public a low-threshold opportunity to participate in risk management processes. This is the basic requirement for effectively utilising local knowledge and recognising problem areas before they can lead to damage. The app has both a documenting and an educational function. Numerous help and information buttons are offered to provide users with further ~~information~~ guidance on ~~the topic of~~ heavy rainfall, ~~recognising~~ the recognition

of problem areas, and ~~taking~~ appropriate personal precautions. ~~At the same time, the app serves as a tool for informing and~~
750 ~~sensitising citizens to pluvial flood risks, thereby strengthening individual and collective risk awareness.~~ The GDW gives those
responsible access to all relevant data and ~~their analysis~~ ~~corresponding analytical~~ options. Depending on the ~~analysis~~ ~~analytical~~
~~needs~~, different dashboards can be created that summarise and present information for ~~different~~ ~~distinct~~ target groups.
~~The various, non-representative~~ ~~The~~ test runs showed a high level of acceptance and improved self-efficacy among the ~~target~~ ~~test~~
group. By using the app, the emotional ~~expression of~~ ~~stance towards~~ the ~~discussed~~-topic ~~developed~~ ~~shifted~~ positively from a
755 ~~feelingsense~~ of fear to ~~a feeling~~ ~~one~~ of trust. ~~However, these findings do not have statistical significance due to the limited~~
~~number of participants.~~ This participatory approach together with the technical implementation of the ~~CS~~ ~~CCS~~ app, the GDW
and the associated analysis and presentation tools, can ~~nevertheless~~ be ~~summarised~~ ~~regarded~~ as successful. The ~~CS~~ ~~method~~ ~~CCS~~
~~approach~~ is particularly ~~suitable for~~ ~~well suited to~~ local and ~~hard~~ ~~difficult~~-to-predict pluvial events, as the ~~amount~~ ~~volume~~ and
level of detail of the ~~resulting~~ data ~~obtained~~-could not ~~realistically~~ be ~~managed~~ ~~gathered~~ by ~~staff in the~~-public ~~sector~~ ~~authorities~~
760 ~~alone.~~

In everyday use, there ~~are some~~ ~~remain~~ technical limitations that cannot yet be ~~solved~~ ~~resolved~~. Depending on the user's mobile
phone network connection, ~~the~~ map services ~~offered~~-may not load and users may not be able to locate themselves on the map.
Although ~~there is a function to save a message~~ ~~reports can be saved offline~~ and ~~send it when~~ ~~submitted once~~ reception is restored,
the maps are unfortunately not visible in offline mode. In addition, inaccuracies in GNSS positioning can lead to incorrectly
765 ~~positioned~~ ~~placed~~ problem areas. This is one of the reasons why the validation of submitted user data is useful. ~~This has~~ ~~Such~~
~~validation mechanisms, including automated plausibility checks or image-based content verification, have~~ not yet been
implemented ~~either~~-and must be ~~taken into account afterwards when analysing the data~~ ~~addressed in future development.~~

The potential for further development of the app and the GDW is therefore in the areas ~~of~~ ~~such as~~ offline functionality and
accessibility, among others. Furthermore, user frequency could be increased through possible gamification elements and
770 feedback systems. ~~However, direct feedback mechanisms must be designed carefully, as they risk creating expectations among~~
~~users that municipalities may not be able to meet due to administrative, financial, or procedural constraints.~~ Thanks to the open
~~source approach~~ ~~used~~, the app also offers the possibility of scaling to other regions or countries. In addition, ~~an expansion of~~
~~the functionalities~~ ~~functional extensions~~ could be ~~considered~~ ~~envisaged~~ that would make the app usable for ~~rescue teams in~~
~~an emergency services during~~ actual heavy rainfall ~~event and point out particularly~~ ~~events, highlighting~~ acute danger spots.
775 Another use case would be ~~for its application by~~ engineering companies and other experts ~~to take stock of endangered~~ ~~in~~
~~surveying at-risk~~ areas.

The ~~CS~~ ~~CCS~~ app together with the GDW is an innovative and effective tool for urban heavy rain risk management that can be
scaled to other regions and use cases. Due to the involvement of citizens, data gaps can be closed and ~~citizens~~ ~~the public~~ can
~~participate~~ ~~take an active role~~ in risk management. In this way, the ~~CS~~ ~~CCS~~ app and the GDW contribute to a resilience-
780 orientated, sustainable approach to climate impacts in urban areas.

Code availability

The [ESCCS](https://gitlab.rlp.net/ISS/florest/florest-smart-app) app code can be accessed via the following link: <https://gitlab.rlp.net/ISS/florest/florest-smart-app>

Author contributions

785 PFS and AA planned the project; SN, SA and VT programmed the app; JJ and AA set up the Geo Data Warehouse; JH, SN and JJ analysed the data; JH and JJ wrote the draft manuscript; JH, JJ, AA and PFS reviewed and edited the manuscript.

Competing interests

The authors declare that they have no conflict of interest.

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