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RESEARCH ARTICLE

Laboratory capacity-building during COVID-19 in Somalia: improving access to essential diagnostics for national health security in a fragile setting

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Abstract

Introduction Even before the COVID-19 pandemic, Somalia's national laboratory services had insufficient diagnostic capacities. We describe how the country moved rapidly from no testing capability to molecular testing and genomic sequencing for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and other pathogens.

Methods We reviewed primary sources information as well as data and records from secondary sources from 1 January 2020 to 31 December 2023. We also analyzed laboratory surveillance data of cases of COVID-19 and other epidemic diseases reported during the same period and the number of laboratory tests performed during the same period. We used this information to demonstrate improvements in laboratory diagnostic capacity in Somalia before, during and after the COVID-19 pandemic.

Results The country was able to rapidly scale up testing for SARS-CoV-2 using reverse-transcriptase polymerase chain reaction assays. At the same time, other innovative solutions were used for testing, such as repurposing tuberculosis GeneXpert diagnostic platforms to increase access to testing at points-of-care and introducing antigen rapid diagnostic tests for hard-to-reach communities. Somalia also acquired new generation sequencing capability for detection and characterization of circulating SARS-CoV-2. These laboratory and testing enhancements have enabled Somalia to participate in surveillance for priority diseases and detection of outbreaks caused by emerging pathogens.

Conclusion Somalia's strategic approach to COVID-19 is an inspiring example of resilience and adaptability. Utilizing resources, technology and lessons from COVID-19 enabled the country to increase and improve laboratory services, expand testing capacity, and strengthen workforce capability. As such, Somalia can now better respond to other infectious disease threats and has significantly improved national health security.

Keywords COVID-19 · Laboratory capacity · Testing · Genome sequencing · Somalia

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1 Introduction

On 16 March 2020, Somalia reported the first case of coronavirus disease 2019 (COVID-19) in a returning traveler [1]. The notification happened at a time when there was no diagnostic facility in the country with testing capability for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) or seasonal influenza or any other acute respiratory viral infection [2].

Somalia, with a population of more than 17 million, has been suffering from active armed conflict, civil war, and political instability for almost three decades. These conflicts, resulting in an enduring humanitarian crisis, have destroyed all state level public institutions and caused a complete collapse of public services. There was a massive out-migration of skilled workers who left the country out of fear owing to insecurity and active war in the country. The protracted conflict and collapse of state institutions also adversely impacted the health system in the country making it extremely week, fragile and fragmented and having one of the worst health indicators in the world [3].

The collapse of Somalia's health infrastructure had a profound impact on people's health in the country. Owing to chronic underfunding and lack of new investment on infrastructure and human capital as well as acute shortage of health workers meant that the country struggled to provide even basic health care for large majority of its people. The universal health coverage index for Somalia is one of the lowest (27 out of 100) in the world against a global average of 60.3 [4] and the country has probably one of the lowest per capita healthcare workers- less than 1 skilled health worker per 1,000 people in a population of nearly 17 million [5]. Somalia has one of the highest infant and under 5 mortality rates in the world estimated at 68 deaths per 1,000 live birth and 106 deaths per 1,000 live births respectively in 2022 [6]. The maternal mortality ratio in 2022 is estimated at 621 deaths per 100, 000 live births with the lifetime risk of a mother dying from pregnancy-related conditions in the country at 1 in 25- one of the highest in the world [7]. The combination of ongoing and new conflicts, climate change, and the impact of the COVID-19 pandemic created a perfect storm to drive back any gains that might have been made during the Sustainable Development Goal (SDG) era in Somalia [8].

Even before the COVID-19 pandemic, Somalia's laboratory system, which is an integral component of the healthcare system, was operating at a very limited capacity. It lacked even the basic equipment, infrastructure, biosafety practice and trained workforce for molecular testing using the reverse-transcriptase polymerase chain reaction (RT-PCR) assay which is considered the gold standard for testing a novel high-threat pathogen such as the SARS-CoV-2 [9]. Somalia's central public health laboratory, established during the 1950s, collapsed after the breakdown of the state government in 1991 [10]. In 2015, the laboratory was reestablished as the National Public Health Reference Laboratory (NPHRL) and its main functions were to: support the country's health system with essential diagnostic testing for clinical and public health; detect epidemic; and coordinate all public and private sector laboratories to improve and monitor quality testing. However, the NPHRL's capability remained limited to some basic clinical tests and diagnostics for selected epidemic-prone diseases, such as bacterial culture for cholera, basic parasitological tests by microscopy and serological tests for measles. The service availability and readiness assessment done in 2016 showed that only 19% of health facilities were able to provide routine laboratory tests for few selected health conditions, most of these health facilities were located in urban areas, leaving rural and hard-to-reach areas underserved [11]. The joint external evaluation (JEE) for the implementation of the International Health Regulations (IHR 2005) core capacities conducted by in 2016 identified severe weak laboratory capacities for timely detection and confirmation of emerging and re-emerging pathogens [12]. At the time of COVID-19 pandemic, the country had only three state public health laboratories-one each in Mogadishu, Garowe (Puntland) and Hargeisa (Somaliland) with limited bacterial, serological, and microbiological testing capability. These laboratories were severely understaffed with only 8 trained laboratory technologists managing these three laboratories and the country did not have any equipment or any testing capability for identification of emerging or reemerging viral pathogens using molecular diagnostic assay.

The COVID-19 pandemic presented an unprecedented challenge to the Somali government as no laboratory testing and detection capability for SARS-CoV-2 was initially available in the country. For almost two (2) months, the Ministry of Health relied on WHO's polio infrastructure and its workforce to ship COVID-19 samples for testing by air to the nearest designated laboratory – Kenya Medical Research Laboratory (KEMRI) [2]. The wait time for the test results was between days and weeks as KEMRI was also testing samples collected in Kenya. In late April 2020, Somalia acquired the first in-country testing capability for SARS-CoV-2 in the NPHRL using the RT-PCR assay [2]. Later, this testing capability was expanded throughout the country with the establishment of six additional decentralized testing facilities, which increased the total public health laboratories to seven across the country, one laboratory per state. Additionally, every laboratory technician at the National Public Health Laboratory was trained to conduct COVID-19 testing, after which they trained the staff at the seven State public health laboratories. By 2022, Somalia also attained the

capability to sequence SARS-CoV-2 when three of its state laboratories were equipped with new generation sequencing (NGS) technology – the Oxford Nanopore MinION platform [13]. The roll out of antigen-detecting Rapid Diagnostic Tests (Ag-RDT) enabled the country to introduce point-of-care testing for SARS-COV-2 infection in the primary health care centers as well as improve access to testing for communities living in the hard-to-reach areas which effectively contributed to increased testing, screening, and contact tracing for COVID-19 cases across the country [14].

In this article, we highlight the rapid scaling up of laboratory capacity for testing SARS-CoV-2 in Somalia during the pandemic when the country was cut off from rest of the world owing to lockdowns, closure of commercial and cargo flights and global supply chain disruption. We also highlight, in this article, how the country capitalized on this opportunity to expand the capacity of public health laboratories for testing and diagnosis of other high-threat pathogens, which contributed to improving surveillance and response for national health security.

2 Methods

We have used both primary and secondary sources to collect information on laboratory capacity building during the COVID-19 pandemic in Somalia. We have collected laboratory testing data for SARS-COV-2 and other nationally notifiable diseases from January 2020 to December 2023 to indicate if the testing and diagnostic services of the laboratories have improved over time during this period. We have collected these data on testing from the laboratories which were cross-checked and verified through personal communications as well through review of the surveillance reports and situation reports published officially by the Ministry of Health and posted on its web sites. The national health information system of the country such as the DHIS-2 (District Health Information System 2) was the additional source used to cross-check the data on testing of COVID-19 and other notifiable diseases.

Taking into consideration that the country notified its first case of COVID-19 on 16 March 2020 and there was no testing capability for SARS-COV-2 in the country when the first case was notified, we have considered the increased number of in-country testing for SARS-COV-2 and other pathogens between 2020 and 2022/2023 as an indication of improved laboratory capacity in the country during the COVID-19 pandemic. Additionally, we have assessed if any sample of SARS-COV-2 was tested for genomic sequencing in those laboratories which were equipped with sequencing capability and if the laboratories, where the capacity support was provided, were able to detect and confirm any other epidemic during the ongoing COVID-19 pandemic which was caused by other emerging and re-emerging pathogens. This information was used to indicate if the laboratories could use the molecular testing platforms to identify and detect other emerging pathogens. Whenever possible, we have cited information from published papers in peer-reviewed medical journals as a proof and demonstration of improved capacity of the laboratories in Somalia in the post-pandemic period. The information which we have used as a proof of improved laboratory capacity includes- participation of the newly established laboratories of Somalia in the WHO's external quality assessment project (EQAP) and its successful Proficiency Testing (PT) result, sharing of genomic sequencing data by Somalia with the Global Initiative on Sharing All Influenza data (GISAID), participation of Somalia in the Global Influenza Surveillance and Response System (GISRS). In addition, we have also used published data on Somalia's participation in the WHO UNITY Study and in-country serological testing of SARS-COV-2 infection as an indication of enhanced serological testing capability of the public health laboratories in the country. We have supported this with data on increased number of serological tests performed in the country between 2020 and 2023 as a proof of enhanced serological testing capability attained in the country.

For the data on laboratory workforce trained, and type of training conducted during January 2020 and December 2023, we have extracted such information from secondary sources such as the official training reports. We have been careful in cross-checking this information and in case of any discrepancy, we have followed up with the concerned officials and relevant stakeholders who have supported and funded these training programmes to resolve inconsistencies.

2.1 Rapidly scaling up COVID-19 diagnostic services

Somalia followed a phased stepwise approach (Fig. 1) to establish its laboratory capacity for testing of SARS-CoV-2. The only three public health laboratories functioning in Mogadishu, Garowe and Hargeisa before the COVID-19 pandemic had limited testing capability such as some basic clinical tests, bacterial culture for cholera, basic parasitological tests by microscopy and serological tests for measles. These laboratories did not have any molecular testing platforms. During the COVID-19 pandemic, these laboratories were expanded to biosafety level (BSL) 2 laboratories by equipping with BSL-2 cabinets, RT−PCR molecular testing platforms and other necessary automated viral RNA extraction kits after the first COVID-19 case was notified in the country. WHO and the United Nations World Food Programme (WFP) helped overcome the logistical difficulties of shipment and transportation of this equipment within the country [2]. Necessary supplies and reagents were also procured internationally and delivered on site. By early June

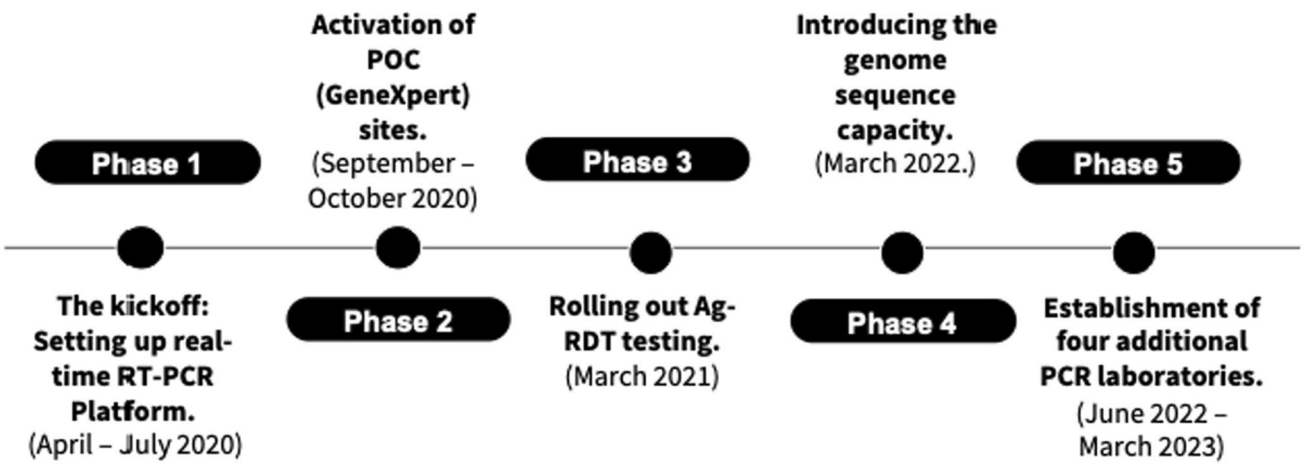

Fig. 1 Steps and timeline for scaling up COVID-19 diagnostic and testing services, Somalia

2020, these three public health laboratories became fully operational and started testing for COVID-19. At the same time, the Ministry of Health identified 22 of the 64 tuberculosis (TB) diagnostic laboratories in the country, mostly in remote areas, that already had GeneXpert equipment for TB diagnostics. These laboratories were repurposed to function as the points of care testing platforms for COVID-19, especially in remote areas without any access to COVID-19 testing. However, global supply chain challenges delayed their full functionality until October 2020 owing to disruptions in the procurement and distribution of Cepheid GeneXpert System SARS-CoV-2 cartridges worldwide.

Towards the end of 2020 and early 2021, the SARS-CoV-2 antigen rapid diagnostic test (Ag-RDT) was rolled out in the country. After training, thousands of community health workers, especially in hard-to-reach areas, started using these rapid tests. With the increasing demand for COVID-19 testing, the NPHRL, developed interim guidance for use of the SARS-CoV-2 Ag-RDT at the health facility and community level [14]. Between 2022 and 2023, four additional BSL 2 laboratories were established and equipped with RT-PCR machines to detect SARS-CoV-2.

2.2 Establishing genomic sequencing capacity for SARS-CoV-2

Somalia acquired the operational capability for new generation sequencing (NGS) of SARS-CoV-2 by September 2022. The three public health laboratories in Mogadishu, Garowe and Hargeisa were equipped with Oxford Nanopore MinION platforms to acquire this genomic sequencing capability. Necessary reagents and supplies were also delivered, and online bioinformatics support was provided for data analysis by the WHO collaborating center for reference and research on bacterial pathogens in the American University of Beirut, Lebanon.

2.3 Operationalizing SARS-CoV-2 national data management system

The NPHRL led the establishment and operationalization of SARS-CoV-2 national laboratory data management system for storage and analysis of all case-based SARS-CoV-2 infections in the country using the DHIS 2 platform. This was the only data portal in the country for reporting suspected and laboratory-confirmed cases of COVID-19 in the country during the pandemic.

2.4 Building laboratory capacity for serological testing

Before the COVID-19 pandemic, only three state level public health laboratories in Mogadishu, Garowe and Hargeisa had the capacity for serological testing. During the COVID-19 pandemic, the country received additional funding from its international partners for establishing additional 11 sub-national laboratories with ELISA machines with a view to expanding serological testing for SARS-CoV-2 infection and other pathogens. This investment was made as part of Somalia's participation in WHO's Unity Study. Additionally, the new four state laboratories with RT−PCR molecular testing platforms were also provided with ELISA machines, thereby bringing the total number of laboratories with serological testing capability to 18 in the country from three (3) during the pre-pandemic time.

2.5 Developing the laboratory workforce

A collaborative effort, supported by international partners helped the country's newly established molecular testing laboratories to build and acquire a wide range of essential laboratory skills for molecular diagnostic tests, use of testing protocol, sample processing and preservation, sequencing, bioinformatics, interpretation of molecular test and sequencing result as well as biorisk management. From 2020 to 2023, 551 laboratory personnel were trained out of whom 229 (41.6%) were female and 322 (58.4%) were male. Table 1 summarizes the laboratory workforce developed during this period. The laboratory personnel of NPHRL also participated in international trainings on laboratory protocol associated with sequencing using the Oxford Nanopore MinION platforms.

2.6 Managing quality assurance

The NPHRL participated in the two rounds of the External Quality Assessment Project (EQAP) organized by WHO for all national laboratories of the WHO Eastern Mediterranean Region [15]. The participation of Somalia in the WHO's EQAP ensured the accuracy and reliability of in-country COVID-19 testing.

3 Results

3.1 Rapid expansion of molecular testing capacity

The detection of SARS-CoV-2 by RT−PCR assays became the most common method of testing and confirming COVID-19 cases in the country once the testing capability was established −6 weeks after notification of the first case of COVID-19. The repurposed use of the Cepheid GeneXpert System for TB to test for SARS-CoV-2 helped improve access to testing for populations living in remote areas of the country. The successful roll out of Ag-RDT using community health workers helped fill large testing gaps where populations were hard-to-reach and almost inaccessible owing to security situation in the country. This way, Somalia ensured that laboratory diagnostic services are in place at national and sub-national level for testing and rapid identification of SARS-CoV-2 infection.

Between April–May 2020 and December 2022, 646 116 samples were tested for COVID-19 in the country (Table 2). While only 81 270 COVID-19 samples were tested by RT-PCR in 2020, the number tested in 2021 increased to 320 523 (an almost four times increase). In addition, with the introduction of Ag-RDT tests in 2021, 40 960 additional samples were also tested. In 2022, after the transmission of SARS-CoV-2 gradually slowed down owing to

Table 1 Laboratory workforce development, Somalia 2020–2023

State	Gender	Target pathogen trainings						Total
		Bacterial culture and antimicrobial susceptibility (V. cholerae and other enteric bacterial)	RT-PCR (SARS-CoV-2)	RT-PCR (Influenza)	Genome sequencing (SARS-CoV-2)	Serology-ELISA (Measles/rubella/Rota)	RDT training (SARS-CoV-2, dengue/chikungunya, cholera, malaria)	
Banadir	Male	6	4	3	2	2	45	62
	Female	5	9	4	3	0	40	61
Galmudug	Male	0	3	0	0	2	17	22
	Female	0	0	0	0	0	16	16
Hirshabelle	Male	1	2	0	0	3	38	44
	Female	1	1	0	0	1	47	50
Jubaland	Male	2	3	0	0	2	36	43
	Female	0	0	0	0	0	9	9
Puntland	Male	4	4	2	4	3	33	50
	Female	1	2	2	2	1	22	30
Somaliland	Male	3	6	3	5	7	48	72
	Female	2	4	2	2	3	42	55
South West	Male	2	3	0	0	2	22	29
	Female	0	0	0	0	0	8	8
Total		27	41	16	18	26	423	551

RT-PCR reverse-transcriptase polymerase chain reaction, *SARS-CoV-2* severe acute respiratory syndrome coronavirus 2, *ELISA* enzyme-linked immunosorbent assay, *RDT* rapid diagnostic test

Table 2 COVID-19 samples tested by Ag-RDT and PCR in Somalia, 2020–2022

State	2020 Median = 1340; IQR = 13, 864			2021 Median = 5045; IQR = 64, 343			2022 Median = 805; IQR = 42, 598			Total samples tested (PCR and Ag-RDT) (a + b + c + d + e + f)
	Samples tested by Ag-RDT (a)	Samples tested by PCR (b)	Samples tested (PCR and Ag-RDT) (a + b)	Samples tested by Ag-RDT (c)	Samples tested by PCR (d)*	Samples tested (PCR and Ag-RDT) (c + d)	Samples tested by Ag-RDT (e)	Samples tested by PCR (f)*	Samples tested (PCR and Ag-RDT) (e + f)	
Banadir	0	48 636	**48 636**	18 550	190 359	**208 909**	0	75 314	**75 314**	**332 859**
Galmudug	0	646	**646**	1 264	1 673	**2 937**	0	217	**217**	**3 800**
Hirshabelle	0	821	**821**	1 942	1 951	**3 893**	0	18	**18**	**4 732**
Jubaland	0	1 340	**1 340**	2 897	2 148	**5 045**	28	777	**805**	**7 190**
Puntland	0	9 636	**9 636**	8 649	32 382	**41 031**	24	10 871	**10 895**	**61 562**
Somaliland	0	19 559	**19 559**	7 285	88 323	**95 608**	64	115 253	**115 317**	**230 484**
South West	0	632	**632**	373	3 687	**4 060**	0	797	**797**	**5 489**
Total	**0**	**81 270**	**81 270**	**40 960**	**320 523**	**361 483**	**116**	**203 247**	**203 363**	**646 116**

IQR interquartile range, *PCR* polymerase chain reaction, *Ag-RDT* antigen rapid diagnostic test

*Includes tests by both reverse-transcriptase PCR and GeneXpert platforms

The introduction of Ag-RDTs not only significantly contributed to improving testing accessibility across Somalia, but also provided an affordable, reliable and quick solution allowing immediate decision-making and provision of timely interventions. Ag-RDTs accounted for 17% of the 27 000 positive cases detected in the country in hard-to-reach areas

the introduction of COVID-19 vaccines, a total of 203 363 samples were tested. Between 1 January and 30 April 2023, 64 289 samples were tested (not included in the table). At the beginning of the COVID-19 pandemic in 2020, 1200 COVID-19 samples were tested a day which increased to 10 000 tests a day in 2022 and early 2023 after the number of molecular testing laboratories and laboratories with GeneXpert platforms increased in the country.

3.2 Genomic sequencing of SARS-CoV-2

The establishment of genomic sequencing capability for the country was a milestone for Somalia's healthcare system. Somalia made significant strides in expanding its SARS-CoV-2 testing and genomic surveillance capabilities by establishing sequencing facilities in three public health laboratories (Mogadishu, Garowe and Hargeisa) by equipping them with Oxford Nanopore MinION sequencing platform. Since the country attained the genomic sequencing capability in March 2022, 250 SARS-COV-2 samples were sequenced inside the central NPHRL in Mogadishu. This helped the country to detect the Delta VOC (B.1.617.2) and Omicron VOC (B.1.1.529) circulating between late 2021 and 2022 inside Somalia. Additional tests on some samples previously collected and preserved before 2022 were also performed after the three public health laboratories attained the genomic sequencing capability. By the end of 2022, Somalia also started to actively contribute sequencing data to the Global Initiative on Sharing All Influenza Data (GISAID) [16, 17], demonstrating the success of acquiring and utilizing this new gained capability. This expanded capability of country's laboratory system for genomic sequencing has also strengthened the country's capability for conducting genomic surveillance of other emerging and remerging infectious diseases.

3.3 Enhanced laboratory capacity for serological testing

With the additional investment made on expanding serological testing capability across the country through 11 newly established laboratories at the sub-regional level and four state level public health laboratories, the timeliness of diagnosis and reporting of cases detected through serology improved substantially, Previously, all the samples for serological testing used to be sent to the NPHRL in Mogadishu from the state and sub-national level as no such capacity for validated serological testing existed outside the NPHRL. However, after such capacity was built, serological tests are, now, routinely performed at the sub-national and state level, This improved capacity also helped the country to successfully conduct the population-based seroepidemiological investigation of SARS-CoV-2 infection

as part of the WHO Unity Study [18]. The serological testing of all samples collected during this study was done inside the country using the WHO Unity Study testing protocol. This expanded capability was also used for population-based serological testing of other diseases such as measles, polio, malaria and some of the endemic neglected tropical diseases [19] during 2021 and 2022. The confidence gained through this newly acquired capability has also enabled the Ministry of Health to conduct a population-based seroepidemiological survey for another important coronavirus with epidemic potentials—Middle East respiratory syndrome coronavirus (MERS-CoV)—at the animal–human interface. All the blood samples collected for this survey were also tested in the country.

3.4 Participation in surveillance and outbreak detection

The enhanced testing capabilities and laboratory practice have enabled Somalia to participate in the global surveillance for influenza and share influenza virological data with WHO's Global Influenza Surveillance and Response System (GISRD) platforms as part of future pandemic preparedness. With the support of WHO and the US Centers for Disease Control and Prevention, the country has started conducting sentinel-based epidemiological and virological surveillance for seasonal influenza by transitioning from testing for COVID-19 to influenza using the same molecular-based diagnostic platform [20]. In addition, the country is routinely conducting surveillance for rotavirus. Recently, a dengue fever outbreak was detected through testing and diagnosis within the country [21, 22]. Somalia's capability for detection of measles and cholera cases has also increased substantially year after year since 2020(Fig. 2).

3.5 Enhanced testing for other priority infectious disease

The improved laboratory capacity built in Somalia during the COVID-19 pandemic has yielded many other benefits beyond testing for COVID-19. It has facilitated the testing and surveillance of various pathogens, leading to improvements in the detection and management of pathogens of importance in Somalia, such as influenza, cholera, measles, rotavirus, mpox and others during 2020 to 2023.

The number of samples of four major pathogens- (cholera, influenza, measles and rotavirus) tested in the public health laboratories in the country has increased progressively from 2020 to 2023 (Fig. 2) indicating the increased laboratory testing capability for priority pathogens of public health importance in the country. For example, no influenza or rotavirus samples were tested in 2020 and no rotavirus sample was also tested in 2021. Only few seasonal influenza samples were tested in 2021. However, testing for these two pathogens increased progressively from 2022 to 2023. Testing for cholera and measles also increased between 2020 and 2023 owing to the increase in the number of laboratories with the required infrastructure and trained workforce. This newly acquired laboratory capacity for early detection and improved laboratory surveillance of priority pathogens can significantly contribute to disease prevention efforts in Somalia and could result in substantial reduction of economic burden posed by commonly prevalent infectious

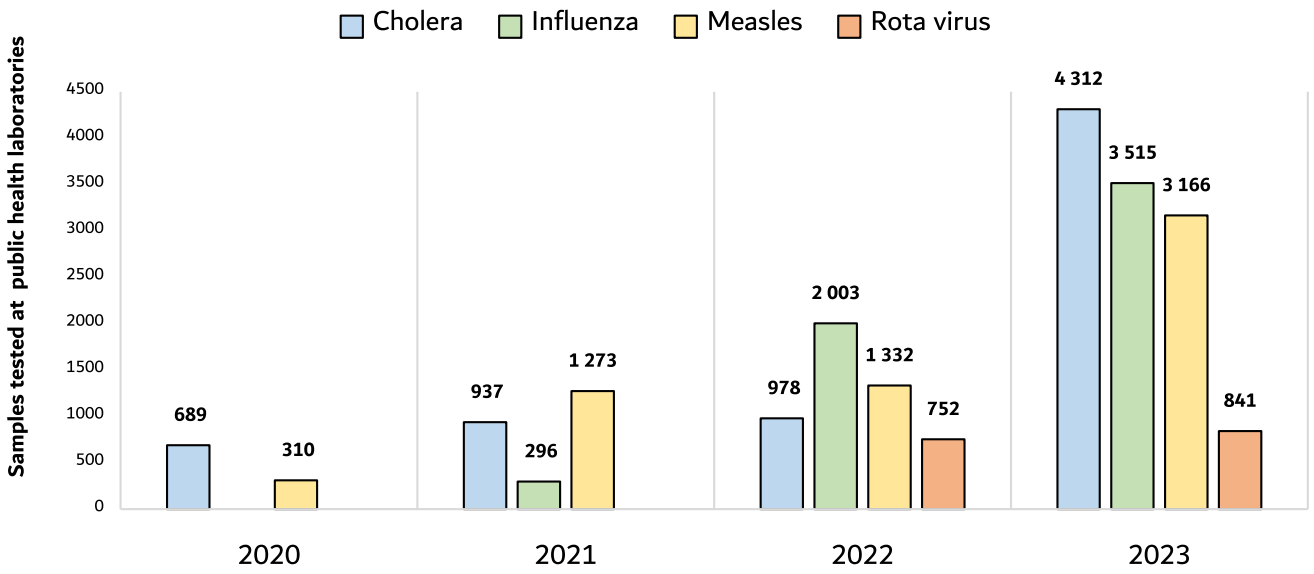

Fig. 2 Samples tested for sentinel surveillance in enhanced public health laboratories, Somalia, 2020–2023

diseases as has been evidenced for cholera in a recent article [23].

The investment in building COVID-19 testing capability in Somalia through the use of RT-PCR diagnostic platform and Oxford Nanopore MinION sequencing platform has provided additional opportunities to build in-country capacity for detection of multiple disease pathogens. Utilizing the same testing platforms, repurposing the resources and providing adequate training of the workforce, the country's in-country public health laboratories capacity for testing of multiple pathogens can be significantly improved (Table 3). This includes the priority list of pathogens having the potential to cause wide spreading and high mortality outbreaks in Somalia [24].

3.6 Self-assessment of laboratory capacity

As part of self-reporting of IHR core capacities by the State Parties using the State Parties Self-Assessment Annual Reporting Tool (e-SPAR), Somalia reported significant improvement in the laboratory capacity from 27% for the laboratory capacity in 2018 to 56% in 2022 [25] an improvement of over 100% before and after the COVID-19 pandemic. Much of this improvement was attributed to country's successful Proficiency Testing (PT) result in the EQAP [15], integration of laboratory services into the newly established IDSRS structure [26] by transforming the laboratory data management system developed during the COVID-19 and reducing the turnaround time of laboratory test results

Table 3 Laboratory testing capacity established in Somalia during 2020–2023 by utilizing the investment made in building testing capability for SARS-CoV-2

Pathogens (high-threat/endemic/epidemic-prone)	Testing platform					
	Bacterial culture	Molecular test using RT-PCR assay	Cepheid GeneXpert platform	Rapid test	Enzyme-linked immunosorbent assay	Oxford Nanopore MinION (detection and sequencing)
Antimicrobial resistance	Competent	Competent				In training
Avian influenza (H5N1) or any other new zoonotic influenza virus		Competent				In training
Cholera	Competent	Competent		Competent		In training
Chikungunya		Competent				In training
Dengue virus		Competent		Competent (NS1)	Competent (IgM and IgG)	In training
Ebola virus			Competent			In training
HIV			Competent			In training
Influenza virus including novel influenza virus		Competent				Competent
Marburg virus		Competent				In training
Measles					Competent (IgM and IgG)	In training
Mpox virus		Competent				In training
MERS-CoV		Competent				In training
Nipah virus		Competent				In training
Polio virus (cVDPV2)						In training
Rift-Valley fever		Competent				In training
SARS-CoV-2		Competent	Competent	Competent	Competent	Competent
XDR-TB			Competent			In training
Yellow fever		Competent				In training
Zika virus		Competent				In training

In training means competency has not yet been acquired

SARS-CoV-2 severe acute respiratory syndrome coronavirus 2, *RT-PCR* reverse-transcriptase polymerase chain reaction, *HIV* human immunodeficiency virus, *MERS-CoV* Middle East respiratory syndrome coronavirus, *XDR-TB* extensively drug-resistant tuberculosis

from a few months (when many of the tests were done in laboratories outside the country) to a few days.

4 Discussion

The COVID-19 pandemic presented an unprecedented global challenge to test for and treat a new infection at all levels of healthcare system in almost every country. The fragile, conflict-affected and vulnerable countries such as Somalia faced multiple challenges owing to having weak, damaged or destroyed health systems and acute shortage of health workforce. Somalia did not even have the required laboratory infrastructure, equipment and trained workforce at the beginning of the COVID-19 pandemic for testing, diagnosis and monitoring the circulation of this pandemic virus in the country. Despite this, the country was able to break the cycle of neglect and underfunding and establish new laboratories with testing capability for SARS-COV-2 infection during one of the most challenging periods in its history. The international partners supported the Ministry of Health of Somalia to build new laboratory infrastructure in the country for pandemic response, but this investment has proved to be catalytical to improve laboratory diagnostic services for public health that are essential for improving national health security in any country.

The new laboratory infrastructure and workforce built during the COVID-19 pandemic with international support have improved the laboratory diagnostic services and in-country testing capability for SARS-CoV-2 infection in Somalia. Furthermore, these efforts and investment have helped build and enhance decentralized testing for other high-priority pathogens and endemic diseases; built a critical workforce for improved laboratory bio-safety practices; expand serological testing for population-based surveillance of measles, influenza, rotavirus and MERS-CoV to better understand the disease burden amongst the population in the country. These achievements have contributed to improved epidemic and pandemic readiness in the country by improving and expanding access to diagnostic and laboratory services for infectious diseases and other high-threat pathogens throughout the country. As evidence suggests such geographic access can significantly enhance case identification, case management and disease surveillance, and facilitate better control of priority infectious diseases in resource-limited countries. [27].

One of the important achievements of laboratory capacity building for Somalia has been the attainment of in-country genomic sequencing capability using next-generation sequencing (NGS) technology. This technological innovation offers opportunities to the country to build and sustain its capacity further for detection of other emerging and new pathogens which can significantly improve national health security in the country [24]. The Oxford Nanopore sequencing technology with its portable sequencer (the MinION) is ideal for the fragile context of Somalia owing to its low maintenance costs [28]. Using such platforms, the country can progressively build its diagnostic capability for other high-threat pathogens and conduct routine genomic surveillance of new pathogens to identify, track and characterize variants of public health concern [29]. This new technological innovation, if properly used, can improve routine surveillance for other infectious diseases of concern in the country too including for drug resistant diseases. The establishment of genomic sequencing capability in a fragile country like Somalia during an on-going pandemic has laid a strong foundation for addressing its current and future health challenges and epidemic threats on a continual basis.

Similar opportunities have been used by other fragile and war-torn countries in Africa to rebuild their laboratory capacity during an ongoing outbreak. For example, Sierra Leone [30], Liberia [31] and Zimbabwe [32] rapidly built and scaled up their laboratory testing capacity for Ebola virus disease (EVD) immediately after the outbreak was declared a Public Health Emergency of International Concern in 2014. These countries did not have the diagnostic capacity and laboratory infrastructure for testing of Ebola virus at the time of the outbreak. They recognized the value of sustaining these acquired laboratory capacities and progressively built both sequencing and RT-PCR detection capabilities for other high-threat pathogens. As a result, these countries were some of the first countries in Africa that were able to test for SARS-CoV-2 during the early days of the COVID-19 pandemic when other African countries struggled [33]. In other low resource countries, such as Zimbabwe [32], Afghanistan [34], Yemen [35], Ghana [36] and Guinea [37], the COVID-19 pandemic catalyzed significant improvements in the laboratory infrastructure, skilled workforce and collaborative partnerships in these countries. These, led to building a strong foundation for improved laboratory diagnostics and surveillance capabilities for these countries after the pandemic making them better prepared to address future public health challenges. While Somalia's experience reflects similar opportunities used by other fragile and war-torn African nations during the 2014 EVD outbreak, it is important to emphasize that the circumstances and context surrounding Somalia's laboratory capacity development were notably more challenging and seemingly unparalleled. The rapid scaling up and expansion of laboratory capacity for Somalia was necessitated during an ongoing pandemic owing to absence of country's testing capability and other logistic barriers in shipment of samples outside the country for testing. The scaling up of capacity for testing and establishment of new laboratories happened during the earlier days of COVID-19 pandemic in 2020 when the country was completely isolated from the rest of the world

owing to lockdowns, closure of international airports, suspension of commercial and cargo flights and disruptions in the global supply chain. Moreover, as a poor and politically week nation and relying heavily on its international partners for global procurement, Somalia also faced unprecedented challenge and difficulties to procure essential equipment, laboratory diagnostics, and supplies for SARS-COV-2 testing from the commercial market which was predominantly controlled by wealthy countries. Due to global pandemic, all countries- especially the rich, powerful, and wealthy significantly increased testing for SARS-COV-2, built new and additional laboratories molecular testing platform to meet the high demand for testing. Consequently, these wealthy nations were holding up the available supplies and equipment in the global market either by import restrictions (most of these international suppliers were from these wealthy and powerful countries), or by panic buying or by pre-purchase agreement and advance payment. Therefore, and mostly for import restriction, the international suppliers were prioritizing the need of these wealthy countries at the cost of the need of other politically week and global south nation countries. In the face of such adversaries and global supply chain disruption, Somalia had to endeavour hard to access global market for procurement of needed equipment and laboratory supplies for testing. However, effective partnerships and successful collaboration between Somalia and its international partners helped the country overcome such logistical difficulties of international procurement and owing to suspension of all cargo flights, the international partners had to help Somalia to bring the necessary equipment and other consumables supplies for new laboratories through chartered flights from the source countries. The other difficulties faced by Somalia, once the procurements were made and goods arrived, the installation of these equipment and making this equipment functioning. As movement of goods and services were suspended, no international in-person support was provided to the NPHRL or to any other state health authorities by the suppliers to install this laboratory equipment and make the laboratory fully operational. Support was rendered remotely and WHO brought in 2 laboratory experts from a neighboring country through a specially arranged United Nations flight to help the country establish new laboratories and equip those with molecular testing platforms and biosafety cabinet. The other difference was that the African countries during the EVD outbreak received containerized laboratories fitted with necessary testing equipment which were deployed in remote areas for testing. To operate these field laboratories, international laboratory experts were also deployed to run and manage these field laboratories and test for EVD. After the outbreak was over, these laboratories were handed over to the national authorities. In Somalia, by comparison, it was the national laboratory staff who built new laboratories from scratch on their own using their own knowledge and expertise and started operating these laboratories as soon as those were set up without the help of any international expert. Despite these unprecedented challenges and constraints, Somalia acquired its testing capability for SARS-COV-2 infection within 6 weeks of detection of its first laboratory-confirmed case showcasing its strength and resilience.

The laboratory workforce development was an integral component of country's laboratory capacity building initiative. These trained workforces need to be maintained for future expansion programme of the laboratories. Most of this workforce development programme took place remotely during the earlier phase of the pandemic owing to travel restrictions. These virtual trainings allowed participants even from remote locations of the country and be trained on essentials of diagnostic using molecular testing platforms. Despite efforts to ensure optimal female representation in these trainings of laboratory workforce from remote regions, most of the participants were male. This disparity could be explained by societal norms and security challenges, which disproportionally impact women more than males as female workers in Somalia represent only 31% of the country's total labour force [38].

The long-term benefits of these investments on building and expanding laboratories' capacity for public health go beyond routine disease surveillance and epidemic and pandemic response activities. Diagnostic testing is essential for quality health care and hence the increased laboratory capacity attained during the pandemic provides Somalia an opportunity for strengthening its fragile and week health system. The service availability and readiness assessment (SARA) done in 2016 showed that only 19% of health facilities across the country were able to provide routine laboratory tests for few selected health conditions only. This huge diagnostic gap can be addressed if the laboratory systems are integrated within the health system as its essential component and essential diagnostic is included as part of service delivery at every tier of health system. Using the data from the burden of disease in the country, a tiered system for essential diagnostics can be developed and integrated at every service delivery point. Given that the biggest diagnostic gap is at primary health care level, which is also the entry point to the care cascade, a set of point-of-care diagnostics that are affordable and feasible to manage at that level by the primary health care workers can be introduced. Given the fact that large parts of the country remain inaccessible and hard-to-reach owing to insecurity, it will be important to consider using the point-of-care diagnostic platforms in primary health care settings in the country to reduce diagnostic gap for large majority of its people. At the same time, access to diagnostic can be expanded for other communicable and non-communicable disease and as part of clinical care at the higher tiers of health system especially at higher level

hospitals. The investments made on building molecular testing platforms and genomic sequencing using the NGS are multi-disease platforms. These platforms can be re-deployed now to help detect, track and diagnose other diseases including drug-resistant infections in the country. As the country is currently implementing the Essential Package of Health Services [39], we strongly believe that the current momentum should be seized to improve essential diagnostic at all levels of the healthcare system in the country, especially at the primary care level. Based on our analysis, we have suggested a list of recommendations (Box 1, 2) on how this can be effectively done to maximize the impact of laboratory capacity development in the post-COVID-19 era. In order to so, the country will require to establish a network of laboratories with specific roles and functions and specifying how this network can support improving access to essential diagnostics in the service delivery level. This way, the investments made on improving diagnostics for pandemic response can be transformed into ensuring better access to essential testing for different health conditions in the population. As a global good, evidence shows that access to essential diagnostic is critical to achieve the goal of universal health coverage [40]. Reducing the diagnostic gap also has an important effect on reducing morbidity and mortality in the general population [41].

Although diagnostic testing is at the core of good quality healthcare, the Lancet Commission on diagnostics [41] has highlighted that 35–62% of the populations in low- and middle-income countries do not have access to the diagnostic resources essential for six common medical conditions. The commission has also highlighted that the diagnostic gap is most severe at the level of primary health care, in which only about 19% of populations in low-income and lower-middle-income countries have access to the simplest of diagnostic tests (other than those for HIV and malaria). In view of this, while integrating laboratory services into the health system, emphasis should be given to improve diagnostics at the primary health care level in fragile countries like Somalia if these poor, rural, and marginalized communities are to be brought within optimal access to essential laboratory services.

5 Conclusion

The Ebola virus outbreak in West Africa in 2014 and the COVID-19 pandemic in 2020 have highlighted the importance of access to diagnostics as a health equity issue as well as a key component of a resilient health system for detecting and controlling emerging infectious diseases. Having a network of strong laboratories-both clinical and public health is essential not only for national health security, but such network is also necessary for disease control and patient care across all care cascades. This is especially true in fragile and conflict-affected countries, where the access to health care remains limited owing to insecurity and the need for reliable and affordable diagnostic testing at the point-of-care, and close to the community, is paramount.

The current momentum can be leveraged to build and enhance laboratory capacity for tracking, monitoring and early detecting zoonotic pathogens with epidemic and pandemic potential using a One Health approach. The establishment of NGS capability offers the opportunity for the health sector to integrate genomic surveillance into One Health surveillance system through multisectoral partnerships, collaboration and coordination across human, animal, and environmental health sector. Using this integrated approach, the country can further expand and sustain the capacities of its public health laboratories as cross-sectoral collaboration, data and resource sharing between these sectors will eventually lead to increased efficiency and affordability of all sectors to maintain its surveillance and laboratory system function by avoiding fragmentation. This will contribute to both national and global health security as identifying, tracking and characterizing zoonotic pathogens of public health importance circulating at the animal-human-environmental interface can be detected in a timely manner if One Health approach is promoted and advanced effectively.

Box 1. Recommendations to maximize the impact of laboratory capacity development in the post-COVID-19 era in Somalia

A. Short-term (To be implemented within six months to one year)

1. Set up a national task force with the main function of developing an essential diagnostic list by levels of care and by type of care (public and private). This list should be based on burden of disease in the country and should be prioritized for addressing the diagnostic gaps at primary care level and underserved communities using points-of-care and other available rapid diagnostics. The list should also prioritize what tests to be performed at different levels of care including turnaround time for test result
2. Set up a tiered laboratory network with clear lines of function and authority from central level to primary health centers. The network should identify type of laboratory personnel to be hired and retained for every level, standards for laboratory tests performed at all levels, specimen referral system between the laboratories and how resources can be shared and leveraged between the laboratories in the network for an integrated laboratory services in the country
3. Foster the establishment of One Health Laboratories in the country through cross-sectoral collaboration with animal, food and environmental health sector with clearly defined roles and responsibilities for data and resource sharing including participation of each sector's laboratories in One Health surveillance. A situational analysis of existing laboratories' strength and weakness and its resources should be conducted as foundational steps

Box 1. Recommendations to maximize the impact of laboratory capacity development in the post-COVID-19 era in Somalia

4. Develop a standard list and operating procedure for maximizing the use of molecular testing platform and genomic sequencer for routine surveillance as well as for testing of multiple pathogens that are of public health importance to the country. In doing so, prepare and maintain an active stockpiling of essential laboratory reagents, primers and consumables supplies both at central and decentralized level
5. Expand the quality management system of the External Quality Assessment Project introduced in the country during the pandemic and its participation in proficiency testing to other pathogens to ensure accuracy, reliability, and timely release of test results for other pathogens
6. Retain the trained laboratory workforce built during the COVID-19 pandemic in the public sector through various means of service incentives -such as exposing them to professional trainings to acquire new skills, offering short-term overseas training and fellow ship opportunities, arranging exposure and study tours as well as supporting them with opportunities for higher education
7. Integrate the existing on-line laboratory information management system of the NPHRL developed during the pandemic with the IDSRS and DHIS 2 and expand this information management system to other laboratories in both public and private sector in the country

Box 2. Recommendations to maximize the impact of laboratory capacity development in the post-COVID-19 era in Somalia

B. Medium and long term (To be implemented between 1 to 5 years)

1. Designate the NPHRL as the main reference laboratory in the country for: governance and regulation; development and implementation of new testing strategies and testing standards; capacity-building; laboratory accreditation; and quality assurance of laboratory testing
2. Restructure the national health laboratory system in the country, moving away from the current fragmented and vertical laboratory services for communicable diseases (malaria, tuberculosis and human immunodeficiency disease) and noncommunicable diseases to a tiered structure coordinated by the National Public Health Reference Laboratory (NPHRL)
3. Develop and fund a national laboratory policy and plan on stockpiling of testing materials and reagents; equipment maintenance; workforce development; internal and external quality assurance; and bio-risk management
4. Develop a national diagnostic strategy in accordance with the 2023 resolution WHA76.5, that is fit for the country's context
5. Maintain and maximize the use of the new generation sequencing capacity for genomic surveillance and broader diagnostics for other health threats such as antimicrobial resistance, detection of extensively drug-resistant tuberculosis, HIV/AIDS, circulating vaccine-derived poliovirus type

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Authors contribution Authors contributions SF and SMMRM conceptualized the study and its methodology SF, SMMRM, DT, ML, MJK, SCA and SB curated the data included in the study SF prepared the tables and figures in the manuscript SF, SIM, DT and SMMRM interpreted the data and wrote the main manuscript text SF, SMMRM, SIM, DT, AMM, HMA and, AYO and AMS contributed to writing SF, SIM, DT, AMS, ML, AMM, MJK, HMA, SCA, SB, AAF, AHA, AYO and SMMRM reviewed the manuscript All authors have read and agreed to this version of the manuscript.

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Data availability This study did not generate new data. All relevant data analysed in the study are provided within this manuscript and its supporting information.

Declarations

Conflict of interest The authors declare no conflicts of interest concerning the research presented in this study. We have no financial, professional, or personal affiliations that could be perceived as potential sources of bias or influence on the results and interpretations presented in this article.

Ethical approval This study is exempt from ethical clearance as new data were not generated and the data do not involve human subjects.

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