ICA2025OSLO
14th IWA Specialised Conference on
Instrumentation, Control and Automation

# Opportunities and challenges of interoperable Open Data sharing for decision support in the water domain

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**Abstract:** Digitalizing the water sector has great potential for addressing current and future challenges, particularly due to climate change and the increasing global need for sustainable practices. Data is at the core of this digitalization process, highlighting the need for frameworks and tools for efficient and robust data sharing across domains and to support smart decision-making. As part of the WaterFRAME project, our research focuses on creating dynamic knowledge graphs, data standards, and decentralized open dataspace to enable smart and circular water management. This study highlights key aspects that require attention, including the evolvability of data models and APIs, discoverability of datasets, scalability of data publishing, and the ability to query across diverse data sources through semantic interoperability. By addressing these challenges, this study underscores the potential of digital transformation to foster a more resilient and sustainable water economy.

**Keywords**: Circular water; dataspace; data standards in water

## Introduction

The current digital landscape in the water sector lacks an adaptive and future-proof pathway. The development of open dataspaces, ontologies, and dynamic knowledge graphs is essential for creating a comprehensive understanding of the water domain (Yan et al., 2018), integrating data from diverse sources, and fostering interoperability. Existing digital transformation initiatives have focused on air quality, traffic, energy (Debnath & Mourshed, 2018; Spyrou et al., 2019), and mobility, leaving a noticeable gap in addressing the specific challenges in circular water. Initiatives such as the UK National Digital Twin program (Ivanoff, 2023),(Department for Business & Trade, n.d.) and Digital Flanders' DUET project (Digitall Vlaanderen, n.d.; Raes et al., 2022) have demonstrated the potential of dataspaces, ontologies, and knowledge graphs in other domains but have not been extended adequately to the circular water sector. A holistic approach to the digital transformation of the circular water sector is imperative, transitioning from unitary to interconnected and dynamic scenarios. This involves establishing specific data standards for water reuse, developing adaptive ontologies and dynamic knowledge graphs (Cohen & Gil, 2021) and creating forward-looking digital tools that can effectively support decision-making processes. Addressing these challenges will pave the way for a more resilient and sustainable water management system.

In this study, and within the context of the WaterFRAME project, we propose a circular water-specific framework that can collect, standardize, and distill the unstructured data of the various initiatives to realize interoperability. Upon data collection and standardization, creating unified models and open dataspaces should allow for ease of Interaction. This would not be possible without a collective effort from producers and consumers to agree on set standards concerning semantics, terms, and definitions. This would lead to a unified modeling representation unifying our global domain understanding. The framework should support data sharing within a data ecosystem. It shall provide a clear structure for data producers and consumers to share and collaborate on data assets that are compliant with laws and regulations while also providing fair treatment to all parties involved. Creating an open dataspace would enable sharing of data across different sectors (e.g. water and energy). This would, in turn, lead to an increased demand and use of the data and its enabled products.

## Material and Methods

A dataspace focusing on the specific water domain of Circular water is proposed. The dataspace shall utilize standard technologies to facilitate data exchange between producers and consumers as shown in Figure 1. The dataspace will also promote data discoverability aiming to locate, access, and understand datasets efficiently. Data will not mainly be stored centrally in a unified repository, but rather stored by producers and linked together through knowledge graphs. This eliminates single-point-of-failure dependency and facilitates data updates.

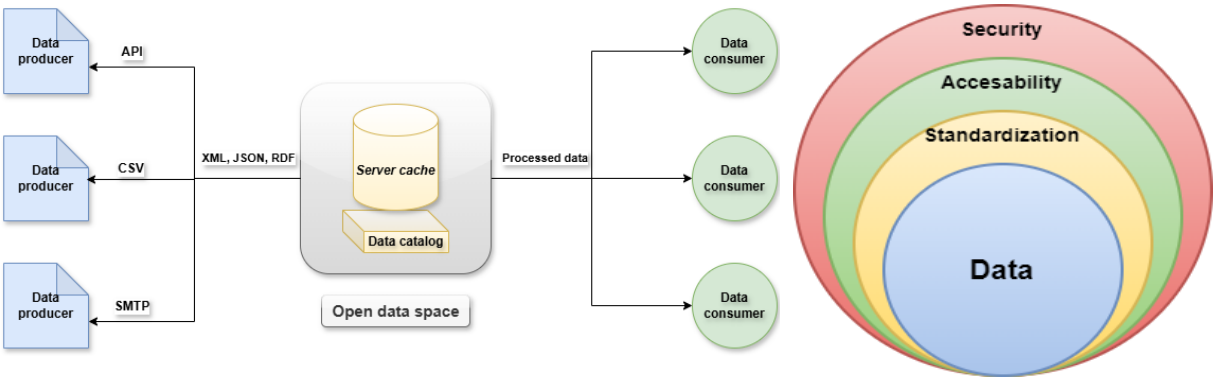


**Figure 1** In an open dataspace, data from various producers will be cached and indexed by intermediary participants in various formats facilitating consumers to access the processed data.

Data exchange across the dataspace would not be possible without standardization of data models and exchange. A semantic model was developed to focus on rainwater reuse. Standardization of data models ensures the use of consistent definitions and structures for data representation across different datasets. Standardization is critical for multi-source data integration, sharing, and analysis. In return, this would lead to better decision-support systems that would aid stakeholders as shown in Figure 2.

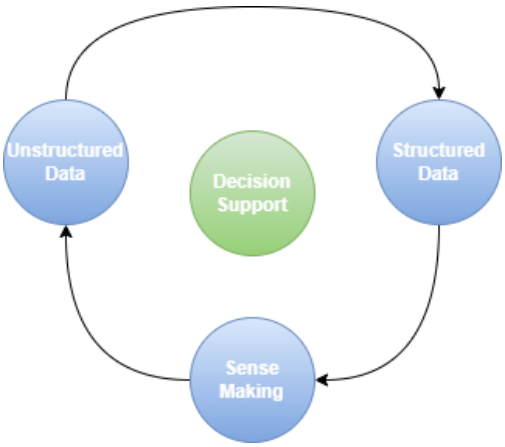


**Figure 2** The scheme of WaterFRAME for transforming unstructured data, turning it into a structured form, and aiding in decision support.

## Results and Discussion

The developed Ontological model focuses on rainwater, covering key aspects such as reuse, collection, storage, distribution, monitoring, and treatment as shown in Figure 3. A considerable part of the ontology development focused on metadata collection through water quality sensors. Capturing important data such as sensor's reading, unit of measurement,

exact location, and date time stamp. The ontology is complemented by SHACL (Shapes Constraint Language) shapes that provide a mechanism to define and enforce constraints on data and relationships within the ontology. Additionally, they support ontology debugging and quality assurance by detecting errors and enforcing completeness in relationships. By pre-validating data, SHACL shapes improve querying and decision support, while their modular nature simplifies ontology expansion and maintenance, making them essential for managing complex, domain-specific requirements.

There is a plan to integrate well-established ontologies such as SSN SOSA(Lefrançois et al., 2025). These ontologies provide a robust framework for describing sensors, observations, and related processes, enabling seamless data integration and harmonization across systems. Such integration will facilitate the adoption of standardized vocabularies, improve reasoning capabilities, and support cross-domain data exchange. Furthermore, there is a plan to expand the ontology into other domains, such as energy, to support holistic and interdisciplinary approaches to resource management.

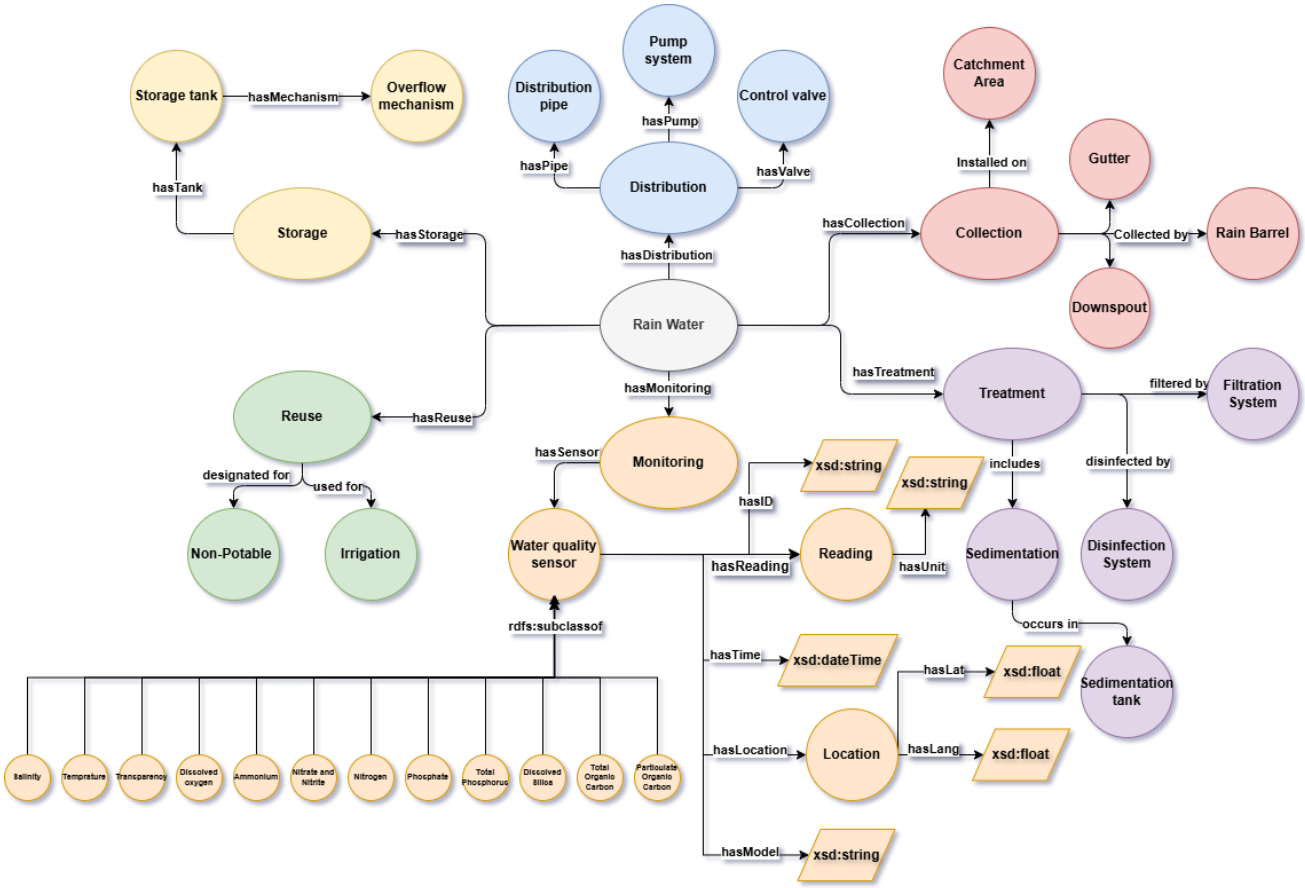


**Figure 3.** Rainwater ontology along with its five main subsystems which are reuse, storage, monitoring, distribution, and treatment.

With the development of circular water dataspace, it sets rules and protocols that define how data is exchanged between different organizations. Setting standards for data exchange through the open dataspace ensures that the data can be shared accurately and efficiently as it aims to establish a common language that enables seamless data interoperability. The rules set by the dataspace (Data Spaces Support Centre, 2023) ensure proper API governance, data access control, data format specification, standard communication protocols, and data discoverability.

**Conclusions**

Data sharing and decision-making for water reuse are critical to the ongoing digital transformation of circular water. By emphasizing the development of open dataspaces, standardized data models, and dynamic knowledge graphs, our proposed framework aims to overcome existing challenges in interoperability, data sharing, and data integration.

The findings underscore the importance of collaborative efforts among stakeholders to establish unified standards and promote seamless data exchange. This work paves the way for resilient and sustainable water management systems, demonstrating the transformative potential of a data-driven approach in fostering a circular water economy. Future research should focus on refining the proposed framework and extending its application across broader water management contexts.

**Acknowledgments**

This work has been carried out within the FWO-SBO WaterFRAME project (S001124N).

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