



# Validation of a framework for assessing healthcare facilities in low-resource settings: a field study in selected facilities in Ethiopia

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## Abstract

**Purpose** The aim of this paper is to expand and further validate a framework to assess healthcare facilities in low-resource settings, with a specific focus on the challenges related to medical equipment, facility infrastructure, and oxygen devices. The collected information will allow informing practical solutions and scalable interventions applicable to similar settings, globally.

**Methods** The study employed a mixed-method approach, combining field observations and notes with an online-based survey to gather data and insights. The survey was developed based on an existing one and expanding it to include more details related to oxygen devices.

**Results** A total of 20 hospitals was assessed in Ethiopia. The findings highlight significant challenges, including resource limitations, inadequate staffing, and a lack of maintenance scheduling and spare parts. Notably, issues relating to oxygen supplies and deficiencies in essential safety devices were identified in the majority of healthcare facilities.

**Conclusions** In conclusion, the resulting framework has been instrumental in identifying and addressing the gaps and challenges related to health facilities in Ethiopian hospitals. The results can help promote stakeholder engagement to enhance capacity-building initiatives, promote local manufacturing and collaboration, improve infrastructure planning and maintenance, strengthen partnerships with international organizations, and address the existing challenges in the region.

**Keywords** Low-resource settings · Medical devices · Hospitals · Health technology management · Oxygen supply · Spare parts

## 1 Background

In low-resource settings (LRS), achieving universal health coverage (UHC) and developing a robust medical device (MD) infrastructure is hindered by challenges such as limited financial resources, inadequate infrastructure, and shortages of skilled professionals [1–4]. Healthcare facilities in these settings often struggle with inadequate utilities such as access to good quality electricity and clean water, along with insufficient spaces for patient care, which severely limit the scope and quality of services provided [5–6].

Before delving into further details, it is useful to specify that LRS is not a synonym for low-and middle-income countries (LMICs). In fact, LRS exist beyond the mere economic considerations and can also be found in high-income countries (HIC) in remote areas or in times of emergency [7].

These challenges are further compounded by global disparities in the access to advanced medical technologies, emphasizing the need for sustainable and scalable solutions aligned with the United Nations' Sustainable Development Goals (SDGs) to bridge these gaps and improve healthcare equity. Among these goals, published with the aim of “leaving no one behind”, SDG3 – Good health and Wellbeing – is particularly important in the context of global health and is at the heart of this specific project. Despite these ambitious goals and the fast growth of the global MD market (5.7% annually over the past decade) [8], it is the high-resource settings, especially in HICs that benefit the most. Over 70% of MDs are produced in the United States (46.6%) and

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Europe (26.4%), leaving LMICs and their LRS significantly underserved [9]. In fact, MDs are designed for HICs following standards and regulations that are often too strict for LRSs [10, 11], without considering the complex challenges faced by LRS, including environmental ones such as high temperatures, dust, and humidity [12] or without taking into consideration the end users, including their culture and traditions [13]. As a result, the healthcare needs of the area are often undeserved, limiting their access to essential medical technologies [14].

In LRS, especially, in LMICs, a significant portion of medical equipment is acquired through donations, but the availability of evidence-based data regarding MD infrastructure and regulatory processes remains limited [11–15]. The lack of appropriate equipment and suppliers further inhibits healthcare providers' ability to diagnose and treat patients effectively, leading to compromised patient care outcomes. This shortage is compounded by supply chain issues and regulatory barriers, making it difficult for LRS to establish sustainable MD systems.

To address these inequities, there is a pressing need for technological innovations that are affordable, durable, sustainable, and adapted to the specific environmental and operational contexts of LRS. Implementing such technologies requires global collaboration, capacity building, and supportive policy frameworks. Piaggio et al. [20] and Montesinos et al. [21] have proposed some relevant work in this area. Sustainable financing mechanisms, including public-private partnerships and health innovation funds, are essential for scaling healthcare solutions in a manner aligned with the aforementioned SDG 3's goal of ensuring healthy lives and promoting well-being for all at all ages.

In our research, we seek to address these challenges by assessing healthcare facilities in LRS using a modified version of a previously established framework [3]. This framework allows us to evaluate key aspects such as the ratio of MDs to patients, the availability of biomedical engineers and technicians (BMET), and the need for proper maintenance and regulatory processes of MDs. Specifically, we have adapted the framework to include an additional focus on medical oxygen device systems, given their crucial role in sustaining healthcare services [22] and our specific interest in this area as proven by previous [23] and ongoing works. By conducting on-site assessments in hospitals, engaging with biomedical engineers and technicians, and gathering data on the maintenance and performance of oxygen concentrators, we aim to identify critical needs and gaps in healthcare provisions. Ethiopia, a LMIC, was selected as the main focus of this study, due to the existing networks of some of the authors of this paper.

The Ethiopian health system is organized into eleven regional states and two chartered cities, each with its own

health bureau responsible for managing healthcare services [16–19]. Ethiopia's healthcare infrastructure follows a tiered approach, consisting of primary, general, and specialized hospitals, with each level providing progressively more advanced services [24, 25]. However, like many LMICs, Ethiopia faces infrastructural limitations, such as the lack of access to critical MDs and diagnostic tools.

## 2 Methods

In order to assess the condition of local health facilities, a survey was planned, and it involved a combination of field observations and notes, as well as a questionnaire. The latter was either performed in person or online, depending on the circumstances. Twenty hospitals were included in our study, and they were selected based on an existing network of local biomedical engineers and technicians known by one of the authors. The study area, i.e., Ethiopia, was selected due to its suitability as a case study and because the lead author of this paper, who also carried out the local field study, is from Ethiopia. The field study was conducted from March 1st to April 30th, 2023.

The questionnaire consisted of 76 questions organized into nine sections: Introduction and Authorization, Personal Information, Facility Information, Facility General Characteristics, Electrical Access, Human Resources, Facility Environment, Medical Electrical Equipment, and Database. It included a variety of question types such as Yes/No, multiple-choice, and Likert-type scale questions to assess specific dimensions and gather respondents' perceptions. For the latter, respondents were presented with six possible answers based on a 5-step Likert-type scale: Very Low, Low, Middle, High, Very High and Do Not Know. This scale allows the interviewees to express their level of agreement, satisfaction, or perception regarding the given dimensions on a continuum from Very Low to Very High. The "Do Not Know" option provided an opportunity for respondents to indicate uncertainty if they were unsure of their answer. These different question types and scales aimed to gather a comprehensive understanding of various aspects related to the surveyed hospitals, including their characteristics, resources, infrastructure, and perception of different dimensions.

The inclusion criteria for hospitals in the study required that they had biomedical engineers or technicians available for participation. Hospitals lacking biomedical engineers or technicians or those unwilling to take part and give their informed consent were excluded. Regarding the survey participants, eligibility was limited to individuals working as biomedical engineers or technicians, with professional experience of at least 1 year, and holding at least a college or

university degree to ensure that survey participants possess a foundational level of practical knowledge and relevant work experience in the field of biomedical engineering or MD maintenance.

The lead author personally visited some of the hospital, where he could also perform visual inspections on the local conditions, while in other cases the study relied on the information collected via an online questionnaire shared with key biomedical engineers working in those hospitals after informed consent was obtained from all individual participants before starting the study.

Additionally, six oxygen concentrators available at the NCSH (Nekemte Comprehensive and Specialized hospital) workshop (Hospitals maintenance center) were assessed, in terms of oxygen concentration output, to gather insights into device maintenance and purity status, as well as the main challenges they face.

### 2.1 Questionnaire preparation and validation

The survey employed a questionnaire based on the framework established in the previous study by Di Pietro et al. [3]. The questionnaire was thoroughly reviewed to ensure compatibility with the study's objectives. Feedback from the authors of the previous publication was carefully considered, and necessary adjustments were made to strengthen its relevance to the research goals. Specifically, an additional question was included in Sect. 8 of the original questionnaire focusing on evaluating the oxygen device system.

### 2.2 Ethical approval

An ethical approval was sought from the BSREC of the University of Warwick to allow for this study to be performed (REGO-2018-2283).

## 3 Results

The survey included 20 respondents, each representing a different hospital. The characteristics of the respondents are as follows: 17 were males (85%), 3 were females, and their ages ranged from 21 to 40 years old. All respondents held a college or university degree and worked as Biomedical engineer/Technician in their roles for 1–9 years.

### 3.1 General information about the facilities

Amongst the 20 hospitals assessed, there are 19 public hospitals and one Non-governmental Hospital (NGO). Tertiary-level hospitals account for 40%, secondary-level hospitals for 20%, and primary hospitals for the remaining 40%. The

inclusion of different levels of hospitals in the assessment allowed for a comprehensive understanding of the health-care landscape, considering their diverse capabilities, services, and resources available.

In terms of water sources, 13 hospitals (65%) primarily use piped water, while a mix of tanker water and open well water is common; three hospitals (15%) rely solely on tanker water; and the remaining hospitals (15%) use various water sources, except for one hospital (5%) that relies on open well water. Regarding communication infrastructure, 16 hospitals (80%) have operational landline telephones, while three hospitals do not (15%). One (5%) respondent was unsure about the type of communication system used by their hospital. Additionally, 15 hospitals (75%) have functional mobile phones, while four hospitals do not. None of the hospitals have short-wave radio wave facilities. Approximately, 90% of the facilities have at least one operational computer for staff use. Finally, 75% of the hospitals have a working internet connection, and all the hospitals assessed have at least one ambulance available.

### 3.2 Electrical access and safety

The assessment found that all hospitals had electricity access: eight relied on central power, two on generators, and ten had both. In the previous month, 11 hospitals experienced over 10 power disruptions, two had 7–9 disruptions, four had 4–6, and three faced 1–3 disruptions.

For electrical safety, ten hospitals used grounding, three had both grounding and isolation transformers, and two relied only on isolation transformers. No hospitals had equipotential grounding devices, and five hospitals were unsure of their safety systems. Electrical safety ratings varied: four respondents rated it as “Very Poor,” eight as “Poor,” seven as “Acceptable,” and one as “Very Good” (Table 1).

All hospitals had a voltage supply of 220V for single-phase and 380V for three-phase connections at 50Hz. Perceptions of voltage compatibility with MDs differed: two respondents rated it “Very Poor,” five “Poor,” seven “Acceptable,” four “Good,” and one “Very Good” and one did not know how the hospital voltage is compatible with MDs.

### 3.3 Human resource

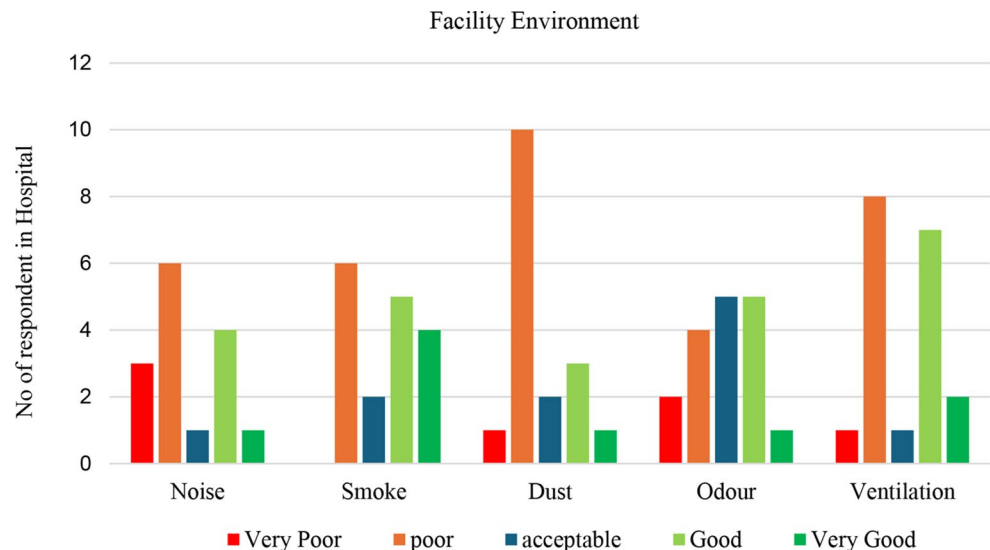
According to the respondents, the quantity of physicians in the surveyed facilities shows variation. The majority of respondents (58%) reported that one medical doctor is responsible for attending to more than 30 patients daily, followed by 16% who indicated that one doctor manages 20–30 patients per day. Across all facilities the ratio between medical doctors and patients was evaluated as “Very Poor”

**Table 1** Shows summary of the electrical access and safety

Hospitals	Power Outage/month	Access to Electricity	Quality <i>n</i> Reliability	Electrical Safety device	Electrical Safety	Voltage Compatibility
H1	10 or more	poor	Very Poor	IDK	Poor	Very poor
H2	10 or more	Good	Good	EG	Good	Good
H3	10 or more	Good	Good	EG	Acceptable	Acceptable
H4	4 to 6	Acceptable	Poor	EG	Poor	Acceptable
H5	1 to 3	Very Good	Very Good	EG	Poor	Acceptable
H6	4 to 6	Good	Acceptable	EG+ITR*	Acceptable	Acceptable
H7	4 to 6	Acceptable	Good	EG+ITR*	Poor	Good
H8	4 to 6	Good	Good	IDK*	Very Poor	Good
H9	10 or more	Good	Acceptable	IDK*	Acceptable	Acceptable
H10	10 or more	Good	Good	EG	Acceptable	very good
H11	10 or more	Very Poor	Very Poor	EG	Acceptable	Acceptable
H12	10 or more	Very Poor	Very Poor	EG	Very Poor	Poor
H13	1 to 3	Poor	Poor	ITR	Very Poor	Very poor
H14	10 or more	Poor	Acceptable	IDK*	Poor	Poor
H15	7 to 9	Poor	Good	EG	Acceptable	Poor
H16	10 or more	Very Poor	Very Poor	EG	Very Poor	IDK*
H17	1 to 3	Acceptable	Acceptable	IDK*	Poor	Acceptable
H18	10 or more	Poor	Poor	EG+ITR	Poor	Poor
H19	10 or more	Acceptable	Acceptable	ITR*	Acceptable	Good
H20	7 to 9	Poor	Poor	EG	Poor	Poor

\*EG-Electrical ground, \*ITR- Isolation Transformer, \*IDK- I don't know

**Fig. 1** Graph below shows summary of Premises distance from Noise, Smoke, Dust, odour and ventilation



by 47% of respondents and “Poor” by 37% of respondents. This suggests a concerning shortage of medical doctors in meeting patient needs.

Moreover, the assessment revealed a deficiency of clinical officers and laboratory technicians in all the facilities assessed. These professionals are tasked with attending to more than 30 patients each day. The ratio of clinical officers and laboratory technicians to patients was rated as “Very Poor” and “Poor,” indicating an inadequate staffing level to address patient care needs.

### 3.4 Facility environment

Most responses (Fig. 1) indicated a negative perception regarding the insulation or distance from facility excessive noise, smoke, dust, and unpleasant odours. Additionally, the adequacy of ventilation was largely deemed poor or very poor by a significant proportion of respondents.

### 3.5 Waste disposal

Based on the information provided by the respondents (Fig. 2), it appears that the frequency of cleaning in these



**Fig. 2** Waste disposal summary

facilities generally ranges from less than once a week or 1–2 times a week. However, five respondents mentioned that the facilities are undergo cleaning five or more times a week, indicating a higher frequency of cleaning in their respective environments.

Another issue raised relates to the materials utilized in the building. Respondents expressed varying perceptions of material quality concerning walls, ceilings, floors, and furniture. Among those who provided information on material quality, two rated it as “Very poor”, six as “Poor”, five as “Acceptable”, and five as “Good”. It is important to highlight that some respondents expressed uncertainty or lack of knowledge regarding the materials used within the building.

### 3.6 Medical and electrical equipment

In 60% of the evaluated hospitals there were well-established biomedical engineering departments, however, the remaining 40% lacked such departments.

The number and variety of MDs differed across facilities, with each having a very different range of different devices available. For instance, Facility H11 and H18 (Both are primary hospital) do not have an x-ray machine, However, several other facilities (H2, H3, H8-H10, and H19) possess more than two x-ray machines, indicating a higher availability of this type of device in those hospitals. Colonoscopy and Gastroscopy equipment are absent in all facilities except for H4 and H10, each having one device. This discrepancy does suggest a varied availability of specialised equipment across the hospitals.

The overall observation highlights a lack of essential capital MDs, particularly in radiology and specific imaging areas. Devices mentioned include X-ray, CT scan, Colonoscopy, Gastroscopy, Ultrasound, ECG, and mammography. These devices play crucial roles in various medical procedures, diagnostics, but their availability seems limited in the facilities under assessment.

Additionally, there is a notable lack of regular maintenance scheduling across most facilities. For most medical equipment, inspections and preventive maintenance activities are performed less than once a year or only once a year. This infrequent maintenance schedule can increase the risk of equipment failures, reduce the overall reliability of devices, and could potentially compromise patient care.

Based on our survey data, 12 (65%) of the assessed facilities implemented a maintenance program for their medical equipment. This indicates that the majority of the facilities have established protocols for the upkeep and repair of their medical devices. However, it is concerning that the remaining eight (35%) do not have a maintenance program, suggesting a lack of a structured processes for equipment maintenance. Furthermore, despite the presence of maintenance programs, numerous MDs across all assessed hospitals are awaiting corrective maintenance (See Supplementary Material 1). This delay is primarily due to the shortage of spare parts and consumables, which are essential for replacing faulty parts or components in the equipment. The scarcity of consumables and spare parts hampers the timely repair and maintenance of medical devices, potentially leading to a prolonged downtime for medical equipment and affecting the quality of healthcare services provided.

### 3.7 Medical oxygen device system

The primary sources of oxygen available in these facilities can be categorised as follows: in 70% of the facilities, oxygen is sourced from oxygen cylinders filled with compressed O<sub>2</sub> gas. However, these cylinders would need to be refilled or replaced when its oxygen supply is depleted. In 20% of the facilities, they utilised oxygen concentrator machines, and in 10% of the facilities, there is an oxygen plant that serves as a central supply of oxygen for the patients.

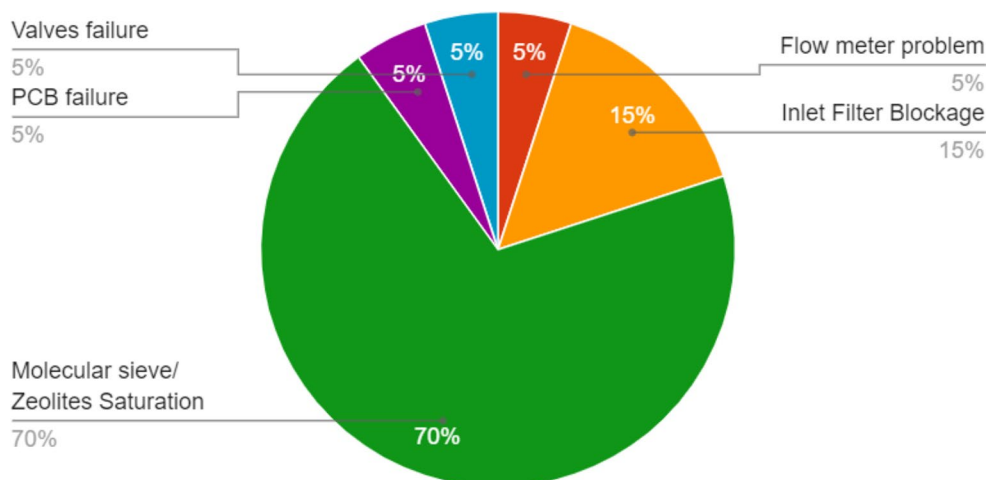
The delivery of oxygen supply to healthcare facilities faces several various challenges. One significant issue arises from the predominant use of oxygen cylinders as the main source of oxygen in most facilities. Obtaining these cylinders from external sources can involve supply and logistical complexities which hinders their procurement. Transportation challenges, such as delays or disruptions in the delivery process, coupled along with budget constraints, can affect the consistent and timely provision of oxygen to healthcare facilities. This is supported by the respondents that indicated approximately 80% of the facilities face difficulties in maintaining a continuous oxygen supply due to supply chain and logistical problems. Fourteen hospitals further lack oxygen analysers, which are important devices for measuring and verifying oxygen concentration delivered to patients. Without an oxygen analyser, healthcare providers are unable to confirm the concentration of oxygen being delivered to

**Table 2** Oxygen concentrator oxygen purity output (these devices are stored in the workshop being going under maintenance during the visit)

Inventory code	Model	Oxygen purity /saturation/ in %	Comment/Cause of problem
NCSH025	7 F-5	57	Low oxygen concentration
NCSH036	7 F-5	65	Low cycle pressure
NCSH067	7 F-5	45	High cycle pressure
NCSH053	7 F-5	37	Compressor circuit is opened
NCSH088	7 F-5	34	High cycle pressure
NCSH111	7 F-5	42	Low oxygen concentration

patients. This lack of quality control increases the risk of the improper administration of oxygen, which can be harmful or ineffective in-patient care.

Another challenge arises from the limited accessibility to spare parts and consumables for the oxygen concentrators utilised in some of the assessed facilities. Table 2 illustrates the oxygen concentrator output and purity measured from six specific models of oxygen concentrators in NCSH during the survey, focusing on the YUWELL 7 F-5 (0.5–5 L/Min) model. The data collected by one of the authors revealed that the quality of the devices output was quite low and as a result it is damped in the workshop. Despite attempts to troubleshoot the device, it remained inoperable due to limited access to spare parts. “Oxygen concentrators require regular maintenance to ensure their continuous functionality and proper output of oxygen during patient care” said one of the senior biomedical engineers. Spare parts such as molecular sieve beds, inlet filters, flow meters, and valve blockages are crucial for repairing and maintaining oxygen concentrators. From the field note and answer to the survey as indicated in Fig. 3, the molecular sieve bed represents a significant challenge for 70% of the respondents, while 15% face difficulties with the inlet filter. The lack of access to these necessary spare parts and consumables can hinder the proper functioning of oxygen concentrators, impacting patient care.

**Fig. 3** Component failure of oxygen concentrators according to respondents

Additionally, there is a requirement for capacity building and training in the maintenance and operation of oxygen supply devices. The respondent stressed that “proper training ensures that healthcare staff are equipped with the necessary skills to effectively maintain and troubleshoot the devices. However, the lack of training and capacity building programs for healthcare professionals can further contribute to challenges in maintaining the oxygen supply infrastructure and addressing issues that may arise.”

Several oxygen concentrator machines were left at the Nekemte Comprehensive Specialized Workshop, awaiting maintenance as indicated in Table 2, due to a shortage of various spare parts at the time of the visit.

### 3.8 Data base handling

Approximately 65% of the assessed health facilities use paper-based systems for managing medical equipment, while 35% have adopted computer-based systems. Despite this, most respondents rated data management as “Poor” (39%) or “Very Poor” (26%), highlighting major deficiencies. Although some facilities record basic data like manufacturing year, acquisition date, and serial numbers, crucial information such as warranty duration, service dates, technical manuals, and European Conformity (CE) compliance is often missing.

## 4 Discussions and conclusions

This study assessed and validated a framework for assessing healthcare facilities in LRSs, focusing on medical equipment, facility infrastructure, and oxygen devices in 20 Ethiopian hospitals.

The hospitals surveyed, mostly public, varied in care levels, resources, and capabilities. Shortages of medical personnel, including doctors and technicians, led to significant

gaps in patient care and service delivery. Inadequate ventilation and poor waste disposal practices highlighted the need for better facility management. Disparities in essential medical equipment further challenged diagnostic capabilities and patient care. Reliance on oxygen cylinders caused logistical challenges, while limited spare parts and trained professionals hindered the maintenance of oxygen concentrators. The predominant use of paper-based data systems caused inefficiencies in managing crucial equipment information.

A lack of centralized oversight for maintenance, inspection, and calibration of MDs emerged as a key management issue. Many facilities lacked dedicated staff for equipment management. Even where responsible authorities existed, accountability for maintaining MDs was often insufficient and unsustainable. This issue worsened due to inadequate financing, training, and a lack of clear MD management guidelines. Consequently, maintenance and repair were often neglected, leading to higher rates of equipment breakdowns and reduced functionality [26]. The survey revealed inadequate preventive and corrective maintenance of key medical devices, such as imaging machines like X-ray and ultrasound systems, oxygen concentrators, and vital monitoring equipment. Common maintenance challenges included a lack of spare parts, limited technical expertise, and infrequent servicing schedules, which collectively hinder the operational readiness of essential healthcare technologies. Additionally, procurement practices often fail to consider clinical needs, such as the patient-to-device ratio or the specific working conditions of the region [27].

Inadequate building materials and poor environmental waste management practices were identified, posing risks to patient safety and operational efficiency. Chemical waste and pollution poorly impact human health, requiring better standards to ensure patient safety, infection control, and operational efficiency [28]. Distance from foul odour sources, adequate ventilation, and dust control are crucial for maintaining a healthy environment. Proper air ventilation is especially important in minimizing the risk of airborne infections and ensuring comfort for patients and staff [29]. Moreover, the lack of electrical safety devices and awareness about electrical grounding, equipotential nodes, and isolated transformers in healthcare facilities is a major concern. Without proper electrical safety measures, medical devices may be handled improperly, posing risks to patients and healthcare personnel [27].

As regards oxygen systems, supplying and transporting oxygen cylinders posed logistical and budgetary challenges. Oxygen concentrators, indeed, offer an alternative but depend on electricity and require consistent maintenance. Their maintenance is difficult due to a lack of spare parts, especially the molecular sieve bed, a key component for producing medical-grade oxygen. Proper management of

oxygen systems, including functional inventory and spare parts forecasting, is critical for their long-term viability [22]. Innovative approaches such as 3D printing zeolite monoliths as spare parts for oxygen concentrators have shown promise. Coro et al. (2024) demonstrated that locally produced, 3D-printed zeolite monoliths could replace conventional molecular sieve beds, enhancing the sustainability and availability of oxygen concentrators in low-resource settings [30]. A group of other researchers, including some of the authors of this manuscript, are also performing a study investigating the causes of the saturation and malfunctioning of the molecular sieve beds and the possible solutions to regenerate such parts in a frugal way.

Like similar studies, this research has limitations. The selection of facilities, based on a pre-established local network of biomedical professionals, may introduce selection bias. Moreover, despite covering a good part of Ethiopia, not all facilities in different regions were included, limiting diversity in the data and potentially missing valuable insights. Future research should address this by using alternative sampling methods or expanding the network of professionals to ensure broader inclusion of facilities.

Overall, the framework effectively identified healthcare gaps and challenges in Ethiopian hospitals, confirming similar findings to those from Uganda and Benin [3]. This gap helps to promote stakeholder engagement to enhance capacity-building initiatives, promote local manufacturing and collaboration, improve infrastructure planning and maintenance, strengthen partnerships with international organizations to tackle the existing challenges in the region, contributing toward equity, UHC, and the United Nations SDGs.

### Abbreviations

LRS	Low resource settings
NCSH	Nekemte comprehensive specialized Hospital
SDGs	Sustainable Development Goals
UHC	Universal health coverage
MD	Medical Device
SPHMMC	Saint Poul's Millenium medical collage
NGO	Non-governmental hospital
EG	Electrical ground
ECG	Electrocardiogram
CT	Computed tomography
ITR	Isolation Transformer
IDK	I don't know
BMET	Biomedical Engineers and Technician
CE	European Conformity

**Supplementary Information** The online version contains supplementary material available at <https://doi.org/10.1007/s12553-025-00943-1>.

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**Data availability** Data related to this study are available as Supplementary Materials and upon request to the authors.

## Declarations

**Ethics approval and consent to participate** The study was performed in accordance with ethical approval REGO-2018-2283. Consent to participate was collected before the start of the survey.

**Conflict of interest** The authors declare that they have no conflict of interest.

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## References

- Kodali PB. Achieving Universal Health Coverage in Low- and Middle-Income countries: challenges for Policy Post-pandemic and Beyond. *Risk Manag Healthc Policy*. 2023;16:607–21. <https://doi.org/10.2147/RMHP.S366759>.
- WHO. World Health Organization. (2010). Medical devices: Managing the mismatch: An outcome of the priority medical devices project. Accessed: Jun. 12, 2023. [Online]. Available: <https://apps.who.int/iris/handle/10665/44407>
- Di Pietro L, et al. A Framework for Assessing Healthcare Facilities in low-resource settings: Field studies in Benin and Uganda. *J Med Biol Eng*. Jul. 2020;40:1–9. <https://doi.org/10.1007/s40846-020-00546-3>
- Makuku R, Mosadeghrad AM. Health workforce retention in low-income settings: an application of the Root Stem Model, *J Public Health Policy*. Sep. 2022;43(3):445–455. <https://doi.org/10.1057/s41271-022-00361-x>
- Murthy S, Adhikari NK. Global Health Care of the Critically Ill in Low-Resource Settings. *Ann Am Thorac Soc*. Oct. 2013;10(5):509–513. <https://doi.org/10.1513/AnnalsATS.201307-246OT>
- Luxon L. Infrastructure - the key to healthcare improvement. *Future Hosp J*. Feb. 2015;2(1):4–7. <https://doi.org/10.7861/futurehosp.2-1-4>.
- Kovacevic P. Can the terms ‘low resource setting’ and ‘low-income country’ be used interchangeably in the context of intensive care medicine? *Intensive Care Med*. Oct. 2023;49(10):1274–1275. <https://doi.org/10.1007/s00134-023-07203-8>
- Market -. MedTech Europe - The European Medical Technology in Figures, MedTech Europe. Accessed: Mar. 06, 2024. [Online]. Available: <https://www.medtecheurope.org/datahub/market/>
- MedTech Euroe. The European Medical Technology in Figures Accessed: Feb. 08, 2024. [Online]. Available: [https://www.medtecheurope.org/wp-content/uploads/2023/10/the-european-medical-technology-industry-in-figures\\_2023-1.pdf](https://www.medtecheurope.org/wp-content/uploads/2023/10/the-european-medical-technology-industry-in-figures_2023-1.pdf)
- Maccaro A, et al. On the universality of medical device regulations: the case of Benin. *BMC Health Serv Res*. Aug. 2022;22(1):1031. <https://doi.org/10.1186/s12913-022-08396-2>
- Pecchia L, Piaggio D, Maccaro A, Formisano C, Iadanza E. The Inadequacy of Regulatory Frameworks in Time of Crisis and in Low-Resource Settings: Personal Protective Equipment and COVID-19. *Health Technol*. Nov. 2020;10(6):1375–1383. <https://doi.org/10.1007/s12553-020-00429-2>
- WHO. Medical devices. managing the mismatch: an outcome of the priority medical devices project. Accessed: Jul. 01, 2023. [Online]. Available: <https://www.who.int/publications-detail-redirect/9789241564045>
- Vignigbé M, Maccaro A, Checa Rifà P, Piaggio D, Pecchia L. Précaution ou prévention? Des responsabilités de la politique et de la société pendant la gestion de la pandémie de COVID-19 au Bénin. *Can J Dev Stud Rev Can Détudes Dév*. Apr. 2024;45(2):332–347. <https://doi.org/10.1080/02255189.2023.2268794>
- Hopp WJ, Brown L, Shore C, editors. Building Resilience into the nation’s medical product supply chains. Washington, D.C.: National Academies; 2022. <https://doi.org/10.17226/26420>.
- Piaggio D, Medenou D, Houessouvo RC, Pecchia L. Donation of Medical Devices in Low-Income Countries: Preliminary Results from Field Studies, in *CMBEBIH 2019*, vol. 73, A. Badnjevic, R. Škrbić, and L. Gurbeta Pokvić, Eds., in *IFMBE Proceedings*, Cham: Springer International Publishing, 2020;73:423–427. [https://doi.org/10.1007/978-3-030-17971-7\\_64](https://doi.org/10.1007/978-3-030-17971-7_64)
- Judd TM, David Y, Hernandez A. Impact analysis: CE success stories, *InClinical Engineering Handbook*, 2nd Edition., Academic Press. 2019:243–252.
- Wagstaff A, Neelsen S. A comprehensive assessment of universal health coverage in 111 countries: a retrospective observational study. *Lancet Glob Health*. Jan. 2020;8(1):e39–49. [https://doi.org/10.1016/S2214-109X\(19\)30463-2](https://doi.org/10.1016/S2214-109X(19)30463-2).
- Babigumira JB, Jenny AM, Bartlein R, Stergachis A, Garrison LP. Health technology assessment in low- and middle-income countries: a landscape assessment. *J Pharm Health Serv Res*. Feb. 2016;7(1):37–42. <https://doi.org/10.1111/jphs.12120>.
- Medenou D, et al. Medical devices in Sub-saharan Africa: optimal assistance via a computerized maintenance management system (CMMS) in Benin. *Health Technol*. May 2019;9(3):219–32. <https://doi.org/10.1007/s12553-018-00283-3>.
- Piaggio D, Castaldo R, Cinelli M, Cinelli S, Maccaro A, Pecchia L. A framework for designing medical devices resilient to low-resource settings. *Glob Health*. Dec. 2021;17(1):64. <https://doi.org/10.1186/s12992-021-00718-z>.
- Montesinos L, et al. Sustainability across the medical device lifecycle: a scoping review. *Sustainability*. Feb. 2024;16(4):1433. <https://doi.org/10.3390/su16041433>.

22. WHO. Foundations of medical oxygen systems. Accessed: Jul. 01, 2023. [Online]. Available: <https://www.who.int/publications-detail-redirect/WHO-2019-nCoV-Clinical-Oxygen-2023.1>
23. Williams E, Piaggio D, Andellini M, Pecchia L. 3D-printed activated charcoal inlet filters for oxygen concentrators: a circular economy approach. *Dev Eng.* 2022;7:100094. <https://doi.org/10.1016/j.deveng.2022.100094>.
24. ETHIOPIA| Summary, Columbia University Mailman School of Public Health. Accessed: Jul. 01, 2023. [Online]. Available: <https://www.publichealth.columbia.edu/research/others/comparative-health-policy-library/ethiopia-summary>
25. Mengistu B et al. Dec., Barriers to the uptake of community-based curative child health services in Ethiopia, *BMC Public Health.* 2021;21(1)Art. no. 1. <https://doi.org/10.1186/s12889-021-11558-2>
26. Walia D, Huria J, Cordero I. Equipment maintenance and repair, *Community Eye Health.* Sep. 2010;23(73):26–29.
27. Salvaraji L, Jeffrey MS, Awang Lukman K, Saupin S, Avoi R. Electrical safety in a hospital setting: a narrative review. *Ann Med Surg.* Jun. 2022;78:103781. <https://doi.org/10.1016/j.amsu.2022.103781>.
28. Tafesse S, Girma YE, Dessalegn E. Analysis of the socio-economic and environmental impacts of construction waste and management practices. *Heliyon.* Mar. 2022;8(3):e09169. <https://doi.org/10.1016/j.heliyon.2022.e09169>.
29. CDC, COVID-19 and Your Health, Centers for Disease Control and Prevention, Accessed. Feb. 01, 2024. [Online]. Available: <https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/improving-ventilation-in-buildings.html>
30. Candidori S et al. Design and 3D printing of a modular phantom of a uterus for medical device validation, *Rapid Prototyp. J.* Dec. 2023;29(11):7–20. <https://doi.org/10.1108/RPJ-01-2022-0032>

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