Biomedical Equipment for COVID-19 Case Management

Malawi Facility Survey Report

January 2021

PATH

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The work described in this report was carried out as part of PATH's COVID-19 Respiratory Care Response Coordination project, which is a partnership between PATH, the Clinton Health Access Initiative, and Every Breath Counts Coalition to support country decision-makers in the development and execution of a comprehensive respiratory care plan to meet the demands of COVID-19. The project is also pursuing strategies to help prioritize and improve access to oxygen therapy and other essential equipment involved in respiratory care as an integral part of health systems strengthening, beyond the pandemic response.

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Abbreviations

CHAM	Christian Health Association of Malawi
ECG	electrocardiogram
HDU	high dependency unit
ICU	intensive care unit
LPM	liters per minute
PSA	pressure swing adsorption
WHO	World Health Organization

Executive summary

To assist the government of Malawi in its COVID-19 response, PATH conducted a biomedical equipment survey in health facilities across the country. The survey aimed to quantify the existing capacity, including supplies and equipment, for providing respiratory care. In total, we sampled 76 health facilities ranging from Malawi's largest central hospitals to a cross section of rural and community hospitals.

Survey results suggest a significant scarcity of oxygen production and delivery equipment and supplies, limited health facility capacity and infrastructure to treat patients, and inequitable distribution of resources for respiratory care across health zones in Malawi. The data show that intensive care unit bed capacity is a key constraining factor to oxygen therapy across most health facilities, while the amount of available oxygen equipment is often far below the number of reported beds. Moreover, critical oxygen production and delivery equipment is unequally distributed across health zones in the country. For instance, only 72 functional ventilators were reported across all surveyed facilities, with 62 percent of these concentrated in the Central and South West Zones. There is also an observed imbalance between oxygen delivery equipment and vital signs monitoring equipment, with national totals of oxygen delivery devices far greater than national totals of patient monitors and pulse oximeters combined.

After quantifying baseline oxygen availability, the study team compared the observed equipment totals to estimated equipment needs for COVID-19. First, we used a simple model to estimate oxygen needs during a six-month COVID-19 surge. We then created a gap assessment to quantify the respiratory care equipment that surveyed facilities must procure to meet their oxygen needs at peak demand. PATH, the MOH, and UNICEF are using a similar modeling and gap assessment method to inform an oxygen ecosystem road map that will guide Malawi's national oxygen and respiratory care system strengthening.

The current gap analysis and upcoming road map can be used to advocate to donors, partners, and other decision-makers who can influence policy and funding decisions around the availability of respiratory care equipment. Another recommended use for the data is to inform equitable allocation (and potentially reallocation, after the COVID-19 pandemic) of procured supplies. This will help ensure that new equipment is placed in facilities where it can be maximally utilized.

Introduction

The COVID-19 pandemic has highlighted the need for oxygen and other respiratory care supplies and equipment around the globe. In response, PATH conducted a biomedical equipment survey in 76 health facilities across Malawi. The purpose of the survey was to quantify the existing oxygen production and delivery equipment, consumables for administering oxygen therapy, bed capacity, and facility infrastructure that are relevant to providing respiratory care. The facilities sampled included all central hospitals, all districts hospitals, all Christian Health Association of Malawi (CHAM) hospitals and selected rural and community hospitals.

Observations on the current availability of oxygen delivery equipment, oxygen production equipment, and consumables within health facilities are highlighted throughout the report. This includes ventilators, pulse oximeters, patient monitors, oxygen concentrators, oxygen cylinders, pressure swing adsorption (PSA) plants, and various types of oxygen masks and airways. This report summarizes observations from the collected data and is intended to help global and national stakeholders understand COVID-19 treatment capacity in Malawi.

Methods

The survey used a data collection tool created by the World Health Organization (WHO) and adapted by PATH for use in Malawi, in collaboration with the Ministry of Health (MOH) Physical Assets Management division and Acute Respiratory Tract Infection Program. The questions included in the survey were informed by the WHO list of priority medical devices for COVID-19 case management.[1]

We surveyed 76 health facilities across five health zones in all 28 districts of Malawi. Urban districts, such as Nkhata Bay and Lilongwe, are more heavily populated than rural districts, contain more facilities, and were therefore more heavily sampled. The types of facilities surveyed included selected primary (community hospitals), secondary (district hospitals), tertiary or specialized (central hospitals), and COVID-19 dedicated treatment centers. The focus of the survey was on health facilities that routinely provide inpatient care. These are the facilities admitting COVID-19 patients and they require the minimum equipment to care for critically ill patients.

Most of the sampled health facilities fell under the secondary health care category, which comprises district hospitals, community hospitals, and CHAM facilities. Overall, this data collection effort covered 30 percent (76/255) of hospitals in Malawi as defined in the country's most recent Service Provision Assessment report.[2] When compared to all health facility types in Malawi, this data collection effort covered 7 percent (76/1060) of the total. Figures 1 through 3 show the distribution and type of facilities surveyed.

[1] *Priority Medical Devices in the Context of COVID-19* https://www.who.int/publications/m/item/list-of-priority-medical-devices-for-covid-19-case-management.

[2] *Malawi Service Provision Assessment Report (SPA) 2013-14* https://dhsprogram.com/pubs/pdf/SPA20/SPA20%5BOct-7-2015%5D.pdf.

Figure 1: Percentage of facilities surveyed per zone.

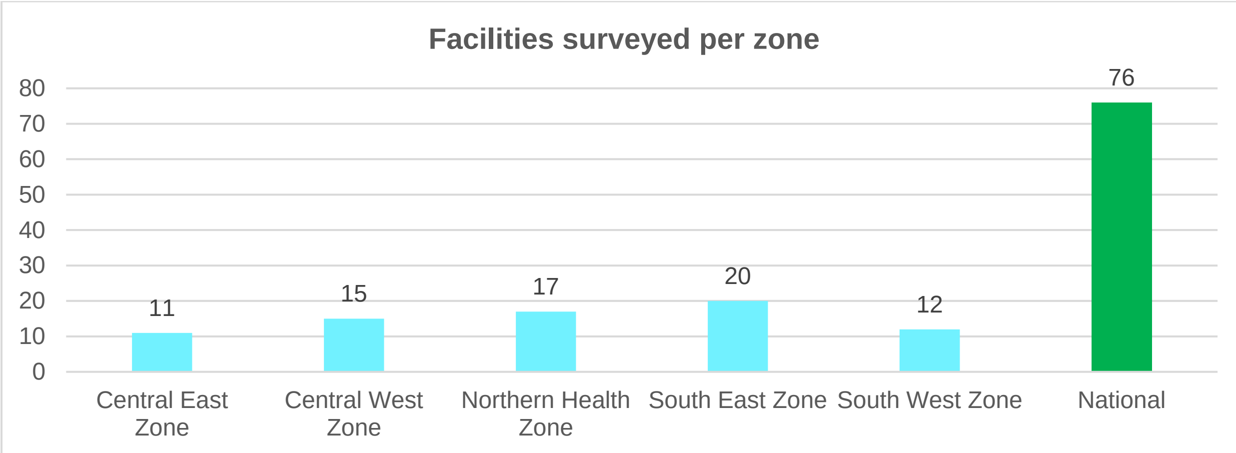


Figure 2: Percentage of facilities per district.

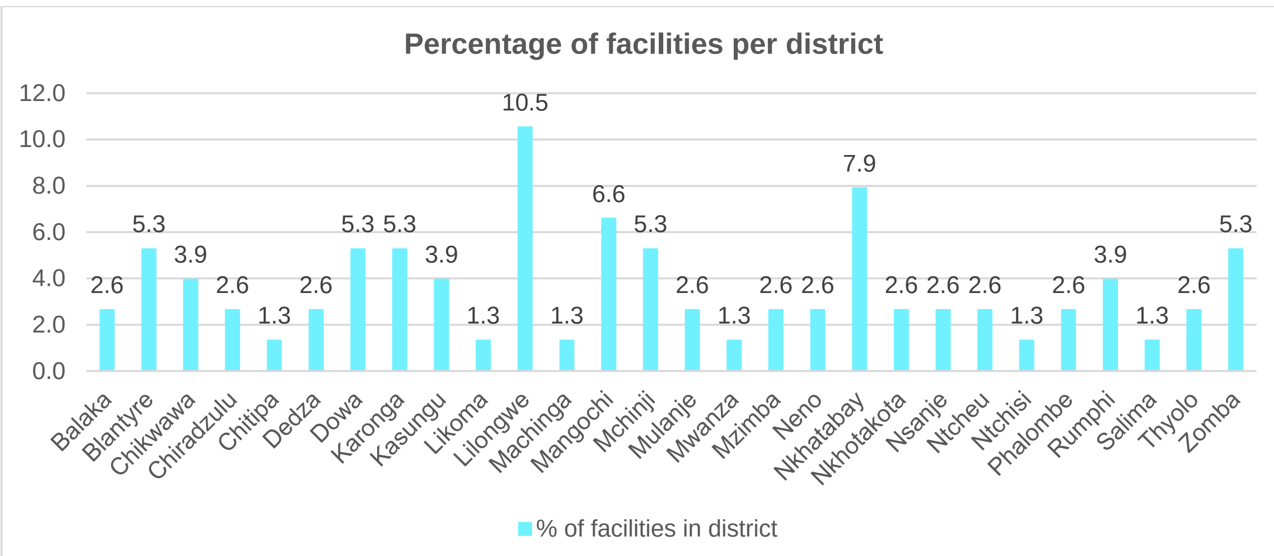
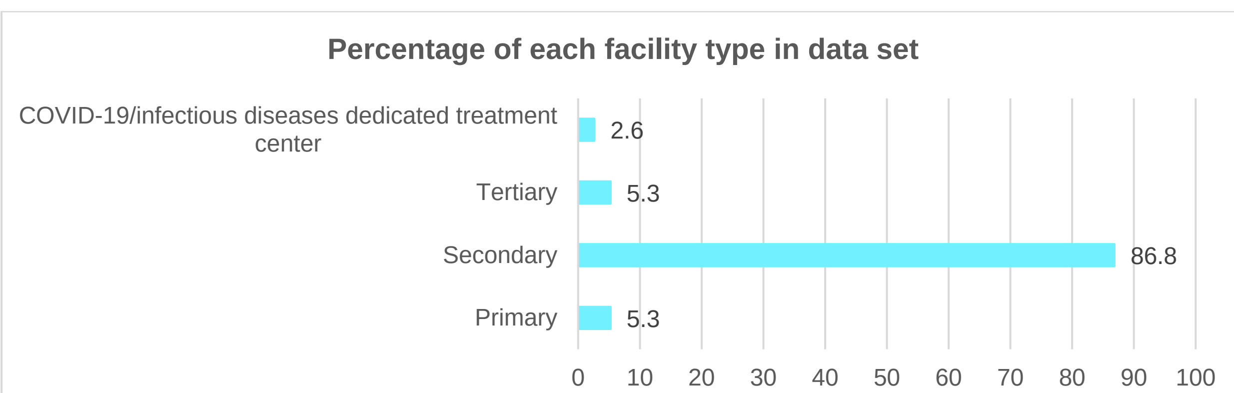


Figure 3: Percentage of each facility type.



Baseline treatment capacity

Survey results show that treatment capacity is constrained by the number of available beds, including general beds, ICU beds, and high dependency unit (HDU) beds. ICU and HDU beds are especially important for treatment of severe and critical COVID-19 cases, as they are needed to provide consistent oxygen therapy at higher flow rates; severe patients typically require an average of 10 LPM of oxygen and critical patients require an average of 30 LPM. Our survey defined an ICU bed as a bed with access to mechanical ventilation, hence equipped with a ventilator. Our survey further defined an HDU bed as a bed without added services, but access to oxygen therapy, so while it would likely provide treatment to severely ill patients, it is not equipped with mechanical ventilation. Many health facilities in Malawi have HDU beds, while far fewer have ICU beds (by these definitions). Figure 4 shows the five health zones of Malawi and their constituent districts.

Key findings

- The South East Zone reports having the highest total number of beds (table 1), yet only 5 ICU beds and 0 HDU beds. These ICU beds are all located at Zomba Central Hospital (table 3) which highlights that all other health facilities in the South East Zone do not provide advanced care.
- The Central West and South West Zones report the highest number of ICU beds, with Kamuzu Central Hospital accounting for all counted ICU beds in the Central West Zone, and Queen Elizabeth Central Hospital accounting for all counted ICU beds in the South West Zone.
- Across the entire set of facilities surveyed, only central hospitals reported having ICU or HDU treatment capacity, and ICU beds only accounted for 0.15% (25/16028) of all beds counted. Overall treatment capacity for severe and critically ill COVID-19 patients is extremely limited and centralized in larger facilities.
- The district reporting the highest total number of beds was Lilongwe, while the district reporting the lowest number of beds was Likoma (table 2). This matches the population density of these districts and is expected (table 4).
- Several districts reported zero ICU beds (table 2).
- The districts with the most ICU beds are Lilongwe and Blantyre, both reporting eight total. These two districts also reported the highest counts for HDU beds (Lilongwe, 25; Blantyre, 43), followed closely by Mzuzu (20).

Table 1: Bed counts by zone.

Zone	**Beds** (including general, ICU, and HDU)	**ICU beds**	**HDU beds**
South East Zone	4,128	5	0
South West Zone	3,290	8	43
Northern Health Zone	2,753	4	20
Central East Zone	1,927	0	0
Central West Zone	3,930	8	25
Grand total	16,028	25	88

Table 2: Bed counts by district.

District	**Beds** (including general, ICU, and HDU)	ICU beds	HDU beds
Lilongwe	2,581	8	25
Blantyre	1,915	8	43
Zomba	882	5	0
Mzuzu	876	4	20
Mangochi	758	0	0
Mchinji	583	0	0
Thyolo	570	0	0
Dowa	543	0	0
Chiradzulu	500	0	0
Nkhotakota	480	0	0
Kasungu	475	0	0
Nsanje	450	0	0
Rumphi	431	0	0
Chikwawa	420	0	0
Mzimba	397	0	0
Karonga	367	0	0
Nkhata Bay	350	0	0
Mulanje	340	0	0
Ntcheu	326	0	0
Balaka	325	0	0
Dedza	300	0	0
Machinga	300	0	0
Chitipa	280	0	0
Neno	255	0	0
Mwanza	250	0	0
Phalombe	233	0	0
Ntchisi	229	0	0
Mulanje	220	0	0
Salima	200	0	0
Dedza	140	0	0
Likoma	52	0	0
Grand total	16,028	25	88

Table 3: Bed counts for central hospitals.

Health zone	District	Hospital	**Beds** (including general, ICU, and HDU)	ICU beds	HDU beds
Central West	Lilongwe	Kamuzu Central Hospital	1200	8	25
South West	Blantyre	Mercy James	100	0	4

Northern	Mzuzu	Mzuzu Central Hospital	376	4	20
South West	Blantyre	Queen Elizabeth Central Hospital	1500	8	39
South East	Zomba	Zomba Central Hospital	600	5	0

Figure 4: Malawi health zones.[3]

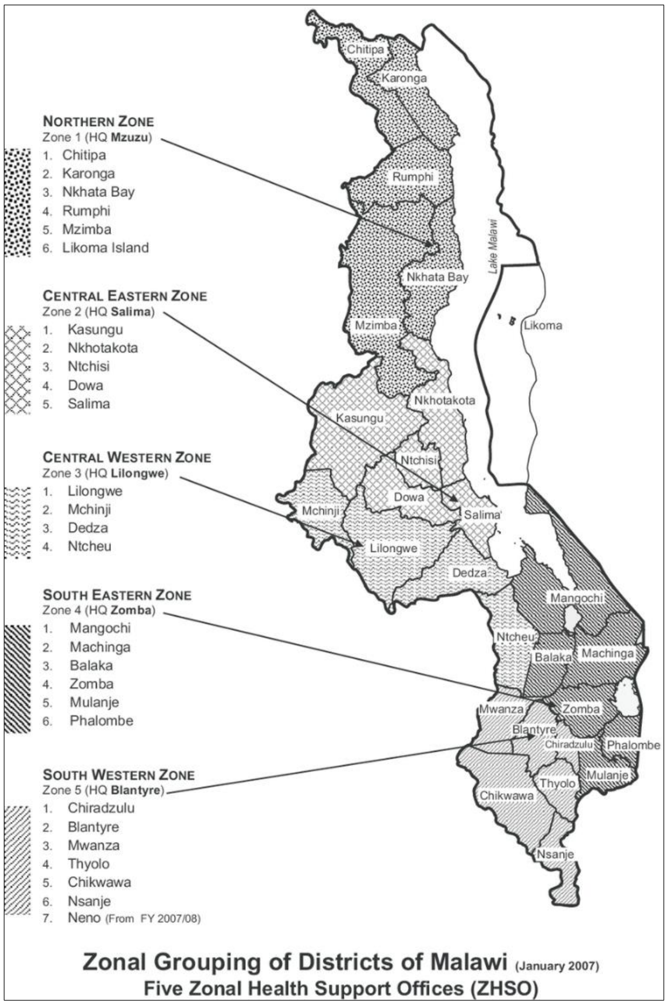


Table 4: Population size per district.

District	Population
Lilongwe	646,750
Blantyre	584,877
Zomba	80,932
Kasunga	42,555
Mangochi	40,236
Karonga	34,207
Salima	30,052

[3] Baseline Trachoma Mapping in Malawi with the Global Trachoma Mapping Project (GTMP) - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Map-of-Malawi-Health-Zones_fig1_279967133 [accessed 26 Jan, 2021

Nkhotakota	24,865
Liwonde	22,469

Facility characteristics

While bed counts are important for evaluating health facility capacity, additional health facility characteristics can impact effective utilization of beds. For instance, ICU beds that rely on piped medical oxygen could be constrained by the number of wall units installed in an ICU ward. Additionally, facility characteristics, such as type of electricity source, can limit treatment capacity if using oxygen delivery devices that require power, such as oxygen concentrators. Furthermore, oxygen therapy and patient ventilation require trained clinical staff, including specialized training to safely intubate patients for the latter treatment. Durable medical equipment also requires biomedical engineers and/or trained health facility staff to preform preventative and corrective maintenance as needed. Tables 5 through 7 summarize collected data on electricity sources, use of piped oxygen, and health facility staff. Piping is very critical to the supply of oxygen in medical health facilities because of its capacity to provide a continupus supply to patients. The study assessed the status of the piping system of sampled facilities.

Table 5 Electricity sources across facilities in Malawi.

Electricity source	**Number of facilities**
Both central grid and generator	63
Central electricity grid only	8
Electricity central grid/generator/solar	5

Table 6: Use of piping systems in Malawi.

Piping system	**Number of facilities**
No piping system	70
Piping system for oxygen	1
Piping system for oxygen, air, and vacuum	5

Table 7: Health facility staff with experience in mechanical ventilation and/or intubation in Malawi.

Staff training	**Facilities reporting trained staff**
Staff with experience in invasive mechanical ventilation and/or intubation	53
Staff dedicated to management, installation, and maintenance of medical equipment	49

Most health facilities surveyed relied on electricity from both a central grid and generator. Many facilities did not have any kind of piping system to deliver oxygen (or other gases) directly to the patient bedside. Only five facilities reported having a piping system for medical oxygen: Kamuzu Central Hospital, Queen Elizabeth Central Hospital, Daeyang Luke Hospital, Nkhata Bay District Hospital, and Mercy James. A large proportion (53/76, 70 percent) of facilities reported having staff with experience in mechanical ventilation or intubation; however, we did not quantify the number of trained staff per facility. Similarly, forty-nine facilities (64 percent) reported on-site staff for maintenance, installation, and management of medical devices. Although more information is needed on how many staff are available per facility, subsequent data collection using WHO's *A Guide to Rapid Assessment of Human Resources for Health*[4] to understand human resource constraints could be deployed to learn more about these needs. The survey could also assess the skills capacity for each facility to effectively assess the quality of the management, maintenance, and installation of the equipment.

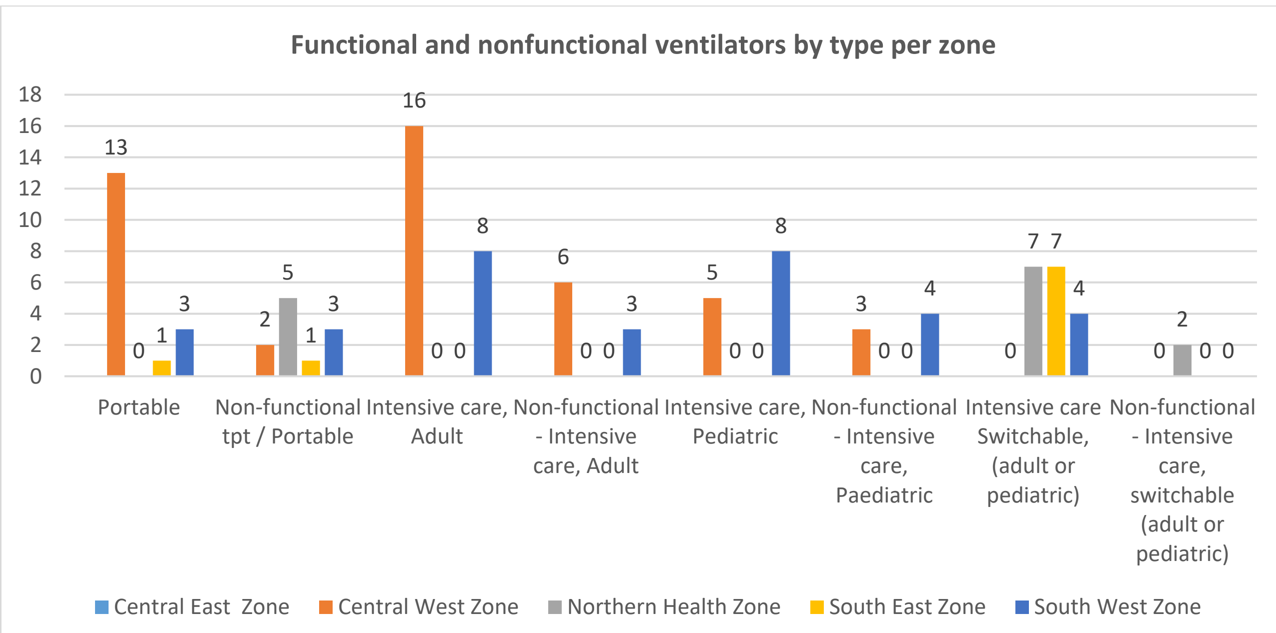
Oxygen delivery equipment

The facility survey quantified existing functional and nonfunctional respiratory care equipment by device type, including ventilators, pulse oximeters, and patient monitors.

Ventilators

Ventilators assist patient breathing in cases of severe respiratory distress. Through the survey, we collected data on various types of ventilators, including portable, intensive care for pediatrics and adults, and intensive care (switchable) for adults and pediatrics. Figure 5 quantifies functional ventilators by type, across the surveyed zones.

Figure 5: Functional ventilators by type per zone.



Key findings

- Ventilators were unavailable in most hospitals, with only 72 functional ventilators reported across all health facilities surveyed. Sixty-two percent of these ventilators are located in the Central and South West Zones, which contain the two most populous districts in Malawi; Lilongwe and Blantyre.

[4] *A Guide to Rapid Assessment of Human Resources for Health* https://www.who.int/hrh/tools/en/Rapid_Assessment_guide.pdf?ua=1.

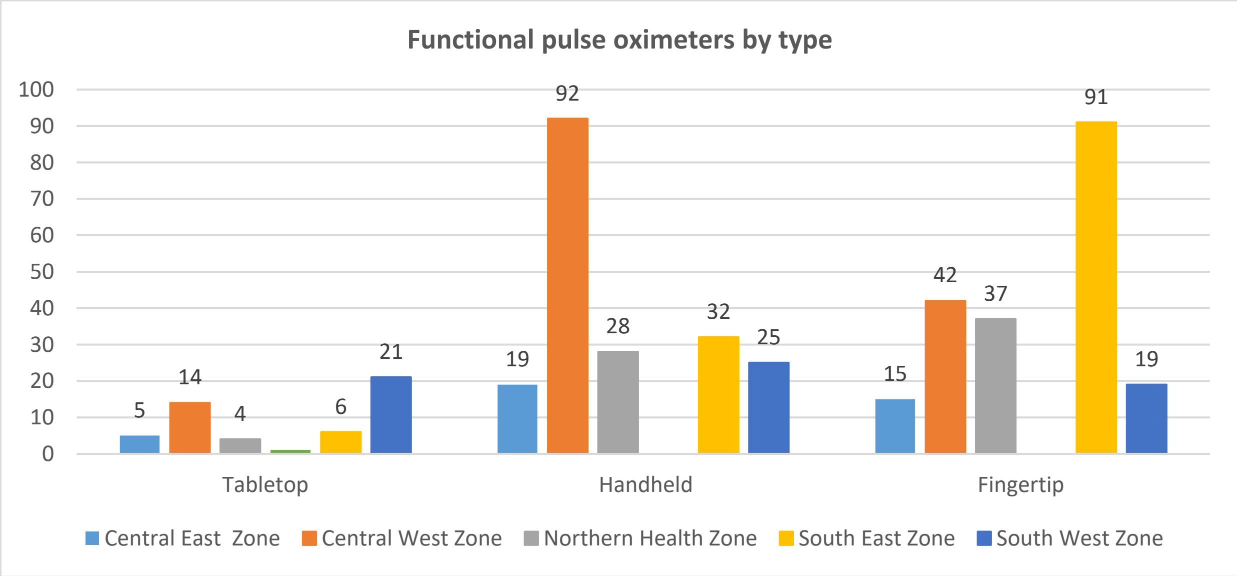
- The Central East Zone was the only zone to report no functional ventilators of any type, likely because no facility in the zone had an ICU capable of providing mechanical ventilation.

There is a significant need to procure and distribute additional ventilators in Malawi. Likewise, patient monitors and pulse oximeters should be procured and paired with these devices to ensure safe oxygen administration. Additionally, our data did not cover whether ventilators were deployed alongside proper training for health care workers. Increasing the number of staff trained in invasive mechanical ventilation and intubation will improve safe practices around oxygen therapy and will be required when increasing ventilator availability.

Pulse oximeters

Pulse oximeters and patient monitors equipped with functions such as electrocardiogram (ECG), and spO2, are critical to safe oxygen administration. These devices help monitor the level of oxygen in a patient's blood and alert the health care worker if oxygen drops below safe levels. This allows for timely identification of hypoxemia and an opportunity for a health care worker to intervene. These devices are essential in any setting in which a patient receives oxygen—such as in surgery, emergency and intensive care units, and hospital treatment and recovery wards—and for treatment of respiratory disease, including but not limited to COVID-19. The facility survey collected data on three types of pulse oximeters: fingertip, tabletop, and handheld (Figure 6).[5]

Figure 6: Functional pulse oximeters by type per zone.



Key findings

- There is a total of 450 functional pulse oximeters across the surveyed facilities (50 tabletop, 196 handheld, 204 fingertip).

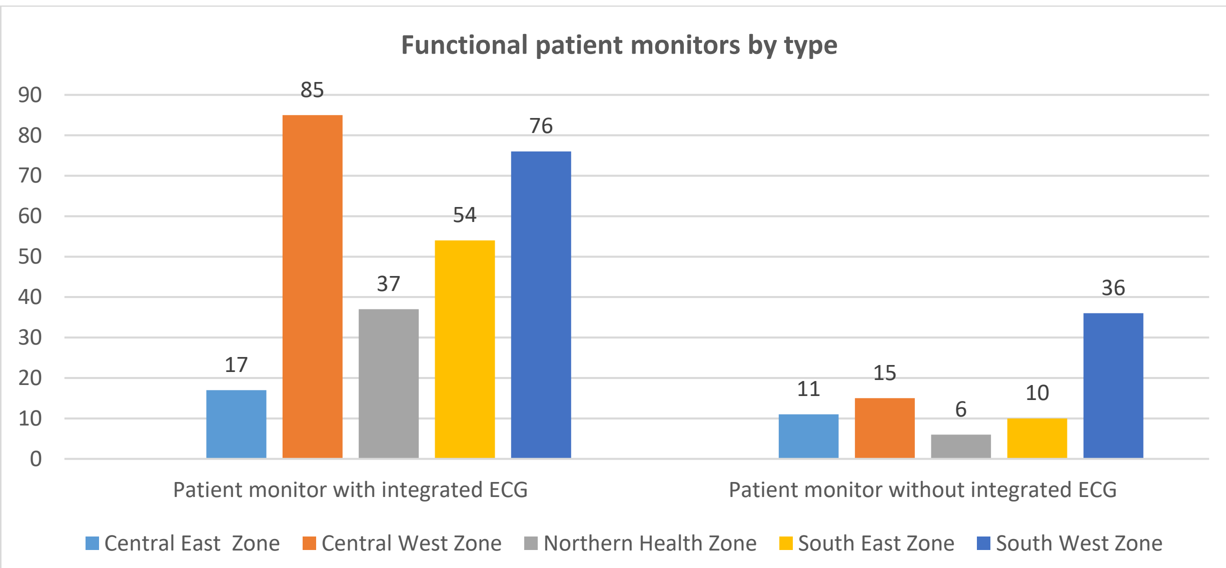
[5] Recent studies have suggested that clinical guidance should include consideration of the effect of skin pigmentation on pulse oximetry measurement accuracy. As pulse oximetry is expanded, efforts should be made to identify and disseminate the most recent clinical recommendations for patient care, to effectively treat all patients: https://www.nejm.org/doi/full/10.1056/NEJMc2029240.

- Fingertip and handheld devices were the most commonly found across facilities, but the total count of devices was low considering the recommendation to always administer oxygen therapy with pulse oximetry.
- The Central West and South East Zones reported far more devices than the other health zones.
- Tabletop, handheld, and fingertip devices were commonly available in the Central West Zone. The South East Zone reported more fingertip devices as compared to the other zones.

Patient monitors

Similar to pulse oximeters, patient monitors provide information on patient vitals, enabling health care workers to effectively deliver oxygen therapy. Two types of patient monitors were surveyed: monitors with integrated ECG and monitors without ECG. Across the facilities sampled, 269 monitors had integrated ECG and 78 monitors did not. The Central West Zone had more monitors (85) with integrated ECG than any other zone, followed by South West Zone (76). There was no significant difference across zones for monitors without integrated ECG. Figure 7 compares counts of patient monitors by type across health zones. The national total of functional patient monitors of both types is 347.

Figure 7: Functional patient monitors by type per health zone.



Key findings

- Patient monitors with integrated ECG were more prevalent in health facilities than monitors without ECG, potentially signaling that ECG is a desired device feature.
- The South West Zone had the most (112) recorded patient monitors (32 percent), despite containing only 12 facilities (or 16 percent of the entire data set). The South West Zone contains the major urban center of Blantyre, which could account for a density of equipment in health facilities of that zone.

This survey also collected data on several other device types that facilitate oxygen therapy delivery. The total number of adult BiPAP was recorded at 16, pediatric BiPAP at 13, neonatal BiPAP at 125, and high-flow nasal cannula at 8. Observations on these devices are not included in this report.

Oxygen production equipment and supply

This section quantifies equipment that can produce and store oxygen for patient care. This includes oxygen concentrators and PSA plants, which can purify atmospheric oxygen for medical use, as well as oxygen cylinders for medical oxygen storage.

Malawi's common sources of oxygen production include oxygen concentrators and PSA plants in selected health facilities. These oxygen production sources, as well as oxygen supply sources (liquid oxygen and cylinders) were assessed by the facility survey. Table 8 summarizes the availability of each oxygen technology in all the central hospitals in Malawi.

Table 8: Availability of oxygen equipment at central hospitals in Malawi.

Facility	Liquid oxygen	PSA oxygen plants	Oxygen cylinders	Oxygen concentrators
Mzuzu Central	-	-	26	40
Mercy James*	-	1	17	1
Kamuzu Central	-	-	100	25
Queen Elizabeth Central	-	1	100	19
Zomba Central	-	-	16	7

*Mercy James is not a central hospital, but it is listed here to account for and identify the PSA plant located at this facility.

Key findings

- Liquid oxygen is not available in any of the central hospitals in Malawi, and there are only two PSA plants in the major referral facilities.

Table 9 lists the availability of oxygen in the health zones in Malawi. Our data showed a considerable shortage of oxygen equipment in all health zones, and liquid oxygen was nonexistent. However, the South West Zone had three PSA plants. The Central West and South West Zones accounted for 68 percent of all oxygen cylinders in all health zones, and most of the oxygen cylinders were available in the central hospitals. However, these numbers still fall short of expected requirements (see the "Estimates of national oxygen need" section of this report).

Table 9: Availability of oxygen equipment by health zones in Malawi.

Health zone	Liquid oxygen	PSA oxygen plants	Oxygen cylinders	Oxygen concentrators
Central East	-	-	12	22
Central West	-	1	204	43
Northern	-	1	75	22
South East	-	-	92	49
South West	-	3	183	37

Total	-	5	566	173

Oxygen concentrators

Oxygen concentrators are devices that intake ambient air, compress it, and filter out nitrogen to supply purified oxygen. These devices allow for provision of oxygen to patients in wards without centralized piping systems and can be easily moved. Oxygen provided via concentrators can be shared between multiple patients depending on the concentrator model and output volume. Although concentrators provide a good source of oxygen, they are dependent on electricity and require regular maintenance to provide high-quality oxygen, which often poses challenges for their use in facilities.

The survey collected data on oxygen concentrators of various sizes, including 3, 5, 8, 10, and greater than 10 liters per minute (LPM). Table 10 below shows total functional oxygen concentrators by district, as well as the national total.

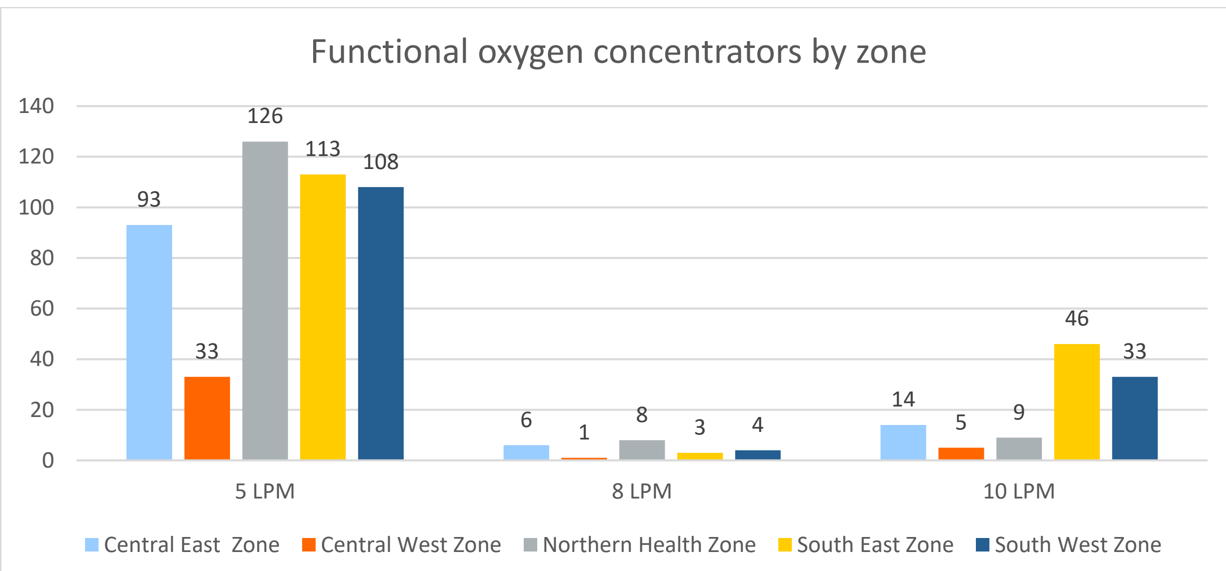
Table 10: Oxygen concentrator availability and functionality by district.

District	Functional concentrators	Nonfunctional concentrators
Lilongwe	168	87
Blantyre	81	28
Mzuzu	55	22
Karonga	31	11
Mangochi	30	11
Mchinji	29	11
Thyolo	29	15
Nsanje	28	10
Zomba	27	10
Salima	26	10
Rumphi	24	4
Ntcheu	23	4
Ntchisi	22	0
Dowa	21	2
Chiradzulu	19	8
Nkhotakota	19	4
Mzimba	17	16
Dedza	15	9
Chikwawa	14	10
Mulanje	12	7
Mwanza	12	2
Kasungu	11	1
Neno	10	3

Phalombe	9	1
Machinga	8	3
Chitipa	7	8
Nkhata Bay	7	11
Likoma	6	1
Balaka	3	1
National	**809**	**310**

The number of functional oxygen concentrators varies significantly across districts. For instance, Lilongwe reported 168 functional concentrators, while Balaka recorded only 3 functional concentrators for the entire district. Lilongwe has a much greater population density than Balaka; however, more information is needed to understand if population density is proportional to device availability. Either way, total device availability is very low, which could have an adverse impact on patient care, especially during a disease outbreak. Many districts reported a high percentage of nonfunctional devices in proportion to functional devices.[6] Depending on the types of repairs needed, fixing nonfunctional devices could be a more effective alternative to procuring new ones. Figure 8 show the number of functional concentrators across the surveyed zones.

Figure 8: Functional oxygen concentrators by zone.



Key findings

- Oxygen concentrators of size 5 LPM were most prevalent across all surveyed zones (235 total).
- 10 LPM concentrators were the next most common type (142 total), followed by 8 LPM (23).

[6] For several types of medical devices, respondents were given the option to report why devices were nonfunctional. Some of the responses included the following: no spare parts, no funds for maintenance, no consumables, no training to use or repair the device, not installed, or no distributer in the country.

Low-flow (e.g., 5 LPM) concentrators are suitable for many patients; however, those who become critically ill require higher flows of oxygen, yet high-flow concentrators are in short supply. Low-flow oxygen concentrators are appropriate for most patients receiving basic oxygen therapy; severe and critical cases of COVID-19 patients will require, at a minimum, 10 LPM concentrators and often other sources of oxygen supply altogether. The availability and functionality of concentrators in Malawi is insufficient to meet the respiratory care requirements in most facilities.[7]

Oxygen cylinders

Oxygen cylinders are metal canisters that contain pressurized oxygen. Cylinders can be refilled at a health facility using a PSA plant but are often delivered by an oxygen supply firm from a centralized production facility. They require minimal maintenance and no electricity, making them a suitable oxygen source in settings with poor infrastructure. However, they require a reliable refill source; therefore a functional supply chain and logistics system is necessary to make effective use of oxygen cylinders as a primary supply source. Like other oxygen production and delivery devices, oxygen cylinders are dependent on availability of oxygen consumables, such as masks, tubing, and cylinder assembly units, to facilitate oxygen delivery.

Cylinders are typically refilled at centralized depots and require routine distribution to facilities, over variable distances. However, some facilities such as Mercy James, Queen Elizabeth Central Hospital, Nkhata Bay, Daeyang Luke, and Neno have an oxygen plant on-site equipped with a compressor for filling cylinders. In Malawi, BOC Afrox of Linde Group distributes oxygen via cylinders, which are used by health facilities for a fee. Cylinders can be used directly at the patient’s bedside along with accessories and consumables to control their oxygen flow and delivery, or they can be connected to subcentral manifold systems (groups of cylinders linked in parallel) to supply piped oxygen throughout the facility.

The facility assessment established that the total number of cylinders varies significantly across health zones in Malawi. For example, facilities surveyed in the South West Health Zone reported the highest number of cylinders at 180 (31 percent). In comparison, the Central East Zone reported the fewest cylinders at 12 (2 percent). This could hint at underlying facility characteristics or infrastructure capabilities, such as unreliable electricity, that dictate the types of oxygen delivery equipment that can be effectively utilized. Table 11 shows quantities of cylinders by size and connection type (either bullnose or pin-index) by zone.

Table 11: Number of oxygen cylinders by size and connection type by health zone.

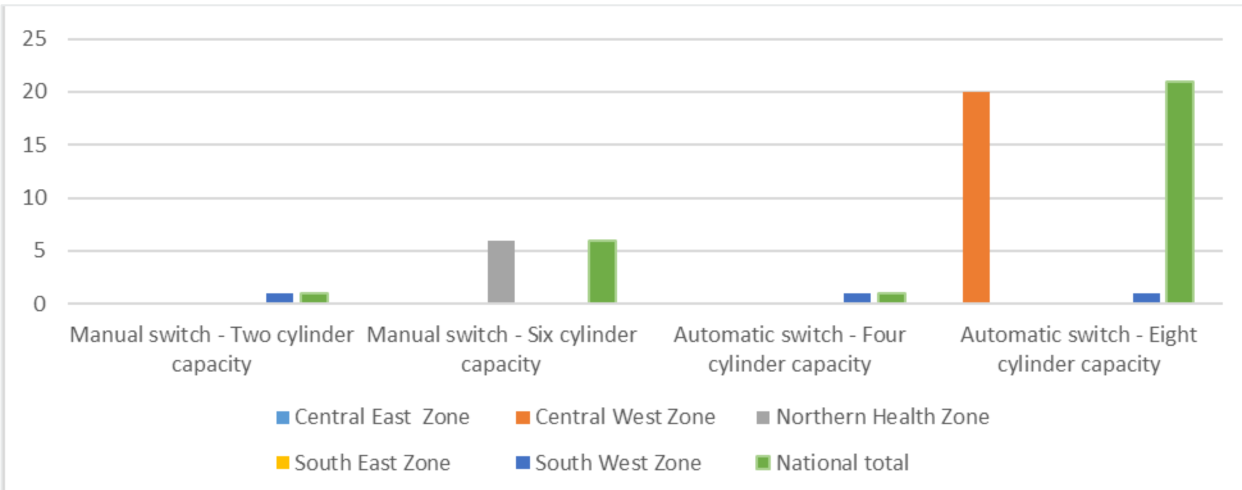
Zone	“D” (340L) Pin-index	“D” (340L) Bullnose	“E” (680L) Pin-index	“E” (680L) Bullnose	“F” (1360L) Pin-index	“F” (1360L) Bullnose	“G” (3400L) Pin-index	“G” (3400L) Bullnose	“J” (6800L) Pin-index	“J” (6800L) Bullnose
Central East Zone	0	0	0	4	0	0	0	0	0	8
Central West Zone	6	55	8	14	6	28	6	6	6	69
Northern Health Zone	9	3	4	6	0	0	0	0	0	53
South East Zone	7	3	0	13	3	0	0	2	0	64

[7] The Supply Chain and Logistics Committee of the Malawi MOH is currently tracking procured equipment through the WHO supply portal; as of November 26, 2020, 246 oxygen concentrators were recorded as received by warehouses in the country. PATH is continuing to track newly procured devices and map them to their deployed location.

South West Zone	0	46	0	0	0	0	0	3	0	134
National total	22	107	12	37	9	28	6	11	6	328

Size "J" bullnose is the most common cylinder size and type across all zones. Overall, bullnose assemblies were more common than pin-index. Some facilities reported having cylinder manifolds of various sizes, but overall, there were very few (Figure 9).

Figure 9: Cylinder manifold sizes and types by zone.



Facilities in the Central East Zone reported having far more cylinder manifolds than any other zone, and all of the same type; automatic switch manifolds with eight-cylinder capacity. Surprisingly, the South West Zone only reported 3 total manifolds, although facilities in this zone reported the highest overall counts for cylinders generally. This suggests bedside use of cylinders is common in this zone.

Pressure swing adsorption plants

PSA plants are health facility–based factories that use pressure to separate oxygen from the atmosphere and purify it to medical grade oxygen. Only a few facilities reported having an on-site PSA plant, which indicates a higher dependence on either smaller oxygen production equipment such as oxygen concentrators or cylinders provided from suppliers. Table 12 highlights these five facilities and some key details about their PSA plants.

Table 12: Characteristics of PSA plants at five facilities.

Facility Name	Zone	Model	Maximum production capacity of the plant in cubic meters per hour	Average consumption per month in cubic meters
Mercy James	South West	Intakatek	1.375	165
Neno District Hospital	South West	Foxolution	1.375	550
Nkhata Bay District Hospital*	Northern	Intakatek	42	n/a
Daeyang Luke Hospital	Central West	MVS Engineering	10	3.2

		ltd/medical oxygen plant		
Queen Elizabeth Central Hospital	South West	Intakatek	1.375	880

*Nkhata Bay District Hospital did not report PSA plant capacity in this survey; instead, data were collected by PATH through a separate assessment of overall oxygen production capacity of plants across Malawi.

All the PSA plants were reported as functional. The South West Zone had the highest reported quantities of cylinders; the concentration of plants in this zone (three out of five) indicates that cylinders were likely being filled on-site, rather than being provided by a private oxygen supplier.

Oxygen consumables

In this study, oxygen consumables refer to devices or oxygen delivery interfaces that facilitate administration of oxygen therapy to the patient. They are not designed to be reused. Because consumables are not durable devices, their availability can greatly fluctuate over time. As with all the equipment and supplies surveyed, but particularly for the consumables, the quantities observed were a snapshot in time and could be lower or higher than average for an individual facility, depending on whether that facility had recently ordered new inventory. Examining consumable quantities across zones and nationally helps stabilize this variation. This study did not obtain trends of consumable stockouts for facilities, and therefore we cannot make observations about variables such as average availability for specific consumables. Table 13 shows the quantities of key oxygen consumables across Malawi.

Table 13: Oxygen consumable quantities in Malawi by zone.

Consumable Item	Central West	Central East	Northern	South East	South West	Total	Average quantity per zone
Nasal cannula / prongs - Adult	1,458	256	331	682	1,767	**4,494**	642
Nasal cannula / prongs - Pediatric	760	181	402	416	1,108	**2,867**	410
Nasal cannula / prongs - Neonate	469	159	239	169	1,085	**2,121**	303
Nasal catheter - Adult	5	5	0	0	10	**20**	3
Nasal catheter - Pediatric	8	2	0	0	2	**12**	2
Nasal catheter - Neonate	3	0	3	0	0	**6**	1
Oxygen mask - Adult	604	30	392	424	597	**2,047**	292
Oxygen mask - Pediatric	92	22	99	242	276	**731**	104
Venturi mask - Adult	30	8	216	216	15	**485**	69
Venturi mask - Pediatric	12	7	163	51	5	**238**	34
Laryngoscopes- Macintosh (Curved blade)	139	40	87	65	46	**377**	54

Laryngoscopes-Miller (Straight blade)	21	109	61	27	19	**237**	34
Nasopharyngeal airway - Single use	247	3	2	55	465	**795**	114
Nasopharyngeal airway - Reusable	273	74	58	23	23	**451**	64
Oropharyngeal (Guedel) airway - Single use	663	8	10	344	238	**1,263**	180

As indicated, there is significant variation in consumable quantity by type across the zones. Overall, cannula and oxygen masks were more prevalent than nasal catheters at the time of the assessment. Comparing the relationship of oxygen consumables to oxygen delivery equipment is important in evaluating how effectively medical equipment is being used in facilities. For instance, if a facility has a very large number of oxygen concentrators but very few masks for oxygen delivery, then treatment capacity is constrained. This comparison was not performed because a slice-in-time quantification of consumables, as was done in this survey, does not help us understand how often they are available in relationship to their related devices. It is recommended for facilities to maintain inventory management systems; this will allow facility staff to track stock over time and evaluate if stock is available in the quantities needed to effectively use related devices.

Estimates of national oxygen need

One intention of the biomedical facility assessment was to provide data for oxygen need estimation. The PATH team used the data to model the oxygen need due to a surge, such as COVID-19, and evaluate gaps in oxygen availability. We then used the gap assessment created from this scenario to recommend the quantity of respiratory care equipment that facilities must procure to meet the oxygen need at peak demand. Our “emergency preparedness model” estimates the gap between existing oxygen delivery capacity in Malawi and the oxygen delivery capacity required to respond to a six-month COVID-19 outbreak peaking at 200 new cases per day nationwide. The Malawi Oxygen Ecosystem Roadmap employs similar modeling to estimate the quantity of national oxygen required to treat hypoxemia across diseases and conditions, beyond the demand scenarios specific to COVID-19.

Respiratory care for COVID-19 is more complex than traditional oxygen provision. Information on projected case number, distribution, and severity can influence forecasts for total oxygen and delivery interface needs, and ideal supply source, storage, and distribution strategies. In response, we recommend for country governments to rapidly assess their projected oxygen supply needs, available delivery systems, prevailing infrastructure constraints, and develop strategies for immediate increase in oxygen supply. Figure 10 presents PATH’s recommendations for responding to the respiratory oxygen requirements and needs in Malawi.

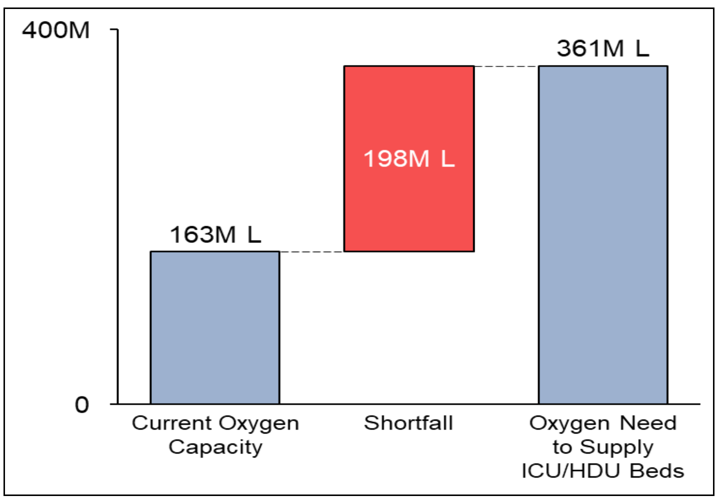
Figure 10: PATH's respiratory care framework on oxygen.

Rapid assessment	Demand quantification	Gap calculation	Strategy design	Product distribution	Device management
Measure the current availability of equipment through biomedical equipment survey	Estimate need for oxygen and respiratory care equipment	Determine the presence and size of equipment gap	Costed estimates of equipment needs	Allocation of equipment based on current gaps	Asset tracking and maintenance overtime

Base case model results

Given the scenario of a six-month COVID-19 outbreak peaking at 200 new cases per day, we estimated an oxygen need of approximately 361 million liters to adequately supply ICU and HDU beds at Malawi's five central hospitals (Figure 11). At the time of the survey, the central hospitals were the only facilities providing ICU and HDU services to COVID-19 patients across the country. The modeling could be expanded using other parameters; for example, time-period of estimation.

Figure 11: Oxygen shortfall in scenario of 200 new COVID-19 cases per day for six months.



M L: million liters.

The study team estimated the national oxygen needs for the above scenario using a model that presumed 20 percent of active COVID-19 cases at any given point would require hospitalization with some degree of oxygen therapy; 75 percent of these cases were presumed to be in the "severe" category requiring 10 LPM oxygen for one week. The remaining 25 percent were presumed to be in the "critical" category requiring 30 LPM of oxygen for two weeks.[8]

Predictions about the number of COVID-19 cases in Malawi over the six-month period were created using the WHO Essential Supplies Forecasting Tool Version 2. We specified a Susceptible-Infectious-Removed case forecast, which was further informed by epidemiological inputs observed in Malawi, such as case

[8] WHO Essential Supplies Forecasting Tool, 2020. https://www.who.int/publications/i/item/WHO-2019-nCoV-Tools-Essential_forecasting-Overview-2020.1.

doubling rate, average contacts,[9] clinical attack rate, and reproduction number. Data on COVID-19 case progression was taken from the Malawi MOH COVID-19 National Information Dashboard.[10]

As indicated in prior sections, PATH surveyed health facilities in each of the 28 districts to quantify ICU and HDU bed capacity, current oxygen production capacity, and availability of essential respiratory care equipment for treating COVID-19 patients.[11] The biomedical equipment survey did not collect information on every piece of equipment in the essential equipment list, so where data were unavailable, the model assumed there were zero pieces of that equipment type. It was also assumed that 40 percent of total beds (HDU + ICU) would be reserved for non-COVID-19 patients.

In addition, we modeled shortfalls in respiratory care equipment to service ICU and HDU beds at the five central hospitals. Table 13 outlines the current availability of durable respiratory care equipment (reusable equipment for care of multiple patients) both nationwide and in the five central hospitals as well as the estimated shortfall in this equipment to adequately service ICU and HDU beds at these hospitals. Table 14 shows the data for consumable equipment (usable for treating only a single patient) at these facilities.

Table 13: Durable equipment supply gaps—nationwide and central hospitals only.

Equipment	**Nationwide**	**Central hospitals only**		
	Current equipment availability	Current equipment availability	Equipment needed to fully supply beds	Estimated equipment shortfall
Infrared thermometer	0	0	6	6
Pulse oximeter (adult + pediatric probes)	254	36	113	77
Patient monitor, multiparametric with ECG, with accessories	269	146	25	0
Patient monitor, multiparametric without ECG, with accessories	78	21	22	1
Oxygen source (i.e., concentrator, cylinder, or pipe supply)	174	53	113	60
Laryngoscope (direct or video type)	377	64	17	0
Patient ventilator, intensive care, with breathing circuits and patient interface	48	39	17	0
CPAP, with tubing and patient interfaces, with accessories	141	51	4	0
High Flow Nasal Cannula, with tubing and patient interfaces	2	0	4	4
Electronic drop counter, IV fluids	0	0	88	88
Infusion pump	0	0	22	22
Blood Gas Analyzer, portable with cartridges and control solutions	0	0	3	3
Ultrasound, portable, w/transducers and trolley	0	0	3	3
Drill, for vascular access, w/accessories, w/transport bag	0	0	3	3

[9] Average contacts were based on country-specific percentage change in mobility from the Institute for Health Metrics and Evaluation, which was collected from mobile phone data.

[10] Malawi MOH COVID-19 National Information Dashboard https://covid19.health.gov.mw/.

[11] Essential equipment for COVID-19 treatment was defined by the WHO COVID-19 Essential Supplies Forecasting Tool: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/technical-guidance/covid-19-critical-items.

Electrocardiograph, portable w/accessories	0	0	3	3
Suction pump	645	110	47	0
Bubble humidifier, non-heated	0	0	97	97
Tubing, medical gases, int. diam. 5 mm	0	0	3	3
Flow splitter, 5 flowmeters 0-2 L/min, for pediatric use	219	27	3	0
Flowmeter, Thorpe tube, for pipe oxygen 0-15 L/min	312	172	8	0
Conductive gel, container	0	0	208	208
Catheter, nasal, 40cm, with lateral eyes, sterile, single use; different sizes: 10 Fr, 12 Fr, 14 Fr, 16 Fr, 18 Fr	26	10	839	829
Compressible self-refilling ventilation bag, capacity >1500 mL, with masks (small, medium, large)	1,749	509	8	0

Table 14: Consumable equipment supply gaps—nationwide and central hospitals only..

Equipment	**Nationwide**	**Central hospitals only**		
	Current Equipment Availability	Current Equipment Availability	Equipment Need to Fully Supply Beds	Estimated Equipment Shortfall
Nasal oxygen cannula, with prongs, adult and pediatric	6,615	3,716	8,420	4,704
Mask, oxygen, with connection tube, reservoir bag and valve, high-concentration single use (adult)	2,047	714	8,420	7,706
Venturi Mask, with percent O2 Lock and tubing (adult)	485	215	8,420	8,205
Airway, nasopharyngeal, sterile, single use, set with sizes of: 20 Fr, 22 Fr, 24 Fr, 26 Fr, 28 Fr, 30 Fr, 32 Fr, 34 Fr, 36 Fr	795	46	5,537	5,491
Airway, oropharyngeal, Guedel, set with sizes of: No. 2 (70 mm), No. 3 (80 mm), No. 4 (90 mm), No. 5 (100 mm)	1,263	588	5,537	4,949
Colorimetric End Tidal CO2 detector single use (adult)	360	206	5,537	5,331
Cricothyrotomy, set, emergency, 6 mm, sterile, single use	0	0	2,768	2,768
Endotracheal tube introducer	619	375	5,537	5,162
Tube, endotracheal	0	0	5,537	5,537
Laryngeal mask airway (LMA)	496	72	5,537	5,465
Lubricating jelly - for critical patient gastro-enteral feeding and airway management & intubation	0	0	208	208
Filter, heat and moisture exchanger (HMEF), high efficiency, with connectors, for adult	0	0	8,222	8,222

Future emergency preparedness - modeled results

PATH was advised that the Malawi MOH is considering a plan to increase ICU bed counts at each central hospital to 25 beds and add 12 HDU beds to every district hospital. To support this effort, we modeled equipment and oxygen needs to adequately service the increase in beds hypothesized by the MOH plan. This will be reflected in an oxygen ecosystem road map that the MOH is developing in collaboration with PATH and UNICEF. Similar to the "base case" analysis shown above, we used a six-month outbreak scenario with a peak of 200 new COVID-19 cases per day. All other assumptions and methods except for available HDU and ICU beds were maintained from the base case. Table 15 outlines the hypothesized HDU and ICU bed counts by facility per the MOH plan.[12] This projection is subject to change based on current requirements and will be confirmed by the MOH's plans on respiratory care.

Table 15: Hypothesized (projected) Malawi Ministry of Health plan for ICU and HDU beds by facility.

Type	Health facility	ICU beds	HDU beds
Central hospitals	Queen Elizabeth Central Hospital	25	39*
	Mercy James	4*	4*
	Mzuzu Central Hospital	25	20*
	Kamuzu Central Hospital	25	25*
	Zomba Central Hospital	25	0*
District hospitals	Balaka District Hospital	0	12
	Bwaila District Hospital	0	12
	Chikwawa District Hospital	0	12
	Chiradzulu District Hospital	0	12
	Chitipa District Hospital	0	12
	Dedza District Hospital	0	12
	Dowa District Hospital	0	12
	Karonga District Hospital	0	12
	Kasungu District Hospital	0	12
	Machinga District Hospital	0	12
	Mangochi District Hospital	0	12
	Mchinji District Hospital	0	12
	Mulanje District Hospital	0	12
	Mwanza District Hospital	0	12
	Mzimba district Hospital	0	12
	Neno District Hospital	0	12
	Nkhata Bay District Hospital	0	12
	Nkhotakota District Hospital	0	12
	Nsanje District Hospital	0	12
	Ntcheu District Hospital	0	12
	Ntchisi District Hospital	0	12
	Phalombe District Hospital	0	12
	Rumphi District Hospital	0	12

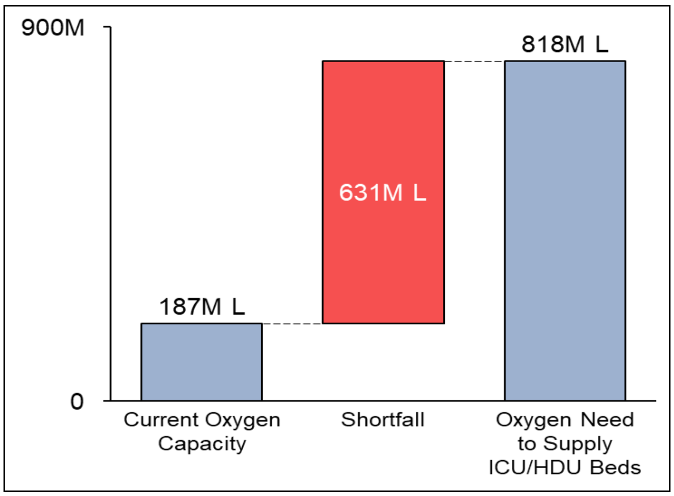
[12] Emergency and Critical Care Strategy, Ministry of Health, 2020.

	Salima District Hospital	0	12
	Thyolo District Hospital	0	12
	Total	**125**	**388**

*These are the currently existing HDU beds in central hospitals. The Ministry of Health does not have plans to project or estimate HDUs in central hospitals according to the Emergency and Critical Care Strategy. However, the strategy projects 25 ICU beds in central hospitals and 12 HDU beds per each district hospital. For Mercy James, there are already 4 ICU beds and 4 HDU beds.

Given a six-month COVID-19 outbreak scenario peaking at 200 new cases per day, we estimate an oxygen need of approximately 818 million liters to adequately supply ICU and HDU beds at the five central hospitals and 25 district hospitals. Therefore, we estimate a shortfall of 631 million liters for this six-month period (Figure 12).

Figure 12: Oxygen shortfall in scaled-up bed scenario.



M L: million liters.

Similar to our analysis of the five central hospitals, we also modeled shortfalls in respiratory care equipment to service ICU and HDU beds at the 25 district hospitals. Table 16 outlines the current availability of durable respiratory care equipment both nationwide and in the five central plus 25 district facilities combined as well as the estimated shortfall in this equipment to adequately service ICU and HDU beds at these facilities. Table 17 shows the data for consumable equipment. The survey results highlight significant gaps in the durable equipment supply.

Table 16: Durable equipment supply gaps—nationwide and central and district hospitals.

Equipment	**Nationwide**	**Central hospitals + district hospitals**		
	Current equipment availability	Current equipment availability	Equipment needed to fully supply beds	Estimated equipment shortfall
Infrared thermometer	0	0	17	17
Pulse oximeter (adult + pediatric probes)	254	123	331	208
Patient monitor, multiparametric with ECG, with accessories	269	196	124	0
Patient monitor, multiparametric without ECG, with accessories	78	46	52	6
Oxygen source (i.e., concentrator, cylinder, or pipe supply)	174	126	331	205

Laryngoscope (direct or video type)	377	132	83	0
Patient ventilator, intensive care, with breathing circuits and patient interface	48	39	83	44
CPAP, with tubing and patient interfaces, with accessories	141	112	21	0
High Flow Nasal Cannula, with tubing and patient interfaces	2	1	21	20
Electronic drop counter, IV fluids	0	0	207	207
Infusion pump	0	0	52	52
Blood Gas Analyzer, portable with cartridges and control solutions	0	0	8	8
Ultrasound, portable, w/ transducers and trolley	0	0	8	8
Drill, for vascular access, w/accessories, w/transport bag	0	0	8	8
Electrocardiograph, portable w/accessories	0	0	8	8
Suction pump	645	333	176	0
Bubble humidifier, non-heated	0	0	228	228
Tubing, medical gases, int. diam. 5 mm	0	0	8	8
Flow splitter, 5 flowmeters 0-2 L/min, for pediatric use	219	137	8	0
Flowmeter, Thorpe tube, for pipe oxygen 0-15 L/min	312	223	41	0
Conductive gel, container	0	0	628	628
Catheter, nasal, 40cm, with lateral eyes, sterile, single use; different sizes: 10 Fr, 12 Fr, 14 Fr, 16 Fr, 18 Fr	26	15	1,584	1,569
Compressible self-refilling ventilation bag, capacity > 1500 mL, with masks (small, medium, large)	1,749	884	41	0

Table 17: Consumable equipment supply gaps—nationwide and central and district hospitals.

Equipment	**Nationwide**	**Central hospitals + district hospitals**		
	Current equipment availability	Current equipment availability	Equipment needed to fully supply beds	Estimated equipment shortfall
Nasal oxygen cannula, with prongs, adult and pediatric	6,615	4,669	12,740	8,071
Mask, oxygen, with connection tube, reservoir bag and valve, high-concentration single use (adult)	2,047	1,270	12,740	11,470
Venturi Mask, with percent O2 Lock and tubing (adult)	485	263	12,740	12,477
Airway, nasopharyngeal, sterile, single use, set with sizes of: 20 Fr, 22 Fr, 24 Fr, 26 Fr, 28 Fr, 30 Fr, 32 Fr, 34 Fr, 36 Fr	795	528	16,759	16,231
Airway, oropharyngeal, Guedel, set with sizes of: No. 2 (70 mm), No. 3 (80 mm), No. 4 (90 mm), No. 5 (100 mm)	1,263	711	16,759	16,048

Colorimetric End Tidal CO2 detector single use (adult)	360	208	16,759	16,551
Cricothyrotomy, set, emergency, 6 mm, sterile, single use	0	0	8,379	8,379
Endotracheal tube introducer	619	434	16,759	16,325
Tube, endotracheal	0	0	16,759	16,759
Laryngeal mask airway (LMA)	496	199	16,759	16,560
Lubricating jelly - for critical patient gastro-enteral feeding and airway management & intubation	0	0	628	628
Filter, heat and moisture exchanger (HMEF), high efficiency, with connectors, for adult	0	0	24,886	24,886

Conclusion

The data collected through our biomedical equipment assessment yields new insights into the respiratory care treatment capacity of health facilities across Malawi. This report can be used to identify the availability of oxygen delivery equipment, oxygen production equipment, and consumables that are critical to providing respiratory care treatment for COVID-19 and a multitude of other medical applications. Understanding the availability of respiratory care equipment is the first step to accurately estimate the gap in equipment supply and understand health facility capacity and limitations for treating COVID-19 patients. We observed an overall scarcity of critical equipment and unequal distribution across facilities in Malawi. Equitable allocation of new equipment will be a more complex task than simply purchasing equipment to fill the gap and then dividing it among facilities.

The gap analysis and oxygen needs estimation described herein can help key stakeholders involved in policy and financing for respiratory care make data-driven decisions that lead to greater oxygen availability. Furthermore, the emergency preparedness model, which estimates oxygen need based on an increase in ICU and HDU beds across facilities, demonstrates the utility of baseline data to strengthen support for the proposed strategy. Overall, these data can be used for stronger positioning and advocacy to donors, partners, and procurement agencies, as well as to make informed and equitable allocation decisions.

PATH is eager to support the Malawi MOH in continued need estimation, demand modeling, creation of a road map to fill oxygen gaps, and equitable allocation of procured equipment. While this report focuses on biomedical equipment availability and recommends oxygen gap fulfilment in terms of devices only, oxygen systems in Malawi would benefit from comprehensive improvements beyond procurement of respiratory care equipment. The upcoming Malawi oxygen ecosystem road map will be a helpful resource in estimating the quantity of national oxygen required to treat hypoxemia across diseases and conditions and beyond COVID-19 scenarios. The road map recommends a mix of equipment and other respiratory care products to meet the oxygen need, as well as other oxygen interventions that contribute to health system strengthening. Upon publication and dissemination in the coming months, the road map will further help to align stakeholders on oxygen strategies.

Acknowledgments

This report was generated from data submitted via the WHO Oxygen Therapy Assessment hosted on the SurveyCTO data collection platform. PATH, in partnership with the Physical Assets Management division and Acute Respiratory Tract Infection Program of the Malawi MOH, organized and conducted the data collection.

Data collection team

Facility data collection was conducted over a span of 11 days. Enumerators were MOH officers selected based on their experience in medical oxygen delivery in health facilities. A two-day training on the use of the data collection tool was conducted prior to fieldwork. All data were captured via a digital survey platform, SurveyCTO, using tablets, and uploaded to the server daily. *Note: some of the facility figures may be affected by recall bias, as some of the equipment may have been in maintenance units.* The data collection team comprised the following individuals:

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APPENDIX

Table A1. Health facilities per district.

Health zone	District	Health facility
North	Chitipa	Chitipa District Hospital
	Karonga	Karonga District Hospital
		Atupele Community Hospital CHAM
		Chilumba Rural Hospital
		Kaporo Rural Hospital
	Rumphi	Rumphi District Hospital
		Bolero Community Hospital
		Livingstonia Mission Hospital
	Nkhata Bay	Nkhata Bay District Hospital
		Chintheche Rural Hospital
	Likoma DHO	Likoma St Peters Hospital
	Mzimba North	Mzuzu Central Hospital
		St Johns Mission Hospital
		Ekwendeni Mission Hospital
	Mzimba South	Mzimba District Hospital
		Embangweni Mission Hospital
Central East	Kasungu	Kasungu District Hospital
		Kaluluma Rural Hospital
		Nkhamenya Community Hospital CHAM
		St Andrews HC CHAM
	Nkhotakota	Nkhotakota District Hospital
		Alinafe Community Hospital CHAM
		St Annies Hospital CHAM
	Dowa	Dowa District Hospital
		Madisi Mission Hospital CHAM
		Mponela Rural Hospital
		Mtengowanthenga Hospital
	Salima	Salima District Hospital
		Sengabay Baptist CHAM HC
	Ntchisi	Ntchisi District Hospital

Health zone	District	Health facility
Central West	Lilongwe	Bwaila Hospital
		Daeyang Luke Hospital
		Kabudula Community Hospital
		Kamuzu Central Hospital
		Likuni Hospital CHAM
		Mitundu Community Hospital
		Nkhoma CHAM Community Hospital
		St Gabriel CHAM Community Hospital
	Mchinji	Mchinji District Hospital
		Kapiri Community Hospital CHAM
		Kochilira Rural Hospital
		St Joseph Ludzi CHAM
	Dedza	Dedza District Hospital
		Mua Mission Hospital
	Ntcheu	Ntcheu District hospital
		Sister Tereza Com Hospital CHAM
South East	Balaka	Balaka District Hospital
		Comfort Clinic
	Mangochi	Mangochi District Hospital
		Koche HC CHAM
		Monkey Bay Community Hospital
		St Martin Mission Hospital
		Mulibwanji Hospital CHAM
	Machinga	Machinga District Hospital
	Zomba	Matawale Health Center
		Pirimiti CHAM Health Center
		St Lukes CHAM Hospital
		Zomba Central Hospital
	Phalombe	Phalombe District Hospital
		Holy Family Mission Hospital
	Mulanje	Mulanje District Hospital
		Mulanje Mission CHAM Hospital
	Chiradzulu	Chiradzulu District Hospital
		Nguludi Mission Hospital
	Thyolo	Thyolo District Hospital
		Malamulo Mission Hospital

Health zone	District	Health facility
South West	Blantyre	Queen Elizabeth Central Hospital
		Blantyre Kameza Treatment Site
		Mlambe Mission Hospital
	Neno	Neno District Hospital
		Lisumbwi Community Hospital
	Mwanza	Mwanza District Hospital
	Chikwawa	Chikwawa District Hospital
		Montfort Hospital
		Ngabu Rural Hospital
	Nsanje	Nsanje District Hospital
		Holy Trinity Hospital