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ASSESSING TECHNOLOGICAL INNOVATION FOR SUSTAINABLE
SANITATION SERVICE DELIVERY: INSIGHTS FROM KENYA'S NATIONWIDE
REAL-TIME MONITORING INFORMATION SYSTEM

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ABSTRACT

Technological innovation has become central to enhancing efficiency, transparency, and accountability in public service delivery, particularly in the sanitation sector of developing countries. This study assessed the effect of technological factors on sustainable sanitation service delivery, drawing insights from Kenya's Nationwide Real-Time Monitoring Information System (RTMIS) under the Ministry of Health. Anchored on the sustainability theory and supported by institutional Theory, stakeholder theory and resource-based view theory, the study adopted a descriptive and explanatory research design combining quantitative and qualitative methods. Data were collected from 394 respondents, including Community Health Promoters, County Health Officers, and RTMIS administrators, through questionnaires and key informant interviews. Descriptive and regression analyses were conducted using SPSS version 27. Findings revealed that technological innovation significantly influenced sustainable sanitation service delivery ($\beta = 0.412$, $p < 0.05$), explaining 31.6% of the variance in service sustainability. Key factors included automation, interoperability, and digital infrastructure, while limited user training and system maintenance constrained effectiveness. The study concludes that technological innovation enhances sustainability when supported by institutional commitment, reliable infrastructure, and user capacity. It recommends policy reforms to strengthen digital infrastructure, regular user training, and dedicated funding for RTMIS maintenance to ensure long-term functionality and data-driven sanitation governance in Kenya.

Keywords: *Sustainable service, Digital Infrastructure, Real-Time Monitoring, Sanitation Service Delivery, Technological Innovation*

INTRODUCTION

Globally, technological innovation has emerged as a cornerstone for enhancing the efficiency, equity and accountability for sustainable public service delivery. The integration of digital tools into sanitation service delivery has transformed how governments collect, process, and use data for decision-making. According to the World Health Organization (2022), real-time monitoring technologies enable governments to

track sanitation coverage, operational efficiency, and public health outcomes with unprecedented accuracy. Technological innovation encompassing automation, digital data systems, interoperability, and user-centred design has therefore become vital in addressing persistent gaps in sanitation service delivery. These technologies foster transparency, reduce operational costs, and enhance accountability, especially in resource-constrained environments. However, the degree to which these innovations translate into sustainable service delivery outcomes remains uneven, particularly in developing countries.

Regionally, many African countries have embraced technological systems to monitor and improve sanitation outcomes under the broader Water, Sanitation, and Hygiene (WASH) agenda. Nations such as Uganda, Rwanda, and Tanzania have implemented digital monitoring platforms aimed at enhancing planning and performance tracking within the sanitation sector (African Development Bank, 2021). Despite notable progress, implementation challenges persist, including poor internet connectivity, limited technical capacity, and low data utilization. The World Bank (2020) notes that, while African countries increasingly recognize the value of digital monitoring, sustainability is undermined by fragmented systems and weak institutional integration. Consequently, ensuring that technological innovation supports sustainable sanitation service delivery requires not only technological investment but also institutional alignment and user capacity development.

In Kenya, the Ministry of Health, through its Environmental Health and Sanitation Unit, launched the Nationwide Real-Time Monitoring Information System (RTMIS) to strengthen evidence-based planning and reporting in the sanitation sector. The RTMIS enables county and national governments to monitor sanitation coverage, facility functionality, and progress toward open defecation-free (ODF) status in real time. It provides an integrated digital platform that consolidates data from community health promoters, county health teams, and other stakeholders. Despite its potential to improve accountability and service delivery, the sustainability of the system remains in question. Issues such as inadequate digital infrastructure, system downtime, limited user training, and funding gaps continue to challenge effective utilization (Ministry of Health, 2023). Thus, assessing technological innovations for sustainable sanitation service delivery in Kenya is critical to determining whether they are achieving their intended outcomes.

Conceptually, technological innovation refers to the application of digital solutions including mobile-based applications, data analytics tools, and information management systems that enhance the efficiency, reliability, and responsiveness of public service systems (Li et al., 2022). Sustainable sanitation service delivery, on the other hand, entails the consistent, equitable, and resilient provision of sanitation services that meet current and future population needs while conserving environmental and financial resources (UNICEF, 2021). The interdependence between technological innovation and sustainable

service delivery is central to understanding how technology can drive long-term sanitation improvements.

The problem addressed by this study is that, despite Kenya's progress in adopting RTMIS for sanitation monitoring, the long-term sustainability of sanitation services remains uncertain. There is limited empirical evidence on how technological innovations contribute to sustainable sanitation outcomes at the community and institutional levels. Without understanding this relationship, investments in real time monitoring risk becoming short-lived interventions rather than sustainable enablers of service delivery. The objective of this study is therefore to examine the extent to which technological factors influence sustainable sanitation service delivery in Kenya's sanitation sector. Specifically, it seeks to assess the functionality and utilization of RTMIS and how its technological features such as automation, interoperability, and digital accessibility affect the sustainability of sanitation service outcomes. The study hypothesizes that technological factors have a significant effect on sustainable sanitation service deliver.

This study is justified on several fronts. Theoretically, it extends the application of the the Sustainability Theory (Brundtland, 1987) to the sanitation context, emphasizing how technological factors interact with user behaviour and institutional structures to shape sustainability outcomes. Practically, the findings provide insights for policymakers, county health departments, and development partners seeking to strengthen digital infrastructure and data use for sanitation service delivery. Contextually, the study addresses a critical knowledge gap in Kenya by evaluating the performance and sustainability implications of RTMIS. Ultimately, the study contributes to understanding how digital transformation can drive the realization of Sustainable Development Goal 6 ensuring access to water and sanitation for all through technology-enabled governance.

LITERATURE REVIEW

Technology has emerged as a transformative enabler of sustainable service delivery in public sector systems globally. Within the sanitation sector, the integration of digital tools, real-time monitoring systems, and automation has shifted traditional approaches from reactive service delivery to proactive, data-driven management. This section presents the theoretical foundations underpinning the study, an empirical review of existing literature, and the conceptual framework illustrating the hypothesized relationships between technological innovation and sustainable sanitation service delivery.

Theoretical Literature Review

The study is anchored on four key theories – Sustainability Theory, Institutional Theory, Stakeholder theory and the Resource-Based View (RBV) each providing a distinct lens for understanding how technological contributes to sustainable sanitation outcomes. The Sustainability Theory (Brundtland, 1987) emphasizes meeting current developmental needs without compromising future generations' ability to meet their own. In the context

of sanitation service delivery, sustainability involves maintaining operational efficiency, equity, and environmental integrity over time. Technological innovation enhances sustainability by improving efficiency in resource utilization, optimizing data-driven decision-making, and reducing environmental impact (UNDP, 2022). However, the sustainability of technological systems themselves through maintenance, adaptability, and long-term funding remains a critical consideration (Adams et al., 2021).

The Institutional Theory (Meyer & Rowan, 1977) provides insights into how organizational structures, norms, and processes influence the adoption and institutionalization of innovations. In sanitation systems, the introduction of RTMIS reflects institutional efforts to align with global best practices in digital governance. However, institutional inertia, fragmented coordination, and weak enforcement mechanisms often undermine full adoption and utilization of such systems (Danielsen et al., 2022). Institutional theory thus explains how contextual and organizational factors mediate the relationship between technology adoption and sustainability outcomes.

Stakeholder theory, first introduced by Freeman (1984), posits that stakeholders, individuals or groups who can affect or are affected by an organization's actions are central to its success and sustainability. It emphasizes that organizations must recognize and manage dynamic relationships with all stakeholders, ensuring that their needs and interests are considered in decision-making to enhance accountability and long-term performance (Bridoux & Stoelhorst, 2022). In the context of this study, stakeholder theory underscores the importance of collaborative partnerships and institutional cooperation for effective implementation of Real-Time Monitoring Information Systems (RTMIS), highlighting that stakeholder engagement enhances policy alignment, regulatory effectiveness, and overall project success.

The Resource-Based View (RBV) (Barney, 1991) conceptualizes technology as a strategic organizational resource capable of delivering sustained competitive advantage when it is valuable, rare, inimitable, and non-substitutable. In public sanitation systems, technology can enhance competitive advantage through improved service efficiency, responsiveness, and accountability. However, to realize this potential, institutions must invest in capacity building, maintenance, and innovation (Grant, 2016). RBV reinforces the idea that technology alone is insufficient; its effective integration into institutional processes determines sustainable outcomes.

Empirical Literature Review

Globally, empirical studies demonstrate the role of technology in improving sustainability across public service sectors. According to the World Bank (2020), real-time monitoring systems have enhanced the accountability and responsiveness of sanitation services in Latin America and South Asia. For example, in India's Swachh Bharat Mission, the use of digital dashboards improved data accuracy and helped reduce open defecation

through real-time progress tracking (UNICEF, 2021). Similarly, in Indonesia, the integration of mobile applications in sanitation management enhanced community engagement and system efficiency (Li et al., 2022). In Africa, technological innovation has shown mixed results in promoting sustainable sanitation. In Uganda, Mukasa et al. (2023) found that integrating real-time data tools improved the accuracy and timeliness of sanitation reporting. However, challenges such as system downtime, inadequate technical capacity, and lack of institutional support limited effectiveness. In Nigeria, Ogunboye et al. (2023) observed that digital health monitoring systems improved information management but required ongoing maintenance and user training to remain functional. These findings highlight that while technology contributes to sustainability, institutional and human factors play mediating roles in determining success.

In Kenya, several studies have evaluated the adoption of digital systems in the health and sanitation sectors. The Ministry of Health's RTMIS initiative aims to strengthen sanitation monitoring, but its long-term sustainability remains uncertain due to funding and infrastructural limitations (Ministry of Health, 2023). Bichang'a and Kimutai (2023) reported that despite the benefits of digital tools, many counties still struggle with intermittent internet connectivity and inadequate ICT infrastructure. Furthermore, a study by Njoroge et al. (2022) revealed that inconsistent data entry practices and limited user support hindered the full potential of RTMIS. These findings suggest that technology adoption alone is insufficient without supportive institutional frameworks and consistent user engagement.

Empirical evidence also highlights the mediating role of institutional support, user capacity, and infrastructure reliability. For instance, Danielsen et al. (2022) noted that sustainability depends on strong institutional coordination and ownership of digital systems. Similarly, capacity development among frontline users ensures accurate data collection and reporting, while reliable infrastructure underpins system functionality (Muli & Waweru, 2021). These mediating factors collectively determine whether technological innovation leads to sustainable sanitation service delivery or becomes an unsustainable investment.

Inter-Variable Relationships

The reviewed literature indicates a multidimensional relationship between technological innovation and sustainable sanitation service delivery. Technological innovation comprising automation, digital integration, and data-driven processes enhances efficiency, accountability, and decision-making (Lee et al., 2019). However, sustainability outcomes depend on contextual factors such as institutional readiness, policy frameworks, and financial support (Makori et al., 2019). Studies reveal both positive and negative associations: while technology can increase responsiveness and transparency, it can also exacerbate inequalities if poorly implemented or inaccessible to marginalized communities (UNDP, 2022).

Summary of Research Gaps

Despite increasing research on digital monitoring in sanitation, several gaps remain. First, most studies have examined the implementation of technological systems but not their effect on the sustainability of outcomes. Second, there is limited empirical evidence linking RTMIS functionality with measurable improvements in Kenya's sanitation service delivery. Third, prior studies often overlook the mediating role of institutional and human factors in sustaining technology-driven systems. Finally, few studies have developed comprehensive conceptual frameworks linking technological innovation to long-term sustainability in the sanitation sector. This study addresses these gaps by empirically examining how technology influences sustainable sanitation service delivery through the RTMIS in Kenya.

CONCEPTUAL FRAMEWORK

As shown in Figure 1 below, the conceptual framework illustrates the hypothesized relationships between technological factors and sustainable sanitation service delivery. The independent variable, which was Technological factors, was measured through indicators such as automation, digital infrastructure, interoperability, data management, and user support. Other mediating variable that explains the relationship between technology factors and sustainable sanitation service delivery include Institutional Support, User Capacity, and infrastructure Reliability.

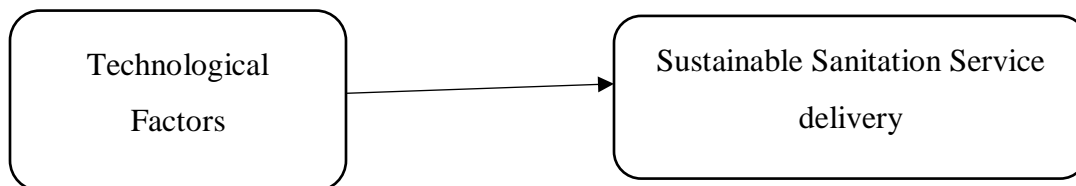


Figure 1: Conceptual Framework

The framework hypothesizes that the effect of technological innovation on sustainable sanitation service delivery is both direct and indirect, mediated by institutional, infrastructural, and human capacity factors.

METHODOLOGY

The overall objective of this study was to assess how technological factors influence sustainable sanitation service delivery within the context of Kenya's Nationwide Real-Time Monitoring Information System (RTMIS). Specifically, the study sought to determine the extent to which automation, digital infrastructure, interoperability, and user support as dimensions of technological innovation affect the efficiency, equity, and long-term sustainability of sanitation services. The study adopted a descriptive research design, integrating both quantitative and qualitative approaches to provide a comprehensive understanding of the relationship between technological innovation and sustainable sanitation service delivery. The research was conducted in Kenya, focusing

on counties implementing the RTMIS under the Ministry of Health's Environmental Health and Sanitation Unit. Kenya provides an appropriate context because it represents one of the earliest adopters of a nationwide real-time monitoring system in the sanitation sector across sub-Saharan Africa. The study targeted Community Health Promoters (CHPs), Sub-county and County Health Officers, National RTMIS administrators, and partner organizations working in sanitation service delivery. The target population was approximately 107,883 individuals drawn from both national and county-level actors involved in sanitation monitoring.

A sample of 394 respondents was selected using a combination of stratified, proportionate, and p sampling techniques. Stratified sampling ensured representation from different counties and administrative levels, while purposive sampling targeted key informants such as Ministry of Health officials, system developers, and partner organization representatives with specialized knowledge on RTMIS. The sample size for the community health promoters was determined using Cochran's formula for large populations, providing a statistically representative and reliable subset for data collection.

Primary data was collected through structured questionnaires administered to Community Health Promoters, while key informant interviews (KIIs) were conducted with RTMIS developers, policymakers, and NGO representatives. The questionnaires captured information on respondents' perceptions of technological innovation components, usability, and perceived sustainability of sanitation services. The KIIs provided deeper qualitative insights into implementation challenges, institutional support mechanisms, and system performance.

The data collection tools were pretested to ensure reliability and validity. Content validity was established through expert review by sector specialists, ensuring that the instruments captured all relevant dimensions of the study variables. Reliability was assessed using Cronbach's Alpha, with coefficients exceeding 0.70 for all key constructs, confirming internal consistency. Ethical considerations were observed throughout the research process, including informed consent, confidentiality, and voluntary participation.

Quantitative data were analyzed using Statistical Package for the Social Sciences (SPSS) version 27. Descriptive statistics such as means, standard deviations, and frequencies summarized respondent characteristics and variable distributions. Inferential analysis included correlation and multiple regression analysis to determine the relationship between technological innovation (independent variable) and sustainable sanitation service delivery (dependent variable).

The regression model used was specified as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + e$$

Where:

Y = Sustainable Sanitation Service Delivery

X = Technological factors (measured through automation, interoperability, user support, and digital infrastructure)

β_0 = Constant term

$\beta_1, \beta_2, \beta_3$ = Regression coefficient

e = Error term

The hypothesis tested was:

H₀: Technological innovation has no significant effect on sustainable sanitation service delivery.

H₁: Technological innovation has a significant effect on sustainable sanitation service delivery.

The decision rule was based on a 5% level of significance ($p < 0.05$). If the computed p-value was less than 0.05, the null hypothesis was rejected, indicating a significant effect. Qualitative data were analysed thematically to identify recurring patterns related to technology adoption, system sustainability, and institutional capacity. The findings from both data sets were triangulated to provide a holistic interpretation of results, strengthen validity, and explain contextual variations in RTMIS implementation across counties.

FINDINGS

The study aimed to assess the effect of technological innovation on sustainable sanitation service delivery, with specific reference to Kenya's Nationwide Real-Time Monitoring Information System (RTMIS). Quantitative findings are presented first, followed by interpretive discussions based on comparative literature.

Descriptive Findings

Descriptive analysis was conducted to determine respondents' perceptions of technology and its role in sustainable sanitation service delivery. Indicators included automation, digital infrastructure, interoperability, and user support. The results are summarized in Table 1.

Table 1: Descriptive Statistics for Technological Innovation Factors (n = 331)

Technological Innovation Indicator	Mean	Std. Deviation	Interpretation
Automation enhances data accuracy and timeliness	4.28	0.62	High
Digital infrastructure supports effective system access	4.12	0.71	High
Interoperability with other government platforms improves data sharing	4.01	0.78	High
User support and training enhance usability of RTMIS	3.89	0.85	Moderate
System reliability and maintenance affect functionality	3.75	0.92	Moderate

Composite Mean = 4.01 (High Agreement)

The results show that respondents had a high level of agreement ($M = 4.01$, $SD = 0.78$) that technological innovation, particularly automation and robust digital infrastructure, positively influences sustainable service delivery. However, moderate ratings on user support and system maintenance suggest challenges in technical assistance and continuous capacity building. These findings align with Bichang'a and Kimutai (2023), who observed that insufficient user training and weak maintenance frameworks undermine digital system sustainability in Kenya's public sector.

Inferential Findings

To determine whether technological innovation significantly influences sustainable sanitation service delivery, a simple linear regression model was used. The hypothesis tested was:

H₀: Technological innovation has no significant effect on sustainable sanitation service delivery.

H₁: Technological innovation has a significant effect on sustainable sanitation service delivery.

Table 2: Regression Analysis Results

Model	Unstandardized Coefficients (β)	Std. Error	t	Sig. (p-value)
(Constant)	2.721	0.185	14.71	0.000
Technological Innovation	0.412	0.092	4.48	0.000

Model Summary: $R = 0.562$, $R^2 = 0.316$, Adjusted $R^2 = 0.311$, $F(1,329) = 20.05$, $p < 0.05$

The regression results reveal that technological innovation significantly predicts sustainable sanitation service delivery ($\beta = 0.412$, $t = 4.48$, $p < 0.05$). The R^2 value of 0.316 implies that approximately 31.6% of the variation in sustainable sanitation service delivery is explained by technological innovation. Consequently, the null hypothesis (H_0) was rejected, confirming that technological innovation has a significant positive effect on sustainable sanitation service delivery in Kenya. These findings corroborate the results of Mukasa et al. (2023), who found that the integration of digital tools in Uganda's sanitation monitoring improved data accuracy and operational efficiency. Similarly, Lee et al. (2019) observed in South Korea that real-time monitoring technologies enhance service responsiveness and citizen satisfaction. However, the findings differ from those of Adams et al. (2021), who cautioned that technological systems may not lead to sustainability unless accompanied by strong institutional and financial support mechanisms.

Insights from Qualitative Findings

Qualitative interviews provided deeper understanding of implementation dynamics and contextual challenges. Three dominant themes emerged:

1. **Dependence on Internet Connectivity:** Many counties face inconsistent network coverage, particularly in rural areas, limiting data synchronization with RTMIS servers.
2. **Inadequate Capacity Development:** Respondents noted that initial RTMIS training was comprehensive, but refresher trainings were infrequent, leading to skill decay over time.
3. **Limited Technical Maintenance:** Several interviewees highlighted that system downtime often takes long to resolve due to centralized technical support at the national level.

These findings align with Ogunboye et al. (2023), who noted that inadequate user support and maintenance schedules hinder the long-term functionality of digital monitoring platforms in Nigeria. The findings also echo the Institutional Theory's assertion that systemic barriers such as bureaucratic inertia and weak capacity can constrain innovation outcomes despite high-level policy endorsement (Meyer & Rowan, 1977).

DISCUSSIONS

The study's results are consistent with global evidence emphasizing the transformative role of digital innovation in achieving sustainable development. The World Bank (2020) reported that countries adopting real-time monitoring technologies have achieved measurable improvements in sanitation coverage and service quality. Similarly, UNICEF (2021) observed that countries integrating digital monitoring platforms achieved faster progress toward Sustainable Development Goal 6 (SDG 6). However, the findings from this study highlight that the sustainability of such systems depends not merely on technology availability but also on governance structures, user engagement, and continued funding.

Comparatively, Addow and Jimale (2023) found that in Somalia, the Internet of Things (IoT)-based sanitation monitoring improved water quality management but required substantial investment in system reliability. In contrast, Kenya's RTMIS demonstrates scalability and functionality but still struggles with recurrent funding and maintenance challenges. These parallels reinforce the need for adaptive strategies to sustain technological systems in developing contexts. In addition, the study confirmed that technological innovation significantly enhances sustainable sanitation service delivery in Kenya. Automation, digital infrastructure, and interoperability emerged as the strongest contributors, improving data accuracy, accountability, and decision-making efficiency. Institutional support and policy alignment were found to mediate the relationship positively, while infrastructure reliability and user capacity remained moderate barriers. Overall, the evidence underscores that digital innovation, when supported by institutional and infrastructural capacity, is a critical determinant of sustainability in Kenya's sanitation sector.

CONCLUSION AND RECOMMENDATIONS

The purpose of this study was to assess how technological innovation influences sustainable sanitation service delivery, focusing on Kenya's Nationwide Real-Time Monitoring Information System (RTMIS). Guided by the hypothesis that technological innovation significantly affects sustainable sanitation service delivery, the study found a strong positive relationship between the two variables. Specifically, automation, interoperability, and digital infrastructure were shown to enhance efficiency, accountability, and reliability in sanitation services. However, limited technical capacity, inconsistent system maintenance, and infrastructural gaps were identified as key challenges undermining sustainability.

The findings affirm that technological innovation is a critical enabler of sustainable service delivery when supported by strong institutional frameworks and adequate user capacity. The study's results therefore lead to the rejection of the null hypothesis and the confirmation that technological innovation significantly influences sustainable sanitation service delivery in Kenya. From a theoretical perspective, the study contributes to the understanding of how technological innovation interacts with institutional and human factors to influence sustainability. It extends TAM by applying it to the sanitation sector and supports the Resource-Based View (RBV) in recognizing technology as a strategic asset for sustainable service efficiency.

From a policy standpoint, the Ministry of Health and county governments should strengthen digital infrastructure, allocate dedicated budgets for RTMIS maintenance, and institutionalize regular capacity-building initiatives for system users. Policies should also promote interoperability across government data systems to enhance coordination and accountability in sanitation planning. From a practical perspective, implementers and development partners should integrate user-centred design and continuous feedback

mechanisms to improve system reliability and usability. Public-private partnerships could be leveraged to support innovation and provide sustainable technical support for RTMIS operations.

Finally, the study identifies several areas for further research. Future studies could explore the long-term cost-effectiveness of digital monitoring systems in sanitation, comparative analyses of RTMIS implementation across counties, and the moderating effect of governance structures on technology adoption and sustainability. Longitudinal studies could also provide insights into how continued investment in digital innovation influences progress toward Sustainable Development Goal 6 (SDG 6) over time.

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