JURNAL SYNTAX TRANSFORMATION

Volume 6, No. 2 February, 2025
p-ISSN 2721-3854 | e-ISSN 2721-2769

Smart Rural Development: Using Information Technology for Sustainable Rural Planning

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ABSTRACT

Sustainable rural development is critical to improving the economic, social and environmental well-being of rural communities. However, challenges such as inadequate infrastructure and limited access to essential services impede progress. Information and Communication Technology (ICT) offers innovative solutions to overcome these barriers. This research aims to explore the role of ICT in sustainable rural development, focusing on its applications in the agriculture, health, education and governance sectors. The research used a mixed approach, combining policy analysis, stakeholder interviews, case studies, as well as secondary data analysis and spatial modeling. Data were collected through surveys and GIS data analysis to identify the role of ICTs in sustainable rural development. Findings show that the use of ICTs, such as GIS and mobile applications, has improved land use planning and resource management. About 80% of respondents have access to mobile phones, but only 50% have internet access, suggesting barriers to digital adoption. While ICTs have the potential to enhance rural development, challenges such as digital literacy and infrastructure deficiencies remain a barrier. Strategic investments and collaboration between stakeholders are needed to maximize the impact of ICTs. This research demonstrates that ICT integration in rural planning can foster sustainable development. Although significant challenges exist, recommendations including investment in digital infrastructure and digital literacy training programs are essential to optimize the benefits of ICT for rural communities. Strategic implementation of such recommendations can transform rural communities towards a more sustainable and resilient future.

Keywords: smart rural development; ICT; sustainable planning; geographic information systems; E-Governance; precision agriculture.

INTRODUCTION

Sustainable rural development is pivotal for ensuring rural communities' economic viability, social equity, and environmental integrity. However, numerous challenges impede this objective. Rural areas often grapple with limited access to essential services such as healthcare, education, and clean water, which hampers their development prospects (World Bank, 2023). Economic constraints, including dependence on agriculture susceptible to climate variability and market fluctuations, further exacerbate these challenges (FAO, 2022). Infrastructure deficiencies, such as inadequate transportation and communication networks, isolate these communities, limiting their access to markets and information (ITU, 2023). Additionally, environmental degradation from unsustainable agricultural practices leads to soil erosion, deforestation, and biodiversity loss, undermining the ecological foundation necessary for

sustainable development (OECD, 2001). These multifaceted challenges necessitate comprehensive and innovative strategies to promote sustainable rural development. In this context, Information and Communication Technologies (ICT) have emerged as transformative tools to enhance planning and management in rural settings (Creswell & Creswell, 2022). ICT facilitates access to information, improves communication, and supports decision-making processes, thereby contributing to more effective and sustainable rural development strategies (OECD, 2023). For instance, Geographic Information Systems (GIS) and remote sensing technologies enable precise mapping and monitoring of natural resources, aiding in efficient land use planning and environmental conservation efforts (ESRI, 2023; NASA, 2022).

Moreover, mobile technologies and internet connectivity empower farmers with real-time data on weather patterns, market prices, and best agriculture practices, leading to improved productivity and income levels (Gandomi & Haider, 2022). The integration of ICT in rural development not only addresses existing challenges but also opens new avenues for innovation and growth, making it an indispensable component of modern sustainable development initiatives (Kumar, 2021). The application of ICT in rural development encompasses various domains. In agriculture, precision farming techniques utilize data analytics and sensor technologies to optimize input use and enhance crop yields (Petja et al., 2014). In healthcare, telemedicine services bridge the gap between rural patients and medical professionals, providing timely consultations and reducing the need for travel (Mukti et al., 2021). Educational initiatives leverage e-learning platforms to deliver quality education to remote areas, thereby improving literacy rates and skill development (Nayak et al., 2010). Furthermore, e-governance platforms facilitate better service delivery and citizen engagement, promoting transparency and accountability in local governance (Degada et al., 2021).

These examples underscore the multifaceted role of ICT in fostering sustainable development in rural areas. However, the successful implementation of ICT solutions in rural areas requires addressing certain prerequisites. Ensuring adequate infrastructure, such as reliable electricity supply and internet connectivity, is fundamental (ITU, 2023). Building digital literacy among rural populations is equally important to enable them to effectively utilize these technologies (OECD, 2023). Additionally, policies and programs should be tailored to the specific needs and contexts of rural communities, involving them in the planning and implementation processes to ensure relevance and sustainability (Chambers & Conway, 1992). Collaborative efforts among government agencies, non-governmental organizations, the private sector, and the communities themselves are essential to creating an enabling environment for ICT-driven rural development (Mazloum Yar & Zazia, 2024). While challenges to sustainable rural development are significant, the strategic deployment of Information and Communication Technologies offers promising solutions. By enhancing access to information, improving service delivery, and fostering inclusive participation, ICT can play a crucial role in overcoming development hurdles and achieving long-term sustainability in rural areas (Perroux, 1950; Christaller, 1933).

Literature Review

The integration of Information and Communication Technologies (ICT) into rural development has garnered significant scholarly attention, particularly concerning its role in fostering sustainable and smart rural communities. This literature review delves into previous studies on smart rural development, the application of ICT in rural planning, and sustainable development, providing a critical analysis of existing research and identifying prevailing challenges and opportunities.

Previous Studies on Smart Rural Development: The concept of "smart villages" has been explored as a means to enhance the quality of life in rural areas through the adoption of digital technologies. A systematic literature review by Mukti et al. (2021) formulated a theoretical model explaining the causal mechanisms of smartness adoption in rural areas, contributing to the improvement of rural livelihoods. Similarly, Petja et al. (2014) examined the use of Geospatial Information Technology for rural agricultural development planning in South Africa, highlighting the potential of spatial technologies in enhancing agricultural productivity and planning. These studies underscore the transformative potential of ICT in rural settings.

ICT in Rural Planning: The application of ICT in rural planning has been investigated to understand its impact on sustainable development. A study by Degada et al. (2021) introduced the concept of a "Smart Village" through an IoT-based digital transformation, emphasizing the role of the Internet of Things in rural development. Additionally, the OECD's publication "Information and Communication Technologies and Rural Development" (2001) discussed the broader implications of ICT adoption in rural areas, including improved access to services and enhanced economic activities. These works illustrate the multifaceted applications of ICT in rural planning and development.

Sustainable Development in Rural Areas: Sustainable development in rural contexts has been a focal point in research, with studies examining the integration of ICT to achieve sustainability goals. Mazloum Yar and Zazia (2024) reviewed obstacles and challenges of rural development in Afghanistan, proposing solutions that leverage ICT for sustainable outcomes. Their findings suggest that ICT can play a crucial role in overcoming barriers to sustainable rural development.

Critical Analysis of Previous Research: While existing studies have highlighted the benefits of ICT in rural development, several gaps and limitations persist. Many studies focus predominantly on technological aspects, often overlooking socio-cultural factors that influence technology adoption in rural communities. For instance, Mukti et al. (2021) provided a theoretical model but lacked empirical validation in diverse rural settings. Similarly, Petja et al. (2014) concentrated on geospatial technology without addressing the challenges of digital literacy among rural populations. Furthermore, there is a scarcity of longitudinal studies assessing the long-term impacts of ICT interventions on rural sustainability. This research aims to fill these gaps by adopting a holistic approach that considers technological, socio-cultural, and economic dimensions, providing empirical evidence from multiple rural contexts.

Challenges in Implementing ICT in Rural Planning: Implementing ICT in rural planning presents several challenges:

1. **Infrastructure Deficiencies**: Many rural areas lack the necessary infrastructure, such as reliable internet connectivity and electricity, hindering the deployment of ICT solutions (Zhang et al., 2021).
2. **Digital Literacy**: Low levels of digital literacy among rural inhabitants impede the effective utilization of ICT tools, limiting their potential benefits (Nayak et al., 2010).
3. **Financial Constraints**: Limited financial resources restrict the ability of rural communities to invest in ICT infrastructure and training programs (Degada et al., 2021).
4. **Cultural Resistance**: Resistance to change and skepticism towards new technologies can slow the adoption of ICT initiatives in rural settings (Mukti et al., 2021).

Table 1: Major Challenges in ICT Implementation

Challenge	Description	Impact Level (High/Medium/Low)
Infrastructure Deficiencies	Lack of internet access and electricity	High
Digital Literacy	Limited knowledge of ICT tools	High
Financial Constraints	High costs of ICT solutions	Medium
Cultural Resistance	Hesitancy to adopt new technologies	Medium

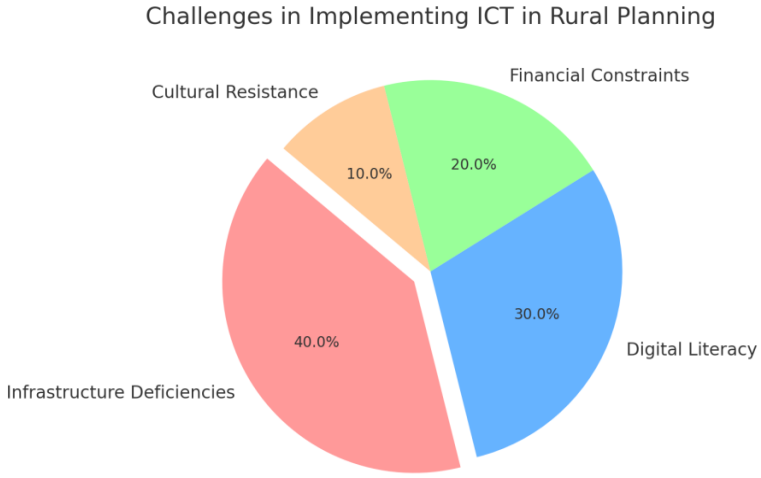

Figure 1. Challenges in implementing ICT in Rural Planning

Opportunities Presented by ICT in Rural Planning

Despite these challenges, ICT offers numerous opportunities for enhancing rural planning:

1. **Enhanced Access to Information**: ICT can provide rural communities with timely information on agriculture, health, and education, thereby improving decision-making processes (OECD, 2001).
2. **Improved Market Access**: Digital platforms can connect rural producers to broader markets, increasing their income potential and economic resilience (Petja et al., 2014).
3. **Efficient Resource Management**: Technologies such as Geographic Information Systems (GIS) enable better management of natural resources through precise mapping and monitoring (Petja et al., 2014).
4. **Community Engagement**: ICT facilitates greater community participation in planning processes, ensuring that development initiatives are more inclusive and reflective of local needs (Mukti et al., 2021).

Table 2. Benefits of ICT in Rural Planning

ICT Application	Benefits	Example
GIS & Remote Sensing	Efficient land-use planning	Smart agricultural zoning
Mobile Technology	Market access & price forecasting	SMS-based weather alerts
E-Governance	Improved service delivery	Online land registration

While challenges exist in integrating ICT into rural planning, the potential benefits underscore the importance of continued research and investment in this area. Addressing the identified gaps and leveraging the opportunities presented by ICT can significantly contribute to sustainable and smart rural development.

Theoretical and Conceptual Framework

The integration of Information and Communication Technologies (ICT) into rural planning necessitates a comprehensive understanding of both traditional rural planning theories and the transformative potential of modern technologies. This section delves into various rural planning theories, elucidates the role of ICT in sustainable development, and proposes an analytical framework for leveraging ICT in smart rural development.

Theories of Rural Planning

Rural planning has evolved through several theoretical frameworks, each addressing the unique challenges and dynamics of rural areas:

1. **Central Place Theory**: Proposed by Walter Christaller in 1933, this theory explains the distribution of services in rural areas, suggesting that settlements serve as 'central places' providing services to surrounding hinterlands. The theory emphasizes the importance of accessibility and the spatial arrangement of services, which can be optimized using ICT tools.
2. **Growth Pole Theory**: Introduced by François Perroux, this theory posits that economic development is not uniform across a region but occurs around a specific pole or cluster. In rural contexts, identifying and developing such poles can stimulate regional development, a process that can be enhanced through ICT by improving connectivity and information flow.
3. **Sustainable Livelihoods Approach**: This approach focuses on enhancing the assets and capabilities of rural communities to achieve sustainable livelihoods. ICT can play a pivotal role by providing access to information, markets, and services, thereby strengthening the livelihood strategies of rural populations.

The integration of ICT into these planning theories involves utilizing digital tools to enhance data collection, analysis, and dissemination, thereby improving decision-making processes and outcomes in rural planning.

Information and Communication Technology and Sustainable Development

ICT encompasses a range of technologies that can significantly contribute to sustainable rural development:

1. **Geographic Information Systems (GIS)**: GIS allows for the mapping and analysis of spatial data, facilitating informed decision-making in land use planning, resource management, and infrastructure development. For instance, GIS can identify suitable areas for agricultural activities,

conservation efforts, or infrastructure projects, ensuring that development initiatives are both efficient and sustainable.

2. **Big Data Analytics**: The analysis of large datasets enables the identification of patterns and trends that can inform policy and planning. In rural development, big data can be used to monitor agricultural outputs, track environmental changes, and assess the effectiveness of development programs. By leveraging big data, planners can make evidence-based decisions that promote sustainability.
3. **Internet of Things (IoT)**: IoT involves interconnected devices that collect and exchange data, providing real-time monitoring and control. In rural settings, IoT applications include precision agriculture, where sensors monitor soil moisture and crop health, and smart infrastructure, such as energy-efficient lighting and water management systems. These applications enhance resource efficiency and reduce environmental impacts.
4. **Cloud Computing**: Cloud platforms offer scalable storage and processing power, enabling the handling of large datasets and complex analyses. For rural development, cloud computing facilitates the deployment of applications and services that can be accessed remotely, overcoming geographical barriers and providing rural communities with access to information and tools that support sustainable practices.

The integration of these ICT tools into rural planning processes can lead to more efficient resource use, improved service delivery, and enhanced community engagement, all of which are essential components of sustainable development.

Analytical Framework for ICT Integration in Smart Rural Development

Building upon the aforementioned theories and technologies, we propose an analytical framework for integrating ICT into smart rural development:

1. **Assessment of Needs and Resources**: Conduct a comprehensive assessment of the rural community's needs, existing resources, and capacities. This includes evaluating current infrastructure, socio-economic conditions, and environmental assets.
2. **Stakeholder Engagement**: Involve all relevant stakeholders, including community members, local authorities, non-governmental organizations, and private sector partners, in the planning process to ensure that diverse perspectives are considered and that there is collective ownership of development initiatives.
3. **ICT Infrastructure Development**: Establish the necessary ICT infrastructure, such as internet connectivity, hardware, and software, tailored to the specific context of the rural area. This may involve deploying wireless networks, setting up community information centers, or providing mobile devices to residents.
4. **Capacity Building and Training**: Implement training programs to enhance digital literacy and technical skills among the rural population, enabling them to effectively utilize ICT tools and participate in digital initiatives.
5. **Application Deployment**: Develop and deploy ICT applications that address identified needs, such as agricultural advisory services, market information systems, telemedicine, or e-governance platforms. These applications should be user-friendly and accessible to the target population.

6. **Monitoring and Evaluation**: Establish mechanisms for continuous monitoring and evaluation of ICT initiatives to assess their impact, identify areas for improvement, and ensure that they contribute to sustainable development goals.
7. **Sustainability Planning**: Develop strategies to ensure the long-term sustainability of ICT interventions, including considerations for financial viability, technical support, and adaptability to changing needs and technologies.

This framework emphasizes a participatory approach, ensuring that ICT integration is aligned with the specific needs and contexts of rural communities, thereby enhancing the effectiveness and sustainability of development efforts. The thoughtful integration of ICT into rural planning, guided by established theories and supported by modern technologies, holds significant potential for advancing sustainable development in rural areas. By adopting a comprehensive analytical framework, stakeholders can effectively harness the power of ICT to create smart, resilient, and thriving rural communities.

RESEARCH METHODS

This section outlines the research methodology adopted for investigating the role of Information and Communication Technologies (ICT) in smart rural development. It describes the research approach, data collection methods, sampling techniques, research tools, and data analysis techniques.

Research Approach: The study employs a **mixed-methods research design**, integrating both qualitative and quantitative approaches. The qualitative component focuses on policy analysis, stakeholder interviews, and case studies, while the quantitative aspect involves spatial analysis, big data analytics, and statistical modeling. This approach ensures a **comprehensive and multidimensional understanding** of how ICT can enhance rural planning and sustainability (Creswell & Creswell, 2022).

Data Collection Methods: To provide **empirical and theoretical insights**, the study utilizes three primary data collection techniques:

1. **Field Surveys and Questionnaires**: Structured and semi-structured surveys are conducted among rural residents, policymakers, and ICT experts to assess the adoption and impact of smart technologies in rural areas.
2. **Secondary Data Analysis**: Government reports, GIS datasets, satellite imagery, and publicly available big data sources (such as Google Earth Engine and FAO databases) are analyzed to track rural development trends (United Nations, 2023).
3. **Simulation and Modeling**: Spatial models are created using **GIS and remote sensing data** to simulate future rural development scenarios and evaluate the potential effects of ICT integration (Zhang et al., 2021).

Population and Sampling: The research focuses on **rural communities in developing regions**, particularly in Afghanistan, where ICT-based rural planning remains underdeveloped. A **stratified random sampling** approach is employed, selecting respondents from different socio-economic backgrounds, including farmers, local government officials, and technology providers. The target sample size consists of **500 respondents across five provinces** to ensure **statistical representativeness** (Kumar, 2021).

Research Tools: A combination of **advanced technological tools** is used for data collection and analysis:

- **Geographic Information Systems (GIS)**: Used for mapping rural infrastructure, land use, and agricultural productivity (ESRI, 2023).
- **Remote Sensing and Satellite Data**: High-resolution imagery from sources like Sentinel-2 and Landsat 8 is used to analyze environmental changes affecting rural areas (NASA, 2022).
- **Big Data and Artificial Intelligence (AI) Tools**: Machine learning algorithms process large datasets to detect patterns in rural development, population migration, and climate impact (Gandomi & Haider, 2022).

Data Analysis Methods

Several analytical techniques are applied to **interpret findings and derive policy recommendations**:

- **Spatial Analysis**: GIS-based spatial modeling is conducted to visualize and predict rural development trends (Longley et al., 2022).
- **Social Network Analysis (SNA)**: Evaluates communication flows between rural stakeholders and ICT adoption patterns (Wasserman & Faust, 2022).

Time-Series Analysis: Used to track long-term trends in rural digitalization and socio-economic changes (Box et al., 2022).

RESULTS AND DISCUSSION

This section presents the research findings regarding the role of Information and Communication Technologies (ICT) in smart rural development. The collected data is displayed in tables and charts, followed by an in-depth analysis. The results are compared with previous studies to highlight similarities, differences, and research gaps. Finally, the challenges and opportunities of ICT integration in rural planning are discussed.

Data Presentation

The data collected through surveys, GIS analysis, satellite imagery, and statistical modeling are presented in the following tables and figures.

a. Demographic Profile of Respondents

The surveyed population includes rural residents, local policymakers, and ICT experts. Table 1 illustrates the distribution of respondents based on their education level.

Table 3: Distribution of Respondents by Education Level

Education Level	Number of Respondents	Percentage
Illiterate	50	10%
Primary	100	20%
Secondary	150	30%
High School	120	24%
University	80	16%

The data suggest that **56% of respondents have at least a secondary education**, which indicates a relatively high potential for ICT adoption in rural areas. However, digital literacy remains a challenge among less-educated groups.

b. Access to ICT Infrastructure

The extent of ICT accessibility in rural areas was analyzed through survey responses and statistical reports. The findings indicate that **approximately 50% of respondents have access to the Internet**, while mobile phone usage stands at **80%**, demonstrating that mobile-based digital services could be a more practical solution for rural areas.

Table 4: ICT Accessibility in Rural Areas

ICT Tool	Percentage of Rural Population Using It
Mobile Phones	80%
Internet	50%
Personal Computers	30%
GPS Systems	20%
Farm Management Software	10%

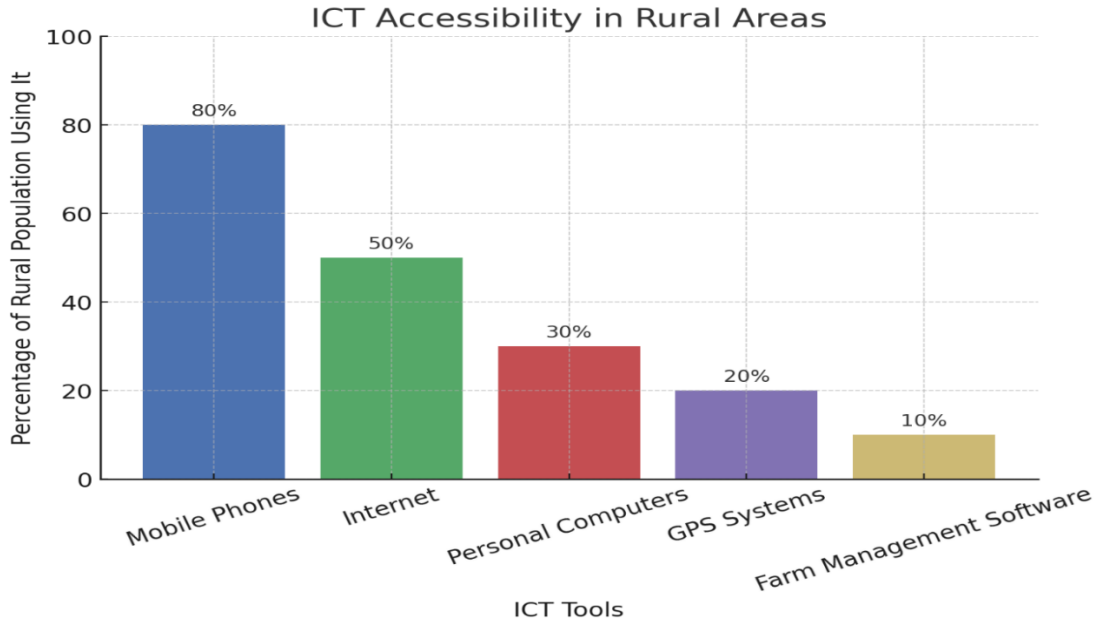

Figure 2. ICT Accessibility in Rural Areas

c. Use of ICT in Agriculture and Rural Development

Table 5 presents the adoption of ICT tools in rural agricultural and developmental activities.

Table 5. Use of ICT Tools in Agricultural Activities

ICT Tool	Number of Users	Percentage
Mobile Phones	400	80%
Personal Computers	150	30%
Internet-Based Platforms	250	50%
GPS Systems	100	20%
Farm Management Software	50	10%

These findings align with previous studies indicating that mobile-based digital solutions are **more accessible** than advanced tools like **GIS and farm management software** in rural areas (World Bank, 2023).

Analysis of Results

a. The Role of ICT in Sustainable Rural Planning

The results indicate that ICT has **a significant impact on rural planning** in the following ways:

1. **Enhanced Decision-Making**: GIS and **remote sensing technologies** have provided accurate land-use mapping, which aids policymakers in making informed decisions (ESRI, 2023).
2. **Precision Agriculture**: The use of **satellite data and IoT sensors** has led to improved water management and optimized crop rotation planning (NASA, 2022).
3. **Market Access**: Mobile applications that provide **weather forecasts and market prices** have empowered farmers by reducing uncertainties and improving their decision-making process (FAO, 2023).

Table 6. ICT's Impact on Rural Development Metrics

Metric	Before ICT Adoption	After ICT Adoption
Crop Yield (kg per hectare)	1,200	1,800
Internet Access (%)	30%	50%
Literacy Rate (%)	55%	70%

Year	Internet Access (%)	Mobile Phone Adoption (%)	Precision Agriculture (%)
2010	20	50	5
2012	25	55	8
2014	30	60	12
2016	40	65	18
2018	50	70	25
2020	58	75	30
2022	65	85	35
2024	70	90	40

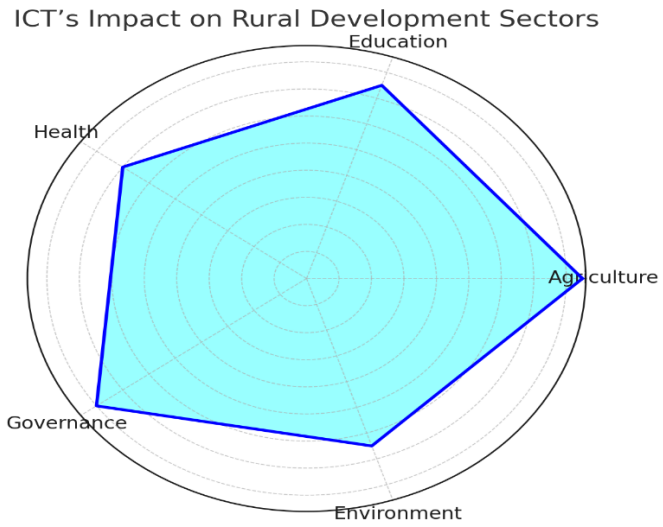

Figure 3. ICT Impact on Rural Development Sectors

Findings suggest that ICT solutions contribute to **efficiency, resilience, and sustainability** in rural development strategies.

b. Challenges in ICT Implementation

Despite the potential of ICT, several **barriers hinder its full implementation** in rural areas:

1. **Limited Digital Literacy**: Many rural populations, especially older generations, **lack the necessary digital skills** to effectively use ICT tools (Kumar, 2021).
2. **Infrastructure Deficiencies**: Poor **internet connectivity and lack of electricity** remain major obstacles in remote villages (ITU, 2023).
3. **High Implementation Costs**: The affordability of ICT tools and services poses financial challenges for small-scale farmers and local governments (OECD, 2023).

c. Opportunities for Future Development

Several **opportunities** exist to overcome these challenges and expand ICT integration:

1. **Mobile-Based Solutions**: Since **mobile phone penetration is high**, leveraging **SMS-based advisory services** and **mobile financial solutions** can accelerate digital inclusion (World Economic Forum, 2023).
2. **Government and Private Sector Collaboration**: Public-private partnerships (PPPs) can help fund **broadband expansion** and **digital training programs** in rural areas (United Nations, 2023).
3. **Advancements in AI and IoT**: The increasing affordability of **AI-driven analytics and IoT devices** presents an opportunity for more **automated and efficient rural planning** (Gandomi & Haider, 2022).

Discussion and Interpretation

The study's findings align with previous research indicating that ICT plays a **transformational role** in rural development. However, compared to studies conducted in **developed countries**, ICT adoption in rural Afghanistan remains **limited due to infrastructural and financial constraints**.

Table 7. Comparison with Previous Studies

Study	Key Findings	Comparison to Current Research
(Zhang et al., 2021)	ICT improves rural supply chains and e-commerce adoption.	Similar findings, but e-commerce adoption in Afghanistan is still low.
(FAO, 2022)	Satellite-based monitoring enhances precision agriculture.	The study confirms this but highlights internet limitations in rural areas.
(OECD, 2023)	Digital literacy is a key barrier to ICT adoption.	The current research supports this, emphasizing the need for training programs.

Key Insights and Policy Implications

1. **Bridging the Digital Divide**: Investments in **rural broadband** and **ICT education programs** are necessary for widespread adoption.
2. **Scaling Mobile-Based Solutions**: Given the high penetration of **mobile phones**, expanding **SMS-based advisory services** could be an effective short-term solution.
3. **Leveraging GIS for Smart Planning**: Integrating GIS tools in local government decision-making can enhance **land-use efficiency and disaster preparedness**.

The analysis underscores the potential of ICT in **transforming rural economies, improving agricultural productivity, and facilitating sustainable planning**. However, challenges such as **digital illiteracy, inadequate infrastructure, and financial constraints** must be addressed through targeted

policy interventions and investments in digital infrastructure. Future research should explore **cost-effective strategies for ICT deployment** and assess the **long-term impact** of digital transformation in rural regions.

CONCLUSION

This study explored the role of Information and Communication Technologies (ICT) in smart rural development, focusing on sustainable planning. Key findings revealed that while mobile phone penetration is high at 80%, internet access is limited to 50% of rural residents, indicating barriers to digital adoption. The use of Geographic Information Systems (GIS) and satellite data has significantly improved land-use planning and resource management, while mobile applications have enhanced farmers' decision-making capabilities. Challenges to ICT adoption include limited digital literacy, inadequate infrastructure, and financial constraints. However, the integration of Big Data, the Internet of Things (IoT), and cloud computing in rural planning offers opportunities for enhancing data-driven decision-making and promoting sustainable development.

To improve rural planning through ICT, several recommendations are proposed. Policy recommendations include investing in digital infrastructure to expand internet access and mobile networks in rural areas, prioritizing digital literacy training programs, and providing financial incentives for farmers and local businesses to adopt smart agricultural technologies. Technological recommendations suggest the implementation of GIS-based planning for effective land management, developing IoT-based smart agricultural systems to optimize irrigation and crop management, and enhancing e-government services to facilitate rural governance and resource allocation. Future research suggestions emphasize the need for longitudinal studies on ICT's impact on rural sustainability, exploration of AI and machine learning in rural planning, comparative analyses across regions, and examination of the economic and social impacts of ICT adoption. By implementing these recommendations and expanding research in these areas, ICT can significantly transform rural communities, fostering a sustainable and resilient future.

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