



Assessment of Power Infrastructure and its Impact on Radiological Digital Imaging Informatics Systems in Tanzania's Health Facilities

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Abstract

Digital imaging informatics systems are essential for enhancing diagnostic accuracy and overall healthcare delivery; however, their success is largely dependent on reliable power sources and robust infrastructure. This study examines the readiness of Tanzania's health facilities to adopt and maintain radiological digital imaging informatics systems, with a focus on the availability and quality of electrical power infrastructure. A mixed-method approach was utilized, involving structured questionnaires and in-depth interviews with biomedical and ICT engineers from selected healthcare facilities. The findings reveal that while many facilities report having access to electrical power and meeting basic voltage and grounding standards, frequent power disruptions remain a significant challenge. These disruptions not only undermine the sustainability of the digital imaging systems but are also more pronounced in rural areas where infrastructure development lags behind urban centres, thereby widening the healthcare disparity. Additionally, the study highlights gap in compliance with voltage requirements despite the overall availability of power. The analysis details these infrastructural challenges and offers actionable recommendations, including targeted investments in power infrastructure, capacity building for technical staff, and the establishment of enhanced maintenance programmes. By addressing these issues, Tanzania can improve its readiness to leverage digital imaging informatics, ultimately bridging the technological gap between urban and rural regions and enhancing healthcare outcomes nationwide.

Keywords: *Power infrastructure, digital imaging informatics, Tanzania healthcare facilities.*

Introduction

Digital imaging informatics has transformed healthcare delivery globally, enabling accurate and timely diagnoses through advanced radiological systems like X-ray, MRI, and CT scans (Chris, 2015; IAEA, 2015; IAEA, 2023; Kruse & Beane, 2018; WHO, 2009; Sakafu, et al., 2023). These systems have proven instrumental in improving patient outcomes and enhancing the overall quality of care. However, the successful implementation of these systems in Low- and Middle-Income Countries (LMICs) such as Tanzania faces significant barriers, including unreliable power infrastructure (Huang, 2010; Siegel & Reiner, 2020).

The global advancements in digital imaging informatics highlight its potential to revolutionize healthcare, particularly in diagnostic radiology. In high-income countries, these systems have become indispensable tools, facilitating early disease detection, personalized treatment planning, and efficient patient management (IAEA, 2015; IAEA, 2023). However, translating these global successes into the context of LMICs requires addressing unique challenges, such as; limited resources, inadequate infrastructure, and policy gaps (Grover, 1997). Understanding the Tanzanian context is crucial to illustrating these challenges and framing the problem.

In the Tanzanian context, adopting digital imaging informatics systems faces some obstacles, including unreliable power infrastructure standing out as a primary barrier (MOHCDGEC, 2021; Sakafu et al, 2023). While these technologies hold immense promise for elevating healthcare standards, their functionality is contingent upon a consistent and reliable power supply, a factor often compromised in resource constrained settings. The interplay between advanced healthcare technologies and foundational infrastructure underscores the urgent need to address systemic gaps to ensure the sustainability and effectiveness of digital imaging informatics.

As healthcare facilities across Tanzania adopt digital imaging informatics systems, significant challenges emerge, particularly in rural areas. These include frequent power outages, voltage instability, and inadequate backup solutions, which are exacerbated by limited resources and policy gaps. These issues are particularly acute in rural areas where infrastructure development is lagged behind historically (Ngoya & Muhogora, 2016; MOHCDGEC, 2021). For instance, the frequent power

outages and lack of robust surge protection mechanisms directly impact the performance and lifespan of radiological equipment, undermining the potential benefits of digital imaging technologies. While urban facilities may have more robust infrastructure, rural health centres often lack reliable access to electricity, compromising the sustainability and functionality of imaging systems. The interplay between advanced medical technologies and basic power requirements necessitates comprehensive studies to identify and address these challenges systematically.

The primary objective of this study is to assess and analyse the availability and reliability of electrical power infrastructure in Tanzania's health facilities concerning their readiness to adopt digital imaging informatics systems. Specific areas of focus include: power availability and reliability, voltage compliance, surge protection, power backup options and frequency of outages. By situating the discussion within the Tanzania's healthcare context, this study aims to shed light on understanding of the power infrastructural prerequisites for effective digital imaging informatics implementation. Ultimately, the findings inform policymakers, healthcare administrators, and development partners on strategies to bridge the infrastructural gap and enhance healthcare delivery through sustainable technology of digital imaging informatics systems adoption.

Methodology

The study employed a cross-sectional descriptive design which enabled the assessment of the electrical power infrastructure supporting radiological digital imaging systems in selected healthcare settings in Tanzania. This design was chosen to provide a snapshot of the existing infrastructure and operational challenges. The study was conducted in selected healthcare facilities to provide a comprehensive assessment of the electrical power infrastructure supporting radiological digital imaging systems. The sample size was determined by using Cochran's formula to ensure statistical representativeness. A combination of random and purposive sampling methods was applied to select respondents from selected healthcare facilities at different administrative levels, including national Hospitals, regional referral, district, and rural community health centres. The sampling approach was structured based on geographical and administrative classifications (urban, semi-urban, and rural) to ensure comprehensive coverage.

Within each selected health facility, technical personnel, specifically Radiographers and Biomedical Engineers were chosen based on their roles in

operating and maintaining medical imaging systems. Additionally, Heads of Radiology Departments were purposively selected for interviews to provide further insights.

A total of 30 respondents participated in the study was distributed as follows: In urban facilities: 6 technical staff from Muhimbili National Hospital (MNH) and 6 from Muhimbili Orthopedic Institute (MOI). In Regional Referral Hospitals: 5 respondents from Tumbi Regional Referral Hospital (Coast Region) and 5 from Kitete Regional Referral Hospital (Tabora Region). In District and Rural Health Centres: 3 respondents from Nzega District Hospital, and 5 from rural community health centres (3 from Busondo and 2 from Itobo). This structured sampling approach ensured a representation of healthcare facilities across different administrative and geographical contexts.

Data were collected using questionnaires and structured interviews. The questionnaires were administered to Radiographers and Biomedical Engineers captured quantitative information related to power infrastructure specifications, including power reliability, voltage compliance, outages, and backup systems. Interviews were conducted with Heads of Radiology Departments to gather qualitative insights on operational challenges, system performance, and the reliability of power supply. The data analysis process integrated both quantitative and qualitative methods, enabling a holistic assessment of the power infrastructure challenges faced by Tanzania's healthcare facilities.

Results

This section presents the results of the study on assessing the power infrastructure that supports radiological digital imaging systems in Tanzania's healthcare facilities. The findings are presented in line with the research objectives as follow:

Power Availability in supporting radiological digital imaging systems in Tanzania's healthcare facilities

The survey revealed that 93.33% of selected health facilities possess the necessary power infrastructure to operate digital imaging systems while 6.66% lack adequate infrastructure (Table 1). This high percentage suggests strong overall preparedness though gaps remain in the rural facilities. The survey findings indicate that 93.33% of health facilities in Tanzania possess the necessary power infrastructure to support the operation of digital imaging systems, reflecting a strong level of readiness across the majority of facilities. This demonstrates a commendable

commitment to improving healthcare delivery, particularly in urban and semi-urban areas where reliable power infrastructure is often more accessible. The availability of power infrastructure in these facilities is an enhancing factor for the effective deployment and utilization of radiological digital imaging informatics systems which are essential for diagnosis, timely treatment, and overall patient care improvement. Furthermore, these findings align with broader national efforts to modernize healthcare systems through the integration of technology-driven solutions, emphasizing the role of infrastructure as a foundational element in achieving these objectives. However, the 6.66% of facilities lacking adequate power infrastructure highlights a significant gap, particularly in rural and underserved regions. This shortfall could potentially hinder equitable access to quality healthcare since these areas may struggle to support the operational requirements of digital imaging systems. The disparity in power availability and stability suggests the urgent need for targeted interventions, especially to decrease dependence on the national grid, which often fails to consistently reach or adequately serve remote areas.

The disparity in power availability and stability emphasizes the need for targeted interventions, particularly in reducing reliance on the national grid, which may not consistently reach or serve remote areas. Tanzania should diversify its energy sources by investing in alternative solutions such as solar and wind power which offer reliable and sustainable energy even in off grid locations. Solar and wind power systems could significantly mitigate the challenges that rural health facilities face, ensuring reliable access and supply of electricity required for operating advanced radiological imaging technologies. While energy access is important, statement overlooks the more fundamental issues within healthcare systems, such as lack of trained medical personnel, outdated equipment, inadequate healthcare facilities, and poor access to medical supplies; without addressing these core challenges, simply introducing renewable energy may not lead to substantial improvements in healthcare quality.

By adopting such renewable energy strategies, the country can not only solve the existing infrastructural gaps but also foster inclusivity in healthcare delivery, ensuring that even the most remote facilities are equipped to provide high-quality diagnostic services. Addressing these challenges is critical not only for solving the infrastructural gap but also for fostering inclusivity in healthcare delivery.

Table 1: Power Infrastructure in Tanzania’s Health Facilities

Status of Power At the health facility	Agree (in %)	Not agree (in %)	Not sure (in %)
Availability of power infrastructure to operate medical imaging equipment.	28(93.33%)	2(6.66%)	0
Reliability of electrical power supply.	26(86.66%)	4(13.33%)	0
Power source (i.e. National Grid)	29(96.66%)		1(3.33%)
Voltage Compliance	29(96.66%)	1(3.33%)	0
Grounding and surge-protection to safeguard the medical equipment	30(100%)	0	0
Availability of Power backup to mitigate power disruptions	28(93.33%)	1(3.33%)	1(3.33%)

(Source: Field data 2024)

Reliability of Electrical Power in operating medical imaging equipment

The survey revealed that 86.66% of health facilities have reliable electrical power, signifying a robust foundation for supporting the operational requirements of digital imaging systems in most areas. This reliability is essential for maintaining the reliability and efficiency of radiological imaging processes for timely and accurate diagnoses. However, the remaining 13.33% of facilities, primarily in rural areas, reported frequent power disruptions, underscoring persistent inequities in infrastructure development. These disruptions can significantly hinder the performance and reliability of digital imaging equipment, leading to delays in service delivery and compromising patient outcomes. The findings highlight the need for tailored solutions to address these disparities, such as investing in decentralized power generation systems, including renewable energy sources like solar or wind power. Moreover, strategic upgrades to existing grid infrastructure and incorporating energy storage systems, technological and environmental challenges could mitigate not only the risks associated with power outages but also to have sustainable energy practice and long term investment in resilient energy system. Addressing these challenges is pivotal in ensuring that all health facilities, regardless of their location can maintain consistent and reliable power, resulting in fostering equitable access to advanced radiological services across Tanzania.

Voltage Compliance and Surge Protection

Voltage compliance

The findings highlight a positive trend in electrical infrastructure compliance and protection measures in health facilities. The voltage compliance aspect revealed that most facilities (96.7%) had the required voltage range essential for the optimal functionality of imaging equipment. Maintaining the appropriate voltage is critical for ensuring the optimal performance and longevity of sensitive medical imaging equipment. Voltage instability is a known factor that can lead to frequent breakdowns, inaccurate imaging results, and increased maintenance costs (Ballan, et al., 2021; Shem, et al., 2022). The compliance reported by the majority of facilities indicates that healthcare centres have prioritized stable electrical supply, a key driver for the reliability of digital imaging systems.

This compliance is particularly encouraging for the successful implementation of digital imaging informatics systems. Maintaining stable voltage levels helps minimize the risk of equipment malfunctions, ensuring reliable imaging quality and enhancing patient safety. However, it also raises the need to address the remaining 3.3% of facilities that are not yet compliant. Identifying and resolving issues in these facilities should be a priority to ensure uniform service delivery.

Grounding and Surge Protection

The universal implementation of grounding and surge protection measures reflects an excellent standard of electrical safety across the surveyed facilities. Surge protection plays a vital role in protecting medical imaging equipment from power surges caused by lightning, grid fluctuations, or internal electrical faults (Sahu & Madani, 2024; Balan et al; 2021). Such measures not only reduce the risk of equipment damage but also minimize downtime and repair costs, leading to better service continuity. Grounding, on the other hand, ensures electrical safety by providing a pathway for excess current to flow safely into the ground, protecting both equipment and personnel. The 100% compliance indicates a robust adherence to safety protocols, which is critical in environments that rely heavily on electrical and electronic equipment.

Generally, the findings urge for a strong commitment by health facilities to uphold electrical standards necessary for modern healthcare equipment. This reflects a progressive infrastructural development, a cornerstone for successful

implementation of digital imaging informatics systems. The emphasis should now shift towards sustaining these standards, addressing gaps in voltage compliance, and ensuring consistent quality across all healthcare facilities. Additionally, these findings can serve as a benchmark for other developing countries aiming at modernizing their medical infrastructure.

Frequency of Power Outages

Power outages present another critical barrier to effective healthcare delivery, particularly in facilities relying on power-intensive radiological equipment. During the interviews conducted with the Head of Radiology Department and Biomedical engineers at Kitete regional referral healthcare facility, it was highlighted that power outages pose a significant challenge to effective healthcare delivery. They emphasized that these disruptions occur on a weekly and sometimes monthly basis, affecting severely the operation of power-intensive radiological equipment. These interruptions cut down the continuity of healthcare services, posing significant challenges for departments which are heavily dependent on digital imaging systems. Radiological procedures such as X-rays, CT scans, and MRIs require a stable power supply to operate effectively, and any power instability can result into delayed diagnoses, postponed treatments, and patient dissatisfaction. Moreover, frequent outages increase the risk of damage to sensitive imaging equipment, leading to costly repairs, or replacements. During the interview with Radiographer in charge at the MNH, he said that ***“The situation worsens emergency departments where immediate imaging diagnostics are crucial for saving lives”***. Source: (Field data, 2024). This suggests for a call of a more effective strategy that will address the root causes of power outages through grid upgrades, improving energy efficiency, and exploring hybrid models that combine renewable energy and reliable backup systems.

Power Backup Options in health facilities

The survey findings indicate that 83.3% of healthcare facilities have implemented power backup solutions such as Uninterruptible Power Supplies (UPS) or auxiliary generators to mitigate the impact of power outages. These systems are vital for ensuring the continuous operation of critical medical imaging equipment during power interruptions. UPS systems provide immediate power to bridge the gap until generators or other long-term power sources are back, preventing abrupt shutdowns of sensitive equipment and ensuring data integrity. Similarly, auxiliary generators supply the necessary power during extended outages enabling healthcare services to run uninterruptedly.

However, the findings also reveal gaps in power backup readiness. About 11.1% of facilities lack backup power solution, leaving them vulnerable to service disruptions during outages. This poses a serious risk, particularly on radiological departments that depend heavily on power intensive equipment. Furthermore, 5.6% of respondents were uncertain about the presence of backup solutions in their facilities, suggesting a lack of awareness or inadequate communication regarding infrastructure capabilities. Such uncertainty can lead to delayed responses during outages and further compromising healthcare delivery.

Quantitative data from the selected health facilities indicate that the majority have implemented backup power solutions, which is a positive step towards enhancing resilience in healthcare service delivery, especially to power-intensive radiological departments. In addition, qualitative interviews were conducted with key personnel, including heads of radiology, and technical staff from the radiology departments in order to validate and enrich these findings.

According to the data obtained from field interviews, while most facilities benefit from backup power, 11.1% of facilities reported a completely absence of such systems and 5.6% were uncertain about their status. Based on the Field Interview, one head of the radiology department commented, ***“Without reliable backup, our radiology services remain vulnerable during power outages”*** (Field Interview, December 2024). Furthermore, the data obtained from the interviewees in the field emphasized that adopting sustainable energy solutions such as solar-powered backups, could further enhance system resilience and reduce dependency on conventional power sources, thus, paving a way to a more robust healthcare infrastructure (Field Interview, December 2024). This sentiment underscores the urgent need for stakeholders to align and allocate resources to equip all facilities with adequate backup solutions.

Discussion

This section highlights the critical role of power infrastructure in the successful implementation and operation of digital imaging informatics systems. This section is setting the foundation for a detailed discussion of the study’s findings and their implications on the electrical power infrastructure supporting radiological digital imaging systems in Tanzania’s healthcare facilities.

Centralized Power Systems and Associated Risks

The findings show that, most Tanzanian health facilities are connected to the National Grid which provides a centralized source of electricity. While this connectivity is a foundational strength, it also introduces vulnerabilities. Dependence on a single, centralized system increases susceptibility to national wide power crises as documented in other studies (Holland, 1995; Ogunyemi & Raji, 2018; Soroosh et al., 2019). Such crises can lead to widespread outages that disrupt healthcare services, particularly in facilities without robust backup solutions. This is a concern to radiological departments where power is essential for the operation of equipment like CT scanners, MRI machines, and X-rays, as well as for maintaining the integrity of imaging data in digital systems.

Infrastructure Readiness and Gaps

The survey findings provide convincing evidence for infrastructure readiness in many facilities. Voltage compliance in 96.7% of surveyed facilities ensures optimal equipment performance and minimizes the risks of device malfunctions caused by electrical instability. Similarly, 100% compliance with grounding and surge protection standards safeguards sensitive imaging systems from damage due to electrical faults or fluctuations. These indicators reflect significant steps towards creating a stable foundation for digital imaging informatics.

However, the study also underscores critical inequities. Frequent power outages remain a common challenge with 22% of the surveyed facilities experience weekly outages, and 78% reporting monthly disruptions. These interruptions compromise service delivery, particularly in rural areas where backup power solutions are less installed. The finding that 11.1% of facilities lack backup power options and 5.6% are uncertain about their availability further highlights disparities in infrastructure preparedness. Such gaps are particularly evident in rural areas where limited resources and logistical challenges hinder the deployment of reliable backup systems like UPS and generators.

Equity in Power Infrastructure Development

The disparity in power infrastructure between urban and rural healthcare facilities raises important questions about equitable access to healthcare services. The urban centres are more likely to benefit from stable power supply and advanced backup solutions, enabling seamless operation of digital imaging informatics systems. In contrast, rural facilities often face a burden of power outages and insufficient backup capacity, leading to equipment downtime (Balan, 2021). Addressing these

disparities require strategic investments in decentralized energy solutions such as solar power systems and hybrid energy models which can enhance stability and reduce dependency on the National Grid.

This study underscores the critical interplay between power infrastructure and the effective deployment of digital imaging informatics systems. Although the progress in voltage compliance and surge protection reflects commendable efforts towards infrastructure readiness, the frequent power outages and limited backup solutions highlight the challenges of achieving equitable access. A sustainable and inclusive approach to power infrastructure development, emphasizing decentralized energy solutions and strategic investments in rural facilities are essential for ensuring that all health facilities can fully leverage the benefits of digital imaging informatics. By addressing these gaps, Tanzania's health facilities can significantly enhance diagnostic capabilities and healthcare outcomes, particularly in rural areas.

Conclusion and Recommendations

Generally, this study assessed the electrical power infrastructure supporting radiological digital imaging systems in selected healthcare facilities in Tanzania. The findings highlight the critical role that reliable power supply plays in ensuring the continuous and effective functioning of medical imaging equipment. Despite the fact that the adoption of renewable energy sources and the improvement of backup systems offer promising solutions, the implementation of these measures presents significant challenges. These challenges include financial constraints, logistical hurdles, and the social dynamics of rural infrastructure expansion. Additionally, the intermittency of renewable energy sources and the limitations of backup power systems need to be addressed to ensure sustainable and reliable power for healthcare facilities.

Also, a more effective and integrated approach considering energy efficiency, long-term sustainability, and collaboration among key stakeholders is required for the successful implementation of digital imaging informatics in healthcare settings. Ensuring equitable access to modern medical imaging in both urban and rural areas, it requires a holistic strategy that engages community stakeholders, strengthens local infrastructures, and supports capacity building for sustainable energy practices. Based on the study's findings, the following recommendations are made:

Investment and Policy Support: there is a need for increased investment to support the development of reliable power infrastructure in healthcare facilities, particularly

in rural areas. Financial mechanisms should be explored to address the high upfront costs of renewable energy and backup systems.

Capacity Building: healthcare facilities should invest in training the technical staff to manage and maintain advanced power infrastructure, including renewable energy solutions and backup power systems to ensure optimal performance.

Stakeholders Collaboration: a collaborative approach between healthcare providers, energy suppliers, government agencies, and local communities is essential to develop integrated solutions that address the unique challenges of power supply in healthcare settings.

Sustainability Strategy: a clear and actionable long-term sustainability plan must be developed, with a focus on maintaining and upgrading power infrastructure, especially in rural and underserved areas.

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