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User Acceptance of Digital Groundwater Technologies: A Data Governance Perspective

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ABSTRACT: This study explores the user acceptance of Internet of Things (IoT) real-time monitoring systems for groundwater management from the perspective of data governance. While user acceptance is widely acknowledged as key to the adoption of digital technologies, existing research often overlooks how data governance structures shape users' willingness to adopt and use such systems. Following a case study approach and drawing on qualitative, semi-structured interviews with representatives of public and private organisations in the region of Freiburg, Germany, the study examines how issues of openness, accountability, and power influence user acceptance. The findings reveal that, while openness in data sharing can foster transparency, trust, and collaboration, unresolved concerns related to data privacy, security, quality, and ownership function as barriers to adoption. Smaller organisations in particular face challenges in accessing or benefiting from real-time data, raising questions about equity and inclusion in digital water governance. The study contributes to the emerging debate on digitalisation and data governance in the water sector, showing that user acceptance depends not only on perceived usefulness but also on the institutional, legal, and political context in which digital technologies are embedded. A more critical, inclusive, and context-sensitive approach to digital water governance is therefore needed.

KEYWORDS: Digitalisation, groundwater management, user acceptance, data governance, Germany

INTRODUCTION AND BACKGROUND

In times of rising demand, climate change, deteriorating water quality, and water security issues, accurate and timely information on the state and condition of groundwater resources is seen as essential for tracking changes, evaluating the progress and effectiveness of policies, and guiding adaptive and sustainable groundwater management strategies (Tsakiris and Loucks, 2023; WMO, 2023). Advanced information and communication technologies (ICTs) such as the Internet of Things (IoT) are increasingly viewed as having enormous potential to improve the knowledge base available to groundwater managers and decision-makers (Hoolohan et al., 2021; Greer, 2023).

Advanced digital technologies are regarded as facilitating the real-time monitoring of groundwater resources, supporting predictive analytics for a more informed planning of water supply and demand, and providing insights into distributional and infrastructure-related challenges. Furthermore, through the provision of more accurate and accessible data, such technologies are often seen as contributing to the early detection of leaks, improvements in groundwater quality control, and enhanced coordination and decision-making among stakeholders (Aivazidou et al., 2021; Popartan et al., 2022).

However, critics argue that, while digital tools like smart meters and dashboards may appear neutral, they often embed assumptions about authority, control, and what counts as 'valid' knowledge, potentially sidelining local perspectives and reinforcing technocratic governance (Kloppenburg et al., 2022). Recognising that digitalisation is not inherently neutral, it becomes crucial to understand the conditions under which users choose to adopt, adapt to, or contest such technologies. This is where user acceptance research plays a valuable role. User acceptance studies explore the diverse motivations, concerns, and constraints that shape how actors engage with technological change. In this regard, the adoption and use of ICTs has been widely seen as dependent on user acceptance (Dillon and Morris, 1996; Hossain and Silva, 2009; Wahdain and Ahmad, 2014; Mlekus et al., 2020).

According to Dillon and Morris (1996), 'user acceptance' is defined as the demonstrable willingness of users to employ information technology for the tasks it is intended to support. Originating in the early 20th century and evolving significantly over time, user acceptance research has sought to explain the conditions under which users choose to adopt, adapt to, avoid, not adopt, or resist new technologies (Davis, 1993; Buck, 2009; Neil and Richard, 2012). Over the decades, this body of work has drawn on psychological, emotional, motivational, and behavioural theories, emphasising that acceptance is not merely a rational cost-benefit calculation but springs from a complex interplay of internal and external drivers (Weeger and Gewald, 2013; Hernandez, 2017). Much of the foundational work in this area stems from the field of information systems research. One of the field’s most influential models is the technology acceptance model (TAM), which proposes that perceived usefulness and perceived ease of use are primary determinants of a user’s intention to adopt a specific technology, thereby influencing actual usage (Venkatesh and Davis, 2000). This model was later expanded into the unified theory of acceptance and use of technology (UTAUT), which integrates a broader set of variables. These include performance and effort expectations, social influence such as encouragement or pressure from peers and superiors (Eckhardt et al., 2009), and the facilitation of organisational conditions. This last can include access to training, technical support, individual user characteristics (Venkatesh et al., 2003), organisational culture, and managerial support (Schönian et al., 2023).

Expanding on this perspective, science and technology studies (STS) offer further insights by emphasising that user acceptance is not solely driven by individual attitudes or technical features. They emphasise how technologies align with existing social practices, institutional settings, and power relations. For instance, users may resist or modify technologies when embedded assumptions, the so-called 'scripts' (Akrich, 1992), conflict with their realities. From this viewpoint, acceptance depends not only on perceived benefits but on whether technologies are perceived as being compatible with governance structures. In this context, increasing research highlights the growing importance of data governance structures in shaping the user acceptance of advanced ICTs (Dhagarra et al., 2020; Quach et al., 2022; Gebremeskel et al., 2023).

In the age of big data and algorithmic systems, adoption and use of ICTs is increasingly influenced by how data is collected, managed, and governed. Core aspects of data governance, such as ownership, privacy, security, and transparency, have become central to how users perceive and trust modern technologies. For example, uncertainty around data ownership or usage can discourage user acceptance, even when systems are technically efficient (Khatri and Brown, 2010; Duch-Brown et al., 2017). Concerns around surveillance, information security, or data misuse further erode trust, especially in sensitive sectors like healthcare and public services (Zwitter, 2014; Wirtz and Müller, 2019).

However, research on user acceptance of digital technologies in groundwater management has only partially engaged with these issues. Most recent studies, grounded in techno-engineering perspectives, focus primarily on user perceptions of usefulness and ease of use as the main drivers of user acceptance, particularly in the field of smart water management (Adams and Jokonya, 2022; Goulas et al., 2022; Madias et al., 2023; Tean, 2023). For example, Adams and Jokonya (2022) highlight how users accept smart water meters primarily due to perceived cost savings and convenience, with limited attention to data-related concerns such as ownership, sharing, or privacy. Similarly, Goulas et al. (2022) and Madias et al. (2023) focus on operational efficiency and integration into existing workflows but treat users solely as technical personnel, overlooking broader stakeholder groups and governance-related issues. Only Tean (2023) provides some insight into citizen engagement with real-time water usage portals, noting that initial enthusiasm often wanes due to a lack of clarity about how personal data is being used or shared.

Thus, the role of data governance in shaping user acceptance of digital water technologies remains under-researched, pointing to an important gap in the current literature. The overall aim of this paper is to fill this research gap and provide initial insights into whether and how data governance issues influence user acceptance of digital groundwater technologies. Specifically, the study adopts a data governance perspective (Gegenhuber et al., 2023) and employs a qualitative research approach (Creswell, 2018) to investigate how factors such as open data sharing, data privacy and security, data ownership, and data management shape user acceptance. Empirically, the study focuses on IoT-based real-time monitoring systems for groundwater management in the Freiburg region of Germany. (These systems are part of a broader shift towards the digital transformation of water resource management in Germany [see Section 3.1], characterised by the increasing use of data-driven tools and infrastructures.) To explore user perspectives, we conducted eleven semi-structured interviews with representatives of public and private organisations involved in regional and local groundwater management. These include water supply companies, government water authorities at the local and district levels, and other organisations that are either already using or could potentially benefit from adopting advanced digital water technologies and utilising the data they produce.

This paper makes several important contributions. At a broader academic level, it advances the field of user acceptance research by explicitly incorporating data governance as a central analytical perspective. In doing so, it addresses a significant gap in both the user acceptance and water management literatures, where the role of data governance, particularly issues such as data privacy, ownership, transparency, and control, remains underexplored. By focusing on digital water technologies in the context of groundwater management, the paper contributes to a more integrated understanding of how data governance frameworks shape users' willingness to adopt and engage with new digital systems. Beyond its theoretical contribution, the explorative case study approach provides an empirical foundation for further research on a broader scale.

A DATA GOVERNANCE PERSPECTIVE ON USER ACCEPTANCE OF DIGITAL WATER TECHNOLOGIES

In this study, we apply a data governance perspective to explore whether and how data governance issues influence user acceptance of digital water technologies. Originally, data governance focused on managing data within a single organisation. Yet in the most recent phase of digitalisation, where digital technologies increasingly shape organisational practices and decision-making, various frameworks have been developed that seek to explore how policies, roles, responsibilities, procedures, and rules determine how digital data is collected, shared, accessed, and used across institutional, technical, and regulatory boundaries (Abraham et al., 2019; Micheli et al., 2020; Ruijer, 2021; Davidson et al., 2023; Gegenhuber et al., 2023; Vial, 2023).

For example, Abraham et al. (2019) propose a managerial and operational approach to data governance that emphasises clearly defined roles, responsibilities, and control mechanisms to ensure data quality, integrity, and compliance within and across organisations. Their framework is rooted in the corporate IT governance tradition and focuses on ensuring data as an asset is effectively managed and aligned with business goals. Micheli et al. (2020), in contrast, offer a more normative and value-sensitive perspective, highlighting the tensions between openness and control in public sector data governance. Their framework emphasises the institutional, legal, and ethical dimensions of data governance, particularly the challenges that arise when balancing transparency, innovation, and accountability in digital government initiatives. Ruijer (2021) further extends this line of inquiry by focusing on collaborative data governance in the public sector, especially in complex, multi-stakeholder environments. She emphasises the role of trust, cross-organisational coordination, and adaptive governance structures in managing data across silos. Her framework reflects an interest in democratic legitimacy and participatory governance, stressing the need for flexible arrangements that accommodate evolving technological and institutional conditions.

While each of these frameworks connects specific aspects of data governance, they focus on either technical-organisational mechanisms or institutional dynamics in isolation. In contrast, we draw on the framework proposed by Gegenhuber et al. (2023), as it offers a more comprehensive and integrated perspective. By conceptualising data governance across three interrelated dimensions – openness, accountability, and power – it captures both the procedural and political aspects of how data is governed. As such, the Gegenhuber et al. (2023) framework provides a robust and comprehensive foundation for exploring how data governance arrangements influence user acceptance of digital water technologies. The following elaboration on each of the three dimensions builds directly on Gegenhuber et al.'s conceptualisation, adapted to the empirical context of this study.

'Openness' involves the free availability, accessibility, and usability of data, enabling data sharing and collaboration across different actors. While it promotes transparency and innovation, this dimension also helps to identify data misuse or a lack of clarity on how data is collected or used, which could reduce user trust and foster scepticism (Gurin, 2014; Gegenhuber et al., 2023). In groundwater management, openness can support coordinated planning, enhance transparency in water use, and facilitate real-time decision-making, particularly when multiple institutions rely on shared monitoring systems (Gaffoor et al., 2020; Fliß et al., 2021; Sugg, 2021; Cullmann et al., 2022). For example, Gaffoor et al. (2020) highlight how the use of big data analytics in groundwater management in the southern African context has helped improve responsiveness and planning, especially when data is made available across different sectors. However, openness also introduces challenges: Sensitive data on groundwater extraction or contamination may raise fears of regulatory sanctions or reputational damage. Stakeholders may be hesitant to share such data unless governance arrangements clearly define access rights and place safeguards against misuse (Theesfeld, 2010; Sugg, 2021).

'Accountability' ensures data is well-managed, secure, and of a superior quality. Clear guidelines on managing data quality, privacy, and security are seen as essential for building trust and fostering user acceptance. Studies have shown that when responsibilities are unclear, concerns about data security, privacy, or quality can hinder the adoption of digital technologies (Abraham et al., 2019; Micheli et al., 2020; Gegenhuber et al., 2023). In groundwater management, accountability is especially important given the fundamental and vital resource of water in general and the long-term nature of water management being dependent on reliable data for monitoring, resource planning, and regulatory enforcement. Research has shown that when roles and responsibilities for data management are unclear, such as in decentralised systems involving multiple local agencies or private actors, stakeholders may question data reliability or hesitate to integrate digital monitoring into operational decisions (Fliß et al., 2021). Institutional trust is further undermined when there is no clear mechanism to address data errors or breaches.

'Power' relates to control over the data, including ownership and decision-making, and raises critical concerns about the 'open' sharing of information, as not all actors, particularly smaller organisations, may have equal access to or the capacity to fully make use of the provided data. This imbalance can lead to a situation where larger entities with more resources benefit disproportionately from open data initiatives, while smaller organisations may struggle to participate, thus undermining the principles of openness and equity (Geiregat, 2022; Gegenhuber et al., 2023; Zygmuntowski, 2023). In groundwater contexts, asymmetries in power are often evident between national agencies, utilities, and smaller municipalities or user groups. Control over digital infrastructures and data flows can reinforce these imbalances – for example, when larger actors dominate monitoring platforms or retain exclusive access to high-resolution data, leaving others dependent on aggregated or delayed information (Walsh, 2022). Gaffoor et al. (2020) also observe that an unequal capacity to engage with data analytics can deepen existing governance gaps, as more technologically equipped actors benefit disproportionately from open data environments. These dynamics raise questions of equity and inclusion, which are central to understanding how power shapes both the governance and acceptance of digital water technologies (Sugg, 2021).

Taken together, these three dimensions offer a nuanced view of data governance that captures both procedural elements and the broader sociopolitical dynamics at play. Building on Gegenhuber et al. (2023), this study applies the three dimensions to examine how data governance enables or constrains user acceptance of digital technologies in complex groundwater management settings.

Based on the theoretical insights presented above, the following specific research questions emerge to guide our empirical work:

- How do data openness aspects such as access, sharing, and transparency influence user acceptance of IoT-based monitoring systems in groundwater management?
- How do data accountability issues such as data quality, privacy, and security shape users' willingness to adopt IoT-based monitoring systems in groundwater management?
- How do issues of power such as control over data and data ownership affect the user acceptance of IoT-based monitoring systems in groundwater management?

METHODOLOGY

Empirical focus

To achieve the overall aim of this study, we adopted an explorative case study approach (Yin, 2006), which allows for an examination of complex variables and interactions among multiple actors within a short period. While multiple case studies could yield broader data, we selected one particular case, which enables a more focused analysis of the factors influencing user acceptance of digital groundwater technologies. In particular, this study focuses on the user acceptance of IoT-based real-time monitoring systems for groundwater management in the region of Freiburg, Germany.

The region itself comprises the city of Freiburg and several surrounding rural districts, each with varying hydrogeological conditions and governance capacities. In Germany, groundwater constitutes approximately 70% of the national drinking water supply, making its sustainable management a matter of strategic importance. However, increasing drought frequency, nitrate contamination, and the competing demands of agriculture, industry, and households are all placing substantial stress on existing groundwater systems (Fließ et al., 2021; Cullmann et al., 2022). Moreover, the sector is facing evolving policy developments at the national level, particularly concerning the equitable allocation and prioritisation of water usage under conditions of scarcity (cf. National Water Strategy). But despite its importance, groundwater management is still in the early stages of adopting and using advanced digital information and communication technologies (UBA, 2020). This presents a compelling opportunity to explore how digital innovations, particularly IoT-enabled real-time monitoring, are being accepted by users through the lens of data governance.

The region of Freiburg was specifically chosen because a larger research project is developing and piloting just such a monitoring system in the region. Thus, the setting offered direct and timely access to key informants (e.g. water supply companies and municipal and district-level water authorities), as well as enabled this embedded study to provide practical insights that could support the adoption and use of the groundwater monitoring system after the project ends. In this way, our research not only contributes to academic debates on user acceptance and data governance but also serves as a framework for translating research into practice in the context of digital water innovation.

Beyond these project-related considerations, Freiburg's groundwater governance landscape and approach to groundwater data collection offer a highly relevant context for examining how data governance issues might affect user acceptance of digital water technologies. More specifically, the groundwater governance in the region is embedded within both EU and national legislation. In line with the EU Water Framework Directive, groundwater bodies are monitored and assessed, both qualitatively and quantitatively, as part of river basin management plans (ICPR, 2022). This task falls to regional environmental authorities in coordination with local actors. Since the 2020 revision of the EU's drinking water directive (Europäisches Parlament 2020/2184, 2020) and the following revision of Germany's drinking water ordinance, which mandates a preventive, risk-based approach (BMJ, 2023), efforts have been underway to implement water safety planning measures in the region. Between 2022 and 2025, a regional initiative has been assessing potential threats to the drinking water supply – particularly in the Dreisamtal area, which is central to Freiburg's drinking water supply – with the aim of proactively identifying sources of contamination and vulnerabilities in the groundwater system (badenovaNETZE GmbH, 2022).

In Germany, water supply responsibilities primarily lie with municipalities, which either manage services directly or in collaboration with other municipalities, through publicly owned municipal utilities as well as private enterprises. In the Freiburg region, this gives rise to a variety of public and publicly owned service providers operating at local and inter-municipal levels. Together with municipal administrations and regional authorities, these actors play a significant role in both regulatory implementation and operational water management. The collection of groundwater data in the Freiburg area is similarly decentralised. Monitoring is conducted by several stakeholders, including local water suppliers, the regional water authority, and private engineering firms.

Taken together, these legal, institutional, and organisational features make Freiburg a particularly suitable setting for investigating how data governance shapes user acceptance of digital water technologies. The coexistence of multiple actors, overlapping responsibilities, and a regulatory push towards transparency and risk prevention presents a rich empirical context.

Data collection

Employing a qualitative research approach (Creswell, 2018), we conducted 11 semi-structured interviews with potential users of an IoT-based real-time groundwater monitoring system between April and June of 2024.[1] This method was well-suited to the exploratory nature of the study, which aims to investigate how data governance issues influence user acceptance of digital water technologies within groundwater management contexts.

Sample sizes in qualitative research typically range from 10 to 50 participants, depending on the study's objectives and design (Creswell, 2018). For this exploratory study, a sample of 11 participants was considered appropriate, as theoretical and thematic saturation had been reached. In other words, by the eleventh interview, recurring concepts and themes were emerging consistently, indicating that additional interviews were unlikely to yield substantially new insights.

[1] Interviews and user groups: Interview 1: Science and academia, 10 April; Interview 2: Science and academia, 24 April; Interview 3: State water authority (local), 25 April; Interview 4: Water-related non-governmental organisation, 29 April; Interview 5: State water authority (regional), 30 April; Interview 6: State water authority (local), 2 May; Interview 7: Water supplier, 13 May; Interview 8: State water authority (local), 13 May; Interview 9: Science and academia, 15 May; Interview 10: Water supplier, 11 June; Interview 11: State water authority (local), 20 June.

Semi-structured interviews were chosen for their flexibility, as they allow participants to articulate their views openly while enabling the researcher to explore emerging themes in greater depth. Participants were identified through a combination of web-based research and the professional networks established within the broader project in which this study is embedded. Selection criteria focused on public and private organisations, with either direct experience in using real-time monitoring systems or a personal stake in the data these systems produce.

The interview sample included representatives from a diverse array of user groups, ensuring a broad spectrum of perspectives. Participants were comprised of individuals from state water management authorities (5, including both regional and local levels), science and academia (3), water suppliers (2), and a water-related non-governmental organisation (1). Water suppliers and authorities are typically those who adopt and operate monitoring technologies, while NGOs in this study were considered data end-users rather than system operators. Given the organisation's multifaceted role in advocacy, public engagement, and research support, three individuals from the same NGO were interviewed. Their collective input provided a more nuanced understanding of how NGOs might use real-time groundwater data.

The interview guide consisted of ten open-ended questions. The first three focused on participants' professional roles, experience, and involvement in groundwater management. The next two addressed their perspectives on the adoption of digital water technologies, particularly their use of real-time monitoring systems and perceived benefits or challenges. The final five questions explored key data governance issues, including data sharing, privacy, security, and control, and how these factors influence technology adoption.

Each interview lasted between 20 and 40 minutes. All interviews were recorded, transcribed, and subsequently translated from German to English for analysis.

Data analysis

In line with the exploratory nature of this study and its qualitative research approach (Creswell, 2018), we conducted a qualitative analysis of the interview data using MAXQDA software. The coding system was developed deductively, based on the distributed data governance framework introduced in Section 2. Pattern coding was then applied to interpret, conceptualise, and categorise the data, with a focus on identifying recurring concerns and themes related to core data governance dimensions. These coded segments were grouped under the key dimensions influencing participants' willingness to adopt and use real-time groundwater monitoring systems. Using MAXQDA, we systematically coded the transcripts by tagging statements that expressed concerns or positive perceptions and experiences in relation to three primary governance dimensions:

- Openness (e.g. benefits of data sharing, transparency)
- Accountability (e.g. privacy, data security, data quality)
- Power (e.g. data ownership, access costs, control over data interpretation and application)

These coded excerpts were then synthesised into broader themes to examine how specific data governance concerns influence user acceptance. For instance:

- Concerns about data security, privacy, and unclear responsibilities in data management often led to diminished trust in real-time monitoring systems, introducing hesitation, questioning, or outright rejection of the technology.
- Positive experiences with open data practices, such as transparency and ease of data sharing, were linked to a greater willingness to engage with and adopt the systems.

- Perceived financial or bureaucratic barriers to data access frequently reflected underlying power imbalances and were associated with reduced motivation, particularly among smaller organisations, to engage with real-time groundwater monitoring.

The findings are presented according to these core dimensions of data governance, using direct quotes from interviewees to support key points and highlight common perspectives. To protect confidentiality, all participant information was anonymised, and no responses are linked to individual identities.

RESULTS

Openness: Data sharing, access, and use

Many interviewees emphasised that openness – understood as transparent data sharing and real-time access to information – is a significant factor in their willingness to adopt and use IoT-based groundwater monitoring systems. Across user groups, positive experiences or expectations around openness were intricately linked to increased trust, operational alignment, and strategic value, all of which reinforced their motivation to engage with these technologies. Representatives from state water authorities and water suppliers noted that openness enhances transparency and reduces information asymmetries, creating a shared basis for decision-making and collaboration. As one participant from a state water authority at the regional level explained:

> Real-time data transparency helps to build trust between stakeholders. Everyone can see the data, which ensures that decisions are based on the same information. That's essential in our work, especially. When different actors operate on different assumptions, the result is mistrust and fragmented responses. Transparency reduces that risk, which makes us more confident in using such a system. (Interview 5)

This emphasis on shared access was also reflected at the local level, where openness was seen to improve crisis responsiveness and management capacity. A local government official commented:

> If we had real-time data and our own monitoring system, we could respond much better and faster when something happens. For example, in the past few summers, we have issued general orders to restrict the public use of surface water. Last year, an extremely dry year, we even restricted groundwater usage. If we had more real-time data, we could set up a small measurement network and react more effectively, helping us to better manage our water resources and respond to crises. (Interview 11)

Academic participants similarly emphasised that openness enhances monitoring systems' relevance to their work, making them more inclined to engage. As one university-affiliated researcher noted:

> Open access to real-time data allows us to align our research more closely with operational needs. This is particularly valuable when collaborating with public authorities to model groundwater recharge or simulate drought scenarios. Without access to actual monitoring data, we're often limited to historical datasets or estimates, which reduces both accuracy and credibility. So the more transparent and timelier the data, the more meaningful our contributions can be. That increases our interest in using and supporting such systems. (Interview 1)

For water suppliers, openness was viewed as a tool for long-term strategic planning and coordination. A representative from a regional water supplier explained:

> Sharing data enables us to anticipate future needs. It's not just about compliance; real-time transparency supports strategic water resource planning. It allows us to coordinate with municipalities and other service providers more efficiently. That level of foresight is a strong incentive to adopt such systems, especially if the data infrastructure is shared and trustworthy. (Interview 10)

An NGO representative also emphasised that open data improves transparency and accountability, even for those who are not direct system operators:

> Transparent access to groundwater data is critical. It helps ensure that decisions made by utilities or regulators are open to scrutiny. Too often, access is blocked or expensive, which reduces public trust. If data is shared openly and in real time, it strengthens our ability to engage with policy processes and hold actors accountable. That's what makes these systems relevant to us, even if we're not the ones installing or running the sensors. (Interview 4)

However, despite broad support for openness, several participants expressed concerns that, without proper governance, openness could introduce new challenges that would reduce confidence in the adoption of real-time monitoring systems. Participants noted issues around data quality, inconsistent reporting, and the risks of misuse. A representative from a local state water authority pointed out:

> Half of our groundwater data comes from companies obligated to monitor it, but many still send incomplete, paper records. If a real-time data exchange is to work, we need digital standards and enforcement. Otherwise, the openness becomes partial and unreliable, and that makes it harder to justify investing in new systems. (Interview 8)

Additionally, concerns over strategic misuse or misrepresentation of open data emerged as a significant barrier. A representative from research and academia warned:

> The danger is not the data itself, but how it is used. Real-time drought data, for instance, can be misrepresented in the media, triggering alarmism and policy overreaction. In some cases, we have seen data being pulled out of context to support political agendas. Without strong data governance, openness can backfire. That makes us cautious about what we share and whether we want to be part of the system at all. (Interview 2)

Together, these findings show that, while openness is widely regarded as a key enabler of adoption, enhancing trust, operational value, and collaboration, it must be supported by clear governance frameworks and technical standards. Without these, openness can create uncertainty, reduce confidence, and deter some users from adopting or fully engaging with real-time groundwater monitoring systems.

Accountability: Data management issues

While many interviewees were supportive of real-time groundwater monitoring systems, their willingness to adopt and use these technologies was strongly influenced by concerns around data privacy, security, and the capacity to manage large volumes of digital data. Across user groups, but particularly among water suppliers, local authorities, and state agencies, data protection was viewed as a non-negotiable condition for adoption. For water suppliers, who manage critical infrastructure, cybersecurity in general was a top concern:

> Data security and privacy are paramount to us due to our critical infrastructure status. Stringent measures are in place to safeguard data against unauthorised access, cyber threats, and operational vulnerabilities. Approximately 99% of our data isn't publicly accessible. Sharing operational details could compromise our infrastructure's security against cyber threats or even physical attacks. (Interview 10)

But while such users emphasised the need for restricted access, others, particularly environmental agencies, expressed fewer concerns about sharing groundwater data, seeing it as inherently public. A representative from a state water authority stated:

> Environmental data is public anyway. That means everyone has a right to access the environmental data that we have captured. Currently, there are no restrictions on the data we capture in terms of public access. As for data privacy, I don't see any problems there. (Interview 6)

However, even among those less concerned with confidentiality, managing real-time data was seen as resource intensive. Many interviewees noted challenges with validating and maintaining large datasets due to limited personnel and technical infrastructure. A participant from a local authority highlighted that

> we are not permanently well-staffed. I don't have the time or resources to keep everything updated. Real-time systems need regular checks: not just data collection, but validation. This takes time, and we don't have enough personnel or financial support to do it properly. (Interview 11)

Others echoed that more data, without the resources to interpret it, does not always lead to better decisions: "More data doesn't necessarily mean better decisions if we don't have the staff or financial resources to process and validate it properly" (Interview 10).

Beyond staffing, some public agencies faced legal and technical constraints on data management from centralised IT governance and data protection laws. A researcher from an academic institution explained:

> We face challenges due to poor IT infrastructure, primarily because of the BIT-BW law that centralises IT services for all public administrations in Stuttgart. This limits our hardware and software development freedom. Although we collect real-time data, we can't yet publish it due to security regulations. We aim to develop real-time systems, but the current framework makes implementation difficult. (Interview 1)

Additionally, as one participant from a state agency noted, "There are no clear responsibilities within our organisation for managing real-time data" (Interview 6). This lack of internal delegation for managing real-time data discouraged investment in such systems.

In summary, while real-time monitoring systems were widely seen as valuable for operational efficiency and resource planning, concerns around data privacy, cybersecurity, staffing limitations, legal restrictions, and internal capacities significantly shaped user attitudes towards adoption. Where safeguards and resources were in place, users were more willing to invest in and use these systems. Conversely, where governance structures were unclear or overly restrictive, or where organisational capacity was insufficient, users expressed hesitation. All this highlights that accountability, in both legal and operational terms, is essential to enabling wider adoption of digital groundwater technologies.

Power: Data ownership and control

The perceived fairness, clarity, and regulation of data ownership emerged as another key factor shaping the willingness of users to adopt and engage with IoT-based groundwater monitoring systems. While public institutions are often expected to retain control over environmental data, our findings show that the way this control is exercised, especially in terms of access and decision-making authority, can create – or mitigate – significant inequalities within the data ecosystem.

Interviewees from larger public authorities, such as regional and state water administrations, described well-established internal frameworks for how environmental data is collected, managed, and shared. These frameworks often support seamless intra-agency cooperation and foster institutional trust in the use of modern technologies. As a representative from a local state water authority noted:

> Within governmental agencies, [data governance] is not a problem; it runs very smoothly. All data fundamentally belongs to the entity that collected and maintains it. We are allowed to access this data. The only thing we are not allowed to do is pass it on externally. (Interview 6)

Similarly, another representative from a regional water authority emphasised an open stance towards data sharing. "Environmental data is public anyway. There are currently no restrictions on the data we capture in terms of public access. (…) There are no issues with exchanging this data with other authorities" (Interview 5).

However, not all stakeholders experienced these favourable conditions. Smaller and less resourced actors (e.g. NGOs, grassroots environmental associations, and independent research institutes) highlighted the practical and political challenges they faced in accessing real-time groundwater data. While legal frameworks may nominally guarantee public access, interviewees emphasised that actual access is often constrained by bureaucratic procedures, financial costs, and the opaque exercise of institutional discretion.

One academic researcher stressed the importance of data control and transparency in building trust. "We manage client data very delicately. It belongs to them, and we don't publish it. But that's not how every engineering office operates. Ownership must be transparent and respected – it's critical for trust" (Interview 2).

More importantly, smaller organisations often occupy a structurally weaker position in the data ecosystem. They may lack the legal expertise, financial resources, or institutional connections to navigate complex data access regimes. As a representative from an environmental NGO explained:

> We tried to get more specific and detailed groundwater data from a regional local authority, and they wanted to charge quite a bit in administrative fees for it. I find it difficult with such data – especially if they're large-scale, like data for groundwater throughout Germany – I find it problematic if they end up in the hands of private companies. Such data should not be with a private firm but with a public administration, because it's for public interest. (…) For a small association like ours, with fewer than 30 members, a fee of 150 euros is quite high. If we must spend 150 euros on each of the 6 or 7 topics we're working on, we quickly exhaust our annual membership fees. (Interview 4)

This example illustrates how even nominally public data can be rendered inaccessible to smaller actors through costs and administrative burdens. These are not merely technical obstacles; they reflect deeper power asymmetries in the data governance landscape. Larger institutions with established infrastructures, legal departments, and secure funding are better positioned to access and shape the use of environmental data. In contrast, smaller actors are often excluded from both access and decision-making processes, reinforcing broader inequalities in environmental governance.

While IoT-based monitoring systems hold promise for democratising data by enabling real-time public access, these technologies are not inherently equitable. Without intentional efforts to address existing disparities in data ownership and control, digital infrastructures may reproduce or even exacerbate current power imbalances. Ensuring equitable access will require not just transparent legal frameworks but also structural support for under-resourced stakeholders to participate meaningfully in data-driven governance.

In summary, our findings show that clear ownership rules and accessible data pathways can increase trust and willingness to adopt IoT systems – particularly among public institutions. However, where ownership and control are exercised in ways that reinforce institutional hierarchies or restrict practical access, smaller actors are marginalised. This raises critical questions about who benefits from digital water management – and who remains on the periphery.

DISCUSSION

This study aims to explore whether and how data governance influences the social acceptance of digital technologies for sustainable water management. Given the broad variety of technological developments for sustainable water management, we have focused on the adoption and use of the IoT real-time monitoring systems for groundwater management in the region of Freiburg, Germany. The data governance perspective is used here as a heuristic tool to identify whether and how key data governance issues influence the willingness of various user groups. In the following sections, we discuss the role of data governance in shaping acceptance of digital water technologies according to three key data governance dimensions – openness, accountability, and power – which our findings revealed to be highly interconnected. We also reflect on the value of our case study approach.

The findings highlight that openness is not just a desirable feature but a vital driver in fostering user acceptance of real-time groundwater monitoring systems. This supports earlier research (Gupta et al., 2020; Kloppenburg et al., 2022) showing that transparency is a key driver for digitalisation in environmental and natural resources management. Our research reinforces the widespread agreement that real-time monitoring systems, through open data sharing, accessibility, and use, can play a key role in fostering transparency. Transparency in principle is seen as the cornerstone for building trust among stakeholders, enhancing collaboration across various sectors, and improving overall decision-making capabilities. This is particularly important in the context of groundwater, which, as an invisible resource, presents unique challenges in management because the public and many actors cannot directly observe changes in its levels or quality (Theesfeld, 2010; Walsh, 2022; Saccò et al., 2024). This invisibility makes the concept of transparency through real-time monitoring even more relevant to the actors, as it allows them to visualise and understand the state of their aquifers – data that is typically difficult to come by for critical resources. By making the invisible 'visible', real-time data systems could help actors to respond much more quickly to changes in groundwater levels and quality.

However, our analysis also revealed that unresolved concerns related to data openness can significantly influence the social acceptance of real-time groundwater monitoring systems. Accountability issues emerged as key factors influencing the adoption of monitoring systems. Specifically, concerns about data security, privacy, data quality, and responsible use were prominent. If not properly addressed, these issues could erode trust and influence whether, how, and by whom real-time monitoring systems are put in place.

For example, while users support greater transparency in groundwater management, this openness is dependent on the presence of strong data security measures to protect both critical infrastructure and sensitive groundwater data. Without adequate safeguards, there is a heightened risk of cyberattacks and data breaches. However, this need for stringent data security protocols, particularly on the part of water suppliers, often clashes with public demands for openness in managing groundwater as a shared resource. The water suppliers must focus on protecting proprietary information and maintaining operational security, as revealing too much data could expose them to competitive risks or highlight vulnerabilities. On the other hand, the public expects transparency, viewing groundwater as a common good that requires responsible, open management, especially in times of climate crisis and risk of drought (Rockström et al., 2023).

These competing demands illustrate a broader tension between protecting sensitive data and enabling public access to information about the management of shared resources (Mazzucato and Zaqout, 2024). And as we have highlighted, these tensions do not just exist between water management institutions on the one hand and the public on the other, but also between the individual institutions involved. While groundwater flows themselves cross-cut administrative borders, the sharing of data between the different authorities responsible for managing those flows has proven to be difficult. Our explorative regional case study approach, while limited to the Freiburg region, might reveal more general structural issues around the sharing of data across Germany and beyond.

At the same time, regional data security laws (e.g. the Law for the Establishment of the State Authority IT in Baden-Württemberg), which are perceived by some interviewees as overly stringent, constrain local water authorities in particular, making it difficult for them to adopt real-time monitoring systems. Such regulations often require advanced technical infrastructure, specialised personnel, and continuous oversight to ensure compliance with strict data security and privacy standards. This demand translates into significant financial and operational burdens for smaller authorities, who may lack the budget or in-house expertise to meet these requirements. Additionally, the laws may restrict the flexibility of local authorities in accessing or sharing real-time data, creating further challenges to system implementation. In this context, it is possible that smaller authorities may hesitate to adopt IoT-based systems not out of a lack of interest but because of the perceived risk of non-compliance and the prohibitive costs associated with meeting legal obligations. This, in turn, may slow the pace of digital transformation in groundwater management, especially at the local level (and potentially exceeding our case study area).

Prohibitive costs and the resources needed to secure and maintain data *quality* are also significant concerns for both water suppliers and public authorities. Managing large volumes of real-time data often exceeds organisational capacity, leading to gaps in data quality and usability. This challenges the assumption of previous scholarship (e.g. Hoolohan et al., 2021; Greer, 2023) that more data automatically improves decision-making capabilities, emphasising the need for proper data validation and processing before it can be translated into actionable insights. Water suppliers and state authorities both underscored the resources required to manage the large volumes of highly complex, real-time data effectively. This aligns with broader critiques of managing big data (Gabrys, 2020; Gaffoor et al., 2020; Cepa, 2021). For example, Gabrys (2020) points out that the increasing reliance on digital technologies and real-time data collection often creates new challenges rather than simply providing more information for decision-making. One of her key arguments is that big data, while offering a more comprehensive and detailed view of environmental phenomena, can lead to an overwhelming amount of information that is difficult to manage, interpret, and act upon. This often results in what she refers to as a "data deluge" – a situation where organisations and decision-makers are inundated with data yet still struggle to derive meaningful insights from it.

Relatedly, concerns about the potential misinterpretation of real-time data, especially during crises like droughts, were also prominent in the interviews. The availability of real-time data to the public could lead to alarmism and put pressure on policymakers to act prematurely. This issue emanates from the larger social construction of risk (Beck, 1992), suggesting that how data is communicated to the public plays a critical role in shaping perceptions of risk and influencing subsequent behaviour. For instance, if real-time data is made publicly available without sufficient context, media or public bodies could amplify concerns, leading to unnecessary alarmism. These concerns highlight how approaches to data sharing are shaped by the need to balance the needs for transparency and responsible data use, with particular attention to the intended audience, purpose, and context of data dissemination. This issue is becoming increasingly relevant in the broader discourse on digitalisation and transparency in environmental governance (Gupta et al., 2020; Dwivedi et al., 2022; Kloppenburg et al., 2022). Data openness is not only about providing *access* to data but also involves how data is interpreted and understood by users. Misinterpretations can generate public pressure or influence policy decisions in ways that may not align with the data's original context or intent. In this context, Dwivedi et al. (2022) argue that open data sharing and access must be accompanied by efforts to contextualise and explain the data to ensure proper use.

Concerns related to power, specifically around data ownership and control, were raised more prominently by NGO representatives than by water authorities and suppliers. Their concerns stem from the observation that larger entities, such as state authorities and water suppliers, are typically the primary users and operators of real-time monitoring systems, giving them direct control over the collection, interpretation, and ownership of the data generated by these systems. Their privileged position grants these organisations easier access to real-time data and allows them to manage it effectively. In contrast, smaller organisations such as research institutes and NGOs, which generally function as secondary users of the data rather than direct operators of the monitoring systems, face significant bureaucratic, technical, and financial barriers that limit their access to real-time information.

This differential access reinforces a power imbalance, perpetuating existing hierarchies within the sector and hindering the ability of the smaller organisations to contribute meaningfully to groundwater management discussions and decisions. Without direct control or timely access to real-time data, NGOs and smaller groups often depend on delayed or second-hand information, which weakens their ability to advocate effectively, influence policy, or hold larger entities accountable. This dynamic mirrors broader debates on data sovereignty (Reyes-García et al., 2022), where questions of who owns and controls data are central to discussions of environmental data governance. In the context of groundwater management, control over critical data, such as information on water extraction, quality, and usage, can create tensions between various stakeholders, including farmers, NGOs, and regulatory bodies. The uneven distribution of access and control over real-time data can result in imbalanced decision-making power, where larger entities shape policies while smaller groups are sidelined.

In summary, while this study highlights how data governance factors such as the benefits of open data sharing can support the user acceptance of digital groundwater monitoring systems, it also underscores that digitalisation is not universally perceived as desirable – or even necessary. Several interviewees pointed to resource limitations, institutional constraints, and concerns over data misuse as reasons for hesitation or resistance. Moreover, framing digital technologies as the dominant or default solution risks marginalising traditional, local, and analogue knowledge systems that have long played a vital role in groundwater management. To enhance more inclusive and context-sensitive water management, a pluralistic approach that values both digital and non-digital pathways may be essential in the future (Gabrys, 2020; Kloppenburg et al., 2022).

CONCLUSION AND OUTLOOK

This study explored whether and how data governance influences the user acceptance of digital technologies for sustainable water management, focusing on the adoption and use of IoT real-time monitoring systems for groundwater management in Freiburg, Germany. The findings highlight the complex interplay and competing needs between openness, accountability, and power in shaping the user acceptance of real-time groundwater monitoring systems. This requires a balanced data governance approach, which ensures openness and transparency and, at the same time, addresses concerns around data privacy, security, quality, usage, and equitable access to data. A governance framework that balances these factors, ensuring that data is accessible, secure, and equitably distributed, will be key to increasing the willingness of users to embrace IoT systems for groundwater management.

In this context, future studies could explore how data governance frameworks can promote both openness and accountability without compromising one for the other. This includes examining how real-time data can be shared in ways that safeguard sensitive information while remaining transparent enough to build trust, enhance collaboration, and improve decision-making capabilities among diverse stakeholders. Existing dynamics around data access and ownership also raise questions about equity, especially as smaller organisations and NGOs are often less able to engage with or influence real-time data infrastructures. Further inquiry might critically engage with the power relations embedded in these processes, recognising that digitalisation represents not just a technical shift but a broader socio-political transformation. This may involve exploring partnerships, data-sharing agreements, and governance frameworks that enable smaller organisations and marginalised groups to participate on equal terms with larger entities.

From a science and technology studies (STS) perspective, these findings also suggest the importance of viewing user acceptance not merely as an attitudinal or behavioural outcome but as a response to how digital systems are embedded within existing institutional and social contexts. STS literature has long emphasised that technologies are inscribed with assumptions – 'scripts' (Akrich, 1992) – that prescribe certain roles and expectations for users. In this light, user hesitancy or resistance is not simply a barrier to be overcome but often reflects a misalignment between these embedded assumptions and the lived realities, capabilities, or normative positions of the users. Although our study does not directly examine co-design processes or the development phase of innovation, it opens the door to future research that considers how digital groundwater technologies are co-constructed in practice.

Furthermore, given the context-specific nature of data governance challenges, future studies should expand beyond the Freiburg region to include other geographical areas with varying regulatory environments and technological capacities. Comparative studies between regions could provide deeper insights into how different governance frameworks shape social acceptance of digital water technologies.

And while this study emphasised social acceptance and governance, there is a need to further investigate the structural challenges associated with adopting and using advanced digital water technologies. For technologies like IoT real-time monitoring systems, the expectation of seamless integration often clashes with the reality of technical complexities, resource limitations, and operational disruptions.

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