Architecture
Image Studies

Vol.6, Issue 3, pp.2055-2068, 2025
DOI: https://doi.org/10.62754/ais.v6i3.559

https://journals.ap2.pt/index.php/ais/index

Factors Affecting the Adoption of Fourth Industrial Revolution Technologies in Municipal Water Governance: A Case Study of a Selected Rural District Municipality

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Abstract

The fourth industrial revolution is disrupting all sectors of the economy, and the water sector is not spared. However, there remains a slow adoption of the Fourth Industrial Revolution technologies within rural municipalities and there is limited research on the factors affecting technology adoption as a governance tool in water services authorities. Through the Technology Acceptance Model, the study investigated factors affecting the adoption of 4IR technologies in the rural district municipality's water governance. The study adopted a qualitative approach and utilised a sample of twenty-eight participants purposefully selected. Data was collected through semi-structured interviews, and a thematic approach was used to analysed data. Findings revealed various factors such as deficiencies in infrastructure, Information Communication Technology equipment, funding, skills and lack of collaborations and partnerships are hindering the adoption of technology in the municipality to enhance water governance. The study concluded that these factors weaken both the perceived usefulness and perceived ease of use which are the key determinants of the Technology Acceptance Model. The paper recommended the need for policy interventions with the need for government to support these water institutions through enabling conditions such as funding, infrastructure and capacity building to ensure that the municipality's intentions are translated into actual behaviour and usage of technology.

Keywords: *Fourth Industrial Revolution, Technology Acceptance Model Water Governance.*

Introduction

The Fourth Industrial Revolution is disrupting all sectors of the economy and reshaping how things were previously done (Yugandhara, Chandanshive & Varsha Jadhav (Rathod), 2025:45). The water sector, particularly at the local level, is not spared from this transformation. This can be evidenced by a wide range of scholarly work that reveals the potential and opportunities presented by the 4IR technologies, such as big data, artificial intelligence, Internet of Things, and blockchain in managing water at the local level (Stankovich, Hasanbeigi, & Neftenov, 2020:1). Thus, the 4IR technologies are reshaping the way in which municipal water is managed and showing a promising future in enhancing municipal water governance. Industry 4.0 has already begun to drive transformation in the water sector, improving efficiency, sustainability, and effectiveness by providing new possibilities such as remote tracking, intelligent water metering, preventive maintenance, and predictability (Javaid, Haleem, Singh, Suman & Gonzalez 2022:209).

The above-stated benefits and opportunities underscore the urgency needed to integrate the 4IR technologies to enhance municipal water governance. This need is particularly important given the current unfavourable conditions in which municipalities are operating, such as failing water institutions, the devastating impacts of climate change, and the ever-increasing water demands (Liu et al 2021:4; Kumar, 2023; Adedeji, Ponnle, Abu-Mahfouz, Kurien, 2022:2). With such issues at hand, integrating 4IR technologies has become a critical priority in municipal water governance as these institutions are now operating in environments that demand precision, responsiveness, and where decisions need to

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be data-driven; otherwise, the sustainability of these institutions remains threatened (Adedeji et al. 2022:3).

However, despite the recognition of the potential benefits and opportunities presented by 4IR technologies and despite the heavy investments in digital water management systems by various countries (Liu et al. 2021:2) adoption remains slow, not fully scaled, and constrained (Tean, Tan & Wahid, 2023:368), resulting in the reliance on the traditional methods of water governance, which have shown to be insufficient in addressing the 21st century (Stankovich et al.2020:1; Adedeji et al. 2022:2).

Nevertheless, there remains limited research on why technology (4IR) adoption to enhance water governance remains slow, particularly in rural municipalities. Using the Technology Acceptance Model by Davis 1989), this paper investigated the key factors affecting the adoption of 4IR technologies to enhance water governance in a selected District Municipality, Eastern Cape, South Africa, a rural municipality which is a water service authority and a water service provider. While there exist several other models such as the Diffusion Innovation Theory (Rogers 1983), Theory of Planned Behaviour (TPB) (Ajzen, 1985, 1991),and the Universal theory of acceptance and use of technology (UTAUT) ((Venkatesh*et al*. 2003; Venkatesh et al., 2012), Salimon, Goronduste and Abdullah (2018:61) posits that the TAM theories have proven to be the most used and effective theories in understanding technology acceptance.

Given the above insights the current study posits that understanding the factors affecting technology adoption was deemed essential for water institutions, policymakers, and the national governments to devise strategies on how rural water institutions can overcome barriers, which present obstacles in their digital transformation and ensure that they are not left behind, as this will exacerbate inequities in water service provision.

Literature Review

Conceptualization of 4IR Technologies in Water Governance

The Fourth Industrial Revolution (4IR) is defined by the convergence of digital, physical, and biological technologies, offering unprecedented opportunities for industries across the globe (Schwab, 2016). In the context of water governance, 4IR technologies such as the Internet of Things (IoT), artificial intelligence (AI), big data analytics, digital twins, and remote sensing have become vital tools for optimizing water distribution, managing demand, and forecasting infrastructure failures (World Bank, 2020). These technologies enable municipalities to adopt proactive maintenance, reduce water losses, and improve service delivery.

Given the disruption caused by the 4IR era, there exists a wide range of scholarly literature on 4IR and water; however, most of the studies have neglected the factors that affect technology adoption within water institutions at the local level. Rather more focus is given to the technical aspects of which technologies can be used. For instance, a study by Stankovich et al. (2020:1) discussed how 4IR technologies, such as AI and IoT, can improve water governance in Latin America. The study provided case studies in which such technologies have been applied and elaborated on the challenges and opportunities. A study by Liu et al. (2021) in China focused on barriers in implementing circular economy in smart water management systems and identified infrastructural, institutional governance, technological, and a lack of awareness on circular economy as major obstacles. Other studies focused on the application of these advanced technologies in agriculture (Kumar, 2023; Yugandhara et al. 2025). A similar study by Adedeji et al. (2022) explored various technologies and how they can transform water service provision and highlighted the challenges that may be brought by these digitalisations. As such, while existing studies highlight the benefits of 4IR technologies in water service delivery, significant gaps remain regarding what factors affect technology adoption, especially in rural areas, underscoring the need for further empirical investigation and context-specific analyses

Understanding factors affecting technology adoption: The Technology Acceptance Model

The study adopted the Technology Acceptance Model introduced by Davis in 1986 and modified by Venkatesh and Davis (1996), the TAM2 by Venkatesh and Davis (2000), and the TAM3 by Venkatesh and Bala (2008) (Lai 2017:22). The initial and revised models explain how new technologies can be readily accepted or rejected by individuals. The original model is based on two theoretical constructs of Perceived Usefulness (PU) and Perceived Ease of Use (PEOU), which then affect attitude and behavioural intention to use. However, the extended models of TAM2 and TAM3 further offers the external variables which affects both variables of PU and PEOU which later affects the behavioural

intention and actual usage of technology. By doing so, the theory provides a powerful foundation for explaining technology acceptance (Tean et al. 2023:371) behavior which in the context of this research is the adoption of 4IR technologies in municipal water governance.

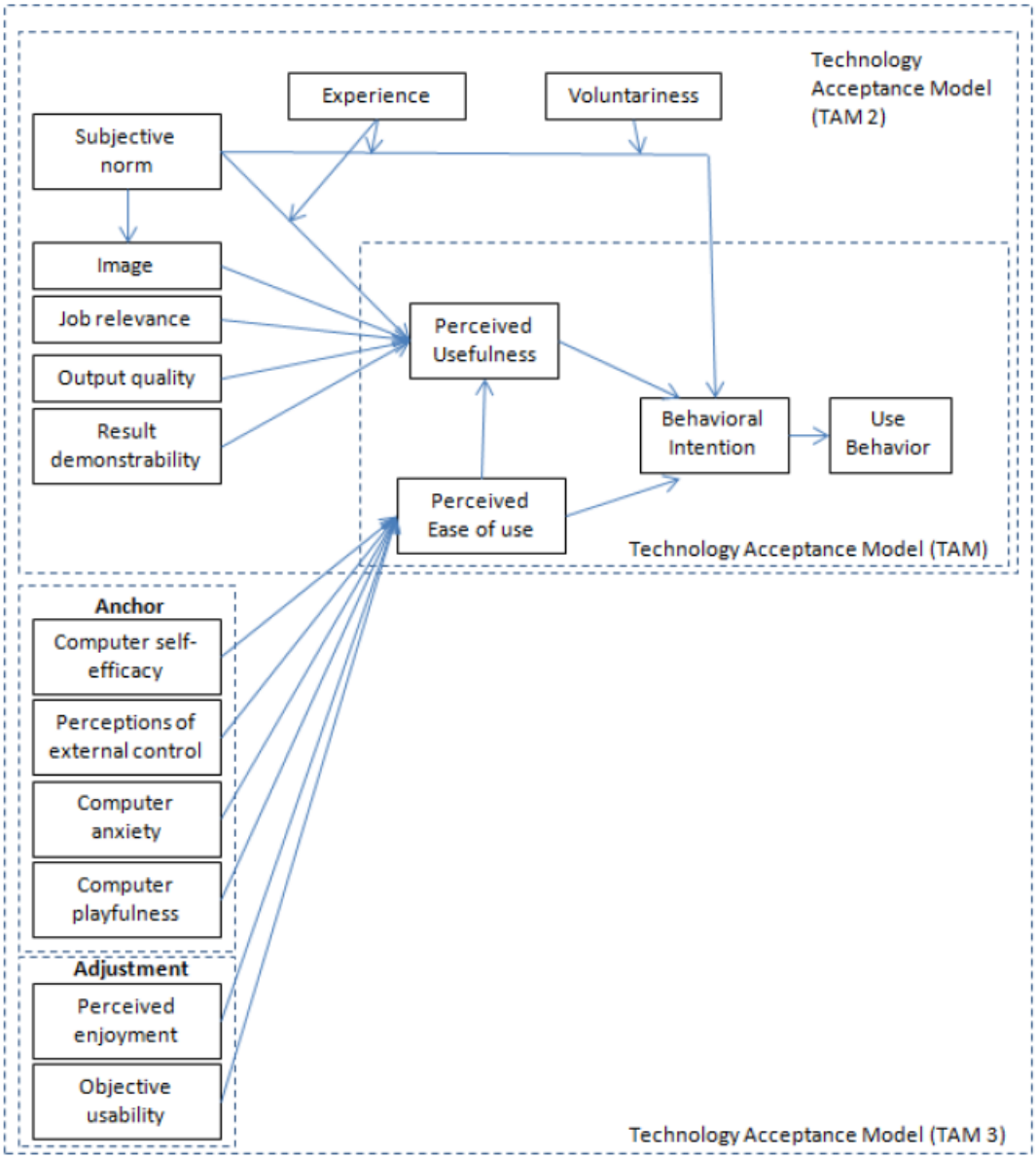

Figure: TAM, TAM2 and TAM 3

Source: Boughzala (2014:169)

Perceived Usefulness and Perceived Ease of Use

The original TAM model argues that the adoption and acceptance of technology is dependent upon the Perceive Usefulness (PU) and Perceived Ease of Use (PEOU). According to Kustono et al. (2020:86) PEOU is defined as the degree to which a user believes that utilising a particular technology would require minimal effort, while PU is the extent to which the technology enhances job performance. These two variables therefore determine the attitude towards the use technology making these two aspects important factors influencing technology adoption and acceptance (David et al. 2022:5). The TAM model asserts that external factors influence PEU and PU, which subsequently provoke cognitive responses that shape a behavioural reaction (attitude towards technology use), ultimately affecting usage behaviour (Marikyan & Papagiannidis 2023:2). Attitude as an aspect of technology acceptance is therefore shows the individual beliefs that his or her behaviour will result to certain outcomes, and these outcomes could be favourable or otherwise based on personal evaluation. As such the more positive attitude, the stronger the behavioural intention to accept, adopt and use the technology

(Salimon et al. 2018:63). The final modified version of the TAM developed by Venkatesh and Davis (1996) however posits that the PEOU and PU are affected by external variables which may include aspects such as political, cultural, and social factors (Afandi et al. 2020:42).

Factors affecting perceived usefulness of technology (TAM2)

The original TAM theory has been modified by various scholars who believed that factors affecting PU were not fully included. This limitation led to the second TAM (TAM2), which had five extensions and two moderators on factors affecting the PU of the technology (David et al. 2022:6; Marikyan & Papagiannidis 2023:2). The elements include the subjective norm, image, job relevance, output quality, result demonstrability, experience and voluntariness.

Table External Variables Affecting Perceived Usefulness

Variable	Meaning
Subjective norm	The degree to which users perception regarding technology is based on others experience and the extent to which it is discretionary or obligatory (David et al. 2022:6).
Image	how using the innovation was perceived to enhance one's status in one's social system; it was linked to the subjective norm (Marikyan & Papagiannidis 2023:4).
Job relevance	The extent to which the user perceives the technology as capable of facilitating the attainment of significant job objectives (Kustono et al.2020:87).
Output quality	Quality output is indicative of the impact of the technology's quality on pragmatic undertakings. The quality of the technology is related to how easy it is to use and understand; the higher the quality, the higher the level of satisfaction among users (Kustono et al. 2020:87).
Result demonstrability	relates to the technology's perceived tangible outputs and benefits (David et al. 2022:5). This aspect was deemed significant, as technologies may not be accepted if users fail to embrace the benefits thereof (Marikyan & Papagiannidis 2023:5).
Experience	Past interactions or exposure of an individual to a system and the accumulated knowledge gained by usage
Voluntariness	

Source: Authors compilation from secondary sources

Factors Affecting Perceived Usefulness of Technology (TAM3)

The first and second models explained the factors affecting perceived usefulness. However, these models were considered lacking in explaining the factors of PEU. This led to the formation of the third model (TAM3), which encompassed direct predictors of PEU (PEU), including computer self-efficacy, perception of external control, computer anxiety, computer playfulness, perceived enjoyment, and objective usability (Marikyan & Papagiannidis 2023:6).

Table External Variables Affecting Perceived Ease of Use

Variable	Interpretation
Computer self-efficacy	The degree to which the users believe they can use computers for their to perform their tasks (Salimon et al. 2018:63).
Perceptions of external control/facilitating conditions	Users' beliefs about the existence of technical and organizational resources and infrastructure to facilitate the use of technology (Jimenez, García, Violante, Marcolin & Vezzetti, 2021:10)
Computer anxiety	confidence and fears possessed by individuals in using computers. It can be associated with issues of privacy and security concerns (Salimon et al. 2018:63).
Computer playful ness	The ability of individuals to experiment with technology for fun
Perceived enjoyment	Refers to how pleasant and entertaining is the use of the innovation, separately from any performance consequence that can be deducted from system usage (Jimenez et al. 2021:10)

Objective usability/system quality	Technical achievements, the accuracy, and efficiency of the system (Jimenez et al. 2021:10)

Source: Authors compilation from secondary sources

TAM has been widely adopted in various information systems (Mugo, Njagi, Chemwei & Motanya 2017:5; Mwiya et al. 2017:745), with Segards and Grover (1993) in Huang, Li, and Chang also attesting that TAM is a widely recognised research model that has demonstrated statistical reliability through its analytical tools (Mugo et al. 2017:5). Other scholars who have used TAM include Mwiya et al. (2017), Lin et al. (2007), and Chen & Chen (2009), among others (Mugo et al. 2017:4).

Although the above-mentioned studies were not specifically about water governance, the researcher contends that TAM can be fully utilised by water service authorities, municipalities, and other stakeholders involved in water governance. The constructs of the PU of 4IR technologies will determine the level and rate of adoption in municipal water governance. If 4IR technologies are perceived to be useful (PU), they are more likely to be adopted by municipalities for water governance (Kustono et al. 2020:87).

The PU of 4IR technologies can be understood by examining the benefits and opportunities that accompany these technologies. For instance, when municipal officials understand that employing IoT sensors, drones, and data analytics will reduce water leakages, enable more effective infrastructure management, and improve asset management, and blockchain will reduce the bureaucratic processes involved in decision-making, as everyone can access information in real-time (see Section 4.5, which discusses the benefits of 4IR technologies in municipal water governance), these perceived benefits are more likely to drive municipalities to adopt 4IR technologies.

The components of PU, such as experiences and voluntariness, the impact of technology, quality of output, risks, costs, benefits, and demonstrability of the technology, influence users' decisions about how and when new technologies can be used (Kustono et al. 2020:87; Kollmann, Nath, Singh, Balasubramanian, Reynaert, Morgenroth & Contzen 2023:6).

The PEU will affect the rate at which these 4IR technologies are used. It will range from complexity and training to the compatibility of the presented technologies. More user-friendly technologies and those requiring minimal disruption of existing operations are more likely to be adopted than those that do not. These assertions align with Lo Presti, De Rosa & Viceconte's (2021:3) observations that TAM's PU and PEU influence other external variables, such as the system characteristics and training.

Although TAM, TAM2, and TAM3 are formulated for information systems, they explain how individuals embrace and utilise technology. They emphasise that individuals' attitudes and intentions regarding technology are crucial, as their intention to utilise it results in usage, which is the objective. The theory posits that technology usage is determined by behavioural intention (Lo Presti et al. 2021:7).

Viljoen and Viljoen (2022:2) state that a positive internal resource that employees can use to navigate disruptive change, strong uncertainty, and a stressful workplace in the 4IR context is employee resilience, which includes the attitudes and abilities of employees to cope with the challenges of an evolving workplace. Olaitan et al. (2024:173) opine that the incorporation of 4IR technologies is also affected by the willingness and ability to adapt to the new changes.

TAM, therefore, offers a framework for comprehending the elements influencing technology adoption, which was the primary purpose of this study. By analysing these components through TAM, one can infer the attributes of municipalities, such as skills, organisational culture, vision, knowledge, and financial support, as these elements influence the perceived ease of use of 4IR technologies.

Research Methodology

The current study was aimed at understanding the factors affecting the acceptance and adoption of technologies in a selected district municipality in the Eastern Cape Province. To do so, the study adopted a qualitative research methodology based on the interpretivism research philosophy. A descriptive case study research design was adopted and enables an extensive and in-depth investigation on the status of the municipality towards technology adoption and factors slowing the process. Through semi-structured interviews from twenty-eight participants purposefully selected to represent various stakeholders such as the municipal officials, academic, political structures and heads of departments, COGTA and Water Boards representatives, rich and in-depth data, various perspectives and opinions and collected. In addition, to ensure rigor in the study through data

triangulation, document review was used to collect additional data. Data was analysed through a thematic analysis approach with ethical considerations such as, consent, anonymity and confidentiality being upheld.

Results and Discussions

Given this current state, the following factors affected the adoption and implementation of 4IR technologies in their water governance, discussed below.

Construct	Determinant	Findings
Perceived Useful	Subjective norm	• Political environment • Organisational culture • Policy and regulation • Collaborations and partnerships
	Image	• Municipal vision
	Job relevance	• Consideration of social economic impacts
	Output quality	• Infrastructure reliability/ICT equipment
	Result demonstrability	Success cases from collaborations
Perceived Ease of Use	Computer self-efficacy	• Skills, capacity and capacity building
	Computer anxiety	• Privacy and cybersecurity concerns
	External control/ facilitating conditions	• Funding • Infrastructure • ICT equipment • Policy and regulation

Source: Authors Illustration

Skills, Capacity, and Capacity Building Challenges

The study findings revealed that skills, capacity and capacity building as factors affecting technology acceptance and adoption. The district municipality staff and officials lack the digital skills and competencies required by 4IR thus hindering the use of these technologies for their operations. One participant stated

"*4IR technologies will require specific skills which we currently do not have as a municipality, and as of now, there is nothing much which have been done to ensure that the staff have these skills*" [Participant 1]. Highlighting the critical need to ensure that these skills are available, Participant 3 highlighted that, "*We have qualified and skilled personnel in the municipality; however, adopting the 4IR technologies will require new skills and upskilling and reskilling, which we haven't done and as a result, it affects the progress in adopting these technologies in water governance*".

The adoption of 4IR technologies to enhance municipal water governance is centered on individuals possessing the requisite digital skills and competencies. This is because human resources play a significant role alongside technological advancement (DCoG and CISR 2021:32). This factor aligns with computer self-efficacy, a determinant of the TAM3 which builds on peoples ability to uses technologies depending on their skills. The study further revealed limited efforts towards training and capacity and capacity building initiatives to ensure that the municipality is able to adopt these technologies due to budget limitations and lack of priority or urgency to adopt 4IR technologies.

One participant expressed these sentiments, stating, "*The municipality has not yet engaged in a journey to equip its staff with 4IR skills or in any digital skills acquisition mainly because of funding issues*" [Participant 14]. Likewise, Participant 9 added " *We have a limited budget which is not enough money to train our staff, especially now. More focus has been put on ensuring those communities do not have access and eradicating backlogs*".

Deficiencies in training, budgets constraints and a reluctancy further reflects TAM3 components of facilitating conditions which affecting the PEOU and the reluctancy towards investing in training reflects TAM2 aspect of subjective norm affecting PU as technology acceptance is based on the obligatory or

discretion to adopt it. To this end, a lack of skills, competencies and support through training, reskilling and upskilling in 4IR technologies will hinder the municipality efforts to leverage these technologies to optimize water management processes, enhance efficiency, and address pressing water-related issues (South African Cities Network, 2022:262).

Key Enabling Infrastructure/ Digital Infrastructure

Digital infrastructure is critical to the Fourth Industrial Revolution (4IR), enabling the delivery of public services like traditional infrastructure but with increased functionality (Alexander 2021:3). In the context of this study, digital infrastructure refers to the physical assets required to operate technologies such as digital communication, data warehouses, base stations, and cloud providers and broadband. However, the study revealed deficiencies digital infrastructure and basic ICT equipment with participant stating:

Participant 13 highlighted that *"There is a need for investment in digital infrastructure if this is to work, and currently, that is still lacking. We struggle with network issues, yet 4IR technologies require stable internet access and base stations"*.

Engaged experts further identified inadequate digital infrastructure as an obstacle impeding the full adoption and implementation of 4IR technologies in most rural areas, such as the district municipality. One expert stated, "*The use of 4IR technologies such as IoT devices, remote sensing, and data analytics involves the collection of petabytes of data and requires storage and high computational power for that data to be processed to information useful to the municipality. This demands stable and strong internet connectivity, something like 4G and 5G networks to be seamless, yet most rural areas in South Africa still use 3G. Most rural areas in the Eastern Cape are still struggling with network issues, yet this is part of the basic factors crucial for adopting such technologies" [4IR Expert]*.

Key enabling and therefore relates to the TAM3 component of **facilitating conditions** or perception of external control. Participants interviewed already viewed the existing infrastructure as in adequate thus affecting the PEOU of the 4IR technologies in such a rural setting. Other respondents raised concerns on the issue of power/energy as part of the infrastructural challenge, stating, *"It is going to be difficult for areas like our district municiplaity to fully engage in 4IR technologies, especially with this rate at which there is load-shedding and yet the digital infrastructures highly depend on Eskom as an energy provider"* [Participant 10]. This followed Alabi et al. (2019:4) observations that the water industry uses much electricity to run its operations daily, especially for things like pumping. The study, therefore, established that Eskom's Infrastructural challenges, which have led to continuous load-shedding, have exacerbated the situation, impeding the full adoption and implementation of 4IR technologies in the district municipality's water governance.

Therefore, the inadequacy of digital infrastructure is consistent with Chetty's (2019) observations that a lack of digital infrastructure poses a challenge in integrating 4IR technologies such as data analytics, remote monitoring, and IoT devices. The challenges range from computational resources, reliable transmission, and restricted connectivity, which affect realizing full potential benefits and opportunities such as data-driven decision-making, enhanced efficiency, and proactive responses in water governance.

Contrary to the above finding, the study also found that one of the local municipalities under the district municipality's jurisdiction has street cameras controlled through a control room, and the system uses some of the 4IR technologies. Moreover, the researcher recognized that district municipality has a telemetry system that uses some 4IR technologies to monitor water levels (although it did not work at the data collection point). Participant 3 highlighted, *"We face network issues when operating this system; however when it's working, it is really helpful for us to identify any abnormalities in water flows and enable quicker responses and actions."* Another respondent echoed, *"We have boosters here and internet connectivity. While this infrastructure may not be enough, we have a starting point if we focus on engaging in 4IR technologies."* [Participant 14].

The study findings, therefore, challenge the general notion that rural areas are struggling with digital infrastructure, as this study reflected that some parts of the district municipality have proven to be engaging in the use of 4IR technologies. However, this is not to say the digital infrastructure is adequate, but rather, there is a starting point should rural municipalities need to engage the 4IR technologies to enhance their water governance and cements the TAM3 component of facilitating conditions as a strong determinant in affecting PEOU and technology adoption.

Basic Information Communication Technology Equipment

The current study conceptualised Information Communication Technology to encompass any device used for creating and/or capturing, storing, processing, managing, as well as any dissemination/ transmission/transfer and/or display of data and information by using digital means (van Heerden & Goosen 2020:146). Drawing from the above definitions, ICT equipment within the district municipality encompasses tools like laptops, desktop computers, and smartphones and constitutes the foundational infrastructure for ICT purposes. However, the study findings revealed the adequacy of basic ICT equipment thus hindering technology adoption.

Participant 4 lamented, "*Our ICT infrastructure is so inadequate that even basic tasks like email correspondence and computer usage pose challenges. Given these limitations, adopting complex 4IR technologies seems daunting when our existing gadgets struggle to sustain current systems*".

In addition, participant 11 stated, *"Most of our current ICT equipment is outdated and ill-equipped to interface with 4IR technologies. Compatibility issues with software, storage limitations, and insufficient computing power loom large. Without adequate ICT infrastructure, adopting advanced technologies becomes an unrealistic prospect*".

However other participants revealed the presents of adequate ICT equipment in their departments however the challenge remained on the possession of skills to use such equipment. Despite the contrary findings further confirms the role of basic ICT equipment and skills as facilitating conditions (TAM3) necessary for technology adoption the perception of output quality (TAM2) to be derived through the available ICT. This follows the realisation that essential ICT equipment is the gateway to digital technology utilization. Beyond mere hardware, they are indispensable for accessing, processing, and leveraging digital information and services. However, the absence of adequate ICT infrastructure in the district municipality poses a formidable barrier to realizing 4IR initiatives in water governance.

Policy and Regulation

South African policy and regulation emerged as another factor affecting technology adoption in the district municipality. Findings revealed that while the current policy supports technology adoption, it is not mandatory to do so thus relating to the subjective norm of the TAM2 where users PU is affected by whether it is obligatory or not to use the technologies.

Participant 3 echoed *"The current legislation speaks of efficiency and effectiveness and the need to ensure we fulfill our mandate. However, it does not directly mention adopting 4IR technologies to improve water governance. So, as it stands, we are still working within the law even if we do not adopt these technologies. As a result, there is a lack of push from the current policy to use these technologies in the municipality's water governance*".

Likewise, the policy and regulation aspect related to the facilitating conditions (TAM3) on whether the policy and regulatory environment is supportive or not for instance through funding and capacity building. Participants stated that adopting these technologies requires a robust framework for dealing with governance issues in this technological era, stating," *As it stands, there is a need for updated water legislation which is evident on how we go about it and how we deal with issues of governance and security, and that is currently lacking. As such, it affects the rate at which we adopt these technologies*" [Participant 4].

The current study therefore opines that policy and regulatory plays a crucial factor in affecting the PEOU and PU of technologies and in the context of this research, the policy and regulatory aspects are not fully supporting technology adoption and acceptance and yet they are essential in digital transformation (Wanyana et al. 2024:10; Manda & Dhaou 2019:247).

User Perceptions (Perceived Usefulness and Ease of Use) and Social Learning

User perceptions and experience emerged as a critical factor in adopting 4IR technologies to enhance effective water governance within ORTDM. Participants agreed unanimously on the potential positive impact of Fourth Industrial Revolution (4IR) technologies on municipal water governance. Participant 1 expressed these sentiments," *Using 4IR technologies will help us a lot. They will improve efficiency and effectiveness in our department and the municipality"*. Another respondent opined," *Imagine if I have all the information on my screen, and I must monitor everything I want there. That will make my job easier than having to do check-ups and follow-ups every time and being told that the information is not yet ready"* [Participant 7]. The study findings reflected an optimistic view regarding adopting the technologies in question. According to Lubinga, Maramura and Masiya (2023:9), this view

focuses on the future and is characterized by ease, immortality, gratification, and dominance, all associated with the narrative that 4IR technologies positively transform society.

This study, therefore, established that while ORTDM has not yet fully engaged 4IR technologies, the perceptions regarding the use of technology play a crucial role in influencing their decision-making regarding the adoption. Additionally, such optimism among stakeholders involved in water governance regarding the potential benefits posed by 4IR technologies in water governance is more likely to motivate the involved actors to have an open mind to explore and consider integrating these technologies into their frameworks, as observed by the Technology Acceptance Model (TAM).

On another note, the study findings revealed the power brought by other water entities in influencing the municipality's perceptions, which then influence the overall adoption of technology. This assertion followed Participant 16 sentiments that , "*We have been discussing using smart meters to address the water challenges we face. We have learned that other municipalities have already started using the smart meters, and they have helped them"*. Likewise, Participant 7 further opined," *We will pay a visit to Chris Hani and learn how they have managed their process of adopting the smart and prepaid meters. ……". Similarly*, Participant 3 added*, "In my house, I am using a smart meter and a digital app where we engage as communities and report faults and share information, and also"*.

The above finding further reflects the theoretical implications on how the subjective norm (TAM2) and experience (TAM2) can affect PU resulting in the actual usage of technologies.

Organisational Culture and Resistance to Change

Culture can be defined as a framework of shared values that collectively represent the organization's coherent culture despite the diverse backgrounds at various levels and offers an essential, creative, and non-mechanistic approach to understanding how organizations function (Rasak 2022:110). Organizational culture emerged as another factor affecting the technology adoption level in the district municipality. Gathered responses revealed that adopting 4IR technologies in water governance may be hampered by old practices and aversion to change. As such, organizations must embrace an innovative culture to overcome these obstacles and promote organizational transformation.

Managers interviewed agreed that while change may be difficult, the municipality staff will gratefully embrace the use of 4IR technologies, with one respondent stating, "*Of course, any case with change has its issues; however, I believe that once we introduce these technologies, our organizational culture will enable our staff to welcome the use of these technologies and once they see the benefits, they will understand that the technologies are there to serve them*" [Participant 1].

Offering recommendations, Participants 8 and 9 highlighted that the technologies will be embraced with strong leadership, capacity building, and training programs, given that other things, such as funding, are in place. Consistent with these findings, the World Economic Forum (2018:18) records that building a strong and diverse culture of innovation is critical for the water community's ability to harness the 4IR opportunities fully. Therefore, simply having technology isn't enough to solve water challenges effectively; without a supportive culture, developed solutions may not tackle the core issues in water governance. Following the above responses, the researcher argues that organizational change and culture through the subjective norm (TAM2) and computer anxiety (TAM3) shape employee attitudes, behaviors, and responses to new technology. An atmosphere that is conducive to the adoption of 4IR technologies can be created by a culture that values innovation, welcomes change, and promotes experimentation.

Political Environment: Structures and Influence

The current study contextualizes the political environment, the political structures within ORTDM, and political influence. The district municipality structure is composed of the council which is responsible for the final decision-making concerning issues such as funding and projects to be implemented (ORTDM 2024:24). Emerging as a factor affecting technology adoption the district municipality revealed a mixed feelings towards the support given by the political structure in technology adoption. Participants raised concerns that while these structures understand the need for these technologies, they are more concerned with immediate issues such as backlogs eradication rather than investing in new technologies. Other participants highlighted the presence of political interference in the municipality as evidence by the invoking of Section 139 which the municipality was operating as hindering the technology adoption. The findings therefore align with the subjective norm (TAM2) and the facilitating conditions (TAM3) which affect both the PU and PEOU of these technologies as without full support or an enabling political environment, decisions on investments in technologies for instance training,

equipment needed, and maintenance may always be compromised resulting in difficulties in the use of the technologies.

Municipal Vision and Integration of the Fourth Industrial Initiatives in the Municipal Integrated Development Plan (IDP*)*

The study findings revealed municipal vision and the integration of 4IR initiatives in the municipality strategic documents as another factor affecting technology adoption. The five-year vision (2022-2027) is centered on "a prosperous, vibrant, innovative and people-centred district (ORTDM 2024a:175). Following this vision, the study findings revealed the acknowledgment of the potential opportunities and benefits offered by the 4IR technologies with participants arguing that the technologies will be useful in their operations. Thus, cementing the PU construct where individuals believes that technologies will enhance performance. Participant 10 added, "*The leadership we currently have from the council and administration side both understand the significance and need for us to engage in these technologies. For instance, we can use smart meters and IoT devices to collect data for our decision-making. The leaders have the vision, although it has yet to be achieved. The main challenge that hinders this vision is the funding issue, which slows progress".*

In addition, the acknowledgement of 4IR technologies as a governance tool further reveals the social pressures form external variables such as the subjective norms and image as external variables affecting technology adoption. While this is the case the findings further reveal a disconnect between the municipal vision and action on the ground for instance, there is absence of records or institutional documents showing the integration of 4IR initiatives and plans within the municipal official documents. The current study therefore argues that without proper institutionalisation of the municipal vision and strategy which mandate the leaders and political structures to establish facilitating conditions which translate the vision into action, adopting 4IR technologies to enhance municipal governance will remain a myth. This a is because despite the recognition of job relevance (TAM 3) such a situation weakens the result demonstrability (TAM3) thus hindering the PEOU of the technologies to be adopted.

The assertion resonates with the idea that the municipal vision is driven by municipal leaders, officials, and decision-makers (Balahurovska 2023:71; Mpofu & Nemashakwe 2023:42). As such, these actors should have a clear, articulated vision delineating goals and targets, which should be featured in municipality strategic documents such as the IDP or an institutional framework for 4IR adoption and implementation. The significance of a cohesive vision and strong leadership cannot be overstated, as it profoundly influences the success of adopting and implementing 4IR technologies in municipal water governance (Naidoo 2019:9).

Funding

Funding and financing are contextualized as money or resources for the adoption of the Fourth Industrial Revolution technologies in the district municipality from various external sources such as the government or private sector (Gracias et al. 2023:1735), and internal sources such as the municipality itself. The adoption and implementation of 4IR technologies in water utilities requires significant investments in digital infrastructure, equipment, software, and skilled personnel (World Economic Forum 2018:16) thus making funding a crucial factor in technology adoption. However, the study revealed deficiencies in funding as a barrier in both investing in systems and personnel and maintaining the existing systems. One participant stated, *"The municipality is financially constrained, and it is currently struggling to maintain just the basic ICT equipment which we are using, let alone the 4IR technologies, which might be more demanding in terms of finance*"[Participant 4].

The findings therefore revealed how the intentions to adopt can be suppressed by poor facilitating conditions such as funding. The findings further revealed poor efforts in sourcing external funding from donors, NGOs and private sector highlighting institutional inertia which further weakens the PEOU built from other variables. Additionally, the study further revealed poor maintance of the existing systems thus further highlighting the significance of sustainable financing when adopting technology. Likewise, the poor result demonstrability due to this failure in maintenance further weakens the belief these technologies can be useful and enhance operational efficiency without raising issues of computer anxiety and output quality.

Considerations on the Socio-Economic Impacts of 4IR Technologies: Manual-Automation Dilemma

The advent of 4IR has brought the need for a shift from manual human-operated processes to automated technology-driven systems (George 2024:18) in governing, monitoring, and distributing

water resources. However, the need to balance the two approaches (manual automation dilemma) while mitigating the impacts of 4IR emerged as an area of concern in in the municipality.

Acknowledging the usefulness and need to engage 4IR technologies in enhancing water governance at the district municipality, Participant 7 echoed, "*We are looking towards engaging 4IR technologies to improve our water governance. This is because we mandate our communities to ensure they have access to safe and reliable water, and these technologies provide us with a chance to do so"*.

Showing concerns about this technological shift and the social implications of engaging these technologies in question, the above respondent expressed these sentiments, "*However, we also have a social responsibility to our communities; hence, we cannot just remove the people working these manual repetitive jobs and replace them with technology. This will create unrest and instability. As a result, the municipality is looking forward to this transition in phases. There are about fifty-four-meter readers in ORTDM, and we cannot just displace them; the issue also affects those who deal with the interface between meter reading and billing, as their scope of work will be reduced*" [Participant 7].

Based on the findings above, it is evident that the municipality is confronted with the intricate task of balancing effective water governance with significant levels of poverty and unemployment. The situation aligns with the TAM2 construct of image, where how using the innovation was perceived to enhance one's status in one's social system; it was linked to the subjective norm (Marikyan & Papagiannidis 2023:4). Additionally, the PEOU is further affected by the facilitating conditions which is this case include issues of poverty and unemployment with the district municipality which then requires careful and a balanced approach in technology adoption (Mtotywa, Manqele, Seabi, Mthethwa, and Moitse, 2022:225). This predicament further aligns with the findings of Nhede, Maxzenda & Masiya (2022:2) regarding South Africa's challenge in dealing with unemployment, poverty, and inequalities in the face of improvements in the Fourth Industrial Revolution (4IR).

External Collaboration and Partnerships

The study revealed the significance of external collaborations and partnerships in technology adoption. Vialle Pereira et al. (2017:529) further asserted that public sector collaboration involves distributing responsibility and decision-making power for government operations, policies, and actions among various stakeholders. Collaborations can lead to improved resource utilization and information sharing and, as such, play a crucial role in technology adoption (Adomako & Nguyen 2020:1182). Experts interviewed emphasized the importance of external collaborations, which involves other public sector entities, Non-Governmental Organizations(NGOs), civil society, and individual citizens as a crucial enabling factor in adopting 4IR technologies, particularly in the public sector, with the water governance expert interviewed expressing these sentiments:" *I think rural municipalities like ORTDM need to engage more in partnerships and collaborations rather than take the journey on their own. This approach will alleviate some of their burdens, for instance, if they partner with WSU and have arrangements for pilot projects, research, training initiatives, and capacity building".* Within the constructs of TAM3, the aspects of collaborations and partnerships play a crucial role in technology adoption through facilitating conditions which affect the PEOU. Additionally, through collaborations and partnerships, the municipality can strengthen their capacity enabling the municipality to get enough funding and harness skills which affect computer efficacy (TAM3). Likewise, through partnerships and collaborations, the municipality can perceive the usefulness 4IR technologies through demonstrating results and job relevance. The necessity for collaborations and partnerships arises from the multifaceted pressures associated with technology adoption, including financial challenges, the imperative to share lessons learned and experiences, pilot projects, and stakeholder engagement. These assertions align with the insights provided by the Department of Cooperative Governance (DCoG) and the Council for Scientific and Industrial Research (CSIR 2021:33), which recorded that the key to success lies in establishing robust partnerships and collaborations that contribute to the effectiveness of initiatives and support the overarching goal of achieving efficient water governance by utilizing 4IR technologies. Likewise, Lopes and Farias (2020:116) emphasise the importance of collaborations in balancing between ongoing and new community needs and limited finances without necessarily increasing public spending.

Cybersecurity and Privacy Concerns

Cybersecurity refers to the strategies, technologies, and processes to safeguard computer systems, networks, digital devices, and data against cyber threats, including unauthorized access, attacks, damage, or theft. It seeks to guarantee the confidentiality, integrity, and availability of digital information and systems (Admass, Munaye & Diro 2024)**.** Cybersecurity carries high significance when

adopting 4IR technologies in the district municipality water governance because it proves the municipality's capability to protect private and customer data while ensuring that only those authorized can access the information (Li & Liu 2021:8181).Participants interviewed raised concerns on the need to ensure secure systems and that without solid systems in place, adopting technologies remains a high risk. The finding therefore relates to the TAM3 construct of computer anxiety which raises of the issues of confidence of users in their systems. Additionally, given the funding constraints, and the huge volumes of privacy data which the municipality deals with, participants perception of the computer anxiety remained high further hindering technology adoption. Concerns raised in the district municipality concerning cybersecurity issues were also noted by Ndou and Madonsela (2020:1114), who opined that industry 4.0 security and data privacy issues have become considerable concerns in the 4IR era, where technology has become the driver. It is important to note that trust and confidence in information are valuable commodities for municipal water governance.

Conclusion

The study was aimed at investigating the factors affecting technology adoption through the lenses of the Technology Acceptance Models. From the findings, the study therefore concluded that while the PU and its tenants affect technology adoption, the PEOU construct through the enabling and facilitating conditions plays a crucial role in determining the actual behavior or usage of technology. For instance, deficiencies in facilitating conditions such as infrastructure, funding, skills collaborations and partnerships and ICT hinder the actual adoption of technology and this is despite having strong motivation through perceived usefulness of technology. From the findings presented it can therefore be deduced that intention without enabling conditions does not translate into actual adoption. The claim is supported by the empirical evidence which revealed that the district municipality technology adoption is hindered by structural and institutional barriers rather than lack of knowledge and awareness.

Policy Implications and Recommendations

The study findings reflected various factors which affects technology adoption showing that there is need for more investments that need to be done in the district municipality and those with the same contexts to accelerate technology adoption. failure to invest and support these water institutions will further exacerbate the gap between the have and the have nots. In addition, utilisation technology as a governance tool may further provide south African water institutions to improve their operations resulting in efficient, effectiveness, equitable and sustainable service delivery. As such the study recommends the government to establish policies that encourage investments in 4IR as a governance tool and ensure that these policies are implementable through support in enabling conditions such as funding, infrastructure, skills and capacity building. In addition, these policies should support the collaborations and partnerships through public, private sector, NGOs and other stakeholders who have the capacity and resources to finance the adoption of 4IR technologies in the district municipality particularly those in rural areas which face extra contextual characteristics such as high unemployment a high poverty rates.

References

[1] Adedeji, K.B.;Ponnle, A.A.; Abu-Mahfouz, A.M.; Kurien, A.M. Towards Digitalization of Water Supply Systems for Sustainable Smart City Development—Water 4.0. Applied. Science. 12 (18):1-25.https://doi.org/10.3390/app12189174

[2] Admass, W.S., Munaye, Y.Y. and Diro, A.A., 2024. Cyber security: State of the art, challenges and future directions. Cyber Security and Applications, 2:1-9. https://doi.org/10.1016/j.csa.2023.100031

[3] Adomako, S. and Nguyen, N.P., 2024. Digitalization, inter-organizational collaboration, and technology transfer. The Journal of Technology Transfer, 49(4):1176-1202.1202 https://doi.org/10.1007/s10961-023-10031-z

[4] Afandi, Y., Astuti, E., Kusumawati, A. and Abdillah, Y., 2020. Analysis of the Effect of Perceived Risk, Perceived Usefulness and Attitude on Usage Intention with TAM (Case Study: Go-Jek Application). Jurnal AKSI (Akuntansi dan Sistem Informasi), 5(1):41-44. http://doi.org/10.32486/aksi.v5i1.476

[5] Alabi, M., Telukdarie, A. and Jansen, N.V.R., 2019. Industry 4.0 and water industry: A South African perspective and readiness. In Proceedings of the International Annual Conference of the American Society for Engineering Management. (pp. 1-11). American Society for Engineering Management (ASEM).Available at: https://www.researchgate.net/publication/339056018_INDUSTRY_40_AND_WATER_INDUSTRY_A_SOUTH_AFRICAN_PERSPECTIVE_AND_READINESS[accessed 21 October 2025]

[6] Alexander, R. 2021. Key Opportunities and Challenges for 4IR in South Africa. SARChI Industrial Development Working Paper Series WP 2021-8d. SARChI Industrial Development, University of Johannesburg.

[7] Balahurovska, I. 2023. The Role of Leadership in Industry 4.0, Sciendo 5(1):66-74.doi: 10.2478/czoto-2023-0008

[8] Boughzala, I., 2014. How generation Y perceives social networking applications in corporate environments. In Integrating Social Media into Business Practice, Applications, Management, and Models (pp. 162-179). IGI Global Scientific Publishing.

[9] Chetty, Y.2019. SAQA and the NQF in the context of the 4th Industrial Revolution: Realities and Implications, 20(1):1-21. ISBN - 978-1-920649-57-9

[10] David, L.O., Nwulu, N.I., Aigbavboa, C.O. and Adepoju, O.O., 2022. Integrating fourth industrial revolution (4IR) technologies into the water, energy & food nexus for sustainable security: A bibliometric analysis. Journal of Cleaner Production, 363(1325):1-13.https://doi.org/10.1016/j.jclepro.2022.132522

[11] Department of Cooperative Governance (DoCG) and Council for Scientific and Industrial Research (CSIR). 2021. A South African Smart Cities Framework: A decision-making framework to guide the development of smart cities in South Africa, DoCG & CSIR.

[12] Gracias, J.S.; Parnell, G.S.; Specking, E.; Pohl, E.A.; Buchanan, R. 2023. Smart Cities—A Structured Literature Review. Smart Cities,6:1719–1743.https://doi.org/10.3390/smartcities6040080

[13] George, A.S., 2024. The fourth industrial revolution: a primer on industry 4.0 and its transformative impact. Partners Universal Innovative Research Publication, 2(1):16-40.https://doi.org/10.5281/zenodo.10671872

[14] Javaid, M., Haleem, A., Singh, R.P., Suman, R. and Gonzalez, E.S., 2022. Understanding the adoption of Industry 4.0 technologies in improving environmental sustainability. Sustainable operations and computers, 3:203-217.https://doi.org/10.1016/j.susoc.2022.01.008

[15] Jimenez, I.A.C., García, L.C.C., Violante, M.G., Marcolin, F. and Vezzetti, E., 2021. Commonly used external TAM variables in e-learning, agriculture and virtual reality applications. Future Internet, 13(1):1-21.https://doi.org/10.3390/fi13010007

[16] Lai, P.C., 2017. The literature review of technology adoption models and theories for the novelty technology. JISTEM-Journal of Information Systems and Technology Management, 14(1):21-38.https://doi.org/10.4301/S1807-17752017000100002

[17] Li, Y.C. and Liu, Q.H. 2021, A Comprehensive Review Study of Cyber-Attacks and Cyber Security; Emerging Trends and Recent Developments. Energy Reports, 7:8176-8186.https://doi.org/10.1016/j.egyr.2021.08.126

[18] Liu, Q.; Yang, L.; Yang, M. 2021.Digitalisation for Water Sustainability: Barriers to Implementing Circular Economy in Smart Water Management. Sustainability, 13:1-28.https://doi.org/10.3390/su132111868

[19] Lopes, A.V. and Farias, J.S., 2022. How can governance support collaborative innovation in the public sector? A systematic review of the literature. International Review of Administrative Sciences, 88(1):114-130.https://doi.org/10.1177/0020852319893444

[20] Lo Presti, A., De Rosa, A. and Viceconte, E., 2021. I want to learn more! Integrating technology acceptance and task–technology fit models for predicting behavioural and future learning intentions. Journal of Workplace Learning, 33(8):591-605.https://doi.org/10.1108/JWL-11-2020-0179

[21] Kollmann, J., Nath, S., Singh, S., Balasubramanian, S., Reynaert, E., Morgenroth, E. and Contzen, N., 2023. Acceptance of on-site wastewater treatment and reuse in Bengaluru, India: The role of perceived costs, risks, and benefits. Science of the Total Environment, 895:1-11.https://doi.org/10.1016/j.scitotenv.2023.165042

[22] Kumar, M.M 2023. Water Governance: effective needs for Sustainable Development, ZBW - Leibniz Information Centre for Economics, Kiel, Hamburg.https://hdl.handle.net/10419/268739

[23] Kustono, A.S., Nanggala, A.Y.A. and Mas'ud, I., 2020. Determinants of the use of e-wallet for transaction payment among college students. Journal of Economics, Business, & Accountancy Ventura, 23(1):85-95.DOI: 10.14414/jebav.v23i1.2245

[24] Manda M.J and Dhaou, S.B . 2019. Responding to the challenges and opportunities in the 4th Industrial Revolution in developing countries. In Proceedings of the 12th International Conference on Theory and Practice of Electronic Governance (ICEGOV2019), Melbourne, VIC, Australia, April 3-5: 244-253.https://doi.org/10.1145/3326365.33263

[25] Marikyan, D.& Papagiannidis, S. 2023. Technology Acceptance Model: A review. In S. Papagiannidis (Ed.), Theory Hub Book. Available at https://open.ncl.ac.uk / ISBN: 9781739604400

[26] Mpofu, Q. and Nemashakwe, P., 2023. The role of leadership in adopting the Fourth Industrial Era technologies in developing economies. The Fountain: Journal of Interdisciplinary Studies, 7(1):41-58.

[27] Mtotywa, M.M., Manqele, S.P., Seabi, M.A., Mthethwa, N. and Moitse, M., 2022. Barriers to Effectively Leveraging Opportunities within the Fourth Industrial Revolution in South Africa. African Journal of Development Studies, (si2):213-216.https://hdl.handle.net/10520/ejc-aa_affrika1_v2022_nsi2_a10

[28] Moji, L., Nhede, N.T. & Masiya, T., 2022, 'Factors impeding the implementation of oversight mechanisms in South African municipalities', Journal of Local Government Research and Innovation 3(0):1-8.https://hdl.handle.net/10520/ejc-jolgri_v3_n1_a94

[29] Mugo, D.G., Njagi, K., Chemwei, B. and Motanya, J.O., 2017. The technology acceptance model (TAM) and its application to the utilization of mobile learning technologies. British Journal of Mathematics & Computer Science 20(4): 1-8.DOI: 10.9734/BJMCS/2017/29015

[30] Mwiya, B., Chikumbi,F., Shikaputo, C., Kabala, E., Kaulung'ombe, B. and Siachinji, B. .2017. Examining Factors Influencing E-Banking Adoption: Evidence from Bank Customers in Zambia. American Journal of Industrial and Business Management, 7: 741-759.https://dx.doi.org/10.2139/ssrn.2987982

[31] Naidoo, V., 2019. Is the water sector ready for Industry 4.0? Water &Sanitation Africa, 14(3):8-8.https://hdl.handle.net/10520/EJC-15bbf45b42

[32] Ndou, A.T., and Madonsela. N. Z.,2020. The era of Digital Technology: Analysis of factors contributing to economic growth and sustainability. Proceedings of the 2nd African International Conference on Industrial Engineering and Operations Management, Harare, Zimbabwe,7-10 December 2020. Available at:https://ieomsociety.org/harare2020/papers/297.pdf[accessed on 21 October 2025]

[33] Olaitan, O.O., Vijayalekshmi, S. and Kumar, D.V., 2024. Integrating 4IR Technologies into Higher Education in South Africa: Opportunities, Challenges, and Strategies. International Journal of Learning, Teaching and Educational Research, 23(11):157-179.https://doi.org/10.26803/ijlter.23.11.8

[34] OR Tambo District Municipality 2024a. Integrated Development Plan 2024/2025, Eastern Cape Province, South Africa. ORTDM.

[35] Rasak, B., 2022. Organizational culture. Industrial Sociology. Industrial Relations and Human Resource Management. Fab Educational Books, Fab Anieh House, Awka, Anambra State, Nigeria,109-122.ISBN: 978-978-8554-05-9

[36] Salimon, M.G., Goronduste, H.A. and Abdullah, H., 2018. User adoption of Smart Homes Technology in Malaysia: Integration TAM 3, TPB, UTAUT 2 and extension of their constructs for a better prediction. IOSR Journal of Business and Management, 20(4): 60-69.DOI: 10.9790/487X-2004016069

[37] South African Cities Network (SACN). 2022. State of South African Cities Report 2021. Johannesburg: SACN.ISBN No. 978-0-620-98277-1

[38] Tean, S.N., Tan, C.L. and Wahid, N.A., 2023. Smart Water Technology Adoption: A Case Study in a Water Supply Company. Global Business & Management Research, 15(3):368-377.

[39] Stankovich, M., Hasanbeigi, A. and Neftenov, N., 2020. Use of 4IR technologies in water and sanitation in Latin America and the Caribbean. Inter-American Development Bank.

[40] http://dx.doi.org/10.18235/0002343

[41] Van Heerden, D. and Goosen, L., 2020. Promoting the growth of fourth industrial revolution information communication technology students: The implications for open and distance e-learning. In Promoting inclusive growth in the Fourth Industrial Revolution (pp. 118-147). IGI Global.DOI: 10.4018/978-1-7998-4882-0.ch005

[42] Viale Pereira, G., Cunha, M.A., Lampoltshammer, T.J., Parycek, P. and Testa, M.G., 2017. Increasing collaboration and participation in smart city governance: A cross-case analysis of smart city initiatives. Information Technology for Development, 23(3):526-553.https://doi.org/10.1080/02681102.2017.1353946

[43] Viljoen JP and Viljoen R. 2022.Coping essential to thriving in the 4IR. The Industry 4.0 Series (pp. 1-4). Available at:https://delivery-cqucontenthub.stylelabs.cloud/api/public/content/industry-4-series-4.pdf [Accessed 17 April 2025]

[44] Wanyama, J., Bwambale, E., Kiraga, S., Katimbo, A., Nakawuka, P., Kabenge, I. and Oluk, I., 2024. A Systematic Review of Fourth Industrial Revolution Technologies in Smart Irrigation: Constraints, Opportunities, and Future Prospects for Sub-Saharan Africa. Smart Agricultural Technology,7 (100412):1-15.https://doi.org/10.1016/j.atech.2024.100412

[45] World Economic Forum, 2018.Fourth Industrial Revolution for the Earth Series: Harnessing the Fourth Industrial Revolution for Water. Geneva, Switzerland: World Economic Forum. Available at:https://www3.weforum.org/docs/WEF_WR129_Harnessing_4IR_Water_Online.pdf[accessed 20 June 2022].

[46] Yugandhara S. Chandanshive and Varsha D. Jadhav (Rathod) (2025) “Water Use Efficiency in Agriculture Through Innovative Management Practices”, in Environmental Science and Sustainable Development: An Integrated Approach. Pune, India: Nature Light Publication, 43–52.DOI: 10.5281/zenodo.15303486.