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Bridging the digital divide: exploring the challenges and solutions for digital exclusion in rural South Africa

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Abstract
Digital exclusion remains a pervasive challenge in rural South Africa, reinforcing existing socio-economic disparities, with communities such as Mkatazo village in the Eastern Cape experiencing compounded challenges, including inadequate infrastructure, prohibitive costs, and low digital literacy. This study examines the nature and consequences of digital exclusion through a localized quantitative assessment, framed within Van Dijk's Model of the Digital Divide and Sen's Capability Approach. A structured survey of 200 residents yielded 65 valid responses, revealing stark disparities: 52.3% lacked internet access, 38.5% cited affordability as a primary constraint, and 66.2% reported insufficient digital skills. Analytical methods included descriptive statistics, chi-square tests, t-tests, regression modeling, and effect size measurements (Cohen's d). Results identified cost, connectivity gaps, and geographic isolation as dominant predictors of exclusion, with affordability exerting the strongest influence. Digital exclusion adversely affects access to education, healthcare information, and economic participation, especially for youth and women. The study proposes a multi-tiered intervention framework that includes, broadband infrastructure expansion; targeted affordability measures such as subsidized device acquisition, zero-rating of mobile data and community-centric digital literacy initiatives and; the adoption of AI-enabled offline tools. The study aligns with global calls for digital equity and the United Nations Sustainable Development Goals, particularly Goals 1, 4, 8, 10, and 16. By responding to the lived realities of rural communities, this research contributes to the broader discourse on inclusive digital transformation and highlights the importance of stakeholder collaboration to address structural inequities, ensuring rural populations are not further marginalized in an increasingly connected world.

Keywords Digital exclusion · Rural South Africa · Digital literacy · Broadband infrastructure · Socio-economic development

1 Introduction

Digital exclusion, as defined by [1], refers to "a situation where a discrete sector of the population suffers significant and possibly indefinite lags in its adoption of Information and Communication Technology (ICT) through circumstances beyond its immediate control" (p. 375). This issue is particularly relevant in rural areas, where systemic barriers such as inadequate infrastructure, geographic isolation, and socio-economic constraints limit access to ICTs. In South Africa, rural areas like those in the Eastern Cape Province exemplify these challenges, with communities such as Mkatazo village facing significant barriers to digital inclusion.

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Mkatazo village was specifically chosen for this study due to the fact that it represents a typical South African community where limited ICT infrastructure, low digital literacy and affordability constraints can be found and was easily accessible to the researchers. Mkatazo village, located in Elliotdale, Eastern Cape, has a population of approximately 748 residents, most of whom rely on subsistence agriculture and informal trading for their livelihoods. The village has limited economic opportunities, with a high unemployment rate and low household incomes, making it difficult for residents to afford ICT resources. Education levels vary, but a significant proportion of the population lacks formal schooling or digital literacy training, further contributing to digital exclusion.

The availability of digital resources in Mkatazo village is limited. Although mobile networks provide basic 3G connectivity, there are no fiber-optic internet services, no public Wi-Fi zones, and no community-based telecentres to support digital access. The high cost of mobile data and the impending shutdown of 2G and 3G networks by 2027 [2] are expected to exacerbate existing digital disparities. In 2023, it was reported that internet speeds in rural South Africa were 14.4% slower for downloads and 29.2% slower for uploads compared to urban areas [3], which further highlights the digital divide.

The lack of digital access profoundly impacts the daily lives of residents. Students struggle to complete school assignments and access online learning platforms, as educational institutions increasingly rely on digital resources [4, 5]. Many small business owners and farmers are unable to leverage e-commerce platforms or digital financial services, limiting their ability to expand their businesses. Additionally, the absence of digital infrastructure restricts access to government services, healthcare information, and employment opportunities, forcing residents to travel to urban centres for basic services [6].

The lack of skills and knowledge required to use digital technologies effectively and safely contributes towards widening digital exclusion. Many residents of Mkatazo village lack adequate digital literacy to use computers or the internet effectively [7]. This skills and knowledge gap means that even when access to ICTs is available, many residents remain unable to use digital tools for education, business, or communication. Without targeted interventions to improve digital literacy, rural communities risk remaining marginalized from the digital economy, online education, and government e-services [8, 9]. The COVID-19 pandemic highlighted the importance of access to technology in education whilst at the same time shedding light on digital exclusion [10]. Digital exclusion barriers related to infrastructure, access, and socio-economic issues were identified as contributing factors to the surge in school and higher education dropout rates during COVID-19 [11, 12].

To conceptualise the multiple dimensions of digital exclusion, this study adopts van Dijk's resources and appropriation theory [13]. This framework emphasizes that digital access alone does not ensure inclusion, rather, it highlights a fourfold process comprising motivational access; material access; skills access; and usage access. These stages are influenced by unequal distribution of personal and positional resources such as income, education, age, and location which ultimately shape an individual's ability to appropriate ICTs for meaningful use. The theory is particularly relevant to the rural South African context, where infrastructural deficits intersect with limited digital literacy, economic marginalisation, and socio-cultural factors, reinforcing digital inequalities even in the presence of mobile connectivity [14–16]. Applying this theoretical lens allows the study to move beyond simplistic access measures and explore how residents in Mkatazo experience and engage with digital technologies across these layered dimensions.

The South African government is guided by the National Development Plan that identifies ICT as one of the critical enablers for economic activity and social development in an increasingly networked world [17]. The United Nations Sustainable Development Goals have placed emphasis on governments around the world to achieve 17 goals by 2030. Digital exclusion impacts on a number of goals such as Goal 1 (Poverty eradication), Goal 4 (Quality education), Goal 8 (Decent work and economic growth), Goal 10 (Reduced inequalities), and Goal 16 (Peace, justice and strong institutions) [18]. However, having ICT infrastructure does not translate into economic growth and social development unless digital exclusion barriers are eliminated. Low digital literacy, language obstacles, and limited access to ICT-integrated services are some of the disincentives for communities to actively participate in the digital economy [19]. According to the ten-year National Planning Commission's review of the National Development Plan – vision 2030, it states that inequality, unemployment and poverty continue to be the major challenges South Africa faces which may imply that an ICT enabling environment has not been fully realized [20].

Current studies on digital inclusion such as the OECD Digital Economy Outlook 2022 [21] and GSMA Mobile Economy Report 2023 [22] often focus on broad national and global trends, with emphasis on well-documented barriers such as infrastructure gaps, affordability, and digital literacy. While these studies provide valuable insights, they often generalize the experiences of rural populations without an in-depth localized analysis. Further, studies on digital exclusion in South Africa focus primarily on urban–rural divides but rarely explore the micro-level implications for specific rural communities

[23, 24]. There is limited research on the lived experiences of digital exclusion in rural South African villages like Mkatazo, particularly in how the absence of ICT access affects education, healthcare access, and local economic participation. This study seeks to fill this gap by providing a case-based, context-driven analysis of digital exclusion in Mkatazo village, examining its unique socio-economic challenges and proposing tailored interventions based on community needs.

Mkatazo village in the Eastern Cape Province is the focus of this study's empirical investigation, which aims to assess the extent and implications of digital exclusion in rural South Africa. To yield deeper insights into the dynamics of digital exclusion, this study adopts an intersectional approach, examining how disparities based on gender, age, education level, and location influence digital access and usage in Mkatazo village. Recognizing that access to ICTs is not uniform across all social groups, the analysis explores how intersecting forms of inequality shape individual and community experiences with technology. The impact of digital exclusion on healthcare, education, and economic participation, as well as the role that digital literacy plays in influencing digital engagement, are all examined in this study. Furthermore, it looks into the institutional and policy barriers that prevent digital inclusion and suggests workable solutions, such as customised digital literacy programs, affordability interventions, and infrastructure upgrades, to close the digital divide and advance socio-economic development in rural areas as envisioned by the UN Sustainable Development Goals and South Africa's National Development Plan vision 2030. The following are the objectives of this study:

1. To assess ICT availability, affordability, and usage in Mkatazo village, and identify key barriers to access.
2. To evaluate digital literacy levels and their effect on education, healthcare, and economic participation.
3. To evaluate digital literacy levels and how they affect ICT adoption.
4. To investigate policy and institutional barriers to digital inclusion.
5. To propose context-specific interventions to enhance digital accessibility and literacy.

The paper is structured as follows. We first consider the research context before presenting the theoretical background and describe our conceptual frameworks. We next describe the research design in terms of aims, data, and analyses. We then present a report on our findings that leads towards a discussion and conclusions.

2 Literature review

In the Amathole District Municipality, 84.6% of households reported having access to electricity, either for lighting alone (6.73%) or for lighting and other domestic uses (77.87%), while 15.4% of households had no electricity access [25]. However, rural settlements such as Mkatazo often experience unstable electricity supply and infrastructural challenges, which exacerbate digital exclusion. Fewer than 20% have a computer [26]. Approximately 35% of households in rural areas do not have dependable internet access [26], while about 70% of adults in Mbhashe Municipality have not finished secondary education [27]. These barriers related to infrastructure, education, and affordability highlight the various levels of digital exclusion that rural communities such as Mkatazo experience.

Digital exclusion is a subset of the digital divide in that it refers to the inability to use technology whereas the digital divide refers to the gap in accessing digital technologies [28]. While the terms *digital divide* and *digital exclusion* are often used interchangeably, they refer to different aspects of digital inequality. The digital divide has typically focused on access inequalities, which are the differences between individuals who possess physical access to ICT infrastructure and those who lack it [29]. Conversely, digital exclusion is a more extensive and complex idea, including not just access but also affordability, digital literacy, skill levels, usage habits, and the capacity to transform access into significant results [30, 31]. For instance, an individual might have internet access yet still face digital exclusion if they do not possess the skills to utilize it efficiently for educational, healthcare, or economic purposes.

Despite its ambitious targets for universal broadband access, SA Connect has largely underperformed, particularly in rural areas like Mkatazo. Phase 1 rollout lagged behind schedule due to funding shortfalls, poor coordination, and regulatory barriers [32, 33]. While it raised national awareness and initiated backbone infrastructure, rural households still lack affordable, stable connectivity [26]. Without major reforms, SA Connect risks further entrenching the digital divide it aimed to bridge.

Even with technological progress and growing internet access worldwide, rural regions continue to fall short compared to urban areas regarding infrastructure, digital literacy, and cost [3, 9]. The recent rapid rate of integration of Artificial Intelligence (AI) into sectors such as education has the potential to further widen the existing digital divide particularly

affecting communities such as Mkatazo village [34]. The next sections explore how digital exclusion manifests in rural areas, the obstacles to inclusion, and strategies to bridge the divide, drawing on recent literature.

2.1 Digital exclusion in rural areas

Digital exclusion in rural areas is marked by insufficient ICT infrastructure, restricted digital literacy, and affordability issues. Research shows that rural areas frequently encounter structural obstacles that worsen the digital divide [35]. In South Africa, the absence of public resources like telecentres, along with expensive internet access and devices, exacerbates the disparity between rural and urban regions [9]. A study by [36] highlighted that the slow pace of internet penetration in rural areas of South Africa was primarily due to factors like low income, poverty, underdeveloped infrastructure, illiteracy, and unemployment. These findings underscore the significant digital divide between urban and rural areas in South Africa, with rural communities facing substantial barriers to accessing broadband internet.

2.1.1 Infrastructure barriers

Dependable broadband infrastructure is fundamental to digital inclusion. Nonetheless, rural regions often do not possess the required connectivity to enable significant digital interaction. For example, [35] points out that merely 47% of rural homes in Europe are connected to high-speed broadband, while 80% of city homes enjoy this access. Comparable patterns can be seen in South Africa, where rural areas frequently rely on unreliable mobile networks due to insufficient funding for broadband infrastructure. Broadband access in rural South Africa faces numerous infrastructural challenges, such as insufficient network coverage, inconsistent electricity provision, and the expensive nature of installing and sustaining telecommunications infrastructure in isolated regions [37]. While infrastructure deficits remain a major barrier to digital inclusion in rural South Africa, mobile networks have emerged as an alternative means of expanding connectivity. However, their potential is not without significant limitations. For instance, mobile networks have expanded internet access in rural areas like Mkatazo, offering a vital connection where fixed-line infrastructure is absent [26]. However, high data costs, unstable coverage, and slow speeds limit meaningful digital engagement [38]. Thus, while mobile access is essential, it remains an incomplete solution for true digital inclusion.

2.1.2 Financial limitations

The steep prices of digital devices and internet connectivity create a major obstacle to inclusion. The Competition Commission South Africa and [39] confirmed that affordability is still a key factor restricting ICT adoption in low-income areas [40]. In South Africa, the costs of data plans and devices frequently surpass what rural residents can afford, compelling them to depend on sporadic and restricted access [4]. A report by [41] highlights that mobile data prices in South Africa are still among the highest in the world, particularly impacting rural regions.

2.1.3 Digital literacy challenges

Digital literacy is essential for empowering individuals to utilize ICT tools efficiently. Nevertheless, rural areas often have limited access to training programs, resulting in many locals being unable to use digital technologies for educational, employment, or business needs. [42] highlights that incorporating digital skills into school curricula and community initiatives is crucial for closing the digital gap. Research indicates that rural teachers frequently lack the training required to integrate digital literacy into their instruction, exacerbating the difficulties encountered by students [43, 44].

2.1.4 Artificial intelligence (AI)

Artificial Intelligence (AI) has the potential to significantly impact various sectors, but its benefits are not uniformly distributed, often leading to exclusion, particularly in rural areas. Rural areas often suffer from inadequate internet infrastructure, which is crucial for leveraging AI technologies. Limited access to high-speed internet widens the digital divide, making it difficult for rural populations to benefit from AI advancement [45, 46]. The high cost of internet access and the lack of technological infrastructure especially in developing nations situated in sub-Saharan Africa and Latin America further hinder the adoption of AI, leading to social and economic exclusion [47, 48]. In healthcare, AI has the potential to transform how access to quality healthcare is experienced through improved diagnosis, disease surveillance, and resource

allocation by improving accuracy and efficiency [34]. In education, AI has disrupted the way of doing things to the extent that it has the potential to offer personalized learning experiences tailored to individual student needs [49]. AI use for economic development has seen transformative changes in various industries through the automation of routine tasks, enhancement in decision-making, and fostering of innovation [50]. Within rural settings AI adoption has the potential to widen digital exclusion because it requires high-speed internet infrastructure; there is a lack of basic services in rural settings and this hinders the implementation of advanced technologies due to the need to balance competing socio-economic needs and; AI requires digital literacy [51]. For rural settings to benefit from AI, there is a need to address these challenges by providing targeted investments in infrastructure, education, and regulatory support to ensure that AI can be a tool for inclusion rather than exclusion.

2.2 Impacts of digital exclusion

Digital exclusion has far-reaching implications for rural areas, affecting education, healthcare, and economic activities.

2.2.1 Education

The lack of digital resources in rural schools limits students'ability to access online learning platforms and educational materials. [44] notes that rural schools in South Africa often lack computer labs and reliable internet access, leaving students disadvantaged compared to their urban peers. A study by [52] highlights that the digital divide in education disproportionately affects girls in rural areas, further deepening gender inequalities. Additionally, there is a need to ensure appropriate strategies are applied within rural contexts to maximize the full potential of technology adoption in education and limit the widening of digital exclusion [53].

2.2.2 Healthcare

Digital exclusion limits access to e-health programs, including telemedicine. Residents in rural areas cannot take advantage of remote healthcare services because of inadequate connectivity and limited digital literacy, exacerbating health disparities [37]. A recent study conducted by [54] highlights those digital resources for health education and disease management are still not widely used in rural South Africa because of infrastructure and skill-related obstacles.

2.2.3 Economic activities

Small businesses in rural areas face challenges in leveraging digital tools for marketing, communication, and operations. High costs and unreliable internet connections hinder their ability to compete in broader markets, perpetuating economic inequalities [55]. Digital inclusion enables entrepreneurs to overcome social and cultural limitations, participate in entrepreneurial activities, and contribute to economic growth [56].

2.3 Strategies for addressing digital exclusion

Addressing digital exclusion in rural areas requires a multi-faceted approach involving infrastructure development, affordability initiatives, and community engagement.

2.3.1 Infrastructure development

Investing in broadband infrastructure is essential for ensuring reliable and affordable internet access in rural areas. Public–private partnerships can play a critical role in bridging the"last mile"connectivity gap, bringing high-speed internet to underserved regions [57]. Additionally, community network models, where local residents manage and maintain infrastructure, have shown promise in expanding connectivity to remote areas [37].

2.3.2 Digital literacy programmes

Thorough digital literacy initiatives are essential to provide rural inhabitants with the necessary skills to maneuver through the digital landscape. [42] supports the incorporation of digital skills into educational programs and the creation of community training centers to tackle these issues. Programs such as Google's"Grow with Google"have effectively improved digital skills in rural areas by offering accessible training resources [58].

2.3.3 Initiatives for affordability

Subsidizing internet service and device costs can greatly enhance digital access for rural households with low incomes. Policies that encourage competition between service providers can additionally aid in lowering costs and enhancing affordability [59]. Despite regulatory efforts, data prices remain high, particularly affecting low-income consumers. There is need for more effective regulatory interventions and increased competition among service providers to achieve significant reductions in mobile data tariffs [60].

2.3.4 Involvement of the community

Involving local communities in the creation and execution of digital inclusion initiatives guarantees that the solutions are customized to meet their unique requirements. Collaboratively designing applications for education, healthcare, and economic functions can enhance adoption and significance [42]. In Africa, initiatives such as Kenya's community-owned broadband networks [61] and Rwanda's Smart Villages project [62] demonstrate the effectiveness of localized, community-driven approaches in extending digital access to underserved rural areas. Similarly, studies by Research ICT Africa [38] show that affordability and infrastructural gaps remain the greatest barriers to digital inclusion across rural South Africa. Furthermore, the"Smart Villages"program, initiated by the European Commission acts as an example of utilizing community-focused strategies to close the digital gap [35].

2.4 Conceptual framework

In order to explain the relationships between key variables in a study, the Van Dijk's model of digital divide and Sen's capability approach theoretical frameworks were found to be relevant. The Van Dijk's model of digital divide [63] conceptualizes digital exclusion as a four-level digital divide that consists of: (1) Motivational Access—The willingness and perception of ICT as useful in daily life; (2) Material Access—Availability of internet-enabled devices and connectivity; (3) Skills Access—The ability to use ICT effectively; and (4) Usage Access—The actual integration of digital technology into work, education, and social life. The Sen's Capability Approach [31] suggests that development should be measured not just by economic growth but by people's ability to exercise freedoms and opportunities in key areas such as education, employment, and social participation. By integrating Van Dijk's Digital Divide Model and Sen's Capability Approach, this study conceptualizes digital exclusion as a multi-dimensional issue that goes beyond access to devices and the internet but also affects education, employment, and economic participation. The framework incorporates three key dimensions as follows:

1. Structural barriers (infrastructure and cost): Aligning with Van Dijk's material access component and Sen's capability limitations.
2. Digital literacy and skills: addressing components in Van Dijk's (skills and usage access).
3. Socio-economic outcomes: using Sen's framework to analyze how digital access (or lack thereof) affects individuals' ability to convert resources into meaningful opportunities.

3 Methodology

The methodology of this study employed a quantitative approach to investigate the extent and contributing factors of digital exclusion in rural areas. The research targeted the rural community of Mkatazo, specifically individuals aged 15 and above, including students, business owners, and unemployed community members.

A probabilistic sampling technique was used to ensure that each respondent in the target population had an equal opportunity of being chosen, reducing selection bias and improving the sample's representativeness. In particular, simple random sampling was used to select respondents from a list of community residents in Mkatazo village, Eastern Cape. This method adheres to established standards in quantitative research [64], ensuring that the results can be generalized to the broader rural population facing digital exclusion. A total of 200 participants were initially selected using a randomization process to ensure diverse representation across age, gender, and socio-economic backgrounds. However, due to logistical challenges and participation constraints, only 65 respondents fully completed the survey, resulting in a response rate of 32.5%. Although the attrition rate was 67.5%, a post-hoc power analysis indicated that a sample size of 65 remains sufficient to detect medium effect sizes (Cohen's $d = 0.5$) with a power of 0.80 at a 5% significance level [65]. Furthermore, to assess potential non-response bias, demographic profiles (gender, age group, education level) of the respondents were compared to those of the initially selected population, revealing a broad consistency that supports the sample's representativeness. Thus, despite the reduced sample size, the probabilistic nature of the sampling method, the statistical sufficiency, and the demographic comparability together strengthen the validity and reliability of the study's findings. Ethical standards were strictly adhered to, with respondents giving informed consent and being assured confidentiality and voluntary involvement. For respondents with low literacy, the study purpose and consent terms were explained verbally in IsiXhosa, and verbal consent was documented in accordance with ethical standards.

Data gathering was carried out through structured questionnaires distributed online and face-to-face. The surveys featured multiple-choice type of questions, translated into IsiXhosa, a predominant language spoken in the region to improve accessibility for those respondents who are less proficient in English.

Data collection was conducted using structured questionnaires administered primarily through face-to-face questionnaires, with a smaller proportion completed online where participants indicated reliable internet access. Of the 65 responses, 83% ($n = 54$) were collected through face-to-face administration and 17% ($n = 11$) through online distribution. Prioritizing in-person data collection ensured the inclusion of participants affected by limited internet access, thus aligning with the study's focus on digital exclusion.

To enhance the reliability and accessibility of the instrument, the survey questionnaire was pilot-tested on a small group of 10 residents from a neighboring rural community before full deployment. Feedback from the pilot informed minor adjustments for clarity and cultural appropriateness. The study also accounted for load-shedding disruptions during fieldwork by scheduling interviews during periods of available power and using battery-operated devices to ensure data collection continuity. Additionally, to ensure linguistic accuracy, the questionnaire was translated into IsiXhosa and then back-translated into English by a second independent translator. This process verified that the meaning of the questions remained consistent across both language versions, minimizing translation errors and improving comprehension among IsiXhosa-speaking participants. The questionnaire included essential subjects

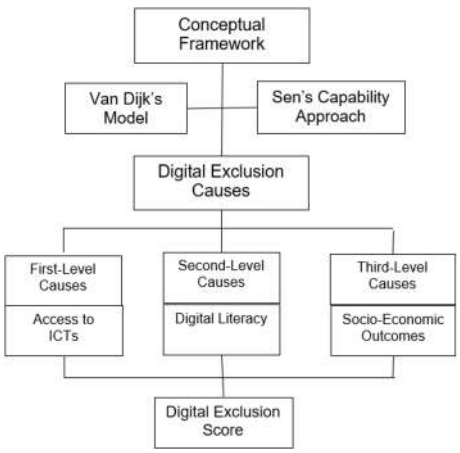


Fig. 1 Conceptual frame on variable linkages to Van Dijk's Model and Sen's capability approach

Table 1 Gender

Gender				
	Frequency	Percent	Valid percent	Cumulative percent
Valid				
Male	25	38.5	38.5	38.5
Female	39	60.0	60.0	98.5
Other	1	1.5	1.5	100.0
Total	65	100.0	100.0	

Table 2 Age

Age group				
	Frequency	Percent	Valid percent	Cumulative percent
Valid				
15–20	29	44.6	44.6	44.6
21–24	21	32.3	32.3	76.9
25 and above	15	23.1	23.1	100.0
Total	65	100.0	100.0	

such as demographics, availability of digital devices and the internet, obstacles to accessing the internet, and the utilization of digital tools for educational, professional, and personal reasons.

The gathered data underwent analysis with descriptive statistics, and the outcomes were shown through graphs, tables, and percentages. For purposes of generalization of results, additional statistical tests beyond descriptive statistics were also undertaken to evaluate the relationships between key variables. As shown in Fig. 1, variables were aligned with the integrated conceptual framework combining Van Dijk's model of stages of access to digital technology and Sen's capability approach. Material access (device ownership, internet access), skills access (digital literacy and confidence), usage access (internet use for education, work, social activities), and achieved outcomes (impact on education and employment) were systematically measured. Digital exclusion was defined as compounded limitations across these access stages, operationalized through survey data, and summarized into a Digital Exclusion Score based on infrastructural and affordability barriers. The tests included Chi-Square analysis, T-tests, effect size measurements (Cohen's d), and regression analysis. Missing data were handled using listwise deletion, where cases with incomplete responses on variables involved in specific analyses were excluded from that analysis. This approach preserved the internal validity of inferential tests without introducing imputed or estimated values, which could be problematic given the small sample size. All statistical analyses were conducted using SPSS Version 26. Hence, the methodology ensured a systematic approach to exploring enhanced inclusivity, cultural relevance, and the validity of findings in a digitally marginalized rural context in the Mkatazo community.

4 Results

This section presents the results of the analysis and interpretation of the data collected during the study. The findings are structured to address the research objectives, highlighting the extent of digital exclusion in Mkatazo, Elliotdale, and its implications for education, employment, and socio-economic activities. As indicated in the previous section, results are presented through Descriptive Statistics (Basic distributions, graphs, and summary tables) and Inferential Statistical Analysis (Chi-Square tests, T-tests, Effect sizes, and Regression) as follows:

Table 3 Level of education

Education level				
	Frequency	Percent	Valid percent	Cumulative percent
Valid				
No response	2	3.1	3.1	3.1
High school	17	26.2	26.2	29.2
Undergraduate	21	32.3	32.3	61.5
Graduate	23	35.4	35.4	96.9
Primary school	1	1.5	1.5	98.5
Junior school	1	1.5	1.5	100.0
Total	65	100.0	100.0	

Table 4 Locality distribution

Locality				
	Frequency	Percent	Valid percent	Cumulative percent
Valid				
Mkatazo	20	30.8	30.8	30.8
Bafazi	17	26.2	26.2	56.9
KwaNditya	28	43.1	43.1	100.0
Total	65	100.0	100.0	

4.1 Descriptive statistics

4.1.1 Respondent demographics

The study surveyed respondents from Mkatazo, representing diverse socio-economic backgrounds. Tables 1, 2, 3 and 4 present key demographic insights that characterize the sample used in this study.

In Table 1, the gender distribution of respondents indicates that the majority (60.0%) were female, while males constituted 38.5%, with a small percentage (1.5%) identifying as other. This distribution is marginally above the national average, with the 2024 Mid-year Population Estimates indicating that women make up 51% of South Africa's population [66]. The higher number of female respondents in this study might indicate larger socio-economic patterns in rural areas, where women tend to participate in community surveys more often because of their involvement in education, caregiving, and local economic roles. Moreover, digital exclusion impacts women in rural regions more significantly, restricting their access to ICT resources, digital literacy education, and job opportunities.

This study categorizes age groups as follows: school-going age, with a high Likelihood of being dependent on caregivers for access to ICTs (15–20 years); transitioning into independent living and careers, often in tertiary education or early job-seeking stage and may show emerging digital needs (e.g., for study or job applications) (21–24 years) and lastly; adulthood, may be household heads, caregivers, or income earners and more likely to interact with ICT for work, small business, or administrative tasks (25 and above). The distribution in Table 2 highlights a predominantly youthful population, with over 76% under the age of 25, which has implications for digital literacy, device ownership, and the types of digital resources needed.

The data in Table 3 highlights significant disparities in educational attainment within the surveyed population, reflecting broader digital inequality challenges in rural South Africa. While 32.3% of respondents were still pursuing post-schooling studies, only 35.4% had completed a graduate-level education. This relatively low percentage of graduates suggests systemic barriers that hinder progression to higher education. This may be attributed to financial constraints, limited access to digital learning resources, and inadequate digital literacy training that continue to

Fig. 2 Computer ownership

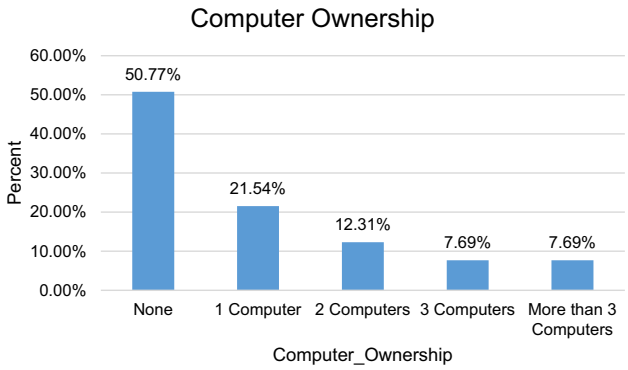
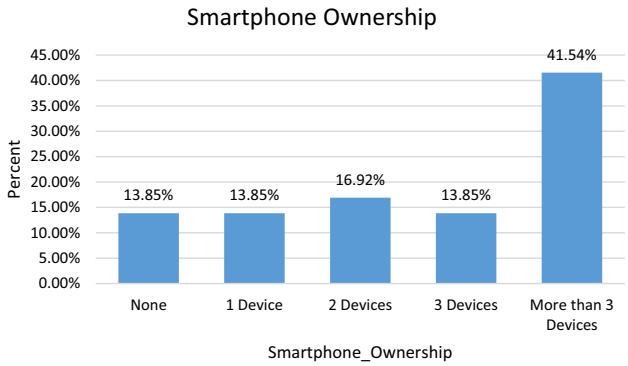


Fig. 3 Household smartphone and digital device ownership



restrict opportunities for academic advancement. Additionally, the presence of respondents with only junior school education (1.5%) or high school completion (26.2%) further underscores the educational divide, which is exacerbated by the lack of digital infrastructure and high internet costs in rural communities. These findings align with existing research on digital exclusion, demonstrating how unequal access to ICTs perpetuates educational disparities and limits socio-economic mobility in digitally marginalized areas. Addressing these barriers through targeted digital literacy programs, improved broadband access, and financial support for students could help bridge the digital divide and promote equitable education opportunities.

Table 4 shows that the survey covered respondents from KwaNditya (43.1%), Mkatazo (30.8%), and Bafazi (26.2%). These are small localities within the Mkatazo village.

These demographics provide a foundational understanding of the community's characteristics and their relevance to digital exclusion. The next set of results represent the structural barriers (infrastructure & cost); digital literacy and skills and; socio-economic outcomes as per the contextual frameworks for this study.

4.1.2 Access to ICT tools

Access to digital tools remains a critical barrier for the community:

4.1.2.1 Computer access The data in Fig. 2 reveals a significant lack of access to computers among the respondents, with 50.77% reporting no computer ownership. Among those who had access, 21.54% owned one computer, 12.31% owned two, while 15.38% owned three or more computers. This disparity highlights the substantial digital divide in rural areas, where limited access to essential ICT tools restricts educational, professional, and entrepreneurial opportunities.

4.1.2.2 Smartphones ownership The data in Fig. 3 indicates that 13.85% of households do not own smartphones. 41.54% reported to own more than three devices, 13.85% indicated they own three devices, 16.92% indicated they own two devices and 13.85% own one device. However, many of these devices were basic models, lacking the advanced functionalities required for educational and professional purposes. This limitation hinders the effective use of ICT tools in

Table 5 Internet access distribution

Internet access				
	Frequency	Percent	Valid percent	Cumulative percent
Valid				
No access	34	52.3	52.3	52.3
Full access	24	36.9	36.9	89.2
Limited access	7	10.8	10.8	100.0
Total	65	100.0	100.0	

Table 6 Reasons for lack of internet connection

Internet barrier				
	Frequency	Percent	Valid percent	Cumulative percent
Valid				
Cannot use from my region	4	6.2	6.2	6.2
Cost too much	25	38.5	38.5	44.6
Connection problems	6	9.2	9.2	53.8
No tower	4	6.2	6.2	60.0
Connection but no access	8	12.3	12.3	72.3
Have connection	18	27.7	27.7	100.0
Total	65	100.0	100.0	

bridging the digital divide, particularly in rural areas where smartphones are often the primary means of accessing digital resources.

A respondent explained, "*I've never used a computer in my life; we only have one at school, and it's always locked.*" Such comments highlight how limited device access affects both exposure and confidence in using digital tools, supporting the finding that over half of the respondents had no computer access.

These findings highlight a significant gap in access to essential ICT tools, emphasizing affordability as a key barrier. The next set of results capture the connectivity aspect that includes availability, barriers, usage intent and access.

4.1.3 Internet connectivity

Internet access was identified as a significant challenge as follows:

4.1.4 Availability of internet

Table 5 presents the distribution of internet access among respondents. It reveals considerable obstacles in internet access faced by the respondents. Just over half (52.3%) of respondents lacked internet access, indicating a substantial digital divide affecting educational and employment opportunities, whereas 36.9% reported full access. A minor proportion of respondents indicated occasional access, with 10.8% experiencing limited access to the internet. These results highlight the significant influence of geographic limitations and insufficient infrastructure on internet access in rural regions. The inconsistency in access restricts chances for education, jobs, and communication while also sustaining the digital divide.

4.1.4.1 Barriers to internet connectivity Table 6 shows information regarding the obstacles to internet access faced by respondents. Cost barriers (38.5%) emerged as the dominant impediment to internet access, consistent with

Table 7 Internet usage at home

Internet usage intention				
	Frequency	Percent	Valid percent	Cumulative percent
Valid				
Education	47	72.3	72.3	72.3
Work	7	10.8	10.8	83.1
Entertainment	3	4.6	4.6	87.7
Don't use at home	4	6.2	6.2	93.8
Social media	2	3.1	3.1	96.9
Education and work	2	3.1	3.1	100.0
Total	65	100.0	100.0	

Table 8 Competences

Competency level				
	Frequency	Percent	Valid percent	Cumulative percent
Valid				
Agree	43	66.2	66.2	66.2
Disagree	7	10.8	10.8	76.9
Neutral	10	15.4	15.4	92.3
Strongly disagree	5	7.7	7.7	100.0
Total	65	100.0	100.0	

prior rural digital inequality research. One unemployed youth noted, "*Even when we have signal, there's no data, it's too expensive. Sometimes it loads, sometimes it doesn't.*" This quote reflects the 27.7% of respondents who reported having a connection but still faced barriers, reinforcing the conclusion that infrastructure alone does not guarantee meaningful access.

This indicates that even with available connectivity, elements like poor digital literacy, lacking device functionality, or unreliable infrastructure may hinder substantial internet usage. Moreover, 12.3% of those surveyed indicated they had a connection lacking reliable internet access, highlighting the shortcomings in infrastructure even more. Additional obstacles comprised 9.2% mentioning ongoing connectivity issues, 6.2% unable to reach the internet in their area, and another 6.2% noting the lack of communication towers. These findings address Objective 1 by quantifying the extent of material and infrastructural exclusion in the Mkatazo community. The results highlight effectively the problem of digital exclusion in rural regions, where possessing a connection does not automatically mean efficient internet use. Tackling this problem necessitates a holistic strategy, which involves improving infrastructure, implementing digital literacy initiatives, and providing affordable internet services to guarantee that connected individuals can fully utilize their access to digital resources and opportunities.

4.1.4.2 Internet usage intention Table 7 highlights the primary reasons why respondents wish to use the internet. The majority (72.3%) of respondents intend to use the internet primarily for educational purposes, underscoring its critical role in supporting learning and skill development in rural areas. A smaller proportion (10.8%) reported a wish to use the internet for work-related activities, reflecting limited opportunities for remote work in these regions. Other use intentions were notably less common, with only 4.6% wishing to use the internet for entertainment and 3.1% for social media. Additionally, 6.2% of respondents indicated that they did not use the internet at home despite having access, and 3.1% combined internet use for both education and work purposes. These findings emphasize the importance of prioritizing digital infrastructure and affordable internet access to support education in rural areas. The low percentages for work and entertainment suggest that while education is a significant driver of internet use, broader access to employment and leisure opportunities through the internet remains underutilized.

Together, the data indicate that cost, poor infrastructure, and unreliable connections are the dominant factors driving internet inaccessibility in Mkatazo. The next section presents digital literacy levels measured by skills gap and confidence levels.

4.1.5 Digital literacy levels

Digital literacy remains a critical barrier to meaningful digital inclusion.

4.1.5.1 Skills gap Participants were asked to indicate their level of agreement with the statement: "*I require assistance when using the internet*." Their responses as presented in Table 8 highlight the notable digital literacy obstacles encountered by the respondents. A significant portion (66.2%) reported needing help with internet usage, underscoring the widespread issue of low digital literacy in the community. At the same time, merely 10.8% disagreed with this assertion, and 15.4% stayed neutral, indicating that a significant segment of the population might lack complete confidence in their digital skills. Moreover, 7.7% firmly disagreed, showing a minority with greater degrees of digital self-sufficiency. These results highlight a significant skills gap that hinders residents from fully utilizing accessible digital technologies and online resources, thereby worsening digital exclusion.

4.1.5.2 Confidence levels Participants were asked to indicate their level of agreement with the statement: "*I feel confident using the internet for basic activities*." Their responses as presented in Table 9 reveals differing degrees of confidence in internet use among respondents. Although 66.2% showed confidence in fundamental internet abilities ("Agree"), a mere 3.1% reported strong confidence ("Strongly Agree"), implying a lack of expertise in more complex digital activities necessary for work and learning. A significant 21.5% of respondents stayed neutral, suggesting possible uncertainty or limited experience with using the internet. Moreover, 4.6% of those surveyed did not feel confident, and another 4.6% strongly disagreed, indicating difficulties even with basic digital skills.

As one young adult put it, "*I only use WhatsApp. I don't know how to search for jobs or do online applications, no one ever taught me*." This reflects the 66.2% who indicated needing help with internet use, emphasizing the digital skills gap even among the youth. These statistics highlight that although numerous respondents have a fundamental understanding of the internet, there remains a notable deficiency in the advanced skills required for complete engagement in the digital economy.

Addressing this skills gap is essential for ensuring that access to digital tools translates into meaningful engagement. The next set of results capture the socio-economic implications that includes purposes of internet access, employment and economic outcomes.

4.1.6 Socio-economic implications

The study revealed far-reaching socio-economic implications of digital exclusion:

4.1.6.1 Internet access for educational purposes Table 10 presents the major digital obstacles encountered by students when trying to access online learning materials. The highest portion (47.7%) of respondents strongly opposed

Table 9 Confidence levels in internet use

Confidence level				
	Frequency	Percent	Valid percent	Cumulative percent
Valid				
Agree	43	66.2	66.2	66.2
Disagree	3	4.6	4.6	70.8
Neutral	14	21.5	21.5	92.3
Strongly disagree	3	4.6	4.6	96.9
Strongly agree	2	3.1	3.1	100.0
Total	65	100.0	100.0	

Table 10 Internet access by students

Student internet access				
	Frequency	Percent	Valid percent	Cumulative percent
Valid				
No response	26	40.0	40.0	40.0
Agree	3	4.6	4.6	44.6
Disagree	2	3.1	3.1	47.7
Neutral	3	4.6	4.6	52.3
Strongly disagree	31	47.7	47.7	100.0
Total	65	100.0	100.0	

the idea that they have sufficient internet access for educational use, suggesting that many students face difficulties in utilizing digital learning platforms. Just 4.6% of respondents agreed, while an additional 4.6% stayed neutral, indicating that a limited number of students might have some access but encounter obstacles. Moreover, 3.1% expressed disagreement, highlighting the extensive absence of dependable connectivity. The absence of internet access greatly limits students'capacity to engage in online learning, perform research, and finish digital assignments. Many are forced to travel to urban centers to access educational resources, which imposes financial and logistical burdens that further widen the educational gap between rural and urban learners.

A student shared, "I missed the application deadline because I couldn't upload my documents — the network kept cutting off." This supports the data showing that only 4.6% of students agreed they had reliable access for learning, highlighting how digital exclusion directly impedes educational progress and upward mobility.

4.1.6.2 Employment and economic activities Job seekers faced significant barriers in accessing online job portals and uploading application documents, this viewpoint is derived from results shown in Figs. 1 and 2, Tables 5, 6 and 10. Low bandwidth and high costs further compounded these challenges.

These technical and affordability barriers such as low bandwidth and high data costs not only block access but also diminish the capability to pursue employment. As Sen's Capability Approach emphasizes, true development requires more than resources; it demands the freedom to convert those resources into meaningful outcomes. In this case, digital exclusion reduces individuals' economic agency and mobility, reinforcing structural poverty and limiting their ability to participate in the broader digital economy.

The findings illustrate the multi-faceted nature of digital exclusion in Mkatazo, driven by limited access to ICT tools, unreliable internet, low digital literacy, and socio-economic constraints. The next section presents inferential statistics such as Chi-Square tests, T-tests, Cohen's d and multiple linear regression analysis.

4.2 Inferential statistical analysis

4.2.1 Chi-square test (testing categorical relationships)

Chi-Square tests were performed to determine whether gender, age, education level, and locality significantly influence internet access and digital exclusion. The findings revealed:

- No significant association between gender and internet access ($\chi^2 = 4.785$, $p = 0.310$).
- No significant relationship between education level and internet access ($\chi^2 = 10.903$, $p = 0.365$).
- No significant effect of locality on internet access ($\chi^2 = 2.999$, $p = 0.558$).
- No significant age-based differences in internet access ($\chi^2 = 5.225$, $p = 0.265$).

These results suggest that internet access disparities are not driven by demographic differences but likely by external factors such as infrastructure and affordability.

Table 11 Effect size

Variable	Cohen's d	Effect strength
Internet access (male vs. female)	0.442	Small effect
Internet barriers (male vs. female)	0.447	Small effect
Education level (male vs. female)	− 0.226	Negligible

Table 12 Significant predictors of digital exclusion

Coefficients[a]							
Model	Unstandardized coefficients		Standardized coefficients	t	Sig	Collinearity statistics	
	B	Std. error	Beta			Tolerance	VIF
(Constant)	6.077	0.274		22.157	0.000		
Exclusion_Cost	− 3.680	0.102	− 0.989	− 35.987	0.000	0.798	1.254
Exclusion_Connection	− 2.236	0.139	− 0.445	− 16.123	0.000	0.789	1.268
Exclusion_Region	− 4.627	0.213	− 0.614	− 21.689	0.000	0.751	1.332
Competency_Level	− 0.058	0.048	− 0.032	− 1.212	0.231	0.873	1.146
Age_Group	0.020	0.061	0.009	0.334	0.740	0.835	1.198
Education_Level	− 0.023	0.048	− 0.012	− 0.478	0.635	0.919	1.088
Locality	− 0.002	0.057	− 0.001	− 0.041	0.968	0.825	1.212
Computer_Ownership	− 0.014	0.037	− 0.010	− 0.363	0.718	0.864	1.157
Smartphone_Ownership	− 0.074	0.031	− 0.060	− 2.399	0.020	0.948	1.055

[a]Dependent variable: Internet_Barrier

4.2.2 Independent samples T-test (comparing means between groups)

To further examine differences between groups, T-tests were performed on gender-based variations in digital competency, education levels, and internet barriers. Key results:

- No significant gender difference in confidence levels ($p = 0.470$).
- No significant gender effect on education levels ($p = 0.382$).
- Showed a trend approaching significance of gender effect on internet access ($p = 0.089$), suggesting men may have slightly better access, which is not conclusive.
- Showed a trend approaching significance of gender effect on digital barriers ($p = 0.086$), suggesting there are different barriers for men and women, but not conclusive.

Although no strong differences were found, internet access and digital barriers showed marginal significance, indicating that external factors beyond individual characteristics shape digital exclusion.

4.2.3 Effect size (Cohen's d)

Effect size analysis using Cohen's d measured the strength of gender-based differences. According to standard thresholds: Small effect: $d = 0.2–0.5$; Medium effect: $d = 0.5–0.8$; Large effect: $d > 0.8$. Table 11 shows the effect strengths of gender differences in internet access, internet barriers and education level:

The analysis revealed small effect sizes for gender differences in internet access ($d = 0.442$) and internet barriers ($d = 0.447$), suggesting that while the statistical differences were not significant, there are small practical disparities in how men and women experience digital exclusion. The effect size for education level by gender ($d = -0.226$) was negligible, indicating minimal difference.

4.2.4 Multiple regression analysis predicting internet barriers

Table 12 presents the results of a multiple linear regression analysis conducted to evaluate the relative contribution of digital exclusion, access, and demographic variables in predicting perceived internet barriers among rural South African residents. The table details the unstandardized and standardized coefficients, significance levels, and multicollinearity diagnostics for each predictor variable included in the model. Its purpose is to illustrate the statistical strength, direction, and relevance of each factor in explaining variations in the outcome variable (Internet_Barrier).

The model was statistically significant, $F(9, 55) = 178.484$, $p < 0.001$, and accounted for 96.7% of the variance in Internet_Barrier ($R^2 = 0.967$, Adjusted $R^2 = 0.961$), indicating a robust explanatory model. Among the predictors, cost is the strongest predictor, $\beta = -0.989$, $p < 0.001$, followed by region ($\beta = -0.614$, $p < 0.001$) and connection ($\beta = -0.445$, $p < 0.001$). These results suggest that cost, geographic constraints, and network quality significantly shape rural residents' perceptions of internet accessibility. Notably, smartphone ownership was also a significant predictor ($\beta = -0.060$, $p = 0.020$), suggesting that mobile device access plays a modest yet statistically relevant role in reducing perceived barriers. In contrast, demographic factors such as age, educational level, locality, and computer device ownership were not statistically significant ($p > 0.05$). Furthermore, competency level, while conceptually relevant, did not reach significance in this model, possibly due to its collinearity with structural variables. Collinearity diagnostics confirmed the statistical independence of predictors (all VIFs < 1.35), ensuring model reliability. Overall, the findings highlight the predominance of structural digital exclusion, especially cost and regional factors over individual characteristics in shaping digital disadvantage in underserved rural communities.

4.2.5 Summary of key insights

The findings of this study offer compelling support for the adopted conceptual framework that combines Van Dijk's model of the digital divide with Sen's capability approach. This framework views digital inequality as a layered phenomenon shaped by interdependent causes: access to ICTs (first-level causes), digital literacy (second-level causes), and the ability to convert access into socio-economic outcomes (third-level causes). The empirical results reinforce this sequence, showing that barriers at the access level, particularly cost and infrastructure form the most immediate and powerful constraints. According to Van Dijk's first-level exclusion, unequal access to ICTs is a foundational driver of exclusion. In Mkatazo, digital exclusion is driven more by structural barriers particularly cost, connectivity, and geographic isolation rather than by demographic differences. This is evident in both statistical and qualitative results: the regression analysis confirmed that affordability ($\beta = -0.989$), regional isolation ($\beta = -0.614$) and connection ($\beta = -0.445$) were statistically the strongest predictors of digital exclusion and; qualitatively, 38.5% of respondents cited cost as the primary barrier to internet access, while others noted challenges like weak signal and unaffordable data. One student remarked, "*I sometimes walk to the town library just to download assignments because I can't get signal or afford data at home*," illustrating how affordability limits educational participation and supports the statistical findings.

Conversely, competency level of respondents ($\beta = -0.032$, $p = 0.231$) was not statistically significant, indicating that digital literacy, while important, does not explain variation in perceived barriers among this sample. This suggests that respondents remain stalled at the first level, with limited opportunity to develop or exercise skills (second level), and even less potential to leverage ICTs for improved socio-economic outcomes (third level) such as education, e-commerce, or digital employment. Van Dijk's third level emphasizes that access alone is insufficient without the skills to use digital tools meaningfully. Sen's Capability Approach complements this view by stressing that digital access must translate into real opportunities, skills enable people to use digital access for meaningful socio-economic outcomes. Despite the fact that 66.2 percent of respondents said they needed assistance using the internet, 66.2 percent said they were confident in their basic internet skills. In the end, respondents'capacity to translate access into economic or educational outcomes was hampered by the inadequate infrastructure and affordability, which decreased agency and participation. The findings produced through Cohen's d and multiple linear regression analysis revealed that demographic factors (gender, age, education, and locality) do not significantly determine internet access. It must be noted that this study found marginal significance of gender differences where women are less likely to own smartphones or use the internet independently. Although gender differences are not definitive in this study, these differences are often tied to broader issues such as income inequality and cultural norms, not intrinsic digital competence. The intersectional analysis suggests that low-income households experience compounded exclusion, navigating both financial constraints and weak infrastructure. These layered disadvantages reduce individuals' capabilities to engage in education, employment, and digital services.

The conceptual framework is further illuminated by Van Dijk's Resources and Appropriation Theory, which explains why individuals and communities struggle to move through these levels. According to the theory, individuals must possess not only access but also the ability to appropriate digital resources, which depends on personal and structural capabilities such as income, education, and social support. The current study found no significant relationships between education level, locality, or age and internet barriers, suggesting that personal attributes alone do not enable digital participation. Instead, respondents lacked the external resources necessary to convert their motivation and confidence into real digital engagement, this is an insight echoed in Sen's Capability Approach, which emphasizes the importance of creating enabling environments for individuals to realize functionings.

In summary, the integration of Van Dijk's Model of the Digital Divide with Sen's Capability Approach helps explain both the stage of digital inclusion (where most respondents are stuck at first level) and the structural constraints (resource deficits) that prevent further progression. In conclusion, rural digital exclusion is not simply a function of skills or demographics, but a consequence of persistent inequalities in access and resource distribution, these are barriers that must be addressed as a matter of digital justice and capability expansion. The empirical evidence underscores that infrastructure development, affordability interventions, and community-based digital literacy programs are more impactful than demographic-specific approaches in closing the digital gap. These findings reinforce the need to address infrastructural and affordability constraints before progressing to interventions focused on skills or usage. Thus, treating digital access as a structural and capability-enhancing priority in rural policy efforts.

5 Discussion

This section critically interprets the findings of the study through the lens of Van Dijk's Model of Digital Divide and Sen's Capability Approach. Instead of merely summarizing statistical results, it explores how structural, economic, and skill-related factors constrain digital inclusion in Mkatazo village, and what these patterns reveal about broader inequalities. This conversation combines the study's results with perspectives from existing literature to explore significant aspects of digital exclusion, highlighting its consequences and possible interventions.

5.1 Structural barriers: infrastructure, power supply, and geography

The lack of reliable ICT infrastructure emerged as the most consistent barrier to digital inclusion. Over half of respondents lacked internet access, with cost and unreliable connections identified as the strongest predictors of exclusion. These findings reflect Van Dijk's first-level digital divide: inequality in access due to infrastructural and regional barriers. Sen's framework reinforces that without basic infrastructure, individuals cannot convert ICT tools into capabilities that enhance their lives. The results are also in agreement with [37], who highlighted the difficulties of expanding broadband access to rural communities in South Africa. Infrastructure challenges are worsened by unreliable electricity. While this study did not directly measure power supply, broader regional analyses identify it as an ongoing barrier in rural South Africa [25, 67]. Power outages disrupt digital access even when internet services and devices exist, deepening patterns of exclusion.

5.2 Economic constraints and affordability

Building on the infrastructural limitations, the economic costs of connectivity emerge as a second major barrier. Cost was the most cited reason (38.5%) for lack of internet access (See Table 6). This supports Sen's notion of capability deprivation, where affordability prevents individuals from exercising agency to use digital tools for education or income generation. These findings highlight that without reducing costs, connectivity remains an empty promise. This discovery also aligns with the Competition Commission South Africa report [40], which points out that data costs in the country surpass those in numerous other African countries, adversely affecting rural communities. Moreover, a comprehensive examination of the ICT landscape in a South African rural area conducted by [37], revealed that the steep prices of communication and equipment force rural inhabitants to rely on intermittent and limited access. Additionally, despite mobile device ownership being more prevalent, people in rural South Africa are more likely to own mobile devices that are feature phones or low-cost devices [68]. This constraint highlights the necessity for solutions like subsidized device acquisition to improve smartphone ownership or the establishment of community-shared digital centers that are outfitted with contemporary equipment. Zero-rating of some community services websites such as job seekers portals and educational

resource repositories [4]. The concept of zero-rating is a practice of removing data charges for access to selected online resources [69].

5.3 Digital literacy and skills access

Cost and infrastructure issues are further magnified by a third barrier: limited digital literacy. As shown in Tables 8 and 9, a significant portion of respondents (66.2%) reported low confidence or a need for assistance in using the internet. This aligns with Van Dijk's concept of the third-level digital divide, which emphasizes skills inequality and supports Sen's assertion that literacy is crucial for turning access into opportunity. These deficiencies, also noted by [43] indicate fundamental flaws in incorporating digital skills into educational programs. The findings show that even when infrastructure is available, low digital literacy impedes progress. Skills-based exclusion is especially prevalent among women and low-income youth.

Although the study found statistically weak gender differences in digital access and confidence levels, broader literature identifies gender as a persistent axis of exclusion. Qualitative insights from [38] suggest that cultural and structural factors such as income inequality, educational disparities, and societal norms continue to restrict women's digital access in rural areas. For example, rural South African women are less likely to independently own or use smartphones. These structural dynamics may not have been fully captured in our sample data, but highlight the need for gender-sensitive, community-led digital inclusion strategies. This distinction between quantitative findings and qualitative insights highlights the value of a mixed-methods perspective, where statistically weak gender differences may still reflect meaningful disparities shaped by deeper social norms and inequalities.

5.4 Socio-economic impacts and capability gaps

Collectively, infrastructure gaps, unaffordable costs, and limited digital literacy produce far-reaching socio-economic consequences. Respondents reported traveling to urban areas to access assignments or job information, further compounding financial stress. Students were particularly affected, as limited internet access directly hindered their educational engagement. As shown in Table 10, 47.7% of respondents strongly disagreed that they had sufficient internet access for educational use, and several students reported having to travel to urban centers to download assignments, highlighting how infrastructure gaps impose additional financial and logistical burdens. These patterns align with Sen's view that unfreedoms, such as a lack of connectivity, prevent individuals from achieving their aspirations. In addition, according to [27], only 20.9% of adults in Mbhashe Municipality have completed secondary education. This low level of educational attainment restricts the uptake of digital skills and access to employment opportunities, especially in ICT-related sectors. Van Dijk's fourth-level divide, which addresses how digital inequality reinforces social and economic inequalities, is clearly reflected in these findings.

5.5 Recommended interventions

Three systemic barriers emerged from the findings: infrastructure gaps, affordability, and skill deficits. Addressing these requires a multi-dimensional approach that aligns with both Van Dijk's layered digital divide and Sen's Capability Approach. It is therefore recommended that, to overcome these challenges, interventions should focus on three key priorities.

1. *Infrastructure investment:* Advocate for municipal partnerships with ISPs to install LTE towers in Mkatazo. These efforts could be modeled on initiatives like the South African Broadband Education Networks (SABEN), which bring low-cost, high-speed internet to schools and libraries. In addition, support the formation of community trusts to co-own and maintain last-mile networks. As an illustration, Zenzeleni and Project Isizwe, are examples of how partnerships can reduce connectivity gaps [37, 70]. Zenzeleni is a community-owned network for residents of the Mankosi community, [37] highlights the possibilities of localized approaches in enhancing connectivity and lowering expenses through smart partnerships and community ownership.
2. *Affordability initiatives:* Launch a subsidized rural internet voucher program through local municipal offices to provide households in Mkatazo with discounted data bundles. Provide subsidized pricing on smartphone ownership. Install public Wi-Fi access points in schools and clinics, and expand zero-rated content. Collaborations between national regulators, mobile network operators, and educational institutions, such as those in South Africa's COVID-era zero-

rating agreements. This could be scaled and localized for lasting impact. The Free Basics initiative from Facebook (now Meta) is an example of how offering residents in developing nations access to a curated list of essential websites and services can lead to an increase in access to online information and resources [71].

3. *Digital literacy training*: Launch a rural digital bootcamp series in Mkatazo through partnerships with schools, NGOs, and community centers. Similarly, universities and TVET colleges could implement certified digital literacy outreach workshops. Local municipalities may also fund digital ambassador programmes, where trained youth provide ICT assistance and mentorship in rural households and schools. The National Electronic Media Institute of South Africa (NEMISA) is an exemplary collaborative effort that brings key stakeholders together for a community-centric digital literacy training agenda. NEMISA contributes significantly towards South Africa's national digital skills agenda, which emphasizes inclusive, community-based training to get citizens especially true for those living in rural and marginalized areas ready to participate in a digitally transformed economy [72].

5.6 Innovative solutions: AI and community networks

While the previous recommendations address structural and economic barriers, emerging technologies like artificial intelligence (AI) offer complementary solutions that can bridge service gaps in low-connectivity settings like Mkatazo. These innovations can enhance access, personalize content delivery, and extend digital services even in resource-constrained environments.

Support the deployment of offline educational resources and optimize infrastructure through AI-driven planning, ensuring technologies are inclusive by design. Advocate for pilot deployment of preloaded offline educational tablets in Mkatazo's primary schools, using content aligned with Curriculum Assessment Policy Statements (CAPS)[73] and developed in collaboration with the Department of Basic Education.

AI-driven offline tools (e.g., preloaded curricula on tablets) could directly address Mkatazo's internet scarcity, mirroring Kenya's eLimu initiative [74]. Similar tools have been deployed in Uganda through the Kolibri platform by Learning Equality [75], and in Rwanda where the Smart Classroom initiative integrates offline digital content into rural schools [76]. For instance, AI-powered network planning tools can guide where to place infrastructure for maximum coverage, while adaptive learning platforms preloaded onto local servers can offer schooling without requiring constant connectivity.

These interventions correspond with the layered structure of Van Dijk's model and respond to Sen's call to expand freedoms by enabling rural residents to access and use ICT tools in ways that meaningfully improve their lives.

5.7 Call to action for policymakers

This study's findings reveal critical gaps requiring immediate policy intervention to address digital exclusion in rural communities such as Mkatazo. We recommend a three-tiered approach:

1. **Infrastructure development**
   a. Prioritize public–private partnerships for broadband expansion in underserved regions.
   b. Allocate dedicated funding for community-based digital infrastructure projects.

2. **Access and affordability**
   a. Implement subsidy programs for affordable digital devices and data plans.
   b. Establish regulatory incentives for ISPs to service rural areas.

3. **Capacity building**
   a. Integrate comprehensive digital literacy programs into national education policies.
   b. Develop localized training initiatives addressing rural communities'specific needs.

These measures should be coordinated across municipal, provincial, and national government levels, with particular attention to aligning technology policies with the socioeconomic realities of rural populations. Regular impact assessments should be mandated to ensure policy effectiveness and equitable outcomes.

5.8 Study limitations

This study offers important insights into digital exclusion in Mkatazo, but four key limitations must be noted. First, while electricity access is a critical factor for digital connectivity in rural contexts, this variable was not directly assessed. Second, the exclusive reliance on quantitative methods constrained the investigation of nuanced experiential factors; incorporating qualitative methods like interviews or focus groups in future work would provide valuable context. Third, despite using probabilistic sampling, the high attrition rate may affect the generalizability of findings. Finally, several access-related dimensions, including device sharing practices and digital safety concerns, were not systematically measured and warrant inclusion in subsequent research to strengthen comprehensiveness.

6 Conclusion

This research highlights the widespread and intricate characteristics of digital exclusion in rural South Africa, illustrated by the experiences within Mkatazo village. The results emphasize significant obstacles concerning infrastructure, cost, and digital literacy, which together impede access to and use of ICTs. Given these systemic barriers, targeted interventions are essential to unlock digital opportunities and promote inclusive rural development. The socio-economic effects of digital exclusion are significant, impacting education, healthcare, and job prospects.

Addressing these broader impacts requires a phased approach that prioritizes infrastructure first, followed by affordability measures, and then digital literacy programs. Reliable broadband infrastructure must first be ensured to support access to digital public services such as remote education platforms and telehealth initiatives. Affordable data access and digital skills training can further enable marginalized populations to participate in educational and healthcare systems.

To effectively bridge the digital divide in this locality, where agriculture and forestry serve as the primary economic activities, stakeholders must adopt more tailored sector-specific solutions. Stakeholders should prioritize investment in broadband infrastructure, as many rural communities lack reliable connectivity. Investing in infrastructure directly addresses Van Dijk's structural exclusion layer by enabling basic access to ICTs as many rural communities lack reliable connectivity. Public–private partnerships can play a key role in deploying affordable, high-speed internet through initiatives such as community-owned networks or satellite-based connectivity solutions, ensuring that farmers, forestry workers, and small businesses have access to digital resources. With 52.3% of respondents reporting no internet access, satellite connectivity in particular could bridge immediate gaps where traditional broadband deployment is delayed or infeasible. However, such partnerships may face challenges in rural areas, including logistical constraints, limited infrastructure, or funding gaps that could delay or restrict implementation.

Beyond connectivity, affordability programs are essential to ensure that marginalized groups can utilize digital services. Subsidized device acquisition, government-backed rural internet programs, and zero-rated platforms for agricultural extension services can reduce financial barriers to digital adoption, particularly relevant given that 38.5% of study respondents cited cost as a primary barrier to internet access. Mobile-friendly agricultural platforms that provide market prices, weather forecasts, and pest control solutions can improve productivity and resilience for smallholder farmers. For example, in Kenya, digital advisory services such as Apollo Agriculture, leveraging AI and satellite data, have helped farmers achieve up to 2.5 times higher yields than average [77]. Complementary initiatives like those highlighted by Farmonaut [78] showcase how satellite monitoring, mobile-based pest alerts, and precision mapping have improved farming productivity and decision-making across rural Kenya. In forestry, remote sensing technology and digital mapping tools can assist in sustainable forest management and monitoring.

Integrating digital literacy into educational and community initiatives is crucial for fostering engagement with ICTs. According to Sen's Capability Approach, digital literacy empowers individuals to convert digital access into meaningful capabilities such as education, employment, and entrepreneurship. This aligns with the finding that 66.2% of respondents reported needing assistance in using the internet, reflecting a significant digital literacy gap. Training programs tailored for farmers, cooperative members, and forestry professionals can empower individuals with the skills needed to adopt e-commerce platforms, digital record-keeping, and precision farming techniques (i.e., data-driven methods to optimize crop yields and resource use). Schools and agricultural training centers should incorporate digital literacy modules into their curricula to prepare younger generations for a technology-driven economy.

Communities and implementing partners must adopt a community-focused strategy to ensure the success of digital inclusion efforts. Policymakers and stakeholders must work closely with local leaders, cooperatives, and agricultural unions to design interventions that align with the specific needs of rural communities. Collaborating with traditional elders and community influencers can help ensure that digital tools are introduced in culturally sensitive ways. For instance, by aligning mobile applications with indigenous farming calendars or integrating local languages into training modules. Providing digital extension services through community centers and cooperatives can enhance outreach and ensure that technology adoption is practical and relevant. To ensure long-term sustainability, community-led maintenance funds should be established for digital infrastructure, alongside local training for technicians to support upkeep and reduce dependence on external service providers. Additionally, incorporating regular monitoring and evaluation frameworks will help track the impact of digital inclusion initiatives and guide adaptive strategies over time. Furthermore, promoting affordable financing for digital tools and mobile devices can increase accessibility for farmers and forestry workers, allowing them to integrate digital solutions into their daily operations.

A visual framework (see Appendix A) maps key digital exclusion barriers, including infrastructure, affordability, digital skills, genderedsocio-cultural norms, and capability mismatches, to proposed solutions, synthesizing the study's core findings and aligning them withactionable strategies.

By tailoring digital inclusion strategies to the economic realities and infrastructure limitations of rural communities, these efforts can foster equitable socio-economic development, improve agricultural and forestry productivity, and expand digital opportunities for rural populations. While this study emphasizes agriculture and forestry, broader implications for sectors like healthcare and education warrant further exploration in future research to ensure inclusive digital transformation across all dimensions of rural life. Urgent collaboration among government, private sector, and community stakeholders is needed to prevent rural communities from falling further behind in the digital era.

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Data availability The data supporting the findings of this study are available from the corresponding author upon reasonable request. Researchers seeking access may be required to provide justification for their request and comply with any relevant ethical and legal considerations set by the author's affiliated university in accordance with institutional policies on data sharing and confidentiality.

Declarations

Ethics approval and consent to participate This study received ethical approval from the IT Department at Walter Sisulu University (WSU). Informed consent was obtained from all the participants involved in the study. All methods were carried out in accordance with relevant guidelines and regulations.

Competing interests The authors declare no competing interests.

Appendix A: Mapping digital exclusion barriers to solutions

The figure below synthesizes the core findings of the study by visually aligning identified digital exclusion barriers in Mkatazo with targeted intervention strategies

Barrier	Impact	Proposed intervention
Infrastructure gaps	No/unstable internet; travel for access	Municipal LTE tower partnerships; community-owned broadband (SABEN model)
Affordability	High data/device costs; underutilization of smartphones	Subsidized device ownership; Subsidized data vouchers; public Wi-Fi; zero-rated services
Digital skill deficits	Inability to use ICT; low confidence and literacy	Rural bootcamps; Digital ambassadors; NGO/university outreach
Gender and socio-cultural norms	Unequal access for women; device sharing	Gender-sensitive training; community norms engagement
Connectivity vs. capability mismatch	Skills exist but can't be applied due to infrastructure limits	AI-powered offline tools; smart classrooms; preloaded tablets

Adapted from study findings and aligned with Van Dijk's model & Sen's capability approach

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