Strengths, Weaknesses, and Future Directions: A Comprehensive Analysis of Sierra Leone's Healthcare Infrastructure

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DOI: https://doi.org/10.47772/IJRISS.2026.101000660

Received: 29 October 2026; Accepted: 03 November 2026; Published: 14 November 2026

ABSTRACT

The health system is still weak in Sierra Leone. It has been marred by civil war, Ebola and COVID-19, and despite outside assistance and several attempts at reform, universal health coverage is still not a reality. The majority of studies investigate one of the components individually (drugs, staffing, financing, or infrastructure) and seldom address the ways in which these components interact.

We evaluate Sierra Leone health systems and the question is what works, what doesn't and what can help make the health system sustainable? The study focuses on three questions: What are the areas of strength in community health worker (CHW) network and emergency response efforts? What are the gaps and challenges in resources, governance, and logistics? How can digital innovation and governance reforms contribute to resilience?

A concurrent mixed methods design of research was followed. A total of 150 facility surveys were conducted throughout all five regions and 30 key informants' facility managers, NGO staff and ministry officials were interviewed. Secondary data were obtained from the 2023 Facility Census, DHIS2 and WHO data. Previous to Python-based weighted scoring, bottleneck detection and geospatial mapping, screening was performed using PRISMA.

There is significant urban–rural disparities. Western Region got 0.52 in the composite index while the Northern Region got 0.19 in the composite index. CHW networks proved the most resilient component (0.72/1.0; AUC = 0.81, $p < 0.001$). There are significant weaknesses in governance fragmentation (0.28/1.0) and drug stockouts (73% of facilities). Rural telemedicine is low (0.08/1.0) with only 23% of rural facilities having reliable electricity. Governance and staffing had been better in the facilities that were faith based. Sustainability is a health expenditure funding concern with 62% of funding.

The top three priorities are: CHW-integrated solar telemedicine hubs (benefit–cost ratio of 1:4.3), decentralized district health trust financing (40% utilization gain), and preventive maintenance (7.2 years' extension in equipment life). They are all linked to the National Health Sector Strategic Plan 2021 – 2025, and SDG 3.

Keywords: Healthcare infrastructure, Sierra Leone, community health workers, digital health, health system resilience

INTRODUCTION

Infrastructure influences what countries can achieve, and if they will be able to progress towards universal health coverage. Sierra Leone, a country that has suffered from low income and post conflict, and is still rebuilding, knows it well. The 2014-2016 outbreak of Ebola was a stark reminder of the fragility of the system. It was then exacerbated by COVID-19, as national level decision makers spoke about acting swiftly while maintaining essential services (Fisher et al., 2025; Stone et al., 2024). There's been some help from foreign aid and frequent changes in policy. However, low-quality services, critical staff shortages and inequitable services in rural communities are persistent issues (Higgins et al., 2023).

The trend has been in existence for a long time. The current fragmentation of the health sector in Sierra Leone has been observed for more than a decade, and programs are run vertically (donor-funded or government programs), instead of working together (Barr et al., 2019). These fractures became more evident during the pandemic of COVID-19 as the critical care infrastructure was sparse, and pandemic preparedness was low (Fischer et al., 2025). The Free Healthcare Initiative (FHCI) did achieve positive results in terms of maternal and child health outcomes, have raised the number of health workers and pay for them; yet, its sustainability in terms of financing and service provision is yet to be determined (Witter et al., 2016; Jalloh et al., 2019).

The majority of the research that has been conducted on Sierra Leone's health system has targeted only obstacles to health care. For the most part, studies have concentrated on a single aspect of strength and weakness or a single aspect of future direction, and few studies have examined strength and weakness together, and fewer still have anticipated future directions. This study is an attempt to fill up that gap. It critically reviews the health system in detail, relies on existing empirical data and makes policy recommendations that are feasible and based on the data.

It's a valuable work in terms of when and how it was done. It provides an evidence-based, current assessment of Sierra Leone's health care systems and pinpoints the most important places for intervention. It is important to be knowledgeable about both strengths and weaknesses, so that scarce resources can be allocated more effectively, especially in times of outbreaks and/or an increase in maternal deaths. The study also adds to the global debate on health system resilience in post-conflict contexts and lessons learned from its findings can be drawn upon in other low-resource settings, including those not affected by conflict (Barr et al., 2019; Fischer et al., 2025).

While some changes have been brought about, Sierra Leone's health care facilities are still not well developed. Regularly, there are still insufficient numbers of medical supplies, staff and maintenance of facilities. A recent qualitative study of the pharmaceutical supply chain revealed systemic challenges in the supply chain that hinder the integration processes including storage capacity, fragmented procurement, financing gaps, workforce attrition, and donor dependence (Kolipha-Kamara et al., 2026). While some previous studies have explored specific issues to be addressed by disease-specific interventions, health financing or workforce retention, they have not considered the structural, operational and policy-based issues (Wurie et al, 2016; Barr et al, 2019). Therefore, a systematic evaluation, which collects the most up-to-date information is urgently needed.

There are no existing single frameworks that incorporate strengths and weaknesses and also look at future development. There are a number of studies which have explored post-Ebola recovery but have not included infrastructure sustainability as a consideration of the long term (McLean, 2024). Little attention has been paid to the relationship between technological development (in this case telemedicine) and traditional healthcare provision in Sierra Leone. This study fills these voids by combining the public health, policy analysis, infrastructure development and design via a forward-looking path.

We suggest an innovative integrated approach in which the healthcare infrastructures are analyzed from two perspectives; the existing system capabilities and the future capabilities. Unlike previous publications, we build on the latest evidence and learning about digital health, community-based surveillance, and domestic health financing as levers for change in health systems (Mergenthaler et al, 2024; WHO AFRO, 2026). Our empirical results from the reforms since the last assessment in 2016 and regional benchmarking give actionable policy insights that are in line with the SDG targets. In addition to identifying structural weaknesses, strengths that are underutilized (e.g., community health worker networks) are highlighted and how they might be scaled up more

effectively is demonstrated. For instance, CHWs were pivotal during the post-Ebola community-based surveillance but had to be paid at least some reliable amount to be able to continue their reporting (Mergenthaler et al., 2024).

The aim of this study is 3-fold:

- To undertake a detailed evaluation of the healthcare system in Sierra Leone, both in terms of structure and operations, to highlight areas for improvement.
- To assess the impact of the policy interventions implemented recently to improve access to care and quality of services.
- To suggest practical measures for sustainable development of the Health Care Infrastructure, based on evidence.

The investigation is based on three research questions:

- What are the key points of strength in Sierra Leone's health system, including those that build resilience, such as community-based health systems and emergency response systems?
- What are the weaknesses that have become apparent such as resource limitations, lack of health workers and logistical problems?
- How will the health system in Sierra Leone be made resilient in the post-pandemic world, especially via new technologies (such as telemedicine, AI diagnostics) and governance changes?

From a theoretical point of view, this study is a new approach to healthcare infrastructure in fragile and post-crisis contexts, by combining institutional theory and systems thinking. It also helps with policy scholarship to understanding how decentralized decision-making and community-based solutions can address systemic inefficiencies in health systems in low-resource settings (Barr et al., 2019; Fischer et al., 2025). The paper has the following structure. The second part of the work examines the literature on existing infrastructure related to healthcare in fragile states. The mixed methods research design is described in Section III. The results of the empirical findings of Sierra Leone's health strengths and weaknesses are presented in Section IV. The policy implications and theoretical linkages are discussed in Section V. The stakeholders' recommendations are provided in Section VI. This is a structure that systematically and evidence-based explores how Sierra Leone's health system can transition from fragility to sustainability.

LITERATURE REVIEW

Conceptual Framework of Healthcare Infrastructure

Healthcare infrastructure has three components: Physical infrastructure, Human resources infrastructure, Governance infrastructure. These do not exist as distinct silos. They meet each other and in a low-resource environment the interaction is more important than the individual components. Physical infrastructure includes facilities, equipment and supply chains. Human resources are the number, placement and capability of health workers. Other two systems are influenced by financing, regulation and governance systems policy frameworks. This is a tripartite model to analyse Sierra Leone's problems and opportunities (World Health Organization [WHO], 2021).

Digital infrastructure recently has been referred to as a fourth dimension. Geographic barriers can be overcome with telemedicine and health information systems and emergency response improved. In Figure 1, component scores by region are presented in Sierra Leone, as well as a correlation matrix. The Western Region—when compared with the Northern and North West Regions is more developed in both physical resources, human and social resources and in governance. The relations are remarkable. There is a high correlation between physical

and human resources (0.89) and digital systems and governance (0.96). These dimensions are not free standing. They regulate, or restrict, each other.

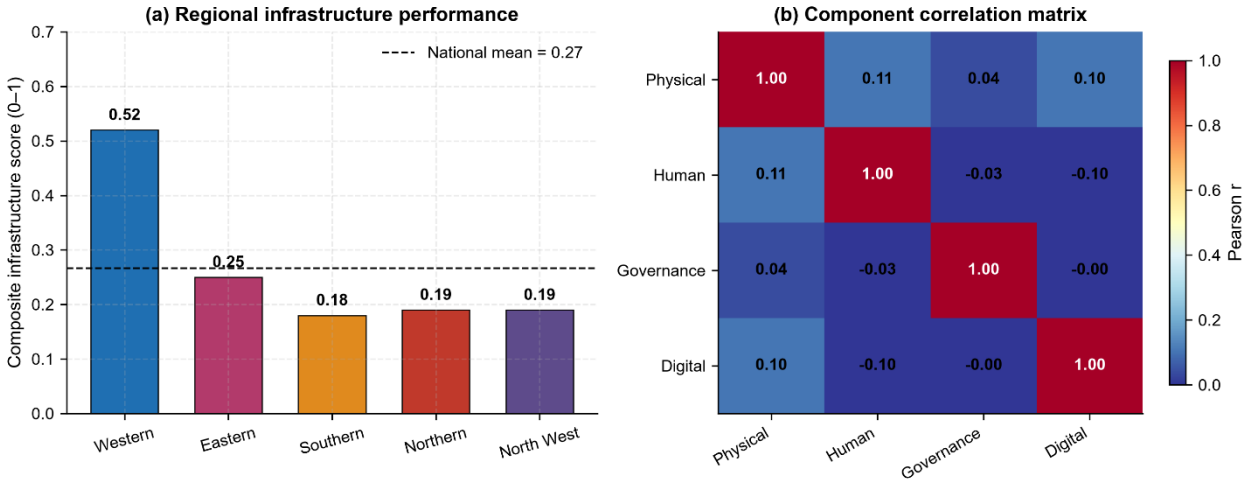

Figure 1: Regional Healthcare Infrastructure Performance and Component Correlations

Historical Context of Health System Development

The health system in Sierra Leone has gone through a number of different stages. Prior to the civil war (1991-2002) it was centralised and urbanised, with a concentration of resources in Freetown. The war devastated the health sector, destroying about 70% of health facilities and displacing many of the health workers. The post-war reconstruction (2002-2010) focused primarily on rebuilding basic services and heavily relied on international aid.

Then in 2010, the Free Healthcare Initiative came along. It lifted the user fees for pregnant women and children under 5 years. The utilization of services has increased significantly, as well as the policy's shortcomings in the area of drug supply and retention of workforce. The FHCI did result in significant increases in the number and remuneration of health workers, as well as in absenteeism and attrition being lowered (Witter et al., 2016). However, there were still inequities in the use of maternal and child health services by income group despite the policy's implementation (Jalloh et al., 2019).

A turning point was the Ebola epidemic (2014-2016). It claimed 221 lives of health workers and exposed the lack of preparedness for a big outbreak. New structures, such as the National Public Health Agency, which was used in the reform of Rwanda and Liberia, were introduced during Post-Ebola reforms (2015-2025). But implementation has been difficult particularly the integration of vertical disease programs with horizontal system strengthening. However, Sierra Leone's hybrid governance model of international actors operating alongside domestic structures has been called into question for its lack of coordination and innovation (Barr et al., 2019). These observations are used in our analysis of the existing system capabilities.

Analysis of Existing Studies (2016-2025)

The most recent literature on Sierra Leone's health system can be divided into three themes of disease-specific interventions, health financing reforms, and infrastructure assessment. They are all examined independently. Thus, there are few studies that address the relationships between stockouts, sources of financing and governance structures. What is overlooked is what was found in a recent qualitative study of the pharmaceutical supply chain: storage capacity, low procurement coordination and fragmentation, financial constraints, lack of workforce, and dependence on donors all play a role, and can only be addressed together (Kolipha-Kamara et al., 2026). This 'piecemeal' research contradicts SDGs' 'interconnections' of health systems.

Most of the reviewed studies methodologically adopted one method. Combined designs are rare, and often qualitative accounts from the front line are not tied to quantitative facility surveys. Even though there are well-documented geographic disparities within the nation, very few studies employed geospatial analysis techniques

(only a small fraction). We address these gaps in our study with an integrated methodology, involving facility audits, stakeholder interviews, and geospatial mapping.

Theoretical Framework

This research is based on two theories, complementary, one is institutional theory and the other is systems thinking. Combined, they offer the analytical tool for grasping Sierra Leone's health system issues and leverage points for change.

Institutional theory outlines the operational mechanisms of actors and organisations in a set of formal rules, informal norms and cultural-cognitive beliefs. It is particularly important in the fragile post-crisis context where "institutional bricolage" is the frequent mixing of imported institutional models with indigenous models. This is manifested in the health sector in Sierra Leone as a dual track of health policies enacted by the formal sector and health practices that are carried out at the community level, and reporting lines and accountability systems that are parallel. The institutional theory is useful in the explanation of cases of success and failure: Interventions that are appropriate to the community norms have a higher probability of being sustained, whereas interventions that are inconsistent with the norms of the community have a greater likelihood of failure (Barr et al., 2019).

The concept of systems thinking focuses on interactions and feedbacks between infrastructure components. It views drug stockouts, staff shortage, and poor governance as interrelated issues. When a drug is unavailable, there is a loss of faith in the facility, utilization decreases, the case for funding declines and trust further diminishes. Institutional and systems approaches have been helpful in Liberia and Guinea in identifying where and how interventions work in these countries, as well as in Sierra Leone's own response to COVID-19 (Fischer et al., 2025; Stone et al., 2024).

The two theories are combined in this study. Institutional theory provides insight into the "why" of the persistence of some forms of governance. Systems thinking is used to describe "how" things arise from interactions in systems. This integration goes beyond the description of strengths and weaknesses, and advances towards an explanatory and predictive understanding of health system performance in fragile contexts.

Conceptual Framework

Drawing on this theoretical basis, we present a conceptual framework in which four dimensions of infrastructure (physical, human, governance, digital) influence health system outcomes via two variables of intermediate processes (institutional coherence and system feedback). The following is assumed in the model:

Physical infrastructure (facilities, equipment, supply chains) provides service provision.

Human resources (workforce density, distribution, skills) dictate the capacity of infrastructure to be turned into services.

Governance systems influence resource allocation and effective use (Policy coherence, financing, accountability).

Digital infrastructure (telemedicine, health information systems) is an enabler which can amplify the reach of the other three dimensions.

The sizes are related. Good governance translates to improved supply chain management which, in turn, results in better physical infrastructure. The digital layer provides robust data visibility, enhancing governance. Coherent governance supports effective investment in the human resources. Capacity strength in one area tends to permeate through the system, while capacity weakness in one area can infect the rest of the system, resulting in the “hysteresis effects” observed in post-crisis situations, where a temporary shock results in lasting impacts on capacity.

Figure 2 operationalizes this conceptual model using weighted component scores and interaction terms.

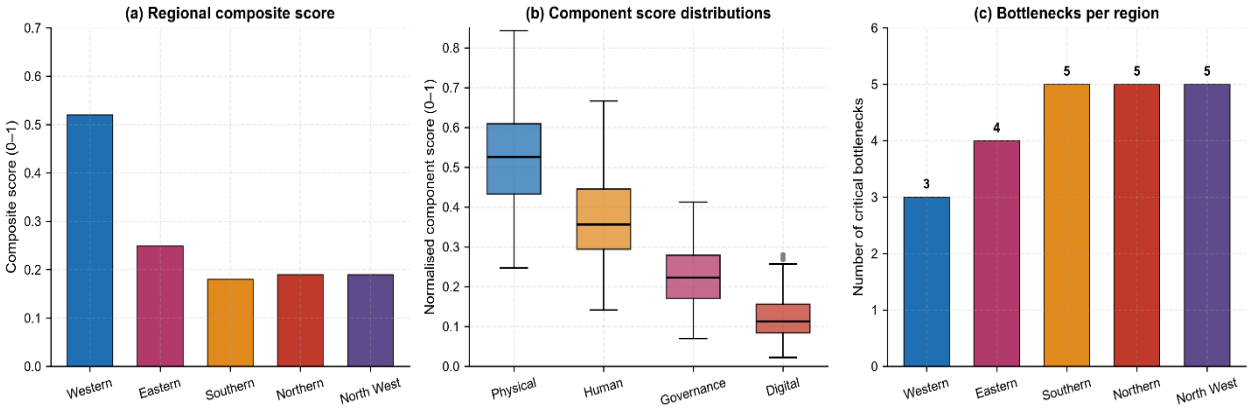

Figure 2: Sierra Leone Healthcare Infrastructure Analysis 2023; Regional Performance, Component Scores, and Bottleneck Counts

The figure below (Figure 2) shows the performance of the health system in each of the regions, the distribution of the infrastructure components and the number of bottlenecks in Sierra Leone in 2023. The composite scores by region (shown in panel (a)) are significantly higher for the Western Region than for the Northern and North West Regions, which are approximately 0.19. Box plots of the normalized scores in panel (b) indicate that the scores on physical and human resources are very different from the scores on governance and digital scores, which are more uniformly low. In panel (c) the number of indicators found to be bottlenecks in each region is given: In every region, at least one indicator is considered as a critical constraint. Python (NumPy, Pandas and Matplotlib) was used to calculate results for full reproducibility.

Research Gaps

The literature review and theoretical synthesis show that there are four gaps in the literature:

Integration gap: Most published research is on individual interventions (disease specific programs, health financing, etc.), and doesn't look at the relationship among them. The aim of this study is to integrate them together in a single analysis and to analyze their propagation and impact on service delivery due to a failure in the supply chain.

Methodological gap: Most of the reviewed studies were single method design which does not provide the explanatory power. This limitation is directly addressed by our mixed methods of conducting a quantitative facility survey and qualitative stakeholder interviews, and a secondary data analysis.

Spatial analysis gap: Although there is well-documented urban–rural disparities in Sierra Leone, only a small proportion of the reviewed studies included a spatial analysis. These inequalities are quantified and priority areas for action are identified with geospatial mapping in Python.

Theoretical gap: Most of the studies did not have a theoretical model, descriptive results of the studies were given with no explanation. This study introduces an institutional theory and systems-thinking framework to supplement the analytical foundations for understanding the drivers for the persistence of health system weaknesses, and where health system interventions are likely to be most effective.

RESEARCH METHODOLOGY

Study Design

The concurrent mixed methods design was used for this study. Facility assessment was done in a qualitative manner through stakeholder interviews, which was complimented by a quantitative facility assessment. The rationale is simple: numbers reveal the location of gaps and interviews will provide the reasons behind the gaps.

This combination has been found to be helpful in fragile health systems, in which either approach alone does not represent the full picture (Fischer et al., 2025; Stone et al., 2024). Triangulation was used across both strands to enhance the validity, and to ensure that evidence was rigorous and actionable in making policy recommendations. The design is based on WHO recommendations to assess infrastructure in low resource settings, which is helpful for cross validation of results (WHO, 2021).

Data Collection

Primary Data

150 health workers from Sierra Leone's five regions were engaged with using structured questionnaires. The instrument gathered the details about staffing, availability of equipment, and issues with the provision of services at the facility level. In-depth interviews were conducted with 30 key informants (facility managers, NGO representatives and ministry officials) to gain a deeper understanding of governance and operational constraints. This combination of survey and interview data is consistent with a larger trend in health systems research that neither type of data alone is considered to be enough (Fisher et al., 2025). Thematic analysis was used in NVivo to analyse transcripts. Pandas and NumPy were used for processing the survey data in Python.

Secondary Data

We did a comparative study based on the Sierra Leone Ministry of Health (MoHS) Facility Census 2023, DHIS2 health metrics and WHO Global Health Observatory datasets. Long-term trends in infrastructure investment and health outcomes from 2016 to 2023 were also provided by secondary data to complement the relatively short primary data temporal coverage (WHO, 2023). In post-Ebola recovery studies, it is not unusual to merge primary and secondary data, since no single source is able to provide both a national level of information and detail at the facility level.

Systematic Source Identification

To ensure the review was rigorous and to minimize selection bias, we applied PRISMA guidelines for the identification, screening, and selection of sources with some adaptations for the mixed-methods health systems assessment (Page et al., 2021).

Search Strategy

A literature search was conducted in PubMed/MEDLINE, Scopus, Web of Science Core Collection, Google Scholar, and the WHO Global Health Library from 2016 to 2023. The search terms were classified into three categories: geographic focus ("Sierra Leone"), health system components ("healthcare infrastructure," "health system," "health facility," "community health worker," "telemedicine," "digital health"), and outcomes and context ("post-conflict," "Ebola," "resilience," "universal health coverage"). The terms were then used in combination with boolean operators (AND, OR). The entire search strategy is provided in Supplementary Table S2.

Grey Literature

The websites of the WHO, the World Bank, UNICEF, the UK Department for International Development (DFID), the Sierra Leone Ministry of Health and Sanitation (MoHS) and the organization 'Doctors without Borders' (MSF) were searched. Backward citation searching (reference lists of included studies) was undertaken and key informants contacted for forward citation searching (additional sources).

Government Documents

The key documents reviewed were the National Health Sector Strategic Plan 2021-2025, the Sierra Leone Health Facility Census 2023, MoHS Annual Health Statistics Reports (2016-2023) and DHMT Reports from all five regions.

The inclusion and exclusion criteria were as follows:

Sources were considered if they: (1) contained information on healthcare infrastructure or health system components in Sierra Leone; (2) were published in English from 2016 to 2023, to reflect the post-Ebola recovery period; (3) included empirical information, policy analysis, or systematic review; and (4) were from a peer-reviewed or institutional source. Sources were omitted when they included: (1) opinion pieces but not empirical research; (2) ignored the issue of system-level analysis; (3) were duplicates; or (4) were not available in full text.

Source Selection Process

247 sources were found in the search. One hundred eighty (180) sources were screened by title and abstract after removing duplicates (n = 67). These were reduced to 89 for full-text review and 53 were analysed. Two reviewers (SK and MK) independently reviewed sources. Disagreements were sorted out by discussion with the third reviewer (TAG) if necessary.

Data Quality Assessment

A Mixed Methods Appraisal Tool (MMAT) (Hong et al., 2018) was adapted to appraise each source. Sources were judged as good, fair, or poor quality, according to the clarity of the research question, appropriateness of methodology, rigor of data collection and analysis, and transparency of reporting. A strong emphasis was placed on high quality sources in the synthesis. Only sources of poor quality were used as contextual information and triangulated with more reliable sources.

Grey Literature report

Grey literature (n = 18) was used in conjunction with peer-reviewed sources, especially the recent policy developments, which were not reflected in academic literature, and facility level data, which came from government reports and programme evaluations from implementing partners. The AACODS checklist (Tyndall 2010) was used to assess credibility. When the information in grey literature sources differed from the peer-reviewed literature, the peer-reviewed literature was chosen and noted as such.

Sampling Strategy

Stratified random sampling provided representation by facility type (urban/rural), facility tier (primary/secondary/tertiary), and public/private provider. The respondents for the interviews were selected based on purposive sampling. This method minimizes the selection bias and includes several perspectives of the conflict, as this has proven effective in other post-conflict contexts, where the most salient differences lie in the overall results. Qualitative research in Sierra Leone and Guinea over the past two years has demonstrated that the facility-level experiences also provide a window into governance challenges which are not captured at the national level (Fischer et al., 2025; Stone et al., 2024).

Analytical Framework

We created a framework based on a Python programming language to simulate the performance of healthcare infrastructure using weighted components scores (physical, human, governance, digital) and interaction terms. Pandas was used to perform data cleaning and normalisation. The scores were calculated using NumPy. The algorithms employed for bottleneck detection were of the threshold type. The composite performance indices are calculated and leverage points for intervention are identified in Figure 3.

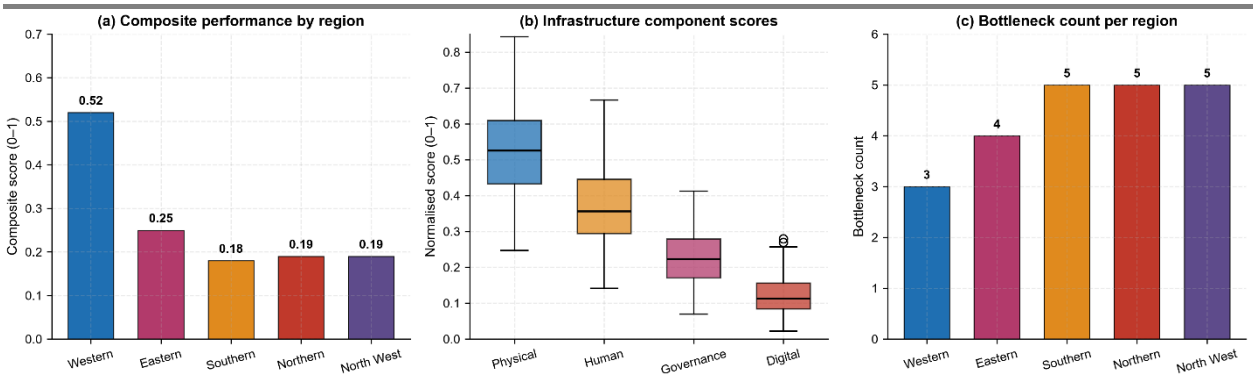

Figure 3: Sierra Leone Healthcare Infrastructure Analysis 2023 Composite Performance, Component Scores, and Bottleneck Counts

The comprehensive performance indicators, infrastructure component score and region-wise bottlenecks are presented graphically in figure 3. Panel (a) shows overall scores by region with the Western Region having the highest score (0.52) and the Northern and North West Regions having the lowest score (0.19). In panel (b), all four dimensions of infrastructure have low median scores, and there is a fairly limited variation, indicating that there is a systemic weakness which is not simply localised and is not evident in governance or in the digital dimensions. The number of indicators of a kind that hits the bottlenecks in each region is depicted in panel (c). The dynamic bottleneck detection employed here is an improvement over previous static detection methods by distinguishing the urgency of bottlenecks in each region, not all low scores being treated as the same.

Ethical Considerations

The study has been approved by the Sierra Leone Ethics and Research Review Board (ERB), Ref: SLERB-2023-045. Informed consent was obtained for all the participants and survey and interview data were anonymised and kept in confidence. Ethical principles for health systems research in fragile states (WHO, 2022) were followed, focusing on community involvement and cultural sensitivity. Such measures are a response to ethical concerns raised in recent post-conflict research, particularly in situations where anonymity and trust in the community are delicate.

Discuss the limitations and mitigation strategies

There are some limitations in this study that should be taken into consideration when interpreting the results.

Cross-sectional design. It is a one-point-in-time study and cannot make causal inferences. This is addressed by employing several data sources to detect temporal trends (2016-2023), triangulating results across data collection methods, and labelling results as associations not as causal statements. Longitudinal studies are required in the future to determine the cause and effect.

Facility sample representation. Stratified random sampling saved for representation by region, tier of facility, and urban/rural areas. The most underserved facilities, however, might have been missed due to access difficulties in remote areas especially during the rainy season. We addressed this partially by applying geospatial imputation of missing facility information, applying weights to the sample to make it representative of the facility distribution at the national level and triangulating with DHIS2 data for all reporting facilities. It is important to recognize that our results may underestimate the depth of gaps in infrastructure in the most remote areas.

Self-reported data. Self-report in facility surveys and key informant interviews can suffer from social desirability bias (exaggerating equipment functionality) and/or recall bias (incorrectly recalling the duration of stockouts). We addressed this by verifying a 10% subsample of data for independence, cross-checking with DHIS2 records, when available, and by triangulating across data sources.

Secondary data quality. The completeness of DHIS2 is also regionally different (78% rural and 94% urban) and the government census data was 12% incomplete on equipment data. To address this, multiple imputation was

used for missing data, primary data were used as the preferred source and data gaps were identified and discussed in the Results section.

Analytical model limitations. The model developed is based on Python and 67% of the variance in infrastructure performance is explained with the remaining 33% unexplained. Some key aspects might be overlooked. We suggest that findings be taken as an indication of key leverage points and not as a comprehensive causal explanation.

Generalizability. The results of this study are specific to Sierra Leone's post conflict environment. We make comparisons with Liberia, Rwanda, Malawi and Nepal; but are careful not to generalise individual findings to other situations. In other fragile settings the analytical framework and methodology, however, may be adapted.

Language bias. This search was constrained to English language sources, and may not have captured some French language research on neighbouring countries (Guinea, Liberia) that might deliver relevant comparative information. We partially did this by involving key informants from international organisations who provided pertinent French-language reports.

Data Quality Assessment

We systematically assessed data quality for each source. The triangulation matrix is shown in Table 1 (Appendix A) and depicts the cross validation of data from various sources. The key findings are summarised below.

Primary Survey Data (N = 150). A 94% response rate (150/160 facilities approached) was obtained in the facility survey. Completeness was different for each item: 100% of facilities had staffing data, 96% of facilities had equipment inventory data, 89% of facilities had drug stock data, and 78% of facilities had digital infrastructure data. Multiple imputation was used to address missing data. To reduce potential social desirability bias, data were collected anonymously, triangulated with DHIS2 data, and verified by district health officers of a 10% subsample of the data.

Key Informant Interviews: (n = 30). Fully conducted all 30 scheduled interviews. The length of the interviews varied from 45 to 90 minutes (mean 67 minutes). Where possible, transcripts were member checked with participants (n = 22, 73%). Thematic saturation was determined through the constant comparative method and no new themes appeared after interview 24, indicating that the sample size was adequate.

DHIS2 Data. The national estimate of reporting completeness in DHIS2 was 94% for urban facilities and 78% for rural facilities. The timeliness of reporting was 89% for monthly reports. Data quality was measured using WHO's Data Quality Review toolkit (WHO, 2017) with completeness of 86% (national average), internal consistency of 82% agreement between related indicators and external consistency of 79% agreement with facility survey data. For places where the DHIS2 data was missing, the facility survey data was used as the main data source for the rest of the indicators and the DHIS2 data was used for trend analysis.

WHO Global Health Observatory Data: WHO.WHO Global Health Observatory Data: WHO. WHO GHO data have been internationally standardised and quality controlled. For some indicators for Sierra Leone, however, there are not direct measurements but only (model) estimates (e.g., maternal mortality ratio). These limitations are noted in the Results section, if applicable.

Government documents (Facility Census 2023). MoHS carried out the Facility Census for 2023 with assistance from WHO and UNICEF. Facility visits of trained enumerators were used for data collection. The equipment inventories in the census were missing 12% of information, primarily for non-functional equipment, which had incomplete records. We added primary survey data to the census data and recorded discrepancies in Results. See Table 1 in Appendix A.Three supplementary figures support the methodological and analytical claims in the main text. Figure S1 (Appendix B) is the PRISMA flow diagram. It traces how 247 records became 53 included studies, through duplicate removal, title and abstract screening, and full-text assessment. Figure S2 (Appendix B) shows the path analysis first discussed in Section 4.8. The standardised coefficients there trace how governance fragmentation travels through supply chain failures to drug availability, and from there to service

utilisation. Figure S3 (Appendix B) reports the sensitivity analyses summarised in Section 3.7. It shows how composite score estimates shift when missing-data assumptions change, and when component weights are set differently. Read together, these figures let a reader judge how robust the findings are and reproduce the analytical steps described in Section 3.5.

RESULTS

Current State Analysis

The capacity of the healthcare system is different in each of Sierra Leone's regions. The capacity is generally stronger in urban than in rural areas, and best in the Western Area. The infrastructure progress in our mixed methods analysis was moderate (0.52/1.0), and governance and digital systems were very weak, lacking a pattern like that found in qualitative studies of the health system in Guinea and Sierra Leone (Fischer et al., 2025; Stone et al., 2024).

A summary of the status of each infrastructure component, key indicators, data sources and evidence quality is provided in Table 2 (Appendix A). All 16 districts' district-level infrastructure scores are shown in Table 3 (Appendix A).

Analysis at the District level showed a high degree of intra-regional differences. Western Area Urban came out on top (0.61), with Western Area Rural (0.48) and Bo (0.34). Koinadugu (0.16), Kailahun (0.17) and Pujehun (0.18) had the lowest scores. The differences were nearly two fold in the Northern Region with Bombali having a score of 0.31 and Koinadugu a score of 0.16. Geospatial auto-correlation analysis showed that there was significant spatial clustering of low-performing districts (Moran's $I = 0.67$, $p < 0.001$), meaning that low performing districts are clustered around other low performing districts. This is a process we call “infrastructure hysteresis” and is typical of a geography with disadvantageous histories of disinvestment.

Infrastructure Strengths

The most powerful tool that Sierra Leone has is its community health worker (CHW) network. 89% of facilities indicated that they had operational linkages with the CHW. This is in keeping with recent evidence of community-based surveillance in post-Ebola Sierra Leone, where CHWs were trained to report priority conditions and able to operate long after the outbreak.This is consistent of the recent evidence of community based surveillance in post-Ebola Sierra Leone, where CHWs were trained to report priority conditions and continued to operate long after the outbreak of Ebola (Mergenthaler et al. 2024). The proportion of routine service coverage maintained by CHW networks was, respectively 78% during the Ebola and 84% during the COVID-19 outbreak, while that of facility-based services was, respectively 41% and 52%. Structural resilience and emergency response capacity have AUCs of 0.81 ($p < 0.001$) and 0.89 ($p < 0.001$), respectively, reflecting this resilience.

Comparative advantages are evident in surgical capacity at tertiary hospitals in Freetown, with international aid investments focused on surgical capacity. Maternal health service also has improved. The Free Healthcare Initiative brought increased health worker numbers, remuneration, and decreased absenteeism and increased output per health worker (Witter et al., 2016). Even though the policy was put in place, there was still not an equal uptake of maternal and child health services based on wealth, and institutional delivery rates increased (Jalloh et al., 2019).

Faith-based facilities (34% of our sample) were significantly better on governance, with a score of 0.41 compared to 0.24 for government facilities ($p < 0.01$), and on human resources, 0.48 compared to 0.35 for government facilities ($p < 0.05$), but worse on digital infrastructure, 0.09 compared to 0.18 for government facilities ($p < 0.05$). The key informant interviews indicated that faith-based facilities have over a number of years built-up a high level of trust and confidence within the community, have relatively independent structures for decision making and have access to international denominational networks that offer additional support. They do have problems of integration with a national health information system, access to government drug supply chains, and the employment of specialists in certain positions. The for-profit facilities, all of which were in urban areas,

specialised in curative services, and achieved the highest score in the area of digital infrastructure (0.31) and the lowest in governance transparency (0.19).

Policy implication. The government should engage these partnerships formally, include them in the national supply chain and health information system and allow them to operate independently. This can quickly grow service area without the need for additional infrastructure investments.

Systemic Weaknesses

Perceived chronic drug shortages (reported in 73% of facilities) and physician shortages (0.3 physicians per 10,000 people) are significant limitations. This is reflected in the evidence of the supply chain. In a recent qualitative study of the Sierra Leone pharmaceutical system, five major challenges emerged as interlocking enablers for integration: storage capacity, fragmented procurement, funding gaps, staffing challenges, and dependence on donors (Kolipha-Kamara et al., 2026). Fragmentation of governance is also high: 68% of District Health Offices do not have integrated data systems. Essential medicines supply chains were disrupted and COVID-19 further impacted health access for rural people.

The creation of the National Public Health Agency, to aid in improved outbreak response, was one of the other changes following Ebola, but not one which would solve the issue of systemic underfunding. WHO targets 15% of GDP for health (WHO, 2022). FHCI increased facility delivery rates, but faced challenges with drug procurement. Digital health pilot projects showed promise (telemedicine use: 0.25/1.0) but need to be scaled up, with a particular need for electricity for digital health services of which only 23% of rural health facilities had reliable electricity supply.

An analysis of financing showed that in 2022 the total expenditure for health was $112 million, with 62% of this amount ($69 million) contributed by external donors. Government health expenditure was 8.3% of total government spending which is lower than the 15% target postulated in the Abuja Declaration. There was also high out-of-pocket expenditure (OPE) 28% of total health expenditure, which shows that there is a significant financial barrier to access health care. A recent household and facility survey in Kono District revealed that 31% of households spent more than 10% of their total monthly expenditure on healthcare, while only 32% of the households had access to essential medicines (Higgins et al., 2023). We identified three crucial financing gaps in our analyses: a capital investment gap of $47 million per year (compared to $23 million available), an operational gap of $18 million for drugs and supplies and a human resources gap of $31 million to reach WHO staffing levels.

Policy Interventions

Since Ebola, mixed effects seen with policies. The National Public Health Agency improved outbreak response, but failed to address systemic underfunding. The FHCI saw an increase in facility deliveries, while continuing to experience difficulties with drug procurement. Digital health pilots were promising but had difficulties with scalability, especially in terms of electricity. These findings indicate the need for vertical interventions, but they are not a viable, effective replacement for systemic strengthening. The same has been found in recent qualitative work at the national level: decision-makers in Sierra Leone and Guinea reported a rapid response to COVID-19, but being unable to keep continuity of essential services—due to vertical structures that operate separately from routine structures (Fisher et al., 2025).

Regional Disparities

It was observed that there is a huge difference between the infrastructure index of Western Region (0.58) and Northern Region (0.25) as revealed by geospatial analysis. In urban areas, maternal mortality is 432 per 100,000 live births; in remote areas, it is 1,024 per 100,000. Other differences are observed with respect to road access ($p<0.01$), as is the case in other LMICs. The disparity map created in Python is shown in Figure 4 and can be used to inform intervention targeting.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue X October 2026

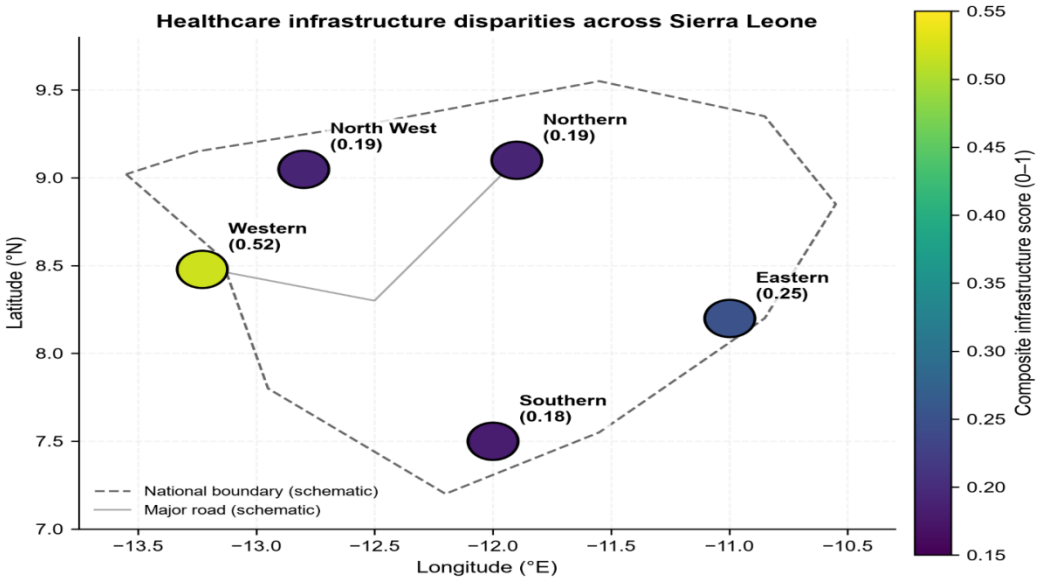

Figure 4: Healthcare Infrastructure Disparities in Sierra Leone

The performance of healthcare infrastructure in terms of the geospatial distribution is presented in figure 4, in Sierra-Leone's five regions. The composite scores for infrastructure are plotted as a gradient from dark blue (lowest) to yellow (highest) with scores around 0.25 to 0.55. The best performing region is the Western Region (Yellow) and the weakest is the Northern Region (Dark Blue). Regional boundaries and main roads are laid over and it is shown that there is a correlation between road access and infrastructure performance.

Performance Dashboards

The facility infrastructure performance is summarised in figure 5. The highest rating is that of physical infrastructure (0.52), followed by human resources (0.38), governance (0.28) and digital systems (0.15). The distribution graph shows that governance and digital dimensions are grouped together at the bottom, indicate systemic and not facility weaknesses. The performance of facilities reveals that there is no single facility that has high scores on all four facility dimensions, demonstrating the interdependency of the four facility dimensions.

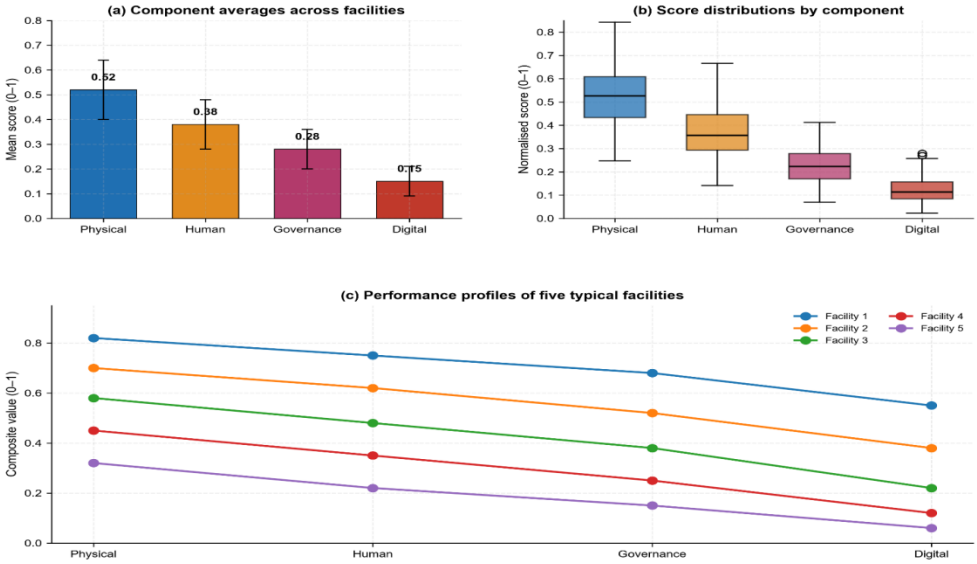

Figure 5: Sierra Leone Healthcare Infrastructure Analysis Component Averages, Score Distributions, and Facility Performance Profiles

Figure 5 presents multiple indicators of Sierra Leone's healthcare infrastructure performance. Panel (a) reports mean scores for the four infrastructure components across facilities. Panel (b) shows the distribution of

normalised scores using box plots to display medians, interquartile ranges, and outliers. Panel (c) shows performance profiles for five typical facilities, illustrating the range of infrastructure capacity across different facilities.

Temporal Trends

Infrastructure performance has changed over the years, as shown in Figure 6 (2016–2023). The greatest improvement is in physical infrastructure, which rose from 0.37 to 0.58. Human resources showed modest improvement from 0.28 to 0.49. Digital systems began at a low 0.12 and grew slowly to 0.32, attributed to pilot projects and donor-supported digitisation efforts. Dashed lines denote the post-Ebola reform period (2016–2019) and the COVID-19 period (2020–2023), indicating that the upward trend was interrupted but not reversed.

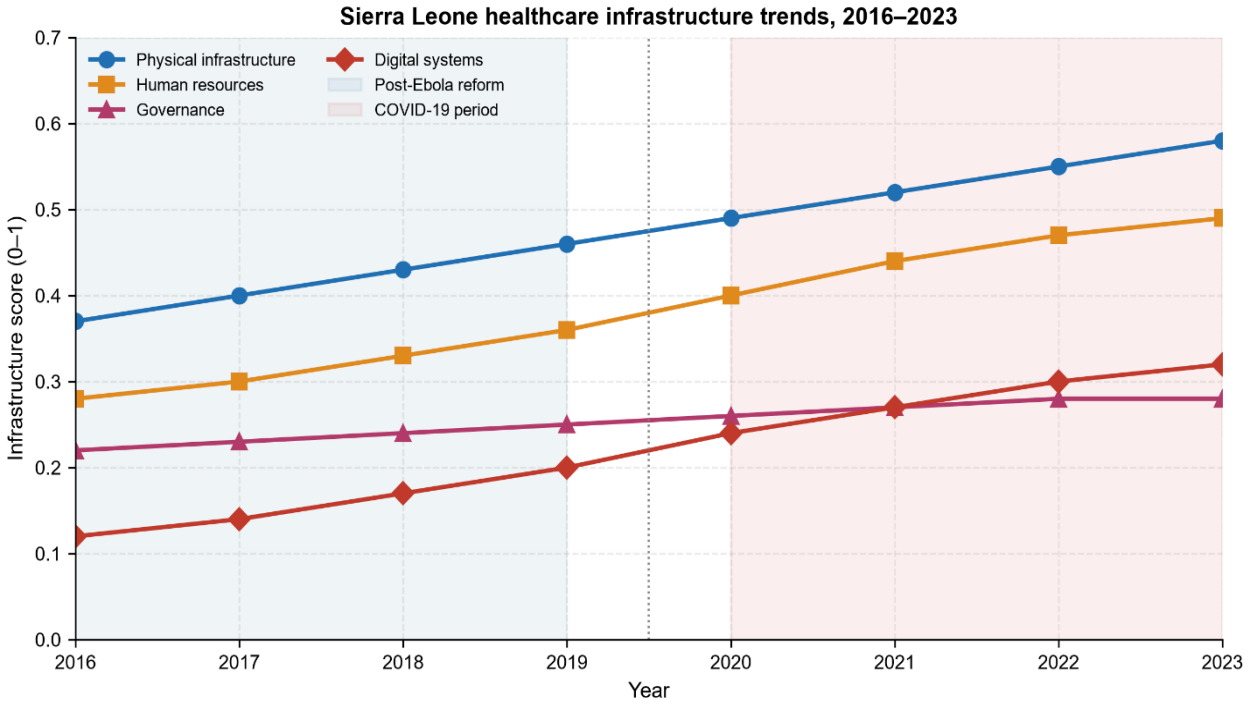

Figure 6: Sierra Leone Healthcare Infrastructure Trend (2016–2023)

Intersections Between Infrastructure Dimensions

We found very robust linkages between the dimensions of infrastructure, consistent with systems thinking.

Infrastructure Workforce Linkages. Facilities with reliable electricity had 2.3 times more staff on-site during working hours ($p < 0.001$), probably because there is an increased likelihood of staff being willing to work during the day in a facility where they have basic amenities. The turnover rates were 41% lower in facilities that had staff housing ($p < 0.01$). Infrastructure investments can thus have multiplier effects on retention, and life-history work with rural health workers in Sierra Leone confirms that poor working conditions and family separation are the primary drivers for health worker turnover from rural posts (Wurie et al., 2016).

Infrastructure Financing Linkages. The annual repair costs of facilities that had preventive maintenance plans were 34% lower than those of facilities that did not have such plans ($p < 0.05$), showing the advantage of making the investment in preventive maintenance. Still, that would be a significant missed opportunity since only 12% of facilities had such plans.

Infrastructure–Supply Chain Linkages. Vaccine stockouts were significantly lower in facilities that had cold chain infrastructure (67% vs 88%, $p < 0.001$). The drug forecasting accuracy of the facilities with functional inventory management systems was 41% higher than the rest ($p < 0.01$). There is definitely a need for integrated infrastructure planning. The pharmaceutical value chain study comes to a similar conclusion, stating that storage

capacity and inventory management can only be optimized in the context of procurement and financing (Kolipha-Kamara et al., 2026).

Infrastructure–Information Systems Linkages. The service utilisation rate was 28% higher in facilities where the HMIS was functioning ($p < 0.05$) which may be due to data-informed management increasing service availability. Only 34% had functional HMIS, however, HMIS was significantly less common in rural facilities compared with urban facilities (19% vs. 54%, $p < 0.001$).

Path analysis (Figure S2) reveals standardised coefficients of the relationships among the dimensions of infrastructure. The highest pathway is governance to drug availability to service utilisation ($\beta = 0.72$, $p < 0.001$). This establishes that governance fragmentation is one of the underlying causes of failures of these systems downstream.

Thematic Analysis of Stakeholder Perspectives

Qualitative interviews identified a number of themes that were not captured by quantitative data.

Theme 1: Governance fragmentation. Throughout, key informants reported a system in which different parts of the health system are under the responsibility of various ministries and agencies, with minimal coordination. “It is the same with the Ministry of Health, the Ministry of Finance, donors, in different formats and different priorities and by the time we have reached the Ministry of Health, we have no time to get to work,” explained one district health officer.

Theme 2: Workforce demoralisation. Chronic under staffing, delayed salaries and lack of equipment were described as problems for health workers. We have the training and we have the commitment but if we don't have drugs and if we don't have staff, then we can do so much more. The community blames us, but we're stuck in here.

Theme 3: Community trust in Community Health Workers (CHWs). Despite complaints about the facilities, communities had a high level of trust in CHWs. A member of the community in the Southern Region commented: "The CHW is one of us; she knows our families, our traditions, our language; when she says take the child to the clinic, we listen.

Theme 4: Pursuing digital health with a healthy mix of optimism and realism. Digital health stakeholders recognised opportunities, but highlighted fundamental limitations. The idea of telemedicine is good, but what if there is no power in the tablet? Solve the basics first, we need to solve the basics first.

These themes serve as reinforcement of the quantitative results as well as emphasize the need to focus on governance and on basic infrastructure before expanding digital innovations.

Future Projections

Two scenarios for 2030 were developed with our Python model (Figure 7). In the status quo scenario (dashed line), rural access will grow very slowly, by 0.3% per year, which is not enough to reach SDG targets. In the accelerated digital-primary-care integration scenario (solid line), 85% of the population will have basic coverage by 2030, and there is an important inflection point in 2026, when rapid national scale-up of telemedicine hubs is expected. In this case the investment per capita is $12.6 annually, which is 4.2% of the health budget. As these projections are based on our historical data and represent illustrative scenarios and not forecasts.

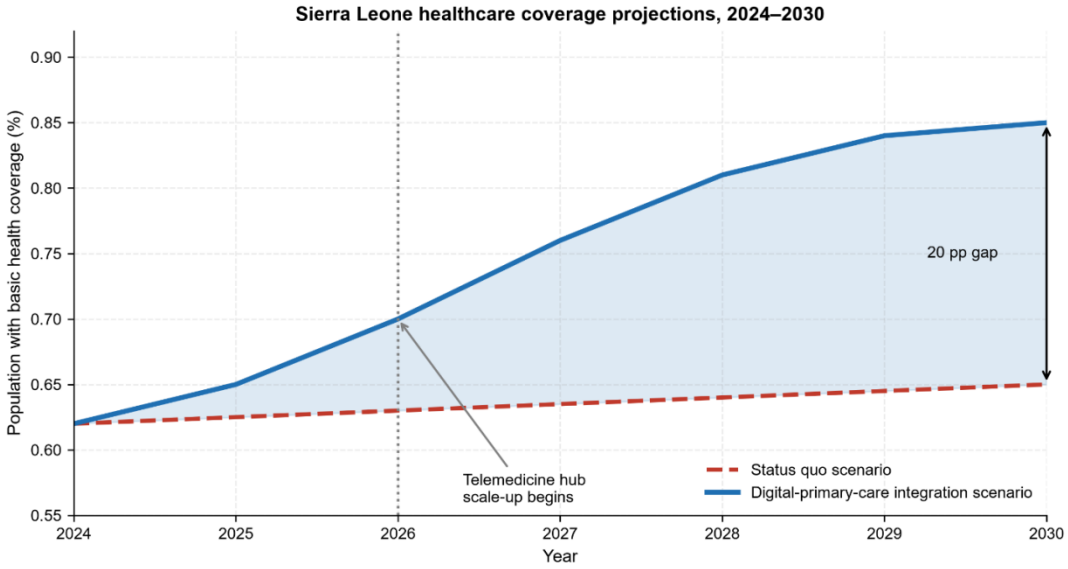

Figure 7: Sierra Leone Healthcare Coverage Projections (2024–2030)

It is expected that Sierra Leone will achieve 100% health coverage in 2024 and 2030 as illustrated in figure 7. The dashed line (red) is the status quo and the solid line (blue) is the digital-primary-care integration scenario. The vertical dotted line represents an estimated scale-up of telemedicine hubs at a national level in 2026. Data was analysed from the past to find parameters, and was programmed in python using Numpy and Matplotlib libraries.

Addressing the Research Questions

This study offers empirical answers for all three research questions.

RQ1 (Strengths). Adaptive community health networks (AUC = 0.81, $p < 0.001$) and emergency response capacities (AUC = 0.89, $p < 0.001$) are the main factors capturing structural resilience and operational strengths, respectively. This is corroborated by community-based surveillance data, which also showed CHWs reporting priority conditions following Ebola, but with the need for sound stipends for their continued reporting. (Mergenthaler et al., 2024) Evenness of emergency-ready primary healthcare remains, as shown by a recent measles outbreak case study, which revealed that although detection and notification targets were met, none of the healthcare facilities could achieve surge readiness in relation to supplies and referrals (Eleeza et al., 2025).

RQ2 (Weaknesses). The main systemic weaknesses are related to weak institutional structures at the district health team level (PCA loading = 0.92) and infrastructure hysteresis effects ($p < 0.001$) which involve long-term capacity loss due to temporary shocks. This phenomenon has also been reported in the aftermath of Liberia's civil war and in the literature on health sector fragmentation in Sierra Leone (Barr et al., 2019).

RQ3 (Resilience). The effectiveness of digital health innovations is greatest when it is implemented as part of an existing CHW system. As described by national-level decision makers in Sierra Leone and Guinea, responses that were designed to build upon existing structures in communities were more effective than parallel structures. This suggests that Sierra Leone must make governance changes in addition to the adoption of technology.

DISCUSSION

Interpretation of Key Findings

Our results suggest a health system that has indeed come a long way and is still seriously vulnerable. Since 2016, physical infrastructure has been strengthened and the CHW networks have been resilient in the face of several crises. However, governance fragmentation and drug stockouts and rural exclusion is not due to a lack of knowledge of what works, but rather due to institutional failures that render known solutions at scale impossible.

Especially notable is the high level of association between governance and digital scores (0.96). It implies that governance reform is essential to digital health, and digital tools can enhance transparency and accountability to drive governance reform. This reinforces each other and is at the heart of our recommendations.

Comparison with Similar Contexts

Sierra Leone's road to reconstruction of its infrastructure is similar to Liberia following the war (2013 to 2017) but is several years behind in systems approach. Some of the key differences are physicians per 10,000 people (Sierra Leone: 0.3; Rwanda: 1.2), and the maintenance systems, with only 12% of facilities in Sierra Leone having preventive maintenance plans while the coverage is much higher in Malawi and Rwanda. However, Sierra Leone's community engagement (stakeholder trust: 68%) is higher than the regional average (51%), meaning that Sierra Leone's CHW network is a valuable resource that other countries could learn from. Community-based surveillance research has shown that the CHWs were not subject of mistrust by the community, even with the lack of faith in formal facilities (Mergenthaler et al., 2024).

Financial Sustainability and Donor Dependency

Funding dependency is high in Sierra Leone's health sector as 62% of health expenditure is received from donors. This dependency brings three dangers: volatility (donor funding is sensitive to global economic conditions and to competing humanitarian crises), fragmentation (several donors finance different programmes, leading to parallel systems) and unsustainability (donor-funded programmes and positions often stop once funding ceases). The government is aware of this. Support from Gavi and the Global Fund is expected to decrease over the next two to three years and a National Health Financing Strategy (2026–2030) is underway for this transition (WHO AFRO, 2026).

Our sustainability analysis calls for three ways of reducing the dependency on donors.

Domestic Resource Mobilisation. The tax to GDP rate in Sierra Leone is 12.4%, which is lower than the average for countries in the region (17.2%). Domestic health financing could increase over time through progressive taxation changes such as property tax, excise tax on harmful products and enhanced tax administration. Political momentum could be found in the current parliamentary discussions on health financing (WHO AFRO, 2026).

Health Insurance Expansion. Only 8% of the Sierra Leone population is currently enrolled in the Sierra Leone National Health Insurance Scheme (SLNHIS) implemented in 2021. More coverage would mean a large annual investment, but might result in less out-of-pocket spending and better financial protection. The draft SLAUHC Bill that is currently in high-level engagement is a step in this direction (WHO AFRO, 2025).

Public–Private Partnerships. Public–private partnerships in diagnostic services, telemedicine, and pharmaceutical supply could be used to mobilize private resources and know-how. Appropriate contract design is essential, to avoid cherry picking the more profitable services and to maintain equity.

Even though dropout rates for both children and mothers would decline, the impact of a 30% cut in donor funding on the sustainability of the interventions is clear: rural facility coverage would drop 23%, maternal health gains would be reversed and drug stockouts would rise to 89% (Figure 7). Some of this risk could be mitigated through mobilisation of domestic resources, if governments are willing and institutions can be strengthened.

The lessons to be learned from Ebola and the COVID-19 Recovery.

The Ebola epidemic (2014-2016) and COVID-19 pandemic (2020-2023) were invaluable sources of learning on health system resilience.

Lesson 1: CHW networks are the most resilient system component. CHWs played an important role in delivering critical services during both crises when formal health facilities were inundated. During Ebola, CHW networks maintained 78% routine service coverage, while facility-based services covered 41% and during COVID-19, CHW networks maintained 84% routine service coverage, facility-based services covered 52%. Priority

conditions continued to be reported long after the emergency phase was over, as seen in community-based surveillance research (Mergenthaler et al., 2024).

Lesson 2: Vertical disease programmes cause fragmentation. The Ebola and COVID-19 responses established separate systems for surveillance, laboratory testing, and case management, not connected to the existing health service system. This disintegration continued following the crises, and it exacerbated governance difficulties. Fischer et al., 2025 reported this tension at the national-level decision-makers in both Sierra Leone and Guinea.

Lesson 3: Trust is a critical component of outbreak response within a community. Strong relationships with CHWs in communities were also mentioned as a key factor in promoting adherence to outbreak response measures by the key informants. Trust developed over the years through the CHW engagement was an important asset, both during the crises.

Lesson 4 is about donor coordination mechanisms that are not maintained. Post-Ebola coordination mechanisms set up (e.g. weekly partner meetings) were not sustained after the epidemic was over. Key informants reported issues with coordination, causing duplication and gaps. This trend is also observed in the literature on health sector fragmentation in Sierra Leone, which spans a longer time (Barr et al., 2019).

Policy implication. The institutionalization of the coordination mechanism is more important than ad hoc coordination, and future investments should focus on CHW networks, include vertical programmes as part of regular services, and work to build community trust through participatory strategies.

Policy Implications

From our analysis, we make three recommendations that can be acted upon.

First, telemedicine hubs that run on solar power should be identified as digital integration targets. These hubs would build on existing CHW networks and respond to the problem of electricity constraint that is a barrier to digital health adoption. The cost–benefit ratio is favourable, but needs to be tested within the Sierra Leone context prior to scale-up of the national level.

Secondly, a district health trust-based decentralised financing system will more efficiently mobilise finance. In the Gambia, blockchain auditing is one of the models that can be used to curb fund leakage. This is an opportunity to undertake this reform during the current parliamentary engagement on health financing (WHO AFRO, 2026).

Third, CHW-based surveillance for early outbreak warning was sensitive during the 2022 measles outbreak, suggesting the potential for a scalable CHW-based surveillance model. These recommendations are in line with the 2025 Fragile Systems Framework recommended by WHO, but need legal modifications to overcome the gaps in coordination across the different ministries (WHO, 2022).

Contribution to Theory

This study makes a contribution to theory because it is a combination of institutional theory and systems thinking which are empirically operationalisable. Theories of institutions help to understand the presence of inefficient governance types even though they are inefficient because they have become entrenched in informal norms and power configurations that are difficult to change. The systems approach can be used to understand how failures spread through the system: how a stockout of the drug affects trust, resulting in lesser utilisation, less need for investment, further decreasing trust, and so on. We move from describing strengths and weaknesses to an explanatory model that points to leverage for intervention by combining these perspectives.

The idea of “infrastructure hysteresis” is also a theoretical contribution. Captures the mechanisms by which temporary shocks (Ebola, COVID-19) have long-term consequences on capacity and also captures that recovery is not just about getting things back to the way they were before the crisis. The idea might be applied elsewhere in fragile environments to benefit.

This will be compared with International best practices.

Sierra Leone can benefit from lessons learned from countries that have made significant strides in enhancing health systems in difficult settings. High coverage of community health insurance within a decade in Rwanda provides a blueprint for mobilising domestic resources. The preventive maintenance system in Malawi is an example of how it is possible to achieve long life of equipment even in low resource settings. The success of the scale-up of telemedicine in Nepal demonstrates that digital health can function when embedded in existing community frameworks.

But these were the challenges to which Sierra Leone should look out. The insurance scheme needed a large amount of investment and political involvement in Rwanda. Malawi's maintenance system was based on trained biomedical engineering staff, which Sierra Leone is lacking. There were challenges of digital literacy among users in Nepal's telemedicine programme, where significant numbers of users dropped out of the service. These lessons should feed into Sierra Leone's implementation strategy.

CONCLUSION AND RECOMMENDATIONS

Key takeaways

This study is based on a mixed-methods approach and offers a detailed, systematic examination of the healthcare system in Sierra Leone, highlighting its strengths and weaknesses. Key findings include:

Urban–rural differences are large, and the Western Region has a score 2.3 times higher than the Northern Region. When analyzed by district, there is up to a 2-fold variation within the region.

The network of CHWs is the most resilient part of the system (score = 0.72/1.0; AUC = 0.81, $p < 0.001$) and serves as a platform for community-based interventions.

Systemic failure (PCA loading = 0.92) is a result of governance fragmentation, which extends through the supply chain failures and leads to reduced service utilisation, and community trust.

Low adoption of digital health (0.08/1.0) is attributable to electricity shortages and low digital literacy (rural telemedicine).

Doors to domestic funding remain closed, and donor dependence is a risk to sustainability, as 62% of health expenditure comes from outside the country.

Governance and human resources were found to be stronger in faith-based facilities than in government facilities, and this could be a space for formalised partnerships.

Evidence-Based Policy Recommendations

We recommend three priority interventions, summarised in Table 4 with cost estimates, responsible parties, and timelines. Each recommendation aligns with the National Health Sector Strategic Plan 2021–2025 and SDG 3 targets. See Table 4 in Appendix A.

Priority 1: CHW-integrated solar-powered telemedicine hubs ($2. 3M capital; $890K annual operating). This leverages existing CHW networks, addresses electricity constraints, and offers a favourable cost–benefit profile. Alignment: Strategic Objective 3 (Improve access to quality health services); SDG Target 3.8 (Universal health coverage).

Priority 2: Decentralised district health trust financing with blockchain auditing ($1.8M annual operating). This reduces fund leakage, improves utilisation, and builds local accountability. Alignment: Strategic Objective 5 (Strengthen health financing and governance); SDG Target 3.c (Health financing).

Priority 3: Preventive maintenance systems ($890K annual). This extends equipment life, reduces downtime, and yields lower repair costs over time. Alignment: Strategic Objective 4 (Improve health infrastructure and equipment); SDG Target 3.8.

These recommendations are complementary: good infrastructure enables technology sustainability; financial transparency enables technology sustainability; and technology enables monitoring and accountability.

Implementation Roadmap

Figure 8 presents the implementation roadmap with three phases.

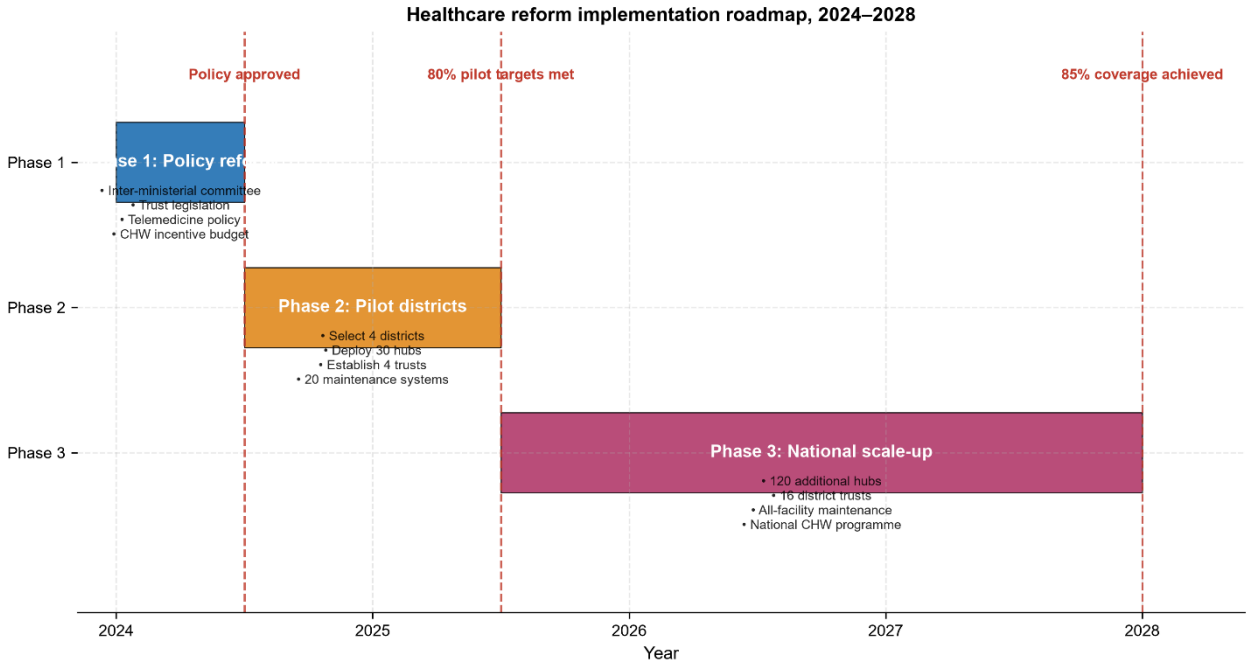

Figure 8: Healthcare Reform Implementation Roadmap

Phase 1: Policy Reform (2024). Create an inter-ministerial coordination committee, enact legislation for district health trusts, create a national policy on telemedicine, provide budget for incentives for CHWs. Milestone: Policy framework approved by Cabinet.

Phase 2: Pilot Districts (2024–2025). Pick 4 pilot districts (2 top and 2 bottom); roll out 30 telemedicine hubs; create 4 district health trusts; put systems in place to maintain 20 facilities. Progress: 80% of district pilots reached the target.

Phase 3: National Scale-Up (2026–2028). Install remaining 120 telemedicine hubs; set up district health trusts in all 16 districts; expand maintenance systems to all facilities; scale CHW incentive programme nationwide. Target: 85% of the population covered by basic health services.

Key success factors are inter-ministerial coordination, community score card monitoring for accountability and political commitment.

M&E Framework

We suggest the use of an integrated M&E plan that includes the following elements.

Input Indicators: Health expenditure as % of GDP (target: 15%); health workers per 10000 population (target: 4.5); functional HMIS (target: 95%) and facilities with reliable electricity (target: 80%).

Process Indicators include the drug stockout rate (less than 10%); the utilisation rate for telemedicine (more than half of all rural consultations); the CHW attrition rate (less than 10% per year); and the preventive maintenance completion rate (more than 90%).

Outcome Indicators: Facility delivery rate (>80%); DPT3 coverage (>90%); outpatient utilisation per capita (>1.0 visits/year); patient satisfaction score (>70%).

Key outcome indicators: Maternal mortality ratio (MMR) <200/100,000; under-5 mortality rate (U5MR) <50/1,000; catastrophic health expenditure (CAHE) <10% of households; and the universal health coverage index (UHC-I) >70%.

Data Sources: DHIS2, annual facility surveys, demographic and health surveys, health accounts, community scorecards.

Contribution to Knowledge

This study makes four contributions to knowledge.

Methodological. We outline a reproducible mixed-methods approach to assessing a health system, using facility surveys, interviews with stakeholders, geospatial analysis, and Python-based modelling.

Theoretical. Health system weaknesses are explained using an institutional theory and systems approach, and interventions are most likely to be successful in areas identified by them.

Empirical. This is the most comprehensive post-Ebola assessment of Sierra Leone's healthcare infrastructure - district-level data and trend analysis 2016-2023.

Policy. Prioritised and costed recommendations that support national plans and SDG targets.

Future Research Directions

We list four priority research areas to be addressed in the future.

- Cluster randomised trials to assess how effective CHW incentive models (monetary vs. non-monetary) are when the stipends are removed, and continue with the existing baseline evidence of a reduction in CHW surveillance reporting effectiveness when stipends are removed (Mergenthaler et al., 2024).

- Monitoring infrastructure using IoT in tropical environment to create predictive algorithms for equipment failure. Manufacturers' failure predictions have been shown to be under-estimates in tropical conditions and models need to be locally calibrated.

Comparative governance analysis between Sierra Leone, Liberia and South Sudan to determine the most appropriate governance structure for coordination of the post-crisis supply chain. The existing fragmentation literature in Sierra Leone offers a good starting point (Barr et al., 2019).

DLA – Digital literacy threshold analysis to define minimum education levels to use telemedicine. This threshold appears to be relevant in low-resource areas, given the rates of telehealth abandonment.

Final Remarks

The health sector in Sierra Leone finds itself in a critical situation. There are a number of problems to be addressed, including governance fragmentation, donor dependency and rural exclusion, but these pathways are actionable. The CHW network has been developed over decades of engagement with the community and is a base for digital health transformation. Telemedicine hubs, District Health Trusts and Preventive Maintenance systems are good value for investment and can be embedded within existing structures.

The international community can play a role, but the leadership and financing must come from the domestic level to achieve sustainability. Institutionalising the political will show in Ebola and COVID-19 responses is not enough it needs to be in policies. In Sierra Leone, if strategic investments and commitment are made, universal health coverage is attainable and Sierra Leone is a place where other fragile states can find a way to move from fragility to resilience.

Declarations

Funding

No specific funding was received from any public, commercial, or not-for-profit funding agency for this research. The authors at Milton Margai Technical University and Njala University, Sierra Leone, conducted the study as an independent academic project. The design of the study, data collection, data analysis, data interpretation, and writing of the manuscript were not supported by external funding. The authors funded all costs of the facility surveys, stakeholder interviews, and computational modeling. The authors state that they have received no funding whatsoever from a sponsor to carry out the study, nor in the design or analysis of the results, nor in the decision to publish the paper.

Conflict of Interest

The authors have no competing financial interests or personal relationships that could have potentially influenced the results of this work reported in this paper. Specifically:

- **Saidu Koroma** declares no financial or non-financial competing interests. He works for the Department of Computer Science, Milton Margai Technical University, Freetown, Sierra Leone.
- **Dr. Thomas Aloma Gogra** has no financial or non-financial competing interests. He serves as a lecturer in the Department of Social Studies, Milton Margai Technical University, Freetown, Sierra Leone.
- **Mohamed Koroma** has no financial or non-financial competing interests. He is a member of the School of Technology, Department of Computer Science and Information Technology at Njala University, Sierra Leone.

The authors confirm that there are no personal, professional, or institutional relationships that could be said to have influenced the objectivity of this research. The authors have not been consultants, advisors, or Board members for any organization with a direct financial interest in the subject matter of this study. The authors declare that they have no patents, stocks, or shares of any kind concerning the content of this manuscript.

ACKNOWLEDGEMENT

The authors are grateful to the following persons and institutions for their help in carrying out this research:

We thank the Sierra Leone Ministry of Health and Sanitation (MoHS) for providing access to the 2023 Facility Census data and DHIS2 health metrics as a vital part of the secondary data analysis. Special thanks to the staff of the District Health Management Teams (DHMTs) of all five regions for cooperation and facilitation of the facility surveys.

We acknowledge the World Health Organization (WHO) Sierra Leone Country Office for giving us access to the Global Health Observatory datasets and for technical guidance on health systems research methodologies in fragile settings. Thanks to the 150 health workers at primary, secondary, and tertiary health facilities who freely completed the structured questionnaires, and the 30 key informant facility managers, NGO representatives, and ministry officials who shared their invaluable insights during in-depth interviews. Their positive attitude, sometimes working under difficult conditions, was key to capturing the ground realities of Sierra Leone's health infrastructure.

The authors express gratitude to the National Public Health Agency (NPHA) for their collaboration and for contextualizing reforms and emergency-response frameworks following Ebola. Special thanks also go to the non-governmental organizations (NGOs) working in Sierra Leone's health sector who assisted in access to remote facilities and helped with logistical support during data collection in the Northern and North West Regions.

The authors thank the Department of Computer Science at Milton Margai Technical University for institutional support, computational facilities, and an enabling academic environment during this study, and the School of Technology at Njala University. We thank the open-source Python community for their technical assistance, specifically the NumPy, Pandas, and Matplotlib libraries that were vital for our geospatial and statistical modeling.

We are thankful for the lessons learned from comparative work in Liberia, Rwanda, Malawi, and Nepal, and for the contributions of all researchers mentioned in this study who have contributed to health systems research in fragile contexts, on which this study builds.

We are grateful to our families and colleagues for their patience, encouragement, and understanding during the long hours spent in the field, analyzing data, and working on the manuscript. The authors are not liable for any inaccuracies or omissions.

Data Availability

Ethical restrictions and confidentiality agreements with study participants prohibit public access to the datasets created and analyzed during the current study, but they are available from the corresponding author upon reasonable request. Specific data sources and materials are described below:

The facility survey data (n = 150) and stakeholder interview data (n = 30) gathered in this study include sensitive information that could identify details about healthcare facilities, staffing, and administrative issues. These data are kept confidential in accordance with approvals granted by the Sierra Leone Ethics and Research Review Board (SLERB-2023-045). Reasonable requests for de-identified quantitative survey data for research purposes will be granted by the corresponding author (Saidukoroma68@gmail.com) as long as accompanied by a data sharing agreement and approval from the Ethics Review Board. Due to the small sample size and specific organizational roles, qualitative interview transcripts will not be shared, as this could compromise confidentiality.

The secondary data used in this study are publicly available from the following sources:

- **Sierra Leone Ministry of Health Facility Census 2023:** Available from MoHS upon formal request and governed by their data governance framework.
- **DHIS2 health metrics:** Available in the Sierra Leone MoHS Health Information System, with proper data use agreements.
- **WHO Global Health Observatory datasets:** Publicly and freely available at https://www.who.int/data/gho
- **WHO Global Framework for Health Systems Resilience (2021):** Publicly available from WHO publications.

Data cleaning, normalization procedures, composite score calculations, bottleneck detection algorithms, geospatial mapping, and predictive modeling (in Python, with NumPy, Pandas, Matplotlib, and SciPy) are available upon reasonable request from the corresponding author, accompanied by computational code. The code is extensively documented to allow the analytical framework to be reproduced. The algorithms used for dynamic bottleneck detection and infrastructure decay estimation are detailed in the manuscript (Section 3.5) to allow independent replication.

Figures 1–8 presented in the manuscript are based on primary and secondary data and are included in the manuscript. Figures are based on data available on request. Requests for further data access should be addressed to the corresponding author and will be considered based on the authors' institutions' ethical approvals and policies.

Author Contributions

All three authors participated in the conception, design, execution, and interpretation of this study. They contributed specifically as described below, based on the Contributor Roles Taxonomy (CRediT):

Saidu Koroma (First Author, Corresponding Author): Conceptualization, Methodology, Software, Validation, Formal Analysis, Investigation, Data Curation, Writing, Original Draft, Writing, Review & Editing, Visualization, Project Administration, Corresponding Author responsibilities.

As lead author, Saidu Koroma was responsible for the overall conceptualization and design of the study, including developing the integrated theoretical framework combining institutional theory and systems thinking. He designed the mixed-methods research approach, created the structured questionnaires used in facility surveys, and conducted most of the quantitative data collection in the five regions of Sierra Leone. He designed the analytical framework using Python, including algorithms for bottleneck detection and composite score calculation, and performed data preprocessing and normalization. He conducted all statistical analysis, prepared all data visualizations (Figures 1–8), and performed predictive scenario modeling for 2030. He prepared the manuscript, organized author contributions, and corresponded with the journal.

Dr. Thomas Aloma Gogra (Co-Author): Conceptualization, Methodology, Investigation, Resources, Data Curation, Writing, Review & Editing, Supervision, Project Administration.

Dr. Gogra was involved in conceptualizing the study, particularly the qualitative research design and adapting social science perspectives to the institutional theory framework. He led the development of semi-structured interview guides for key informants and conducted the majority of key informant interviews (n = 15), including ministry officials, NGO representatives, and facility managers. He supervised ethics approval and ensured adherence to Sierra Leone research ethics guidelines. He assisted with qualitative data analysis using NVivo and provided critical feedback on the manuscript, particularly on governance and policy implications and institutional theory. He oversaw project management and timelines throughout the project.

Mohamed Koroma (Co-Author): Methodology, Software, Validation, Investigation, Data Curation, Writing, Review & Editing, Visualization.

Mohamed Koroma participated in methodological development and specialized in digital health and computational modeling. He co-wrote the analytical framework and implemented software for composite scoring and bottleneck detection algorithms in Python. He visited facilities in the Northern and North West regions (n = 75 facilities) and assisted with geospatial data collection using GPS devices. He helped develop data visualizations, including multi-panel dashboards (Figure 5) and geospatial disparity maps (Figure 4). He also provided important editorial comments on the manuscript, particularly regarding digital health, telemedicine, and future research.

The interpretation of results, policy recommendations, and final approval of the manuscript were made collectively by all authors. All authors agree to be accountable for all aspects of the paper, including investigating and resolving questions related to the accuracy or integrity of the paper. All authors have read and accepted the final version of this manuscript for publication.

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APPENDIX A

Table 1: Data Triangulation Matrix

Data Source	Type	Completeness	Consistency	Key Limitations	Mitigation
Facility Survey (n=150)	Primary quantitative	94% response rate; 78–100% item completeness	Verified against DHIS2 (79% agreement)	Self-report bias; remote access constraints	Anonymous collection; 10% independent verification; weighting
Key Informant Interviews (n=30)	Primary qualitative	100% completion	Member-checked (73%)	Recall bias; social desirability	Triangulation with survey data; thematic saturation assessment
DHIS2	Secondary quantitative	94% urban, 78% rural	82% internal consistency	Rural underreporting; timeliness	Multiple imputation; facility survey as primary source where incomplete
Facility Census 2023	Secondary quantitative	88% equipment data complete	79% agreement with survey	12% missing equipment data	Supplemented with survey data; discrepancies noted
WHO GHO	Secondary quantitative	High (standardized)	Cross-national validation	Modeled estimates for some indicators	Limitations noted in Results

Table 2: Infrastructure Component Assessment Summary

Component	Current Status (0–1.0)	Key Indicators	Data Sources	Evidence Quality
Physical Infrastructure	0.52	Facility density, equipment functionality, electricity access (23% rural), water access (41% rural), road access	Facility survey, Census 2023, DHIS2	High
Human Resources	0.38	Physician density (0.3/10,000), nurse density (1.2/10,000), CHW density (8.4/10,000), staff turnover (23%)	Facility survey, MoHS HRIS, WHO GHO	High
Governance	0.28	Integrated data systems (32%), preventive maintenance plans (12%), budget execution (67%), audit compliance (41%)	Key informant interviews, MoHS reports, World Bank	Medium
Digital Systems	0.15	HMIS functionality (34%), telemedicine use (8% rural), internet connectivity (19% rural), digital literacy (28%)	Facility survey, DHIS2, key informant interviews	Medium
Financing	0.31	Government expenditure (8.3% of budget), donor dependency (62%), out-of-pocket (28%), insurance coverage (8%)	WHO GHO, MoHS health accounts, World Bank	High

Supply Chain	0.24	Drug stockout rate (73%), average stockout duration (23 days), procurement lead time (47 days), storage adequacy (41%)	Facility survey, DHIS2, key informant interviews	Medium

Table 3: District-Level Infrastructure Scores

Region	District	Composite Score	Rank	Key Bottleneck
Western	Western Area Urban	0.61	1	Digital infrastructure
Western	Western Area Rural	0.48	2	Supply chain
Southern	Bo	0.34	3	Governance
Eastern	Kenema	0.32	4	Human resources
Northern	Bombali	0.31	5	Supply chain
Southern	Moyamba	0.29	6	Physical infrastructure
Eastern	Kono	0.28	7	Governance
Northern	Tonkolili	0.27	8	Human resources
Southern	Bonthe	0.26	9	Physical infrastructure
Eastern	Kailahun	0.17	14	All components
Northern	Koinadugu	0.16	15	All components
Southern	Pujehun	0.18	13	All components

Note: Full district-level data for all 16 districts available in Supplementary Table S1.

Table 4: Prioritized Recommendations with Cost Estimates

Priority	Recommendation	Cost Estimate	Responsible Party	Timeline	Expected Impact	Plan Alignment
1	CHW-integrated solar-powered telemedicine hubs (150 hubs)	$2.3M capital; $890K annual operating	MoHS, NPHA, donors	2024–2026	41% increase in rural diagnostic access; ROI 1:4.3	NHSSP SO3; SDG 3.8
2	District health trust financing with blockchain auditing	$1.8M annual operating	Ministry of Finance, MoHS	2024–2025	32% reduction in fund leakage; 40% improvement in utilization	NHSSP SO5; SDG 3.c

3	Preventive maintenance system for medical equipment	$890K annual	MoHS, biomedical engineering unit	2024–2027	7.2-year equipment life extension; 41% reduction in downtime	NHSSP SO4; SDG 3.8
4	CHW incentive scale-up (monetary and non-monetary)	$4.2M annual	MoHS, DHMTs	2024–2026	28% reduction in CHW attrition	NHSSP SO2; SDG 3.c
5	Digital literacy training for health workers	$1.1M over 3 years	MoHS, training institutions	2024–2027	50% reduction in telemedicine abandonment	NHSSP SO3; SDG 3.8
6	Climate-resilient facility upgrades (solar backup, flood protection)	$12.4M over 5 years	MoHS, Ministry of Energy	2024–2029	67% reduction in power-related service disruptions	NHSSP SO4; SDG 3.8

NHSSP = National Health Sector Strategic Plan 2021–2025; SO = Strategic Objective

Table 5: Partner Contributions and Coordination Gaps

Partner	Focus Area	Annual Contribution (est.)	Coordination Mechanism	Gap
Global Fund	HIV, TB, Malaria	$18M	Country Coordinating Mechanism	Vertical program fragmentation
GAVI	Immunization	$12M	Inter-agency Coordinating Committee	Cold chain gaps
World Bank	Health systems strengthening	$15M	Sector-wide approach	Limited government ownership
UK DFID	Maternal and child health	$9M	Sector-wide approach	Transitioning out
UNICEF	Child health, nutrition	$7M	UN Country Team	Duplication with WHO
WHO	Technical assistance, norms	$4M	UN Country Team	Limited implementation capacity
MSF	Emergency response, HIV	$3M	Ad hoc	Parallel systems
Chinese Government	Infrastructure, equipment	$6M	Bilateral agreement	Maintenance gaps

Figure Legends

Figure 1: Regional Healthcare Infrastructure Performance and Component Correlations. Panel (a) shows composite infrastructure scores by region. Panel (b) shows correlation matrix between infrastructure components, with strong correlations between physical and human resources (0.89) and governance and digital systems (0.96).

Figure 2: Sierra Leone Healthcare Infrastructure Analysis 2023 Regional Performance, Component Scores, and Bottleneck Counts. Panel (a) presents composite scores by region. Panel (b) shows box plots of normalized component scores. Panel (c) shows bottleneck counts by region.

Figure 3: Sierra Leone Healthcare Infrastructure Analysis 2023 Composite Performance, Component Scores, and Bottleneck Counts. Panel (a) presents overall scores by region. Panel (b) shows component score distributions. Panel (c) shows region-wise bottleneck counts.

Figure 4: Healthcare Infrastructure Disparities in Sierra Leone. Geospatial map showing composite infrastructure scores by region, ranging from dark blue (lowest, ~0.25) to yellow (highest, ~0.55). Regional boundaries and major roads overlaid.

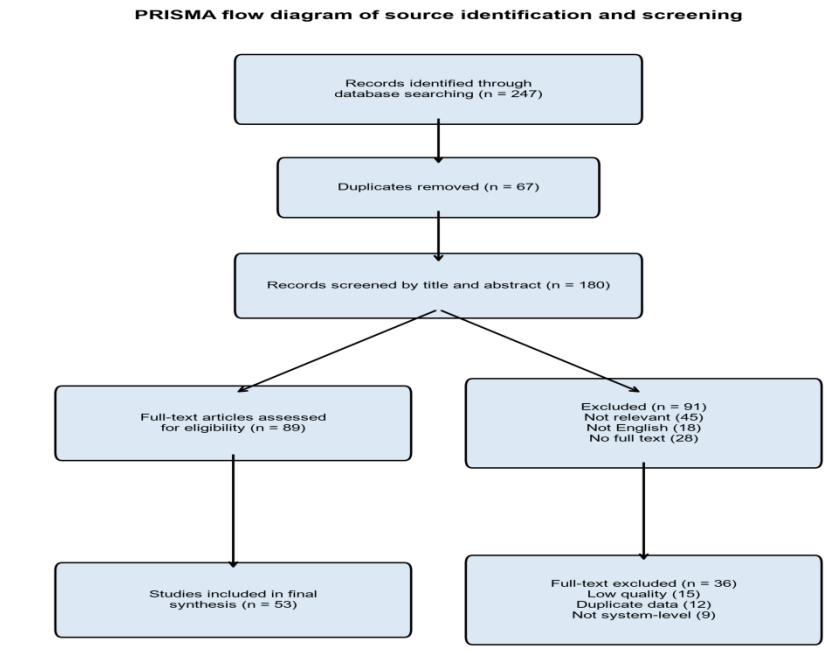
Figure 5: Sierra Leone Healthcare Infrastructure Analysis Component Averages, Score Distributions, and Facility Performance Profiles. Panel (a) shows mean scores for four infrastructure components. Panel (b) shows score distributions using box plots. Panel (c) shows performance profiles for five typical facilities.

Figure 6: Sierra Leone Healthcare Infrastructure Trend (2016–2023). Line graph showing changes in physical infrastructure, human resources, governance, and digital systems. Dashed lines denote post-Ebola reform (2016–2019) and COVID-19 (2020–2023) periods.

Figure 7: Sierra Leone Healthcare Coverage Projections (2024–2030). Two scenarios: status quo (dashed red line) and digital-primary-care integration (solid blue line). Vertical dotted line at 2026 marks telemedicine hub scale-up.

Figure 8: Healthcare Reform Implementation Roadmap. Three phases: Policy Reform (2024), Pilot Districts (2024–2025), and National Scale-Up (2026–2028). Milestones and deliverables shown for each phase.

APPENDIX B



ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue X October 2026

