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A Proposed Framework for the Adoption of the Fourth Industrial Revolution Technologies in Municipal Water Governance in South Africa

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Abstract—The Sustainable Development Goal 6 (SDG 6), which focuses on ensuring universal access to water for all, remains at the center of the sustainable development agenda; however, its realisation continues to be hindered by the persistent water governance challenges. This is particularly concerning given the critical role that effective governance plays in addressing the global water crisis. The advent of the Fourth Industrial Revolution (4IR) technologies offers transformative potential to strengthen municipal water governance systems. Yet, the adoption and implementation of these technologies, especially within South African district municipalities, has been notably slow. Using a selected district municipality in the Eastern Cape in South Africa, the paper aims to develop a framework to facilitate the adoption of 4IR technologies in municipal water governance. Adopting a qualitative research approach, the study purposively selected participants from the municipal officials, stakeholders, and experts who provided insights into the challenges and opportunities associated with 4IR adoption. Data was collected through semi-structured interviews and analysed thematically. The findings reveal a slow uptake of 4IR innovations, underpinned by capacity, infrastructure, and policy gaps. The paper, therefore, proposes a contextually grounded framework designed to guide and accelerate digital transformation within rural municipalities. Thus, the framework provides a roadmap and direction in accelerating the integration of 4IR technologies to strengthen municipal water governance, foster inclusive technological advancement, and ensure that rural communities are not excluded from the benefits of digital innovation. The paper, therefore, underscores the urgency of this shift by highlighting that the 4IR is rapidly transforming all sectors. Consequently, the failure of district municipalities serving both urban, semi-urban, and rural areas to adopt 4IR technologies risk deepening existing disparities and leaving rural municipalities further behind.

Keywords—Fourth Industrial Revolution, Water Governance, Sustainable Development Goal 6, Municipal, Innovation, South Africa

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1 Introduction

The 2024 report on the Sustainable Development Goals (SDGs) for water and sanitation reveals that access to properly managed drinking water has risen from 69% to 73%, while access to sanitation has risen from 49% to 57% [55]. Notwithstanding this rise, the report additionally indicates that as of 2022, populations of 2.2 billion and 3.5 billion continue to lack these fundamental services [54]. Similarly, ref [16] opines that nearly 30% of humanity still lacks access to safely accessible, affordable, and reliable water services. Likewise, the United Nations [54] extended report on SDGs recorded that information gaps exist concerning water quality data [56]. The report recorded a decline in water quality where data was available, and where it was absent, it reported the challenges posed by the situation in ensuring proactive measures [56]. Furthermore, the National Water Security Report of 2023 reported on the challenges in ensuring effective governance, highlighting issues such as poor coordination, inadequacy in funding, and deficiencies in institutional and professional capacity, which all threaten water security [34].

The above information renders achieving Sustainable Development Goal 6 by 2030 nearly unfeasible. The claim corresponds with the [64] and the 2023 SDG Synthesis report on water and sanitation, which recorded that attaining the SDGs for water and sanitation necessitates a sixfold enhancement in the existing progress rates for safely managed drinking water and a fivefold enhancement for properly managed sanitation for these goals to be achieved by 2030 [57]). Likewise, [59] contend that the SDGs will not be met in the original time frame due to issues of global crises such as COVID-19, governance impairments, financial gaps, and other SDGs that require a more extended time frame to be achieved.

South Africa is not immune to the above situation, but rather a reflection of the above statistics, where access to basic water remains challenging. The 2022 reports by the Department of Water and Sanitation and Statistics South Africa [1] reflect that despite a significant increase in access to water (from 61.7% in 2002 to 88.7% in 2021) due to water reforms and deployed water strategies, a significant population (3.4 million households) still lacks access to freshwater resources. To this end, two decades later, the institutional reforms and policy developments remain a work in progress [15].

While the situation above indeed can be intensified by external pressures such as climate change, urbanization, and population increase, this paper argues that the fundamental issue resides in governance challenges [57],[16],[1], underscoring the essentiality of the concept in addressing water challenges [23]. Nevertheless, the importance of governance is undermined as the concept continues to persist as a considerable impediment, as noted by [3] and [49], who observed that the water crisis remains a governance crisis.

However, this paper concedes that without adequate political, administrative, and policy frameworks to direct decision-making, advancements in attaining water-related objectives, such as SDG 6, would remain inadequate as they will fail to withstand external constraints [15],[16]. Governance problems, therefore, frequently obstruct the fair and effective administration of water resources, undermining the promise of access to water for all [1], [35].

Given this background, it is undeniable that effective water governance is crucial for addressing water-related complexities by guaranteeing efficiency, effectiveness, equity, and sustainability in the utilization and distribution of limited resources at the local level [24],[3]. The claim is essential, particularly in the 21st century, characterized by the prevalence of natural disasters such as climate change and droughts [35]. Additionally, this perspective holds considerable importance in developing nations such as South Africa, particularly for rural water service authorities, which inherently possess unique contextual backgrounds characterized by elevated poverty and unemployment rates [22].

The preceding argument underscores the importance of effective water governance as a crucial solution to global water concerns. However, despite the broad acknowledgement of the concept of water governance, water-related problems continue to persist (Organisation for Economic Co-operation and Development (OECD) 2011 and 2021 as cited by [3], underscoring the necessity for a transformation in municipal water governance and a change in the approach to how water challenges have been addressed.

The above claim aligns with [59] observations that there is still hope amidst all these challenges being faced in the efforts to achieve the SDGs, as technological advancements have brought new solutions to the forefront with low-cost digital technologies, even having the power to assist the poor and marginalized. This paradigm shift entails moving from traditional to digital water governance, which includes leveraging innovative strategies such as the Fourth Industrial Revolution technologies for effective water governance [57]. Thus, the emergence of the

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Fourth Industrial Revolution (4IR) offers novel solutions for water-related concerns [43],[11] indicating an urgent need for innovative strategies.

Nevertheless, there has been a slow adoption of the 4IR technologies to enhance water governance in municipalities despite their promises and potential opportunities in addressing water governance challenges [63], [46], [12]. Similarly, the Bonn Dialogue for Results (2021), as cited by [57], asserts that while many innovations exist, deployment, implementation, and upscaling challenges remain prevalent.

To this end, this paper noted a dearth of literature concerning water governance and 4IR frameworks that municipalities can use as roadmaps when adopting and implementing the fourth industrial revolution technologies to enhance their water governance. This paper, therefore, provides a foundation and guideline for adopting 4IR technologies in municipal water governance through the proposed framework. Using the OR Tambo District Municipality (ORTDM), Eastern Cape in South Africa as a case study, the framework is designed particularly for district municipalities, especially those serving rural areas with distinct contextual problems.

The proposed framework offers a foundational approach for municipalities such as ORTDM that lack strategic roadmaps to direct the transformation in their water governance. Thus, the framework seeks to assist rural water authorities in adopting Fourth Industrial Revolution technologies to harness the potential benefits offered by the 4IR era, ensure that they are not left behind as they enhance their water governance, improve their service delivery, and work towards the achievement of the SDGs (Goal 6) targets for 2030.

2 Literature Review

2.1 Defining Water Governance

The concept of water governance has been widely debated in the literature, with scholars approaching it from various theoretical and practical lenses [24]. Some view it as a technical and administrative tool for implementing water policy, while others emphasize its democratic and political dimensions involving participation and accountability (Castro, 2007; Woodhouse & Muller, 2017, as cited by [49]. Although definitions vary from focusing on institutional arrangements and decision-making processes to actor networks and power dynamics, the literature converges on the understanding that water governance involves how decisions about water are made, who participates in those decisions, and the mechanisms that guide access and distribution, as cited by [49] and [24].

The above varied perspectives show water governance's contested nature, ranging from technical administration to deeply political processes. To this end, this paper understands water governance to encompass the social aspects of water-related issues, including decision-making regarding water scarcity, flooding, and pollution [57]. The paper further views the concepts to encompasses the inputs (e.g., stakeholder engagement), processes (e.g., decision-making mechanisms), and outputs (e.g., transparency, efficiency, and equity), which collectively address the “who”, “what,” “why,” and “how” of water management [3]. Being at the forefront of the water crisis, this paper argues that improving water governance requires urgent attention, underscoring the need to integrate Fourth Industrial Revolution (4IR) technologies to enhance water governance.

2.2 Defining the Fourth Industrial Revolution

The Fourth Industrial Revolution is characterized by the convergence of technological breakthroughs with the physical, biological, and digital systems converging, resulting in new lifestyles and integrated workflows [37]. The revolution encompasses various novel technologies, innovative forms of economic interconnectivity with digitalization, and information and communication technology (ICT), which are crucial components of 4IR developments [4]. Furthermore, the 4IR encompasses automation, intelligent systems, and data-informed decision-making [21]. Similarly, [14] contend that 4IR represents a new era of cyber-physical systems beyond mere automation. The 4IR era is therefore expected to have a stronger and wider impact on the economy and communities [37]. Thus, these disruptive technologies reduce distances, break down barriers, and connect people worldwide, thus enhancing global integration and deepening interconnectedness. As a result, essential services like water, energy, healthcare, education, and the economy are increasingly digitized and reliant on 4IR technologies [38].

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2.3 Leveraging the Fourth Industrial Revolution to enhance water governance

Literature indicates that various Fourth Industrial Revolution technologies may be used to advance water governance and assist in achieving the sustainable development goals for water and sanitation [65], [47], [29]. According to [66], a comprehensive compilation of 4IR technologies has been identified, drawing upon the works of De Azevedo et al. (2019) and Poljak (2018) among others. This compilation encompasses a range of technologies, including but not limited to Big Data and Analytics, Autonomous Robots, Simulation, Internet of Things (IoT), Augmented Reality, Additive Manufacturing, Cloud Computing, Cybersecurity, and Horizontal and Vertical System Integration [66]. These technologies are said to have the potential to transform the water sector. Nevertheless, [29] posits that the application of 4IR technologies in the water sector requires a combination of these technologies, methods, and digital solutions instead of stand-alone approaches. Similarly, a study by [67] elaborated on 4IR technologies such as artificial intelligence, Big data, IoT, blockchain, drones, remote sensing, and virtual and augmented reality have been widely applied in Latin America's water and sanitation sector. While there was a consensus among the above authors, [66] further underscores the significance of cybersecurity technologies as critical in the digital transformation of the water sector. On the other hand, [65] emphasizes the importance of 4IR technologies, such as artificial intelligence, in achieving decentralization following the failure of a centralized societal system and how essential these technologies are in monitoring and creating smart cities.

The above-discussed Fourth Industrial Revolution technologies have been regarded as essential in transforming the water sector by offering potential benefits such as sustainability in operations and economic growth for the water sector, which they refer to as "Digital Water" or "Water 4.0" [42]. Some of these benefits include, but are not limited to, leak identification, for instance, through sensors, smart metering, and predictive analytics, which can detect issues, educate consumers, foresee potential failures, and result in improved water conservation and sustainable water services [16].

Adding to the benefits of integrating 4IR technologies in municipal water governance, 4IR technologies have the potential to improve efficiency through effective resource utilization [31], data-driven decision making and improve water quality through monitoring [67]. In addition, predictive technologies in the 4IR era enable proactive measures in infrastructure maintenance and asset management [29]. Likewise, these technologies may reduce the environmental impacts through predictive analysis, which assists in putting proactive measures in place in managing natural catastrophes such as flooding and droughts [63] and improve public participation and stakeholder involvement through breaking geographical boundaries [38]. Thus, such a digital transformation in water governance offers previously unattainable operational efficiency enhancements [48].

While 4IR offers transformative opportunities for water service authorities in South Africa and globally, it also introduces threats and risks, including cybersecurity vulnerabilities, job displacements, exacerbation of the digital divide [32], and inequitable distribution of benefits [18]. Therefore, it is essential to balance leveraging 4IR technologies and upholding the principles of effective water governance, such as equity, effectiveness, and sustainability [14].

Significantly, the risks associated with 4IR technologies can be mitigated through thoughtful and context-sensitive implementation. To this end, [4] put forwards three recommendations arguing that there is the need to consider contextual issues as opposed to specific technologies; technologies ought to be developed to augment human autonomy and decision-making rather than presuming they will govern behavior; and that forthcoming innovations must be deliberately crafted with integrated values and providing room for continuous discourse at each phase. Likewise,[32] underscore the need for careful planning and emphasize the need to prevent the adopted technologies from becoming obsolete or misaligned with local needs, as such outcomes would ultimately undermine the very rationale for their adoption Similarly, the [44] warns the adopters that while it is necessary to learn from international practices, there is a need to avoid copying; instead, water services authorities should only adopt what is appropriate to their context based on their priorities and adapt what is needed to carve a credible space for themselves in the global community.

While the above-mentioned measures are crucial in mitigating the negative impacts of 4IR, key pillars should be considered to ensure successful adoption. For instance, [4], [20], and [62] emphasised the need for basic and digital infrastructure, while [31] and [60] argued that there is a need for sufficient funding as initial investments

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in 4IR are costly. Other scholars, such as [17] and [47], raise concerns regarding the skills and expertise demanded by 4IR, while [52] and [19] emphasises the need to address issues related to technology resistance. Other aspects include the importance of strong and visionary leadership ([7], [40], collaborations and partnerships [9], and training [62].While these studies provided the basis and key factors to be considered when adopting 4IR technologies, they were not focused on municipal water governance, which is considered a fundamental human right and a basic need that should be accessible, reliable, and affordable.

Nevertheless, based on the above discussions, this paper argues that when properly managed, the 4IR technologies have the potential to promote fundamental human rights and constitutional mandates, such as those outlined in Chapter 2 of the South African Bill of Rights, including increased freedom, improved health, enhanced educational opportunities, and reduced economic insecurity [4].

Various scholars have researched using the Fourth Industrial Revolution technologies in the water sector. The research area has, therefore, garnered heightened interest as a prospective remedy to the intricate and escalating water management challenges. Illustrations of such studies include research conducted by [61], which examined the potential of blockchain technology with intricate flow systems to transform water governance. Their analysis underscored opportunities to improve openness and efficiency in water management. Ref [11] investigated the incorporation of Fourth Industrial Revolution technologies into the water, energy, and food nexus, demonstrating the interrelation of these essential sectors. Ref [42] concentrated on the modeling and optimization of water systems, highlighting the capacity of data-driven methodologies to enhance water resource management. [10] presented a hierarchical, multilayer network for water management utilizing Industry 4.0 tools in another study. Their platform amalgamates company operations and sensor networks, providing a comprehensive best-practice solution for data optimization and complete digitalization of the water sector.

Additionally, [5] concentrated on advancing real-time, Internet of Things (IoT)-integrated water quality management systems. Their proposed method employs sensors to assess water quality parameters, rendering it appropriate for residential use. Additionally, a study conducted by [6] introduced an IoT-based framework for monitoring water quality to safeguard health and well-being. Likewise, the United Nations 2023 SDG6 Synthesis report provides an overview of the importance of innovation to accelerate SDG 6, emphasizing the need for funding, an enabling environment, and innovative educational methods to accelerate innovation [57].

Nevertheless, while these studies have a different focus, they all relate to applying 4IR technologies in the water sector and show the growing recognition of how these technologies can improve water management. However, to our knowledge, no study has offered a water governance and 4IR framework that provides a blueprint or guideline for how the Water service authorities can integrate these technologies to enhance water governance with specific reference to the OR Tambo District Municipality, Eastern Cape, South Africa. This was deemed important as the adoption and implementation of these technologies requires context-specific and customized approaches when engaging innovations in water governance [16],[57], underscoring the need for this research

This paper, therefore, proposes a water governance and 4IR framework that can guide the transformation. Underscoring the importance of this framework, this paper contends that the 4IR era is an unavoidable transformation that all aspects of the human economy must embrace to achieve maximum efficiency, effectiveness, resilience, sustainability, and equity in public institutions and particularly in water institutions at the local level, especially when they are faced with economic trajectories [11].

3 Diffusion Innovation Theory

The adoption and implementation of 4IR technologies in municipal water governance vary globally, ranging from early adopters to laggards, a situation that the Diffusion Innovation Theory better explains. The diffusion innovation theory was developed by Rogers (1962). The theory provides the basis on which innovations in technology spread among a population. Describing the DIT, [51] refers to the theory as the process by which an innovation is communicated through certain channels over time among the members of social systems. The theory is based on five qualities that are considered important in technological diffusion. These qualities include the consistency of technology with the values and needs of the users (compatibility); the benefits of the technology

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(relative advantage); the extent to which technology can be experimented with on a limited basis (trialability); the ease of use (simplicity) and how quick the technology's benefits can be observed (observable results) [11],[50].

Additionally, the theory posits four elements of diffusion of innovation: communication, communication channels, time, and social systems [11]. Regarding innovation, the theory postulates that for any technology to be considered innovative, it should be perceived as new, even if it has existed for a long time. The second component refers to the communication channels, which are the process whereby participants create and share information or reach conclusions. [50] states five communication channels which include knowledge (the why, how and what of the innovation); persuasion (attitudes towards the innovation based on the degree of uncertainty); decision (this stage the user can accept or reject the innovation); implementation (the use put the innovation into practice) and confirmation (the user decides to use the innovation but needs further support to cement their acceptance decision or uncertainty attitude). The third component of time entails the period during which people adopt innovation. According to [13] and [50], the innovation process has five categories of adoption that are followed during the introduction of technology. Innovators, making up 2.5% of the social system, are the first to embrace new ideas and innovations. At 13.5%, early adopters have the highest opinion leadership and influence within their communities. The early majority, comprising 34%, adopts innovations ahead of the average member, playing a key role in the diffusion process. The late majority, also 34%, are more skeptical and adopt innovations only after the average member. Lastly, laggards, representing 16%, are the slowest to adopt innovations due to their preference for tradition and past practices. The fourth component is the social system, which comprises integrated groups sharing common goals to address societal problems and is often influenced by a social structure [11].

The Diffusion of Innovation Theory (DIT) components provide a solid foundation for developing a water governance and 4IR framework by highlighting the varying rates at which 4IR technologies are adopted across different water service authorities. This framework accounts for the distinct characteristics of stakeholders, from innovators who can act as pioneers to laggards who require strong incentives, support, and evidence to embrace these technologies. By recognizing these differences, the proposed framework advocates for a phased implementation strategy aligned with the innovation adoption curve. Tailoring communication, resources, and support to each group ensures a smoother integration of 4IR technologies into water governance, enabling more effective and widespread adoption. This strategic approach will accelerate the diffusion of 4IR innovations, addressing critical water challenges more sustainably and efficiently.

4 Methodological Approach

The paper utilized a qualitative case study research methodology to contextualize the proposed framework and address the current gaps in adopting and implementing 4IR technologies. The qualitative research entailed collecting and analyzing empirical literature and non-numerical data to contextualize opinion, understand the experience, and review concepts [33]. Semi-structured interviews were conducted with twenty-eight (n=28) participants selected through purposive sampling and snowballing sampling techniques. The selected sample size was supported by [2], who asserted that a sample between twelve and twenty is recommended for qualitative studies. However, the current research focused on ensuring that a point of saturation is reached to ensure that enough data is collected [8]. The sampling method adopted ensured that data were collected from knowledgeable respondents on the subject under investigation [58].

The participants included municipal officials, councilors, stakeholders, the Fourth Industrial Revolution, and water governance experts involved in ORTDM municipal water governance. The researchers also engaged experts in 4IR, and water governance as think tanks to provide their insights regarding the subject under investigation. The use of semi-structured interviews and the adopted methodological approach provided for the collection of thick, rich, and in-depth data, which was deemed critical for developing the proposed framework [27]. The interviews were conducted in person and for those busy participants, they were conducted online via Microsoft Teams over an average of sixty minutes. This approach allowed flexibility for participants while enabling the researcher to collect as much data as possible [53].

Additionally, literature and document reviews were conducted to supplement empirical data. The literature reviews explicitly entailed reproducing and systematically synthesizing, evaluating, and identifying the existing

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data collected that was not for the primary purpose [41]. A thematic analysis was applied to analyze the data. The approach followed familiarizing and categorizing data, coding, defining, and refining the themes. While the researchers recognized the presence of software such as NVivo and Atlas Ti, which can be used when analysing qualitative data, the current paper adopted a manual approach. This approach aligned with [25] observations that manual data analysis is crucial for early researchers as it helps them understand and grasp the fundamentals of data analysis and may prepare them to adopt any form of analysis in the long run, including the computerized methods. Ethical considerations such as anonymity, confidentiality, voluntary participation, and informed consent guided research [68]. Furthermore, trustworthiness was upheld during the research paper, emphasizing ensuring that the findings are credible and accurate.

The adopted research methodology therefore ensured the collection of rich and in-depth data concerning the challenges in water governance and the views and perspectives regarding the adoption of 4IR technologies in municipal governance, which was deemed necessary for the development of the proposed framework. Furthermore, the adopted methodology was grounded in the idea that the qualitative aspects of water should be prioritized as much as the technical components. To this end, the researcher sought to understand the current water governance challenges, the current state of technology adoption, and suggestions on how technology adoption can be accelerated to enhance water governance in ORTDM.

5 Findings

The following section provides the findings of the study.

5.1 Water Governance Challenges in the OR Tambo District Municipality

The study findings revealed various water governance challenges manifesting in capacity, accountability, information, funding, and administrative gaps. Respondents interviewed revealed that the municipality is facing challenges in terms of capacity, with major challenges coming in the form of a lack of technical skills and insufficient training and development. One participant stated, “We do not have enough technical staff, and this poses a challenge in our operations”. In addition, participation revealed that infrastructural challenges, such as poorly maintained, old, dilapidated, inadequate, and non-completed schemes, exacerbate water governance challenges. Experts interviewed further confirmed these findings, arguing that infrastructural challenges are prevalent in South African municipalities.

Respondents further revealed that the municipality is experiencing funding gaps that manifest in low revenue collection, budgeting process deficiencies, and grant funding complexities. One participant stated” In some cases, monies have to be returned to National Treasury if the rollover of grants is not approved,” while another participant stated” Our revenue collection is low, and this makes it difficult to meet the demands and needs of our communities due to these financial constraints”.

Another major challenge was the information gap manifested through fragmented data sets, deficiencies in reporting quality, accurate and timely information, and dependency on external sources for some of the crucial information, such as the South African Weather Services for meteorological data. One participant stated, “We have to wait for updates from the South African Weather Services as we do not have internal systems in our organisation, which makes it difficult for us to be proactive; rather, we are always reacting after floods occur”. Participants further revealed accountability gaps manifest through weak oversight, regulatory mechanisms, and participation and stakeholder involvement deficiencies. Lastly, participants revealed gaps in the administrative systems of the municipality, with emphasis being put on deficiencies in planning and coordination across departments, which were reflected by failure to meet deadlines, resulting in rollover of funds and the silo approach adopted by departments. These water governance challenges stem from institutional, systematic, and contextual issues within the district municipality.

5.2 Current State of Technology Adoption in ORTDM’s Water Governance

The above section presented the various water governance challenges that exist in ORTDM. However, the findings further revealed that the district municipality has already started to use some 4IR technologies to address

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some of these challenges. Some of the notable 4IR initiatives include an outsourced telemetry system to monitor their water levels and address information related challenges. One municipal official stated "We do have a telemetry system which shows us our water levels from our reservoirs, but at the moment the system is not working, and we cannot fix it as it is outsourced." However, when the data was collected, the system was not working. Data collected revealed that the municipality outsourced the system due to funding constraints to address issues such as skills and equipment needed.

The municipality also has an e-recruitment system used by the human resource department. One municipal official stated, "We have an e-recruitment system, but we just use it to receive applications only". The data collected revealed that the system is underutilised as it is used only for submitting the curriculum vitae. Respondents indicated that the rest of the processes, including the initial screening, were done manually.

In addition, the municipality has a functional website and uses social platforms such as Twitter, now known as X, Facebook, and WhatsApp. A municipal official stated," We have social media platforms which are Facebook, X, and WhatsApp groups where we share some of the municipal communications, for instance, when there are disruptions of water services or information regarding natural disasters". However, data collected revealed that these platforms are underutilised as tools to enhance water governance. For instance, there is limited staffing in this communication department; these websites can have the option of chatbots, which will facilitate communication across the communities and the municipalities with regard to queries and complaints that were revealed to be remaining unattended. Additionally, through data analytics, information and data collected from these social media can aid in decision-making. However, the study findings revealed that the municipality rarely utilises such information in this regard.

Regarding the adoption and implementation process, the study findings further revealed that while discussions on adopting further 4IR technologies, such as such meters, were already in place along with other initiatives discussed above. One participant stated, "There are already discussions on the adoption of smart meters, but we don't have an official document in place yet". Upon further probing, the respondent further stated, "Yes we have already started using some of these technologies, for instance, the telemetry system, but we do not have a framework or document that guides us in this digital transformation". The study findings, therefore, revealed that the municipality does not have a framework that guides the adoption and implementation process. Therefore, such a situation may cause a problem, resulting in a slow adoption and underutilization of the 4IR technologies, which are crucial to enhancing municipal water governance. This is because without a clear plan and framework to guide the transition, it will be difficult to establish the key pillars required to embrace 4IR, such as the funding mechanisms, supportive regulations, and capacity required in terms of skills and infrastructure.

5.3 Measures Required to Accelerate Technology Adoption in ORTDM

The study findings revealed that the stakeholders involved in ORTDM's water governance were optimistic about the adoption of 4IR technologies to enhance water governance. Municipal officials revealed the need for assistance in funding technological advancements, highlighting funding constraints as a major issue. One participant stated, "With the current financial state, we will require funding to support us because, as a municipality, we are already financially constrained". Other officials highlighted the need for reskilling and upskilling if they are to go forward with scaling up adoption. Experts interviewed in 4IR highlighted the need for the national government to support municipalities such as ORTDM in rural areas with poor digital infrastructure, as connectivity is essential in adopting 4IR technologies. In addition, experts in water governance emphasized the need for integration across spheres of government and departments, funding, and collaborations as essential for accelerating technology adoption. Given these findings, the research recommends a proposed framework that may accelerate the adoption of 4IR technology in ORTDM by providing a roadmap or blueprint to guide the transition.

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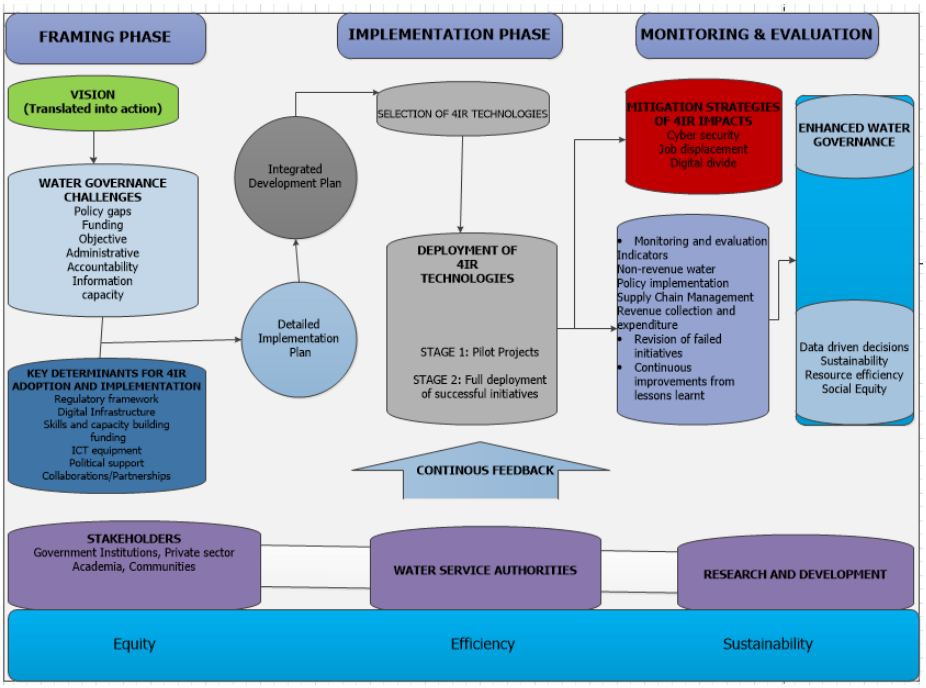
6 Proposed Framework for the Adoption and Implementation of 4ir Technologies in Municipal Water Governance

The proposed Water Governance and 4IR Framework for municipalities presented in Figure 6.1 is intended to assist policymakers and guide water service authorities in adopting 4IR technologies to enhance their water governance. The framework was shaped and heavily influenced by the empirical results, existing literature, and the Diffusion Innovation Theory, making it more realistic as it incorporates the current realities that water service authorities face. As a result, the framework is unique and contextualized for the OR Tambo District Municipality and other municipalities in a context similar to ORTDM. The framework was made easy and simple to understand to cater to a diverse audience who would be involved in the process and can be readily translated into operational terms.

Figure 6.1. Water Governance and the Fourth Industrial Revolution (4IR) Framework for Municipalities



Source: The Researcher (2025)

The framework, therefore, comprises three phases: the framing phase, the implementation phase, and the monitoring and evaluation phase. The details of the framework are further discussed below.

PHASE 1: FRAMING/IDENTIFICATION

The framing/ identification phase comprises three main sections: the vision, the recognition of the water governance challenges, and the key determinants for success.

- **Vision**

The proposed framework emphasizes the need for the municipalities to have a well-articulated vision, as it is critical in adopting and implementing 4IR in water governance. This vision should provide a strategic direction, foster innovation, and shape the processes and systems that guide the implementation. By setting a strategic direction, a clear vision enables ORTDM, and other municipalities to prioritize initiatives that align with their long-term goals in serving their primary responsibilities. Furthermore, the vision should foster innovation by encouraging the exploration of innovative ways, such as using smart technologies that address specific community needs and developmental goals. This forward-thinking approach ensures that technological advancements are not adopted for modernization but are utilized to enhance the core responsibilities of water governance. Equity,

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efficiency, and sustainability should be at the core of municipal vision, ensuring effective water governance. This community-centric approach guarantees that the benefits presented by the technology advancements are felt by all, promoting inclusivity and fairness in resource distribution and efficiency in municipal operations. As such, it can be emphasized that municipalities should not be driven by the mere need to adopt technology but should instead use it to fulfill their primary responsibility. Additionally, a vision incorporating technological integration helps shape policy and regulatory frameworks for water governance. It also guides the adoption and implementation of 4IR technologies, such as attracting investments and collaborating with technology providers and other stakeholders.

- **Identification of water governance challenges**

Water service authorities should understand their current operations towards the set vision. It is crucial to understand the challenges they face regarding water governance. In this case, the challenges identified include capacity, policy, administrative, objective, information, funding, and accountability gaps [23]. After identifying the challenges faced, municipalities should identify areas in which the Fourth Industrial Revolution technologies can be applied to address the identified challenges. In addition, there is a need to understand the reasons behind the existing challenges so that the correct technologies are adopted. Understanding the underlying causes and root problems enables the resources to be channeled to the correct areas [23].

- **Key determinants of the adoption and implementation of 4IR technologies**

This framework is grounded in an optimistic view that digital transformation in the public sector should not be seen as a panacea for government problems and that the introduction of digital technologies does not automatically create a better government unless several conditions are met [52]. In line with this view, the framework recognises that ORTDM and other water service authorities, along with other stakeholders, need to work together and make sure that the pre-conditions for the adoption and implementation of 4IR technologies are met if these institutions and the citizens at large are to harness the benefits presented by the 4IR era [45]. The key determinants and preconditions include:

Policy and Regulatory Frameworks: Municipalities should ensure that they have a strong regulatory framework to guide the adoption process. A strong policy and regulatory framework are critical in protecting the communities and the water service authorities from the harm brought by the Fourth Industrial Revolution. While there is a need for national water policies that guide the adoption of 4IR technologies, municipalities such as ORTDM can work with the current water policies and formulate institutional policies and governance frameworks that guide the process of using the 4IR technologies. These policies should address various aspects such as skills development, infrastructure enhancement, funding mechanisms, and regulatory frameworks. By implementing such policies, ORTDM can create an attractive environment for the growth of the adoption of 4IR technologies in their water governance. However, these policies and frameworks should support the integration of 4IR technologies and prepare the citizens and water service authorities, particularly those in rural municipalities who are at risk of being left behind, to be prepared for the transformative impacts of the 4IR.

Digital Infrastructure: Municipalities need to understand the digital infrastructure in the areas where they intend to deploy the 4IR technologies. This is a crucial component as it determines the types and models of technologies that should be adopted, for what reasons, and for which benefits they should yield. Issues such as connectivity and bandwidth can be considered in the infrastructure. This framework emphasizes the importance of proactively addressing digital infrastructure deficiencies. This includes exploring alternative, cost-effective innovations like the Elon Musk Starlink Project. However, effective implementation and regulation of such initiatives necessitate robust intervention from the national government. Another critical aspect that requires attention regarding the infrastructure issue is adopting alternative energy sources, given the level of load shedding and unreliable electricity in South Africa. Municipalities should look forward to the use of solar energy, and this aspect should be considered when adopting technologies. By addressing these issues, South Africa can bridge the digital divide and promote inclusive development, ensuring equitable access to 4IR technologies to communities and water entities in rural areas and ensuring that the potential benefits of the revolution are enjoyed without leaving anyone behind.

Digital Skills: The framework emphasises the need to address digital skills challenges, which remain one of the obstacles hindering this transformation. Training, upskilling, and reskilling should be a priority. Municipalities

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should utilise 4IR technologies to address the skills gap by addressing physical geographical barriers, as some skills can be obtained through online learning. In addition, the framework emphasizes an integrated approach from all stakeholders, such as all education departments, the Department of Science and Technology, local government, and the private sector, to work together in addressing the skills gap. For instance, ORTDM can partner with Walter Sisulu University in its jurisdiction to help with capacity development. To achieve such integration, the government should be positioned as a strong adopter of emerging technologies in municipal water governance to motivate investments and funding for skills to necessitate the adoption of 4IR technologies in municipal water governance [39]. When adopted, such an integrated approach will provide training programs and foster skill development initiatives as these entities can equip organizations with the expertise needed to drive effective 4IR adoption in water governance.

Soft Skills: Beyond digital skills, this framework emphasizes complementing technical proficiencies with softer leadership skills. The approach not only fast-tracks the pace at which these technologies are embraced but also ensures that 4IR technologies lead to effective water governance. The 4IR era demands creative processes like strategic planning, research, and development to become crucial, demanding skills to recognize, generate, and implement new opportunities [36]. To this end, the framework emphasizes the need for senior leadership in the municipality to develop competencies such as data interpretation, data analytics, open-mindedness, fostering global networks, and agility of thought to adapt to the changing technological environment [26].

The framework posits that such soft skills facilitate the transition to 4IR technologies and enable leaders to advocate for skill acquisition among their teams. For instance, fostering collaborations through academia and the municipality, in this case, Walter Sisulu and ORTDM, as they are both stakeholders in water governance in the same area. Given the municipality's budget, such approaches will allow ORTDM to fast-track its pace in utilizing 4IR technologies to improve its water governance within affordable means. Thus, the successful adoption and implementation of 4IR demands more specialised skills beyond basic digital literacy, as cited by [28] .

Collaborations and Partnerships: The framework emphasizes the need for the municipalities to establish strong partnerships and collaborations if they successfully embrace 4IR technologies in their municipal water governance. The approach follows the recognition that with their current capabilities, most South African water service authorities, such as ORTDM, which are in rural areas, are not sufficiently capacitated to fully adopt and implement 4IR technologies in their water governance. To this end, established collaborations and partnerships provide a chance for the municipality to address the current needs, adopt new technologies, and without adding more strain to its already financial burden. For instance, in the case of ORTDM, it has Walter Sisulu University within its jurisdiction. These collaborations can be used in pilot projects, capacity building, upskilling, and reskilling. This helps the municipality to alleviate the financial burden, which was revealed in the findings as one of the obstacles in adopting and implementing 4IR with its water governance.

Funding: A key component of the framework is funding. As such, the framework posits that with the current financial state of municipalities, more funding for the adoption and implementation of 4IR technologies may be needed. Alternative mechanisms should be sought to supplement the existing financing. Therefore, the framework emphasizes the need for collaboration and partnerships so that they can assist in some areas and relieve the financial burden. For instance, state universities may provide training and capacity building as part of their community engagement initiatives. Such approaches will, therefore, provide shared opportunities and benefits for both the municipalities and tertiary institutions. Moreover, tertiary institutions such as Walter Sisulu University (WSU) in ORTDM can conduct research using these municipalities. They can implement pilot projects for the municipality, and will be part of the research for students as they engage in their academic milestones. Additional municipalities should be forward in approaching the government, donors, and funders and applying for grants to supplement their funding. The government at large should have grants to support the adoption of 4IR initiatives in water governance, just like how they have ones to support infrastructure.

Information Communication Technologies: Municipalities should invest in basic information and communication technologies and equipment that support the adoption and implementation of 4IR technologies. ICTs should be addressed and given equal importance as the one given to the issue of digital infrastructure, such as bandwidth, internet connectivity, storage, and base stations. 4IR technologies require gadgets that support specific software and technologies. As such, municipalities must ensure they invest in these basic ICT gadgets, such as mobile phones, laptops, and internet gadgets that support the 4IR technologies.

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Political support: Political support is essential for successfully integrating 4IR technologies in municipal water governance. While collaboration, partnerships, and community engagement are crucial in providing input for informed decision-making, the ultimate decisions in municipalities rest with the municipality's political structures. Additionally, political support plays a significant role in influencing communities by raising awareness, providing assurance, and motivating the adoption of these technologies. Their support ensures that technological initiatives are aligned with the needs and expectations of the community, fostering a more effective and inclusive approach to water governance.

- **Detailed Implementation Plan linked to the Water Service Development Plan**

The Framework emphasizes the need for a roadmap, strategy, or implementation plan, linked to the municipality's Integrated Development Plan (IDP) or Water Service Development Plan. The link is important as the IDP is the key strategic document guiding municipal operations in South Africa. As such, the link will enable the 4IR initiatives to be pushed forward as part of the municipal goals and strategies. The implementation plan should be informed by information from the framing phase. It should detail the municipal vision and challenges concerning water governance. It should specify the key stakeholders involved and the partnerships and collaborations. It should identify the key regulations and policies that will guide the implementation and the mechanisms to address infrastructure, capacity, and funding issues, among other areas of concern. Additionally, the document should elaborate on a set mechanism for monitoring and evaluation, with key indicators in place. While the document should recognize the benefits to be achieved from the deployed technologies, it should also highlight the challenges of using technologies, such as how issues of data justice and governance will be addressed, as well as issues of retrenchment and cybersecurity, among others. The framework emphasizes the importance of this implementation document because the stakeholders can use it for monitoring and evaluation, it can be used to source funding from donors, and it guides the municipality on implementing these technologies.

PHASE 2: IMPLEMENTATION

After the framing phase, the framework includes the implementation phase. The phase involves the selection of technologies for deployment. The selection of technologies is guided by various factors identified in the framing phrase. If the municipality has managed to secure collaborations from universities or the private sector, it can utilise the technologies. Likewise, if the municipality has managed to secure funding, it can therefore select and deploy certain technologies. Additionally, other municipal realities such as the available skills, the alignment of the technology to the policies, and the compatibility of the available 4IR technologies to the digital infrastructure highly determine which and when the technologies can be implemented.

Therefore, at this stage, the municipality should have the exact areas they want to improve and know their capacity and capabilities in terms of which technologies can be afforded. The stage will therefore involve deploying technologies, with the first stage being pilot projects. These may include the use of systems such as Enterprise Resource Planning systems to ensure an integrated approach in the municipal administration systems. In the context of ORTDM, another example may be deploying a pilot project on smart water metering in one of its communities or using artificial intelligence and data analytics to inform decision-making. After pilot projects, depending on the results produced, the technologies can be deployed on a full scale, terminated, or improved. Continuous feedback should guide this approach to rectify all errors and corrections on time. Additionally, as soon as the technologies are deployed, strategies to deal with the adverse effects of technology are implemented. These should be detailed in the implementation plan from the previous phase.

PHASE 3: MONITORING AND EVALUATION

The framework emphasizes the need for monitoring and evaluation when adopting and implementing 4IR technologies in water governance. This aspect is essential in assessing whether the deployed technologies serve the purpose for which they were adopted. This will also ensure that the technologies are not adopted for mere adoption but to serve communities' needs through enhanced water governance. Various indicators should be implemented to check the results against planned targets. For instance, when leak detection technologies are put in to reduce non-revenue water, then non-revenue water can be measured to see if the leak detectors are working. Also, the response time and reported burst pipes can be among the set indicators. Smart metering in households can be used to assess water consumption, etc. The above steps should be underlined by four crucial aspects: continuous feedback, stakeholder engagement, research, and development, which are conscious of equity, efficiency, and sustainability as underlying values, as explained below.

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- **Continuous Feedback**

A key component of the framework is continuous feedback. This component is essential, particularly in adopting and implementing 4IR technologies to enhance water governance, as the technology adopted is meant to serve the community's needs. As such, there is a need to check whether the intended goals are being achieved continuously. To this end, feedback should be incorporated throughout the lifecycle (planning, development, implementation, evaluation) of the adopted 4IR initiatives and managed via structured loops that emphasize practical insights rather than being regarded as an afterthought [30].The above approach will ensure that issues such as usability, accessibility, relevance, acceptability, trialability, and sustainability issues can be assessed with correctional measures being put in place, terminated, or checked for possible continuity of the technologies. This approach will help save resources, address user resistance, and ensure effective results from the deployed technologies, as the limitations will be addressed in time. Moreover, ORTDM's research and development division must be pivotal in coordinating these initiatives to guarantee that feedback channels are accessible and representative. Particular emphasis must be placed on incorporating disadvantaged and vulnerable populations, who are frequently the most impacted by poor water governance yet are the least represented due to obstacles such as limited access to internet platforms or community forums. Guaranteeing their inclusion is not merely an equity issue but is crucial for formulating responsive, inclusive, and successful water governance plans.

- **Stakeholder Involvement and Community Engagement**

The proposed framework underscores the critical importance of stakeholder engagement, including academia, government institutions, the private sector, and local communities, in successfully adopting 4IR technologies within water governance. Meaningful engagement ensures that diverse voices, especially those of marginalised and vulnerable groups, are heard and considered throughout the decision-making process. This is particularly crucial given that these groups often bear the impact of negative consequences when technologies are adopted without inclusive planning.

Stakeholder involvement enhances transparency and accountability and fosters informed decision-making by leveraging different actors' collective knowledge, experiences, and perspectives. In the context of municipalities like ORTDM, where the adoption of 4IR technologies is still emerging, stakeholder engagement provides valuable platforms for learning, knowledge exchange, and identifying best practices and trends that can guide implementation efforts. Decisions regarding which technologies to adopt and when and how to implement them should be made by the input of all relevant stakeholders. Early and continuous engagement, particularly with local communities, is essential in building trust, reducing resistance to change, and fostering a sense of ownership in the transformation process. Finally, while broad engagement is essential, the framework acknowledges the central role of Water Services Authorities (WSAs) in this process. As implementers responsible for water service provision and governance, Water Service Authorities should coordinate stakeholder interests, mediate competing perspectives, and ensure that the core objective of improving service delivery through 4IR technologies is achieved.

- **Research And Development**

A key component in the framework is the need for extensive research and development. Adopting 4IR technologies in water governance requires extensive research from the initial phase to the monitoring and evaluation phase. Research enables the municipalities to have enough data to make informed decisions, explore various existing opportunities, and identify potential and available opportunities for partnerships and collaborations. Additionally, research informs policy decisions and policy reforms. It is critical in determining issues such as capacity building and sourcing funding. Hence, sound research and development are needed to inform the cycle of adopting the 4IR technologies.

7 Conclusion

The discussion above demonstrates that while integrating the Fourth Industrial Revolution technologies presents a compelling opportunity to transform water governance, it must be approached with a well-articulated and context-specific implementation framework. Without such a foundation, adopting these technologies risks worsening existing inequities and placing additional strain on struggling municipalities. At the same time, opting not to engage with 4IR technologies is not a viable alternative, as the transformation effects are already reshaping all

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sectors and communities. As 4IR is already reshaping every sector, Water Services Authorities that fail to evolve will inevitably be left behind.

In response to this urgent need, the paper proposed a practical framework integrating 4IR technologies within the broader water governance agenda. Grounded in the realities of ORTDM, the framework offers a structured, inclusive, and sustainable pathway for municipal transformation. It ensures that innovation is not a source of disparity but a tool for enhancing equity, resilience, and service delivery. More importantly, the framework emphasizes the need for community-centered and technology-driven vision supported by an enabling environment, including collaboration, robust regulation, and continuous capacity development. The framework further underscores the necessity for stakeholder engagement and iterative feedback to guide and refine the implementation process. Ultimately, the proposed framework serves as a comprehensive roadmap for municipalities like ORTDM and those with similar contexts to navigate the digital transformation in a way that strengthens water governance and secures sustainable, equitable service provision in contemporary water governance.

8 Policy Implications of Study Findings

The current study findings are important in advancing and accelerating the adoption of the fourth Industrial Revolution technologies in municipal water governance locally, nationally, and globally. Such an acceleration may improve water governance, thus assisting in achieving local, regional, and internal obligations related to water service provision, such as the SDG 6. The study findings further provided for the "how" part in which such an acceleration can be achieved by revealing the need for an integrated support system to accelerate technology adoption in municipalities. Water institutions, government departments, communities, private organisations and Higher and tertiary institutions need to work together through collaboration, partnerships, community engagement, skilling, policy and regulation, funding, and donations to support municipalities. More importantly, the study findings revealed the need for water service authorities as institutions with the mandate to provide water services to be at the forefront in seeking opportunities to drive the transformation. One way highlighted is to have a strategic document which guides the digital transitions, as such a document assists in seeking the above discussed support by providing stakeholders with the vision of the municipality.

9 Study Limitations and Areas of Future Research

The study was conducted using OR Tambo District Municipality, which may present limitations in generalizing the framework. Furthermore, the study sample did not include the communities that are the users of these advocated technologies, which may present a limitation in the application of the framework. While the proposed framework incorporates advocates for a community-centred approach in the adoption of the 4IR technologies, future research may look to use a survey to understand the perspectives of the communities in the district municipality regarding their views on technology adoption to enhance water governance.

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12 Authors Contributions

Clarity Hutete- Conceptualization, data collection, data analysis, and writing the original draft, review, and editing.

Shikha Vyas-Doorgapersad-Review and editing the original draft and generated the plagiarism report.

Nqobile Sikhosana- Review and editing of the original draft and second draft from reviewers.

13 AI Generative Tools

No AI generative tools were used.