Laboratory Spatial Analysis (LSA) for Uganda

Spatial analysis of coverage, accessibility and proposed allocation of additional diagnostic equipment

TB-DNA LSA: 2nd – 22nd June 2024

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Acknowledgements

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Acronyms

eHMIS	National Electronic Health Information System
EID	Early Infant Diagnosis
HBV	Hepatitis B
HC II	Health Centre II (most basic health unit and typically serves a parish)
HC III	Health Centre III (HC IIIs provide more comprehensive services compared to HC IIs, and typically serves a sub-county)
HC IV	Health Centre IV (a mini-hospital typically serving a county or health sub-district, providing more advanced healthcare services)
hflevel	Health facility level (hierarchy of facilities within Ugandan PHC system)
HPV	Human papillomavirus
MoH	Ministry of Health
MTB	Mycobacterium Tuberculosis
NHLDS	National Health Laboratory and Diagnostic Services
NTRL	National TB Reference Laboratory
NRH	National Referral Hospital
NSP	TB National Strategic Plan
NTLP	National Tuberculosis and Leprosy Control Programme
RRH	Regional Referral Hospital
mWRD	Molecular WHO-recommended diagnostics
PBC	Pulmonary Bacteriologically Confirmed
TB	Tuberculosis
TB-DNA	Tuberculosis Diagnostic Network Analysis
TIFA	Tuberculosis Implementation Framework Agreement
UNHCR	United Nations High Commissioner for Refugees
UPDF	Uganda People's Defence Force (category healthcare facilities associated with the Ugandan military)
UPF	Uganda Police Force (category healthcare facilities associated with the Ugandan police)
UPS	Uganda Prisons Service (category healthcare facilities associated with the Ugandan prison system)
VL	Viral Load

Executive Summary

This report presents a comprehensive Laboratory Spatial Analysis (LSA) for Uganda, conducted from June 2nd to June 22nd, 2024. The analysis aims to enhance the capacity of the National Tuberculosis and Leprosy Control Programme (NTLP) and the National TB Reference Laboratory (NTRL) staff to strategically analyse and utilize diagnostic data through geo-spatial methodologies.

Background

The initial TB Diagnostic Network Assessment (DNA) conducted in 2019 highlighted gaps in the TB diagnostic network in Uganda. This second assessment, funded by USAID, seeks to evaluate progress since 2019, identify ongoing challenges, and propose evidence-based interventions. The recommendations will be incorporated into the NTRL Operational Plan and the NTLP Strategic Plan to guide resource mobilization and meet the laboratory objectives of the End TB strategy and the UNGA High-level Meeting targets.

Objectives

- Assess population coverage of the current diagnostic network.
- Evaluate the existing sample referral system.
- Identify access gaps considering equipment volume and utilization.
- Optimally allocate molecular WHO-recommended diagnostics (mWRD) equipment in the pipeline.
- Propose scenarios to increase access to mWRD diagnostic instruments.

Methods

Data was collected from multiple sources, including the National Electronic Health Information System (eHMIS), LabXpert DS, WorldPop, and internal and external review reports. The data was cleaned and processed using AwesomeTables and KNIME, and analysis was conducted using ArcGIS Pro. The analysis focused on the distribution of mWRDs, specimen referral networks, and population coverage.

Results

mWRD TB Diagnostic Network Inventory: Uganda's diagnostic network includes 296 GeneXpert MTB Rif Ultra sites, 22 GeneXpert MTB/XDR sites, 41 Truenat sites, and 17 TB LAMP sites. Government facilities host the majority of these tools, reflecting strong public sector involvement.

Specimen Referral Network: The network comprises 100 hubs serving 2,454 spoke facilities, with varying average distances between spokes and hubs, influenced by regional development and urbanization.

Population Coverage and Accessibility: Service areas were created using Euclidean distances, revealing significant disparities in healthcare access between densely populated regions (e.g., Kampala) and sparsely populated areas (e.g., Karamoja).

Allocation of mWRDs: The Ministry of Health plans to place twenty 16-module GeneXpert machines at General Hospitals and reallocate existing 4-module machines to lower-level facilities. Additionally, eight 4-module GeneXpert machines will be allocated to facilities serving congregate populations, with eleven mobile clinics and fifteen replacement machines also in the pipeline.

Whitespace Analysis: Identified gaps in the current diagnostic network indicate a need for strategic allocation to meet NTLP objectives by 2024/25. This analysis provides a data-driven approach to prioritize facilities based on potential additional population coverage within a 5km service area.

Discussion

The report underscores the need for strategic placement of additional mWRD facilities to address gaps in coverage, particularly in less populated regions. The efficient use of the hub-and-spoke model and the optimal allocation of new diagnostic equipment will enhance the TB diagnostic network's ability to meet national and international targets. Formalizing local referral agreements and continuously refining the population coverage analysis will further improve healthcare accessibility and resource utilization.

The findings and recommendations from this LSA are crucial for guiding future resource allocation and improving TB diagnostic services across Uganda.

1. Background

The first TB Diagnostic Network Assessment (DNA) was conducted in 2019 by the Uganda Ministry of Health (MoH), National Health Laboratory and Diagnostic Services (NHLDS). It was a qualitative assessment of the extent to which the diagnosis network adhered to international standards and met the needs of the TB National Strategic Plan (NSP).

National TB Reference Laboratory (NTRL), with support from USAID/TIFA received funding to conduct a 2nd TB Diagnostic network assessment for 2024. The main objectives of the TB-DNA were to; holistically review the diagnostic network, current practices and algorithms; identify challenges that prevent the overall diagnostic network from performing efficiently and effectively; conduct an evaluation of the progress made in the implementation of the 2019 DNA conducted in the Uganda network and proposing evidence-based interventions to improve the overall ability of the TB diagnostic network to meet the goals and targets of National TB and Leprosy Control Program. These recommendations will be incorporated in the NTRL Operational Plan and the Strategic Plan for National Tuberculosis and Leprosy Control Programme (NTLP) to guide resource mobilization for the TB epidemic. These recommendations are focused on meeting the laboratory objectives of the End TB strategy and the UN General Assembly (UNGA) High-level Meeting target, which aims to ensure that all individuals with presumptive TB have access to molecular WHO-recommended diagnostics (mWRD) as an initial diagnostic test.

The TB-DNA process can be broken down into four components: (1) pre-assessment data collection and analysis; (2) self-assessment of TB diagnosis network core capacities by the country undertaking the DNA; (3) review of self-assessment and in-country verification by an external assessment team; and (4) review of the findings, identification of strengths and weaknesses, and development of evidence-based interventions to improve the TB diagnosis network.

The first component included consideration of the network from a geospatial perspective, resulting in this document: a Laboratory Spatial Analysis (LSA) for Uganda. This LSA report is the result of two components (1) a one-week intensive GIS training workshop, and (2) a one-week collaborative workshop on scoping and carrying out analyses integral to the TB-DNA objectives. The spatial analysis consultant provided country-level technical assistance focused on the LSA, aimed at enhancing the capacity of NTP and NTRL staff. This assistance involved training in the analysis and utilization of diagnostic data for strategic decision-making, leveraging geo-spatial analysis methodologies, software, and tools.

2. Objectives

1. Assess the population coverage of the current diagnostic network.
2. Assess the existing sample referral system in Uganda.
3. Identify access gaps considering equipment volume and utilization.
4. Optimally allocate mWRD equipment in the pipeline.
5. Propose scenarios to increase access to WHO-recommended Rapid Molecular (mWRD) diagnostics instruments.

3. Methods

Data was collected from various sources, including the National Electronic Health Information System (eHMIS), LabXpert DS, WorldPop, and other internal and external review reports. The data cleaning process involved using AwesomeTables plug-in for geocoding missing coordinates and KNIME data management tool for data preprocessing and manipulation. Analysis was then performed using ArcGIS Pro, focusing on the distribution of mWRDs, specimen referral networks, and population coverage.

3.1 Data used

The data sources described in Table 1 collectively provide the necessary information for analysing the TB diagnostic network's coverage, accessibility, and utilization.

Table 1: Data sources utilised for LSA

Data Source	Description
National Electronic Health Information System (eHMIS)	A comprehensive, web-based aggregate reporting system that runs on DHIS2 version 2.37.7.1. It is used for managing and reporting health-related data across various facilities.
LabXpert DS	An automated data capture system for GeneXpert, Truenat, and Digital X-ray machines. It enables real-time reporting and management of diagnostic data from these devices.
WorldPop	An online platform that provides high-resolution, open-access, gridded population distribution data globally.
Uganda Bureau of Statistics (with support from WHO)	UBS data has been distributed via HDX platform. https://data.humdata.org/dataset/cod-ab-uga

The datasets extracted from the above sources include:

1. Master Health Facility List (MFL): An extensive and standardized list detailing all health facilities in Uganda, including clinics, Health Centres (HCII, HCIII, HCIV), general hospitals, regional referral hospitals, national referral hospitals, and specialized centres. The MFL outlines the organizational hierarchy, including regions, districts, sub-counties, and health facilities, along with facility ownership types: Public (GOV), Private for Profit (PFP), and Private not for Profit (PNFP). It provides critical information such as facility names, locations, contact details, geographical coordinates, and operational status. The list presented is as of 2020.
2. Diagnostic mWRD Network: A subset of the MFL that identifies facilities offering either GeneXpert (GXP) or Truenat services. These facilities are mutually exclusive, meaning no facility offers both testing types. This subset is crucial for understanding the distribution and accessibility of molecular diagnostic tools for TB across Uganda.
3. Diagnostic Equipment Inventory: A detailed and organized record of all TB diagnostic devices within healthcare facilities or networks in Uganda. The data provided here is extracted from LabXpert DS as of 2024.
4. Diagnostic Equipment Pipeline: Information on planned procurement and placement of GeneXpert machines to improve testing capacity. This includes the number and type of

machines to be placed in various facilities, targeting specific needs and gaps in the diagnostic network.

5. Non-TB Diagnostic Testing Statistics: Data from LabXpert DS on tests conducted for other diseases using the GeneXpert platform, including HIV (EID and Viral Load), HBV, HPV, and COVID-19. This data helps to understand the multi-disease testing capacity and utilization of existing diagnostic equipment.
6. List of Specimen Referral Linkages (the hub system): This outlines the relationships between peripheral health facilities (spokes) and central laboratories (hubs) for the transport and processing of medical specimens. It details each spoke facility's location, the types of specimens collected, and the corresponding hub laboratory responsible for receiving and analysing these specimens. This model is crucial for understanding the specimen flow and optimizing the referral network for efficient diagnostic services.
7. WorldPop population counts (constrained): the latest available WorldPop population count data (2020) at a 100m spatial resolution (100m x 100m raster) for Uganda. A constrained version of the data was used, meaning population estimates only within areas identified as containing built settlements[1]. Total population for 2020 was estimated at 42.1 million, with Uganda Bureau of Statistics (UBOS) preliminary census report released in June indicating that this number has grown to 45.9 million persons. For the specific analyses performed in this report, this 9% increase is assumed to be constant across regions and therefore does not significantly impact results.
8. Administrative boundaries: district level boundaries were consolidated and used to create a health region boundary shapefile which is not currently available online.

3.2 Data cleaning and processing

Data obtained from the national datasets had to be assessed and cleaned to ensure accuracy and completeness. The KNIME data management tool played a critical role data prepping, including merging and appending various datasets with the Master Health Facility List (MFL). The following steps outline the data cleaning process:

1. Handling Missing Coordinates/ Geocoding and Validation:

Out of a MFL of 8 483 facilities, 6 104 (72%) were supplied with coordinates (last updated in 2019). The remaining 2 379 (28%) facilities were geocoded using the AwesomeTables plug-in in Google Sheets. Although the mWRD, a subset of the MFL, site coordinates were validated throughout the data cleaning and analysis processes, further validation is still recommended as a next step to ensure complete accuracy of the remaining facilities.

2. Merging Datasets:

The MFL provides unique identifiers (UIDs) per healthcare facility which ensures connectivity to all necessary corresponding diagnostic data. Therefore, KNIME was utilised to merge the updated MFL to associated datasets, including mWRD equipment, multiplexing data, and hub-and-spoke referral network. Any misalignments between datasets were investigated and corrected.

The MFL and hub system datasets were also combined and validated by NTRL staff to create a bespoke dataset matching the hub name to the hub facility name.

[1] WorldPop. "Top-down estimation modelling: Constrained vs Unconstrained." WorldPop, University of Southampton, 2024. https://www.worldpop.org/methods/top_down_constrained_vs_unconstrained/.

1. Validation of Health Facility Data:

The data cleaning process included assessing and validating health facility names and locations to ensure consistency with the MFL. This involved cross-referencing with the master list and correcting any discrepancies found during the analysis. Where applicable, manual data cleaning was conducted to verify health facility names against the MFL. Several errors found within the mWRD sites and their associated health regions were manually identified by the NTBRL team and corrected.

2. Spatial Data Integration:

To validate the spatial elements within the data, coordinates were assessed for accuracy. Missing, outlying and incorrect coordinates were identified and geocoded using the AwesomeTables plug-in, ensuring that all facilities could be included in the spatial analyses.

By following these rigorous data cleaning steps, the datasets were prepared for accurate and reliable analysis, ensuring that the final report provides a comprehensive and precise evaluation of the TB diagnostic network in Uganda.

3.3 Data analysis

To understand the distribution and accessibility of mWRDs in Uganda, various data analysis techniques were employed using ArcGIS Pro (version 3.1.3) and the Spatial Analyst extension (ESRI, 2024)[2].

3.3.1 mWRDs Distribution

Within Uganda, the private and public health sectors almost equally contribute to the national health system. The public sector includes health facilities under the Ministry of Health (MoH) and the health services under the Ministries of Defence, Education, Internal Affairs (Police and Prisons) and Local Government. The public health sector is structured into: National Referral Hospitals (NRHs); Regional Referral Hospitals (RRHs) and the District Health System (General hospitals, Health Centres II-IV and Village Health Teams) while the private sector is comprised of the private not-for-profit (PNFP) health care providers, and private for-profit (PFP) health practitioners[3]. Public facilities can further be categorised according to association with security forces, namely the Uganda People's Defence Force (UPDF), Uganda Police Force (UPF) and Uganda Prisons Service (UPS).

The distribution of the current network was visualised by plotting the cleaned coordinates of mWRD facilities and their associated attribute data in ArcGIS Pro. Symbology was used to visualise health facility level categories and these locations were overlaid onto Ugandan health regions and population count data from the WorldPop dataset. Facility counts at regional, health facility and ownership levels were also summarised.

3.3.2 Diagnostic Service Interruption

Placement of GXP machines should consider whether the existing machines are being optimised sufficiently, and therefore, whether introducing additional machines into the network the answer to increase public access to diagnostic services.

Uganda is implementing AccessCare Program that supports comprehensive maintenance, service and repair of GeneXpert machines. Equally, there are service level agreements that support

[2] Esri. (2023). *ArcGIS Pro: Version 3.1.3* [Computer software]. Esri. https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview

[3] Uganda National Strategic Plan 2020/21 – 2024/25

Truenat and TB-LAMP maintenance. The graph (Figure 1) below summarises module availability from Jan 2023 to April 2024. The target is that >95% of the modules should be functional. Over the past 5 quarters, this target has been met if not exceeded, with the exception of July and August 2023, indicating that platform availability is not a vital concern or variable to be considered within any analysis which aims to improve access to diagnostic services.

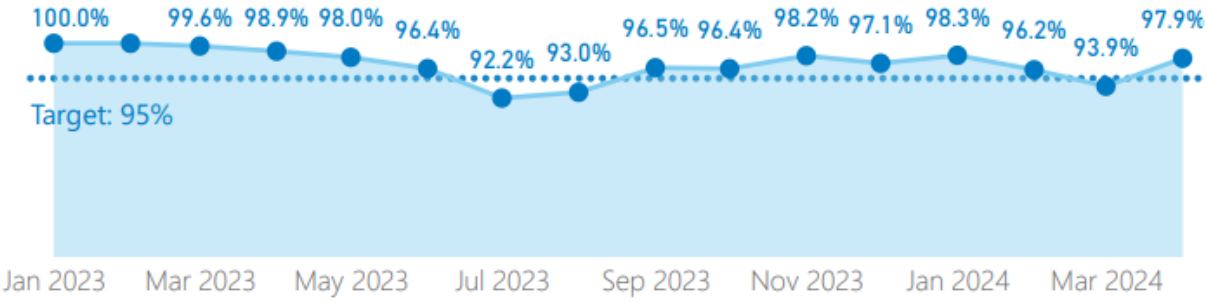

Figure 1: Monthly GeneXpert module functionality (national average)

3.3.3 Specimen Referral Network Analysis

The hub system in Uganda's healthcare framework is a formal network aimed at improving the reach and quality of laboratory services nationwide. Uganda's public healthcare system organises its facilities in a hierarchy within this framework: Health Centre II (HC II), Health Centre III (HC III), Health Centre IV (HC IV), General Hospital, Regional Referral Hospital (RRH), and National Referral Hospital (NRH). Laboratory services are integrated from HC III up to NRH, with increasing complexity of services offered at higher levels.

These hubs are equipped with advanced infrastructure, equipment, and human resources to conduct various diagnostic tests, including TB, HIV (Early Infant Diagnosis (EID), Viral Load (VL)), HPV, and COVID-19. They also manage sample transportation to higher-level reference laboratories as needed. A hub is a laboratory within the health network that has enhanced capacity to perform routine tests for the facility's patients and analyse specimens referred from other health facilities in its catchment area, known as 'spokes'.

Within ArcGIS Pro, the distance between each spoke-hub pair was determined using Euclidean (straight-line) distances. This output could then be compared to an origin-destination (OD) matrix which matched each spoke to its nearest hub.

3.3.4 Population Coverage and Accessibility

Initially, two network approaches were explored for creating service areas for the mWRD facilities. Both methods, however, returned undesirable, inaccurate results due to the quality of available road network data for Uganda. In both cases the outputs were slightly more reliable in the area of Kampala, but results degrade substantially in the rest of the country. The two approaches explored were (1) isochrones created with a rest API from Here.com in RStudio, and (2) 'Service Area' analysis within the Network Analyst extension in ArcGIS Pro used in conjunction with the Ugandan road network dataset provided by UNICEF and University of Edinburgh (2021) (created using data from Open Street Map (OSM) and MapwithAi project roads data[4]).

[4] Uganda Road Data for Travel Time Maps (2021). https://datashare.ed.ac.uk/handle/10283/3946

Instead, service areas were delineated using buffers with Euclidean (straight-line) distances, a method widely supported in literature on healthcare accessibility and spatial analysis. According to the World Health Organization (WHO), an optimal distance from a primary healthcare (PHC) facility should be within 5 km, considered a walkable distance. This threshold ensures that the majority of the population can access healthcare services by foot, while larger distances can accommodate other modes of transportation. Motorised transport considerations estimate respective travel times of 0-15 minutes (0-5km), 15-30 minutes (5-10km), 30-45 min (10-15km), and 45-60 min (15-20km)[5]. Data management tools in ArcGIS Pro were used to create buffers of 5-, 10-, 15- and 20-km rings, dissolved by health region. These service areas were then clipped to the 15 regional boundaries for calculating regional coverage. Any additional coverage from neighbouring regions was included in calculations. Population coverage for each service area was then estimated using zonal statistics to sum pixel values per WorldPop raster grid cell.

3.3.5 Allocation of mWRD's in equipment pipeline

Despite decreased funding for equipment in recent years, there is still a continuous need to identify resources to address gaps in access, especially in facilities where there is high demand for testing both for TB and other disease programs. In response to this, the Uganda Ministry of Health is in the process of signing an all-inclusive agreement with Cepheid to place twenty (20) sixteen-module GeneXpert machines at select General Hospitals to increase testing capacity. The four-module GeneXpert machines in these facilities will be re-allocated to lower health facilities.

Similarly, recent reports have identified gaps in access to molecular testing in congregate settings such as refugee, prison, military, police, and cross-border facilities. There is a plan to procure eight 4-module GXP machines for eight facilities serving congregate populations.

The NTLP also aims to provide an additional eleven mobile clinics equipped with 4-module GXP platforms to ensure that all regions are served. For this purpose, fourteen 4-module GXP machines are in the pipeline. These mobile clinics have been identified or are in the process of being procured, therefore no analysis for allocation is required.

Lastly, the program is procuring fifteen 4-module GXP's to replace the existing R1 GXP machines in fourteen health facilities across the country. Given these instruments have been procured for these specific facilities, no further analysis is required.

Table 1: mWRD instruments within pipeline (as of June 2024)

No. of GeneXpert machines	No. of modules	Target facilities
20	16	General Hospitals with 4 module GXPs
8	4	Refugees, prisons, military, police & cross-border facilities
14	4	Mobile clinics
15	4	Facilities with R1 machines

[5] Kuupiel, D., Adu, K. M., Bawontuo, V., & Mashamba-Thompson, T. P. (2019). Geographical Accessibility to District Hospitals/Medical Laboratories for Comprehensive Antenatal Point-of-Care Diagnostic Services in the Upper East Region, Ghana. *EClinicalMedicine*, *13*, 74–80. https://doi.org/10.1016/j.eclinm.2019.06.015

To determine the optimal placement of the twenty 16-module GXP's currently in the equipment pipeline, a scoring system was created incorporating two key indicators: population coverage and total target tests. Testing targets comprised the sum of TB Presumptives Needed to Test (NTT) and multiplexing total projected demand. The formula used to calculate the Presumptives Needed to Test (NTT) is:

$$NTT = \frac{100}{Yield} \times PBC\ Target$$

where the PBC Target represents the number of positive bacteriologically confirmed (PBC) patients. Since specific multiplexing NTT targets were not available, a proxy variable was calculated using projected demand from the Global Fund GC-7 cycle. This projected demand was evenly distributed across facilities offering multiplexing testing. This assumption was made considering the relatively insignificant number of multiplexing tests being performed, ensuring that the scores were not significantly impacted.

Normalization was performed to ensure that both components are on a comparable scale (0 to 1), allowing for a fair comparison and combination of the two metrics. Scores were calculated with a 60% weighting on testing targets and 40% on population coverage to identify health facilities with the highest needs.

The placement of the eight 4-module GXP's was then considered given (1) the strategic limitations to congregate settings (refugees, prisons, military, police & cross-border facilities), (2) facilities with no or <4 GXP modules, (3) facilities with allocated TB targets (NTT). There is no official dataset for cross-border facilities, therefore through discussion with the NTRL team and triangulation with internal proxy data sources, consideration was given to facilities within a 10 km threshold of the border of Uganda. Notably, there is the opportunity for duplicates between this analysis and the analysis for the 16-module placement given the inclusion of hospitals, therefore the outputs should be compared before finalisation of instrument allocation.

3.3.6 Whitespace analysis to address GXP gap

The NTLP aims to increase the number of health facilities offering GXP diagnostic services by 2024/25[6]. This goal is detailed by health facility level (hflevel), with objectives to equip all hospitals, all HC IVs, and 50% of HC IIIs with GeneXpert machines.

Existing mWRD sites were removed from the MFL, and the remaining facilities were categorized by health facility level. This resulted in a list of all facilities within the Ugandan healthcare system without mWRD diagnostic services. The potential additional population coverage within a 5km service area for each facility was assessed and used as the primary metric to rank facilities for future equipment allocation.

To achieve this, 5km service area buffers were generated for each facility, and the underlying population was summed. This coverage was then compared to existing population catchments, and the difference was calculated. From this analysis, we were able to rank the facilities within each hflevel, prioritizing those with the greatest additional population coverage potential.

[6] Report for the Internal Assessment and Mid-Term Review. NTRL. 2023

This approach accommodates overlapping service areas, recognizing it is the initial step in identifying optimal locations. The population coverage analysis should be iteratively refined after further filtering by knowledge experts and officials within NTLP.

4. Results

4.1 mWRD TB diagnostic network inventory

Uganda has implemented different mWRD tools within its diagnostic network. These include GeneXpert MTB Rif Ultra in 296 sites, GeneXpert MTB/XDR in 22 sites, Truenat in 41 sites and TB LAMP in 17 health facilities.

The coverage for GeneXpert Ultra in government facilities is 83.4% while in private facilities it is 17%, 43 of which are in Private Not-For-Profit (PNFPs) and 6 in Private For-Profits (PFPs). Additionally, the coverage of Xpert MTB/XDR TB Assays is 95.6% in government facilities and 4% in private facilities. Truenat machines are in 41 sites, 85.4% are government while 14.6% are in private facilities, one of which is a PFP and 5 of which are in PNFP.

Of the 17 TB LAMP facilities, 70.6% are in public facilities while 29.4% are in private facilities (Table 2).

Table 2: mWRD diagnostic facilities by test type and ownership

TB mWRD Test	No of facilities offering testing service	Ownership of facilities
Xpert MTB Rif Ultra	296 GXP facilities (143 TB only, and 153 TB and at least one of HIV, EID, VL, Covid 19)	247 government facilities (5 UPDF, 2 UPF, 12 UPS, 228 MoH) 6 PFP 43 PNFP
Xpert MTB/XDR TB Assay	22 facilities	21 government facilities 1 PNFP
Truenat	41 Truenat machines	35 government facilities 1 PFP 5 PNFP
TB LAMP	17 TB facilities	12 government facilities 5 private facilities

4.2 Overview of diagnostic site distribution

As of June 2024, Uganda's TB mWRD network includes 416 instruments in 354 testing facilities. This network comprises 358 GeneXpert machines in 296 facilities, 41 Truenat machines, and 17 TB LAMP machines. These diagnostic tools are distributed among various levels of healthcare facilities: 5 National Referral Hospitals, 16 Regional Referral Hospitals, 80 Hospitals, 155 Health Centre IV's, 53 Health Centre III's, and 3 special clinics. Additionally, five mobile clinics are equipped with 4-module GeneXpert machines, with one clinic each in the Lango, Ankole, and Mbale regions, and two clinics managed centrally by the Ministry of Health.

The distribution of mWRD facilities generally corresponds to the population distribution across the country (Figure 2). For instance, Kampala and the surrounding areas in the South Central region have the highest concentration of mWRD facilities, owing to the presence of all five National Referral Hospitals. Conversely, regions like Karamoja and parts of West Nile and Teso have fewer healthcare facilities and lower population densities, indicating a disparity in healthcare access.

The distribution of healthcare facilities is hierarchical, with National and Regional Referral Hospitals (NRH and RRH) primarily located in regions with the highest population densities to cater to larger populations and provide advanced medical services. Health Centres II, III, and IV, along with clinics, are more evenly distributed across the regions to ensure broader access to basic healthcare services, reflecting a strategy to cover both urban and rural healthcare needs comprehensively.

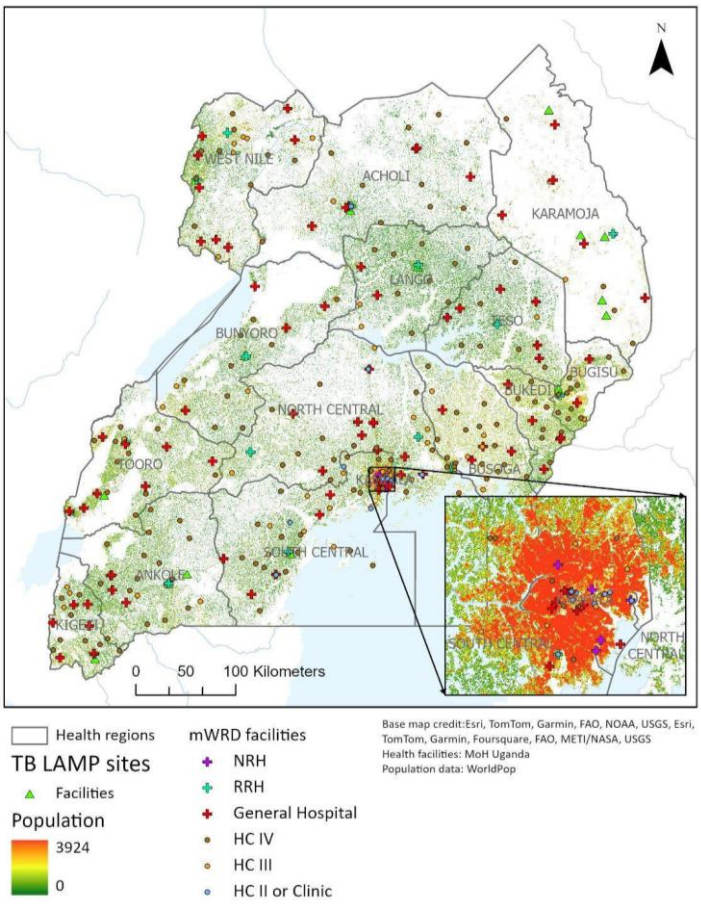

Figure 2: Uganda mWRD site distribution (2024)

4.3 Specimen referral network

As of June 2024, Uganda's Specimen Referral Network includes 100 hubs serving 2,454 spoke facilities. This network comprises Regional Referral Hospitals, General Hospitals, and Health Centre IV's, strategically distributed across the country to facilitate the transportation of specimens from peripheral health facilities to central laboratories for processing.

Regional Referral Hospital hubs serve about 554 spokes (22.6%), General Hospitals serve 983 spokes (40%), and Health Centre IV hubs serve 643 spokes (26.2%). Additionally, the National Reference Laboratory (CPHL) in Kampala serves 274 spokes (11%).

The specimen referral network analysis (Figure 3) highlights the distribution and linkages of hubs and spokes across different health regions. The hubs are more concentrated in densely populated areas, ensuring better coverage and accessibility.

The map provides insight into how specimens are transported from peripheral health facilities (spokes) to central laboratories (hubs) for processing.

The average distance travelled from a hub to its associated spokes varies significantly, influenced by the level of development, urbanization, and available resources in an area. Densely populated areas generally have shorter average distances from spokes to hubs compared to sparsely populated areas. Overall, the average distance travelled across all hubs is approximately 19 km, however there is inter-regional variability to be considered. For example, the highest average travel distances are experienced by Ngoma Health Centre IV hub in Nakaseke District and the Madi-Opei hub in Lamwo District, which each serve 20 spoke facilities with an average distance of 55.48 km and 47.23 km, respectively. Conversely, the Budadiri Health Centre IV hub in Bugisu serves 8 spokes with the shortest average distance of 7.09 km. Within the same Bugisu region, Kapchorwa General Hospital has an average referral distance of 17.14 km, and Mbale RRH has an average distance of 11 km (Figure 3), illustrating intra-regional disparities.

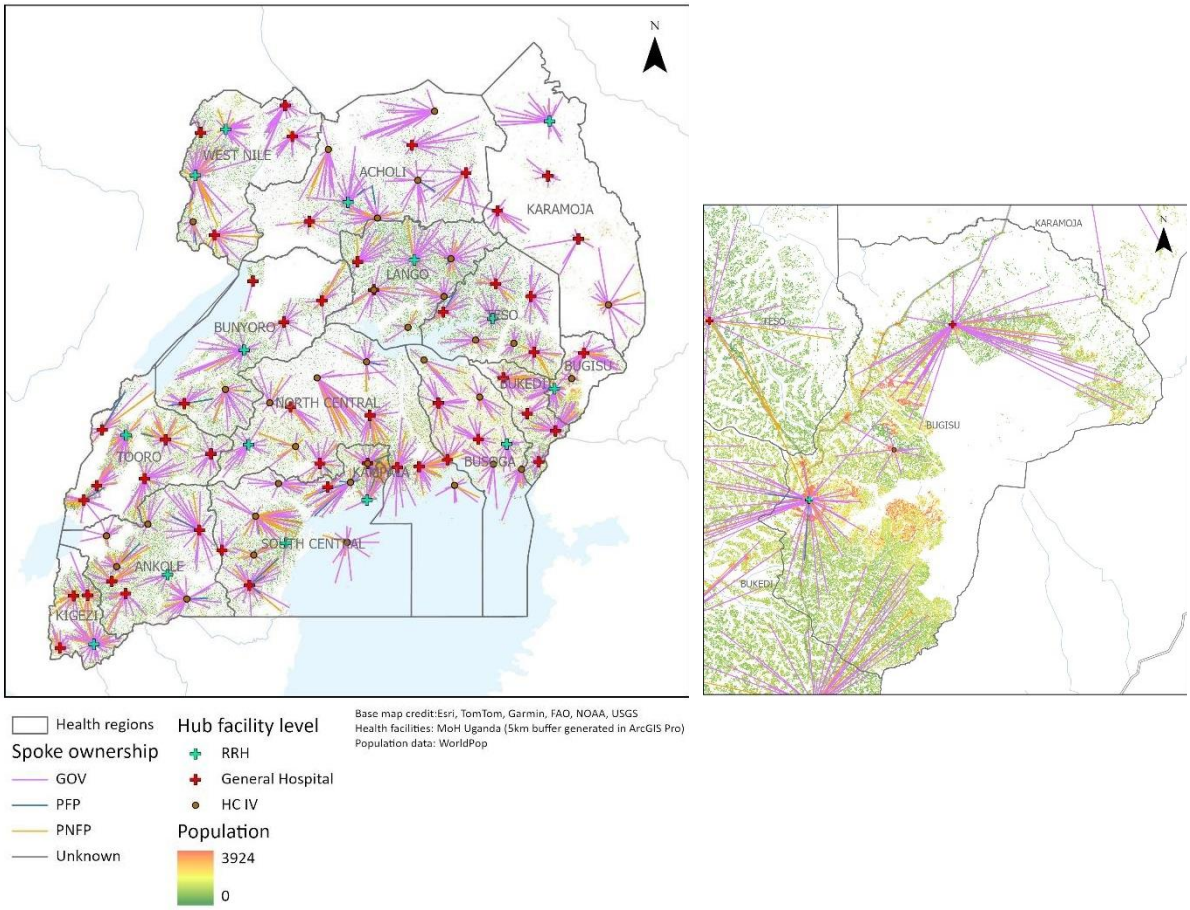

Figure 3: Specimen referral network (hubs and spokes) and the hub referral system within Bugisu region

4.3.1 Facilities not covered by the hub system (gap analysis)

At a national level only 39% of Primary Health Care (PHC) facilities are included in the referral system. From an analysis of private health care facilities not served by the hubs, Kampala health region had the largest proportion of PHCs (95%) not under the hub and spoke network while Karamoja had the lowest proportion of PHCs (34.7%) not covered by this network.

Table 3: Facility gap within hub system, by region

Region	Total # facilities	Total # facilities within hub network	Gap	Gap (%)
Kampala	2 032	98	1934	95.2
South Central	1 263	307	956	75.7
Busoga	599	165	434	72.5
Lango	385	125	260	67.5
Ankole	558	186	372	66.7

North Central	791	273	518	65.5
Bukedi	293	113	180	61.4
Bunyoro	305	121	184	60.3
Kigezi	349	140	209	59.9
Tooro	466	196	270	57.9
West Nile	404	179	225	55.7
Bugisu	283	134	149	52.7
Acholi	350	177	173	49.4
Teso	256	133	123	48
Karamoja	150	98	52	34.7

4.3.2 Assessment of optimal allocation of facilities to nearest available hub

A distance-based assessment was conducted to evaluate the optimal design of the specimen referral network. Out of the 2 454 spoke facilities, only 63 (2.6%) are not allocated to their nearest hubs. These facilities are associated primarily with Karoli Lwanga (Nyakibale) Hospital and Mukono General Hospital. The spokes not allocated to their nearest hubs are located in the following administrative districts: Wakiso District (34), Kamwenge District (18), Kitagwenda District (10) and Kampala District (1).

4.4 Population coverage and accessibility

The current locations of mWRD sites are closely correlated to the underlying population distribution (Figure 4). Kampala Health Region is the smallest region but has the highest population density as it contains the capital city of Kampala. As such, it has the highest 5km service area coverage with full coverage at 10km (Figure 4). Less populated regions like Karamoja and Acholi with sprawled populations are noted to have a smaller concentration of mWRDs and consequently lower population coverage. Coverage by population count as well as proportion were explored, considering a population of 42.1 million people (2020).

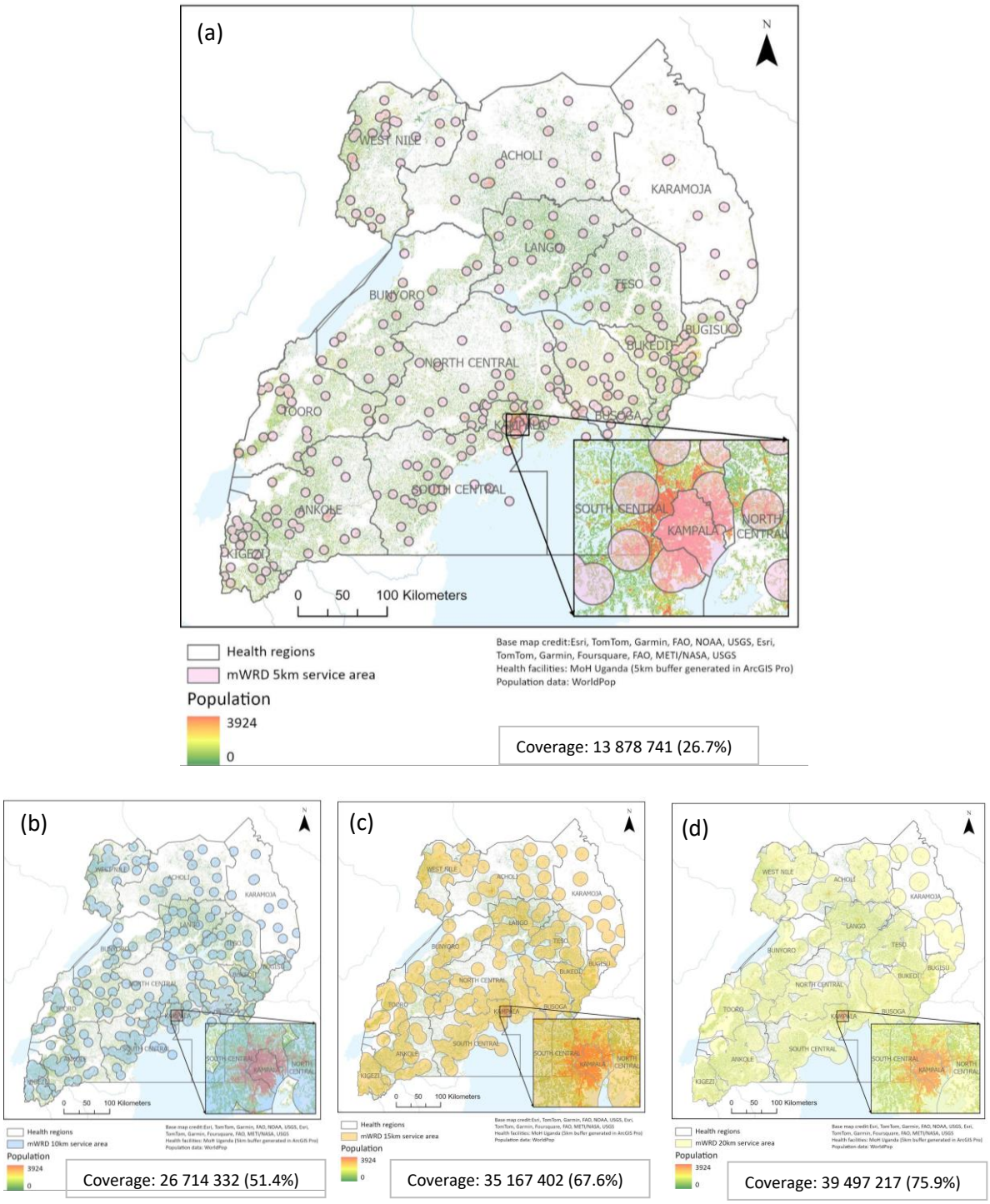

Figure 4: Uganda mWRD facility service areas for (a) 5km (b) 10km (c) 15km (d) 20km radii, and associated population coverage (count and % of total population). Population coverage (%) is calculated as compared to total population of Uganda is 42.1 million.

Regional summaries of accessibility are also provided below:

Table 4: Population coverage by health region and service area distance

Health Region	Count of mWRD Sites	Total Population	Pop 5km	Pop 10km	Pop 15km	Pop 20km

Acholi	19	1 820 122	426 759 (23%)	706 020 (39%)	1 049 679 (58%)	1 429 208 (79%)
Ankole	25	3 363 528	712 556 (21%)	1 740 107 (52%)	2 644 010 (79%)	3 141 003 (93%)
Bugisu	16	2 160 417	1 030 716 (48%)	1 918 394 (89%)	2 134 109 (99%)	2 154 202 (100%)
Bukedi	13	2 297 459	670 899 (29%)	1 668 200 (73%)	2 143 861 (93%)	2 295 064 (100%)
Bunyoro	17	2 655 393	548 093 (21%)	1 318 067 (50%)	2 067 469 (78%)	2 479 285 (93%)
Busoga	27	4 298 860	1 242 649 (29%)	2 712 263 (63%)	3 644 774 (85%)	4 037 355 (94%)
Kampala	32	1 706 854	1 703 482 (100%)	1 706 854 (100%)	1 706 854 (100%)	1 706 854 (100%)
Karamoja	13	1 179 495	223 520 (19%)	529 163 (45%)	767 008 (65%)	970 240 (82%)
Kigezi	18	1 518 615	537 510 (35%)	1 155 214 (76%)	1 429 728 (94%)	1 496 154 (99%)
Lango	15	2 490 076	386 405 (16%)	1 011 435 (41%)	1 693 634 (68%)	2 255 757 (91%)
North Central	37	4 438 618	1 251 391 (28%)	2 536 450 (57%)	3 478 813 (78%)	4 107 212 (93%)
South Central	44	5 602 401	2 289 800 (41%)	4 480 980 (80%)	5 156 365 (92%)	5 396 792 (96%)
Teso	14	2 252 044	347 980 (15%)	1 037 244 (46%)	1 681 031 (75%)	2 145 857 (95%)
Tooro	20	3 197 598	872 141 (27%)	1 796 997 (56%)	2 358 153 (74%)	2 824 070 (88%)
West Nile	27	3 189 853	1 015 821 (32%)	2 024 498 (63%)	2 692 611 (84%)	2 979 996 (93%)

4.5 Placement of GeneXpert already in pipeline

4.5.1 Multiplexing

Multi-disease testing is an approach where different assays, besides the MTB assay, are run on the GXP platform. Currently, the GXP assays include HIV (EID and Viral Load testing), HBV, HPV, and COVID-19 testing.

Out of the 296 GXP sites, 153 (52%) are carrying out multi-disease testing. These sites include:

- 5 National referral hospitals
- 16 Regional referral hospitals
- 55 General hospitals
- 55 Health Centre IVs
- 11 Health Centre IIIs
- 11 Health Centre IIs and clinics

The projected demand for HBV, HPV, and HIV (VL and EID) testing on GeneXpert for the years 2024 to 2026 (Global Fund GC-7 cycle) is as follows:

- 2024: 441 162 tests
- 2025: 425 609 tests
- 2026: 451 880 tests

The projected demand for TB tests for the same period is:

- 2024: 1 016 600 tests
- 2025: 1 192 435 tests
- 2026: 1 227 008 tests

For the multi-disease testing sites, utilization rates are monitored regularly. In the first quarter of 2024, a total of 251 472 tests were conducted on the GeneXpert machines at these sites. The breakdown of tests is as follows:

- TB tests: 96.76%
- EID tests: 1.7%
- Viral load tests: 1.25%
- HPV tests: 2.87%
- COVID-19 tests: 0.04%

LabXpert DS provides additional data for tests conducted on the GeneXpert machine other than TB. Datasets extracted from LabXpert included tests conducted for HIV (EID and Viral Load), HPV, and COVID-19. The data from these 153 health facilities show a significant increase in the number of tests performed for EID, HPV, and Viral Load in 2023 compared to 2022 (Figure 5). This increase is attributed to ramped-up testing efforts and recovery from the decreased testing volumes caused by the COVID-19 pandemic. TB continues to consume the vast majority of tests in the system.

Product Description	2024	2025	2026
Xpert TB	1 016 600 (69.7%)	1 192 435 (73.7%)	1 227 008(73.1%)
Xpert HIV-1 Viral Load	192 720 (13.2%)	98 451 (6.1%)	90 347 (5.4%)
Xpert HIV-1 Qual	63 933 (4.4%)	60 830 (3.8%)	50 399 (3.0%)
Xpert HPV	184 509 (12.7%)	180 328 (11.1%)	225 134 (13.4%)
Xpert HBV	-	86 000 (5.3%)	86 000 (5.1%)
Total	1 457 762	1 618 044	1 678 888

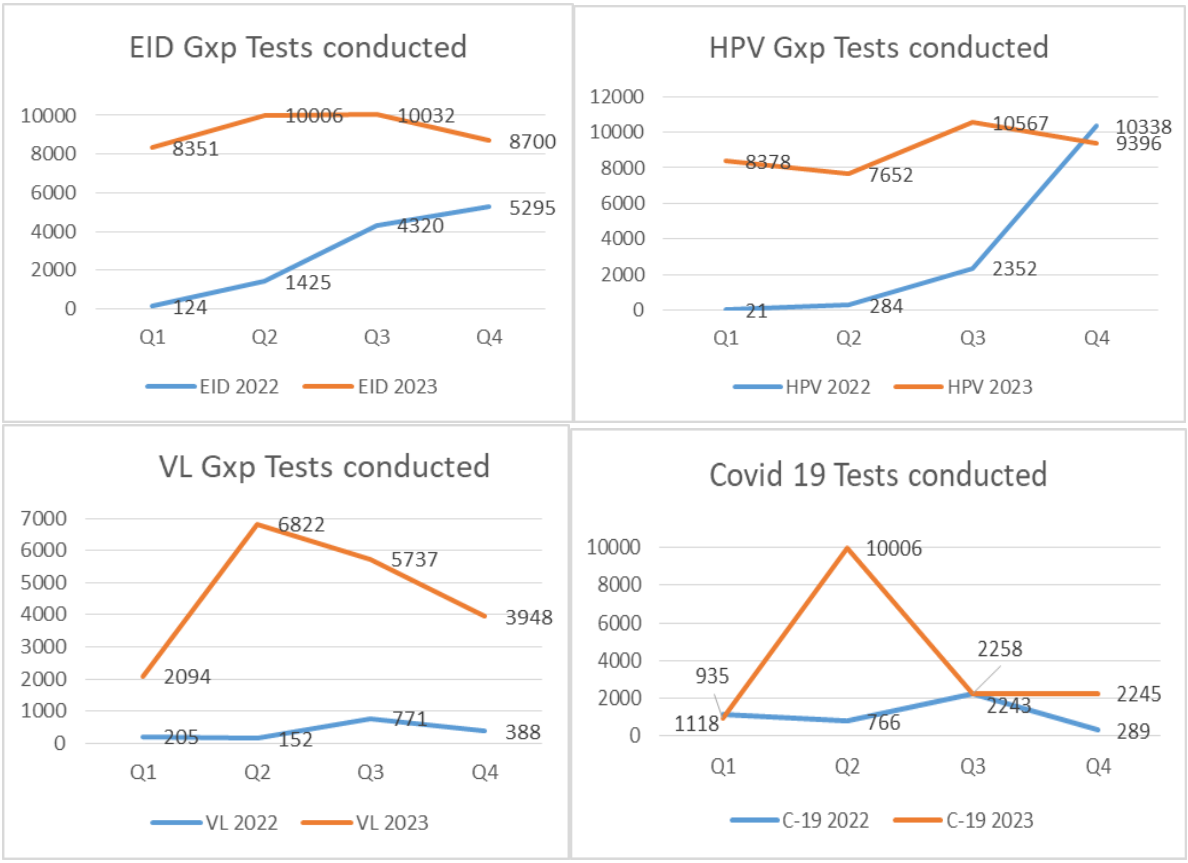

Figure 5: Tests performed for EID, HPV, and Viral Load in 2023 compared to 2022

4.5.2 Allocation of 16-module GXP's in pipeline

The population coverage within a 5 km radius for each hub network (i.e. the hub facility and all associated spokes) was considered for this analysis (Figure 6). Each colour represents an individual qualifying hub system: NRH, RRH, or general hospitals with 4-module GXP machine(s).

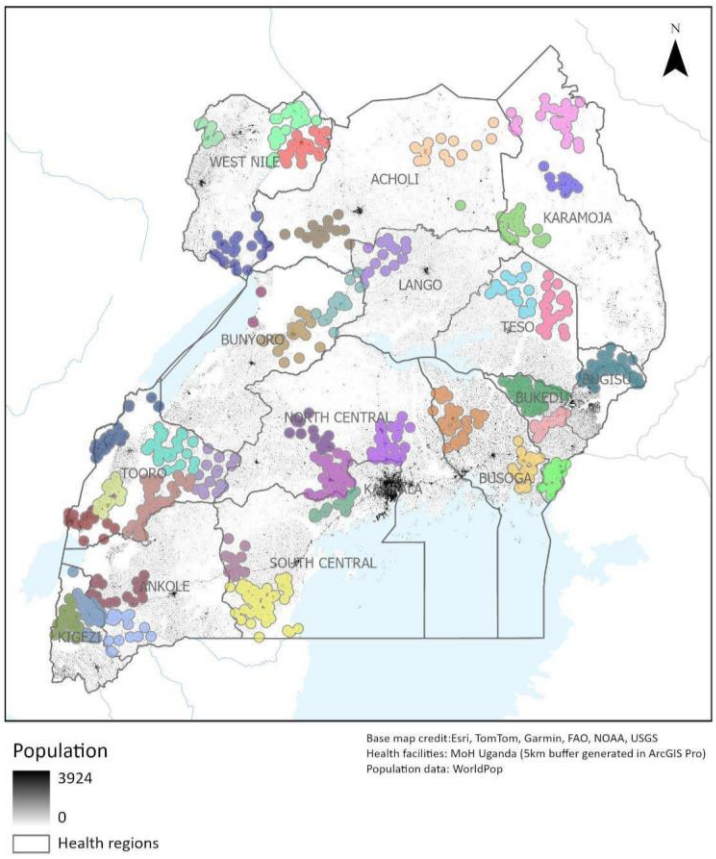

Figure 6: Population coverage by hub network (5km service areas)

The composite scoring system provided the top 20 candidate hospitals currently utilising 4-module GXPs (Table 5). The full ranking list of hubs based on this scoring methodology is provided in the Annex.

Table 5: Top 20 ranked hospitals with 4-module GXPs based on composite score (considering population coverage and TB and multiplexing testing targets) for potential allocation of 16-modules GXPs in pipeline

Hub Name	Hub facility name	District	Region	Hub population	Target test total (MP)	Composite Score	Rank
Pallisa Hub	Pallisa General Hospital	Pallisa	Mid Eastern	814 850	20 883	0.53	1
Kapchorwa Hub	Kapchorwa General Hospital	Kapchorwa	Mid Eastern	645 365	17 124	0.42	2
Rakai Hub	Rakai General Hospital	Rakai	Central 1	504 268	26 383	0.40	3
Luweero Hub	Luwero General Hospital	Luweero	Central 2	478 109	26 392	0.39	4

Kamuli Hub	Kamuli General Hospital	Kamuli	East Central	570 964	14 062	0.36	5
Kilembe Mines Hub	Kilembe Mines Hospital	Kasese	Mid Western	433 302	21 014	0.34	6
Nebbi Hub	Nebbi General Hospital	Nebbi	West Nile	378 159	24 138	0.33	7
Kagando Hub	Kagando Hospital	Kasese	Mid Western	524 565	11 698	0.32	8
Kyenjojo Hub	Kyenjojo General Hospital	Kyenjojo	Mid Western	373 354	21 256	0.31	9
kitagata Hub	Kitagata General Hospital	Mitooma	South Western	346 597	23 416	0.31	10
Rukunyu Hub	Rukunyu General Hospital	Kamwenge	Mid Western	469 248	13 045	0.30	11
Mityana Hub	Mityana General Hospital	Mityana	Central 2	364 304	16 043	0.27	12
Bugiri Hub	Bugiri General Hospital	Bugiri	East Central	443 049	9 449	0.27	13
Masafu Hub	Masafu General Hospital	Busia	Mid Eastern	371 904	12 701	0.25	14
Bundibugyo Hub	Bundibugyo General Hospital	Bundibugyo	Mid Western	337 596	13 733	0.24	15
Amuria Hub	Amuria General Hospital	Amuria	North East	168 107	27 112	0.24	16
Itojo Hub	Itojo General Hospital	Ntungamo	South Western	337 525	12 714	0.24	17
Adjumani Hub	Adjumani General Hospital	Adjumani	West Nile	196 564	22 738	0.23	18
Kyegegwa Hub	Kyegegwa General Hospital	Kyegegwa	Mid Western	289 985	15 128	0.23	19
Kanungu Hub	Kambuga General Hospital	Kanungu	South Western	277 689	12 925	0.21	20

4.5.3 Allocation of 4-module GXP's in pipeline

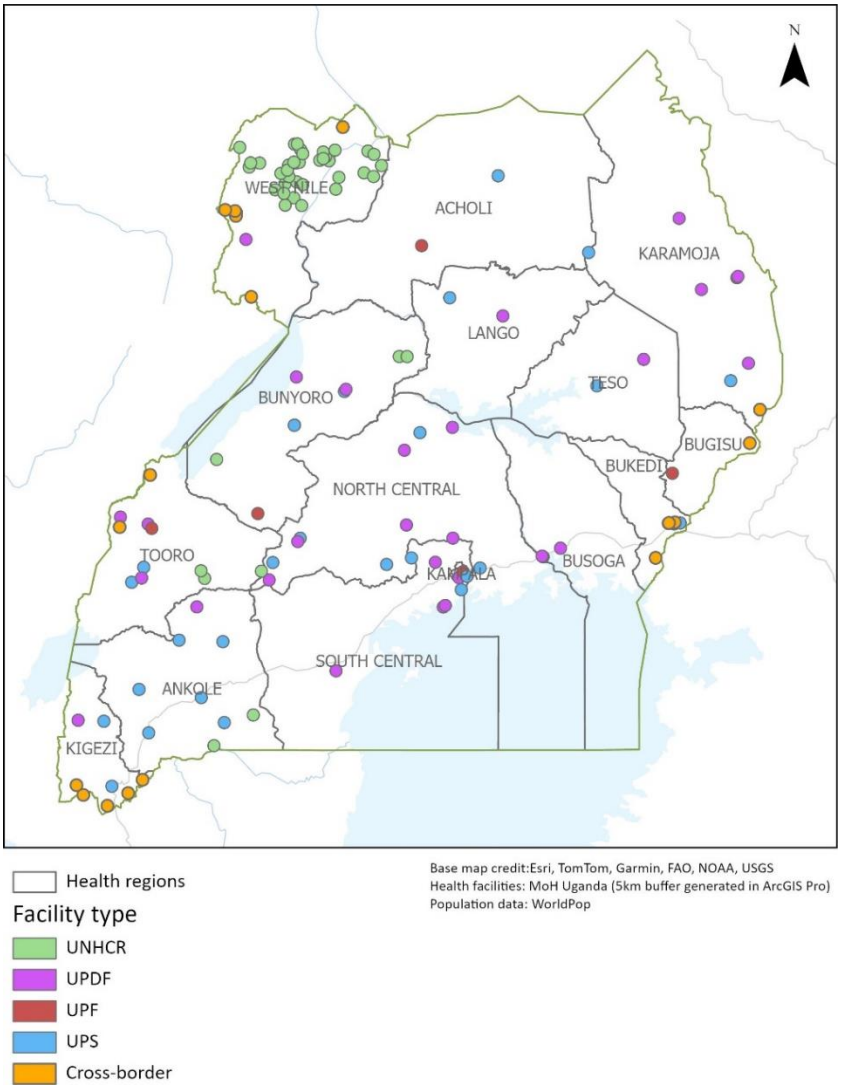

Figure 7: Facilities considered for allocation of 4-module GXP's with 5km service areas

The qualifying 122 facilities comprised of 44 UNHCR refugee facilities, 28 military facilities, 26 prisons, 10 police facilities, 10 cross-border HC IV's, and 4 cross-border hospital (Figure 7). The majority of the refugee healthcare centres are clustered in the West Nile region, whilst the cross-border facilities sporadically line the boundary of Uganda. The facilities associated with the military, police and prisons are more evenly distributed across regions.

Given the outcomes of the composite score methodology, the top eight ranking facilities are provided below (Table 6):

Table 6: Top 8 ranked facilities based on composite score (considering population coverage and TB testing targets) for potential allocation of 4-modules GXPs in pipeline

Health Facility	District	Facility population	TB NTT	Composite score	Rank
Okubani Health Centre III	Yumbe District	9 451	9113	0.60	1
Luzira Health Centre III	Yumbe District	29 966	7778	0.53	2
Makindye Barracks Health Centre III	Kampala District	814 323	72	0.40	3

Yangani Health Centre III	Yumbe District	21 733	5955	0.40	4
Siripi Health Centre III	Terego District	5 794	5822	0.39	5
Swinga Health Centre III	Yumbe District	30 981	5003	0.34	6
Twajiji Health Centre III	Yumbe District	28 626	5010	0.34	7
Naguru Police Health Centre IV	Kampala District	670 396	128	0.34	8

A more comprehensive list of 50 (out of the total 122 considered) is provided in the Annex.

4.6 Whitespace analysis of GXP's to facilities with no GXP achieve targets

There are 8 483 facilities in the current MFL, with government ownership of 3479 (41%) and private ownership of 5003 (49%), and one facility with unknown ownership. Of these 8483 facilities, there are currently 337 (4%) mWRD sites (GeneXpert and Truenat) across Uganda.

The current gap, according to NTLR objectives, compared to equipment already in the healthcare system stands as follows:

Table 7: GXP target gap by hflevel as compared to existing mWRD diagnostic equipment

HC Facility Level	GXP target gap	Existing GXP in system
Hospital	116 x 16-module GeneXpert machines	8 hospitals have 16-module GeneXpert machines
Health Centre IV	149 x 4-module GeneXpert machines	123 HC IV's have four-module GeneXpert machines
Health Centre III	1042* x GeneXpert or Truenat machines	54 HC IIIs are equipped with GeneXpert or Truenat machines

**calculated as 50% of all qualifying HCIII's (2 084)*

The total number of additional GeneXpert machines needed is 1307. Therefore if this gap is filled, the total number of mWRD sites would increase from 337 to 1644.

After plotting the gap facilities' population coverage against existing mWRD 5km service areas (Figure 8), additional population coverage was available from 83 hospitals, 107 HC IV's and 1993 HC III's. Therefore, any remaining facilities identified in the previous step did not offer population not already serviced.

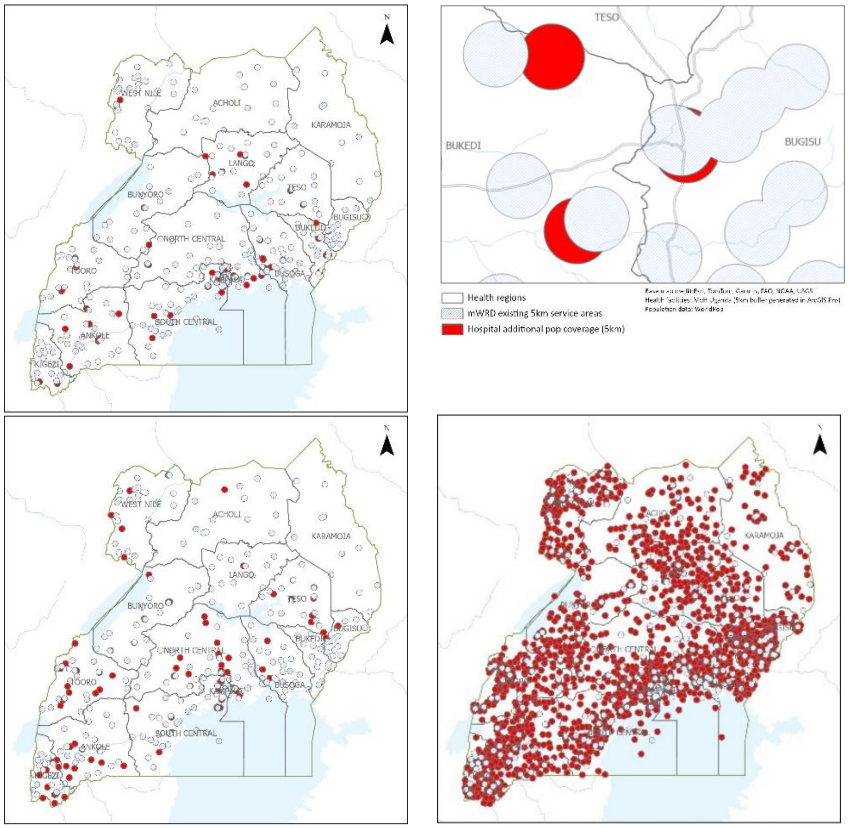

Figure 8: mWRD facilities existing versus potential service area coverage (5km buffer). (a) Additional coverage from hospitals with no current GXP equipment, (b) a zoom in of (a) to illustrate methodology, (c) Additional coverage from HC IV's with no current GXP equipment, (d) Additional coverage from HC III's with no current GXP equipment.

5. Discussion

5.1 Diagnostic network analysis and allocation of equipment in pipeline

The number of facilities offering GXP testing has increased from 236 (258 instruments, 990 modules) to 296 (308 instruments, 1489 modules) since the last Network Analysis in June 2019 indicating additional allocation of resources within the system. Of these facilities, 81% are installed in government facilities, reflecting the government's commitment to leveraging advanced diagnostics in the public healthcare sector to combat TB effectively. The relatively low coverage in private facilities, indicates a potential area for partnerships and policy intervention.

As expected, National and Regional Referral Hospitals (NRH and RRH) are primarily located in regions with higher population densities, ensuring these advanced facilities are accessible to a larger population. Health Centres II, III, and IV, along with clinics, are more evenly distributed across the regions, ensuring wider access to basic healthcare services. This strategic placement of mWRD instruments supports balanced healthcare delivery, addressing both high-need areas and ensuring basic coverage nationwide. This is further supported by the high concentration of facilities in the central and southern parts of the country which suggests a strategic placement to serve the larger populations.

However, there is the need for more mWRD facilities in less populated but geographically large regions to ensure equitable access to diagnostic services. An analysis of population accessibility revealed proximate access (<5km) to facilities with mWRD diagnostic equipment is currently limited. The current distribution of mWRD sites in Uganda shows a concentration in densely populated areas, leaving less populated regions with inadequate coverage. Kampala has the highest coverage given its high population density and relatively small surface area. Conversely, Lango health region has the lowest coverage due to the low density, sprawled nature of its population distribution.

The population coverage of a PHC system can also depend on the efficiency of its network. A distance-based assessment of the hub system distribution identified that 2.6% of spoke facilities are not allocated to their nearest hub. Although this is a relatively low proportion, it suggests the presence of some inefficiencies, and may also be present in the unexplored local agreements. The finding that only two hub facilities are responsible for the ‘misallocated’ 63 spokes suggests that capacity limitations are likely the primary reason for the current allocations. Capacity was not considered in this analysis; therefore respective data should be examined before any re-allocation of spokes.

Potential other reasons for these few discrepancies may be that spokes are managed under the same regional authority as the hub therefore inter-regional allocations are not preferred, or there are preferrable established relationships between these hubs-spoke pairs. These factors should be researched going forward to address whether re-allocation would be appropriate and beneficial to the system.

The greatest hindrance to the current referral network is the absence of data on local referral agreements which accounts for a substantial number of facilities in the network. Formalisation or documentation of local agreements outside of the hub system would allow for a more complete analysis of the system and therefore recommendations could be made.

Given the assumed operational efficiency of the hub system, using the formal system as a representative sample, any deficit in access to mWRD sites is not due to the layout of the current

network. Rather, to improve access to diagnostic services there is a need to strategically place additional mWRD facilities in underserved areas, ensuring a more balanced distribution and better healthcare access for all residents. This would also benefit monitoring within other disease programmes currently utilising GXP instruments. Although TB is the vast majority of current testing utilisation and volumes, the existing testing targets support the scale-up of multi-disease testing.

This calls for examination of GXP instruments currently in the procurement pipeline and their optimal placement; twenty 16-module and eight 4-module GXP's. In both cases, ranked facility lists have been generated using a similar population and testing target indexing approach. The aim of these analyses is to enhance the existing system by increasing capacity to cater for testing targets (TB and multiplexing) whilst ensuring the highest number of people are served. These output lists should be utilised as a foundation, after which more nuanced decisions regarding facility selection can be made.

The strategic placement of the new 16-module GXP machines will significantly improve the diagnostic capacity of hospitals and, through the re-allocation of their now surplus 4-module machines, extend diagnostic services to lower-level health facilities. A similar methodology may be applied when proposing optimal locations for these 4-module GXP's.

The top eight facilities contain seven HC III's, therefore, it is anticipated that more consideration should be given to healthcare facilities with a higher status (i.e. hospitals and HC IV's) despite lower composite scores, given the limited number of procured instruments (eight GXP's). Practically, these facilities may have better resources to manage the instruments and may be better equipped to serve as potential hubs, thus impacting beyond their single service area.

5.2 Whitespace analysis

The allocation analysis in the previous section prioritised enhancing the existing network by 'upscaling' certain facilities already offering diagnostic services. An additional whitespace analysis was conducted to rank facilities not yet in the diagnostic system, but based on location and population coverage should be considered. This analysis was conducted with current NTRL objectives in mind.

Addressing the identified gaps in the current diagnostic network is crucial for achieving comprehensive coverage and improving public access to diagnostic services. By equipping all hospitals, Health Centre IVs, and 50% of Health Centre IIIs with GeneXpert machines, Uganda can ensure a more efficient and equitable distribution of diagnostic resources, ultimately enhancing healthcare outcomes across the country and address the growing demand for TB, HIV, HPV, and HBV testing.

The whitespace analysis conducted highlights a significant gap in the current distribution of mWRD diagnostic services across Ugandan health facilities. With only 337 out of 8,483 facilities equipped with GXP or Truenat machines, there is a clear need for strategic allocation to meet NTLP objectives by 2024/25. Hospitals, Health Centre IVs, and Health Centre IIIs show varying degrees of readiness, with hospitals and Health Centre IVs needing additional 116 16-module and 149 4-module GXP's, respectively. Health Centre IIIs, in particular, demonstrate the largest shortfall, requiring over a thousand diagnostic machines to reach the target. The ranked facility output is based on potential *additional* population coverage within a 5km service area providing a data-driven approach to prioritize facilities, ensuring that those with the greatest likelihood of increasing diagnostic access are addressed first. This method, however, must be iteratively refined with expert insights from key stakeholders to ensure consideration of each facility context, resulting in optimal placement of resources. By focusing on the facilities that can cover the most additional population, NTLP can effectively bridge the diagnostic gap and enhance TB care across Uganda.

6. Annex

Table A-1: Ranked hospitals with 4-module GXPs based on composite score (considering population coverage and TB and multiplexing testing targets) for potential allocation of 16-modules GXPs in pipeline

Hub Name	Hub facility name	District	Region	Hub population (weighted 40%)	Target test total (MP) (weighted 60%)	Composite Score	Rank
Pallisa Hub	Pallisa General Hospital	Pallisa	Mid Eastern	814 850	20 883	0.53	1
Kapchorwa Hub	Kapchorwa General Hospital	Kapchorwa	Mid Eastern	645 365	17 124	0.42	2
Rakai Hub	Rakai General Hospital	Rakai	Central 1	504 268	26 383	0.40	3
Luweero Hub	Luwero General Hospital	Luweero	Central 2	478 109	26 392	0.39	4
Kamuli Hub	Kamuli General Hospital	Kamuli	East Central	570 964	14 062	0.36	5
Kilembe Mines Hub	Kilembe Mines Hospital	Kasese	Mid Western	433 302	21 014	0.34	6
Nebbi Hub	Nebbi General Hospital	Nebbi	West Nile	378 159	24 138	0.33	7
Kagando Hub	Kagando Hospital	Kasese	Mid Western	524 565	11 698	0.32	8
Kyenjojo Hub	Kyenjojo General Hospital	Kyenjojo	Mid Western	373 354	21 256	0.31	9
kitagata Hub	Kitagata General Hospital	Mitooma	South Western	346 597	23 416	0.31	10
Rukunyu Hub	Rukunyu General Hospital	Kamwenge	Mid Western	469 248	13 045	0.30	11
Mityana Hub	Mityana General Hospital	Mityana	Central 2	364 304	16 043	0.27	12
Bugiri Hub	Bugiri General Hospital	Bugiri	East Central	443 049	9 449	0.27	13
Masafu Hub	Masafu General Hospital	Busia	Mid Eastern	371 904	12 701	0.25	14
Bundibugyo Hub	Bundibugyo General Hospital	Bundibugyo	Mid Western	337 596	13 733	0.24	15
Amuria Hub	Amuria General Hospital	Amuria	North East	168 107	27 112	0.24	16
Itojo Hub	Itojo General Hospital	Ntungamo	South Western	337 525	12 714	0.24	17
Adjumani Hub	Adjumani General Hospital	Adjumani	West Nile	196 564	22 738	0.23	18

Kyegegwa Hub	Kyegegwa General Hospital	Kyegegwa	Mid Western	289 985	15 128	0.23	19
Kanungu Hub	Kambuga General Hospital	Kanungu	South Western	277 689	12 925	0.21	20
Masindi Hub	Masindi General Hospital	Masindi	Mid Western	233 956	15 720	0.20	21
kiryandongo Hub	Kiryandongo General Hospital	Kiryandongo	Mid Western	240 489	15 104	0.20	22
Kiboga Hub	Kiboga General Hospital	Kiboga	Central 2	154 504	21 765	0.20	23
Busolwe Hub	Busolwe General Hospital	Butaleja	Mid Eastern	333 907	4 167	0.18	24
Kitgum Hub	Kitgum General Hospital	Kitgum	Mid Northern	135 996	19 301	0.18	25
Koboko Hub	Koboko General Hospital	Koboko	West Nile	215 377	11 353	0.17	26
Kotido Hub	Kotido General Hospital	Kotido	North East	159 168	11 490	0.14	27
Gombe Hub	Gombe General Hospital	Butambala	Central 1	161 185	9 278	0.13	28
Katakwi Hub	Katakwi General Hospital	Katakwi	North East	145 852	10 432	0.13	29
Moyo Hub	Moyo General Hospital	Moyo	West Nile	108 126	11 486	0.11	30
Lyantonde Hub	Lyantonde General Hospital	Lyantonde	Central 1	139 597	7 274	0.10	31
Anaka Hub	Anaka General Hospital	Nwoya	Mid Northern	132 502	6 276	0.09	32
Abim Hub	Abim General Hospital	Abim	North East	142 038	5 316	0.09	33
Kaabong Hub	Kaabong General Hospital	Kaabong	North East	124 369	6 177	0.09	34
Buliisa Hub	Buliisa General Hospital	Buliisa	Mid Western	17 417	502	0.00	35

Table A-2: Top 50 ranked facilities based on composite score (considering population coverage and TB testing targets) for potential allocation of 4-modules GXPs in pipeline

Health Facility	District	Facility population	TB NTT	Composite score	Rank
Okubani Health Centre III	Yumbe District	9 451	9 113	0.60	1
Luzira Health Centre III	Yumbe District	29 966	7 778	0.53	2
Makindye Barracks Health Centre III	Kampala District	814 323	72	0.40	3
Yangani Health Centre III	Yumbe District	21 733	5 955	0.40	4
Siripi Health Centre III	Terego District	5 794	5 822	0.39	5
Swinga Health Centre III	Yumbe District	30 981	5 003	0.34	6
Twajiji Health Centre III	Yumbe District	28 626	5 010	0.34	7
Naguru Police Health Centre IV	Kampala District	670 396	128	0.34	8
Soroti Main Prisons Health Centre III	Soroti City	88 411	4 402	0.33	9
Ocea Health Centre II	Madi-Okollo District	12 428	4 842	0.32	10
Bidibidi Health Centre III	Yumbe District	38 177	4 497	0.31	11
Bangatuti Health Centre III	Yumbe District	32 069	3 814	0.27	12
Luzira Staff Clinic	Kampala District	466 442	294	0.25	13
Ayilo I Health Centre III	Adjumani District	15 977	3 357	0.23	14
Igamara Health Centre III	Yumbe District	18 936	3 255	0.22	15
Bolomoni Health Centre III	Yumbe District	20 734	3 160	0.22	16
Komgbe Health Centre III	Yumbe District	23 318	3 084	0.21	17
Yayari Health Centre III	Yumbe District	38 102	2 965	0.21	18
Nyumanzi Health Centre III	Adjumani District	13 249	3 096	0.21	19
Pagirinya Health Centre III	Adjumani District	9 419	2 782	0.19	20
Bugungu Yp Prisons Health Centre II	Buikwe District	5 188	2 798	0.19	21
Mutolere Hospital	Kisoro District	18	2 766	0.18	22
Bombo General Military Hospital	Luwero District	62 842	1 982	0.16	23
Ayivu Health Centre III	Yumbe District	13 171	2 224	0.15	24
Palorinya Health Centre III	Obongi District	3 155	2 195	0.15	25
Rwamwanja Health Centre IV	Kamwenge District	35 878	1 844	0.14	26
Idiwa Health Centre III	Obongi District	5 268	2 000	0.13	27
Kamwezi Health Centre IV	Rukiga District	16	1 982	0.13	28
Ocia Health Centre III	Terego District	13 837	1 824	0.13	29
Katabi Military Health Centre III	Wakiso District	168 559	648	0.12	30
Lobule Health Centre III	Koboko District	36 190	1 609	0.12	31
Arua Police Health Centre III	Arua City	194 783	381	0.12	32
Mbale Police Health Centre III	Mbale City	222 338	53	0.11	33
Yoyo Health Centre III	Yumbe District	27 034	1 500	0.11	34
Rubondo Health Centre II	Isingiro District	7 648	1 632	0.11	35
Gulu Police Health Centre III	Gulu City	190 604	195	0.11	36
Olujobo Health Centre III	Madi-Okollo District	10 202	1 528	0.10	37
State House Health Centre IV	Wakiso District	131 961	619	0.10	38
Gaddafi Barracks Health Centre III	Jinja City	191 904	52	0.10	39
Kigo Main Prisons Health Centre III	Wakiso District	141 837	420	0.10	40
Kauga Prisons Health Centre II	Mukono District	156 203	287	0.09	41

Jinja Police Health Centre III	Jinja City	186 557	39	0.09	42
Kyempango Health Centre III	Kamwenge District	42 014	1 076	0.09	43
Bukwo General Hospital	Bukwo District	13	1 366	0.09	44
Lira Army Barracks Health Centre III	Lira City	154 144	217	0.09	45
Kabamba Barracks Health Centre III	Mubende District	3 315	1 319	0.09	46
Masindi Military Barracks Health Centre	Masindi District	66 931	754	0.08	47
Kakiika Prisons Health Centre II	Mbarara City	145 982	142	0.08	48
Hoima Prisons Health Centre II	Hoima City	89 474	533	0.08	49
Ayiri Health Centre III	Adjumani District	4 629	1 102	0.07	50