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COUNTRY CASE STUDY

India

Establishing a National Medical Oxygen Grid in India

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Case study focus

The COVID-19 pandemic highlighted and exacerbated the deficiencies of the medical oxygen system in India, presenting a unique and urgent opportunity to solve a critical problem of our time. The pandemic had a catastrophic effect not just because of the rates of contagion and the virulence of the disease, but also because of the drastic scarcity in life-saving resources such as medical oxygen. Pre-COVID-19, hospitals in India relied heavily on third-party vendors to meet their oxygen demand as they could not manufacture it locally.

The increase in oxygen demand during the pandemic led to black-marketing and hoarding,(1) and desperate requests were raised on social media for medical oxygen. At times, hospitals also sought judicial orders against the supplying agencies and the government to replenish their oxygen supplies.(2)

Key messages

- *The medical production capacity in India was rapidly scaled during COVID-19, but as demand has returned to normal, challenges of how to maintain new oxygen production equipment have emerged.*
- *To strengthen the medical oxygen supply chain, strategic storage capacity should be enhanced, along with leveraging technologies such as IoT, GPS, and QR codes for data entry, and asset management and (re)allocation.*
- *The National Medical Oxygen Grid (NMOG) provides an effective solution to integrate data from multiple sources, to better distribute oxygen supplies to meet demand, through forecasting demand, consumption, supply, and storage patterns.*
- *To support the development and nationwide implementation of the NMOG, other structural support systems, such as developing policies and guidelines on the uptake and utilisation of NMOG, along with strengthened advocacy, communications, and partnerships with all the relevant stakeholders, are required.*

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Historically medical oxygen demand, supply, and consumption has not been monitored, making it hard to plan both for routine care provision, but also surge capacity needs. While some hospitals developed an "oxygen policy" during COVID-19 to: (i) monitor the current and future demand and consumption; (ii) ensure adequate supply with rational use, and maintenance of equipment; and (iii) conducting regular audits.(3)

To address the supply chain challenges and mitigate risks associated with disrupted or insufficient supply, one of the most critical aspects is to have a supply chain data system that can support informed decision-making and greater operational efficiencies. This case study outlines the concept of a national medical oxygen grid (NMOG), a state-of-the-art IT platform, which aims to ensure the supply of high-quality medical oxygen in routine and surge scenarios, and smooth out fluctuations in demand.

Country Context

Demography, economy, and epidemiology

Along with overtaking China as the world's most populous country in 2023, India is undergoing transitions on multiple fronts - economic, demographic, and epidemiological. This vast and diverse country is being presented with various challenges and opportunities as it seeks to transform its health sector. Since transitioning from a low-income to a lower-middle-income country in 2009, India has seen improvements in life-expectancy and increased health expenditure (Table 1).

Development Indicators	Historical Value (Year)	Current Value (Year)
Total population	1,291,132,063 (2013)	1,428,627,663 (2023)
Total under-five population	125,709,000 (2013)	113,049,137.5 (2023)
Under-five mortality	55 deaths per 1,000 live births (2011)	30.6 deaths per 1,000 live births (2021)
Life expectancy (m:f)	67.0 : 70.1 years (2013)	70.5 : 73.6 years (2023)
Gross Domestic Product	$US 1.83 trillion (2012)	$US 3.39 trillion (2022)
Healthcare expenditure	$US 44.90 per capita (2010)	$US 56.63 per capita (2020)
Income status	Low income (2009)	Lower middle income (2023)

Table 1: Demography and economy of India[4,5]

In India, non-communicable diseases account for 56% of all deaths and were the leading cause of death between 2017 and 2019 (Figure 1). Communicable, maternal, perinatal, and nutritional conditions constitute another 22% of deaths during the same period. Overall, cardiovascular disease (29%) was the leading cause of death. Respiratory diseases also accounted for a substantial proportion of deaths in all the regions, with the highest burden reported in the Central region (10%) followed by the Northern region (9%) and the lowest burden in the North-Eastern region (6%).

Age and gender distributions of deaths in India due to respiratory infections and respiratory diseases between 2017 and 2019 can be found in Table 2, and demonstrate a dual burden of infections in young children and the elderly.(6) With a current Sustainable Development Goal (SDG) index score of 63.45, the country is working towards achieving all its SDGs, with action on poverty and improving health, but India still ranks 112th globally on this metric and therefore needs to accelerate action.(7)

		Percentage of deaths							
	Cause of death	Overall	0-4	5-14	15-29	30-44	45-54	55-69	70+
Overall	Respiratory infections	3.6	17.4	6.3	1.0	0.9	1.2	1.9	3.7
	Respiratory diseases	7.3	0.3	0.9	1.4	2.2	4.3	8.9	10.5
Male	Respiratory infections	3.2	16.8	6.0	0.6	0.7	1.0	1.7	3.7
	Respiratory diseases	7.0	0.3	0.8	1.1	1.8	3.7	8.4	11.0
Female	Respiratory infections	4.2	18.1	6.7	1.6	1.4	1.7	2.3	3.8
	Respiratory diseases	7.7	0.2	0.9	1.9	3.1	5.6	9.6	9.9

Table 2: Distribution of deaths in India due to respiratory infections and diseases between 2017 and 2019[6]

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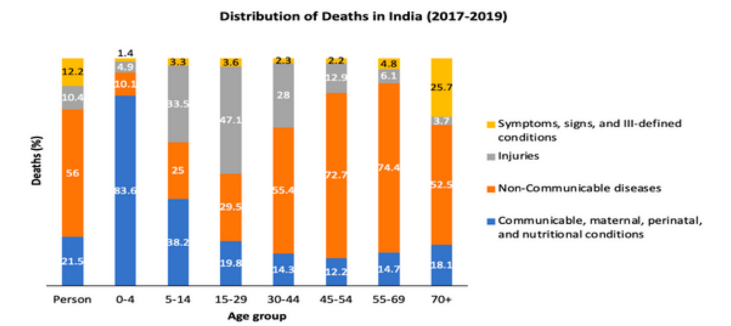

Figure 1: Distribution of deaths in India (2017-2019)[6]

Health system

In India, services in the public health system include both curative and preventive services. Health is a State subject, and therefore each State operates its own health facilities, organized under the Department of Health and Family Welfare (DoHFW), headed by a Minister of Health and Family Welfare and a Minister for Medical Education. The Health Secretariat within the DoHFW is administered by Principal Secretaries and Commissioners of Health and Family Welfare Services and Medical Education. These are officers of the Indian Administrative Services (IAS) and are supported by other administrative officials. Moreover, the activities of the National Health Mission (NHM) at the state-level are carried out through State Health Societies (SHS).

The Central Government, through the Ministry of Health and Family Welfare (MoHFW), oversees policymaking, planning, guiding, assisting, evaluating, and coordinating the work with state health authorities. To achieve nationally or internationally desirable health goals, the Central Government also finances national health schemes such as Ayushman Bharat, PM-JAY, Free Drugs and Diagnostics Service Initiative.

This is to help ensure adequate coverage of health services and consistency in performance across different states. Currently, the MoHFW has two independent departments: (i) the Department of Health and Family Welfare (DoHFW); and (ii) the Department of Health Research. The Ayurveda, Yoga, Naturopathy, Unani, Siddha, and Homeopathy (AYUSH) services, which was earlier a department under the MoHFW, has now been established as a separate ministry (Figure 2). The departments are staffed by IAS officials, technical advisors, and administrative staff, supported by a network of public-funded autonomous research and training institutions, and technical advisory bodies.

Apart from health facilities operated and funded by the State and National Ministries of Health, public sector employers such as the Ministry of Defense and the Ministry of Railways, also provide health services through institutions directly owned, financed, and managed by them. The All India Institute of Medical Sciences (AIIMS), India's main tertiary-level health facility in the public sector, is funded directly by the Central Government, and is the highest-ranking tertiary care institution in India.

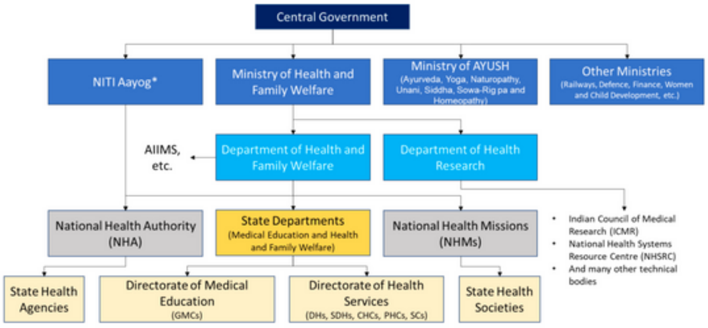

Figure 2: Governance structure for healthcare in India.[8] AIIMS: All India Institute of Medical Sciences; GMCs: Government Medical Colleges; DHs: District Hospitals; SDHs: Sub-Divisional Hospitals; CHCs: Community Health Centres; PHCs: Primary Health Centres; SCs: Sub-health Centres. *NITI Aayog is the premier policy think tank of the Government of India, providing directional and policy inputs.

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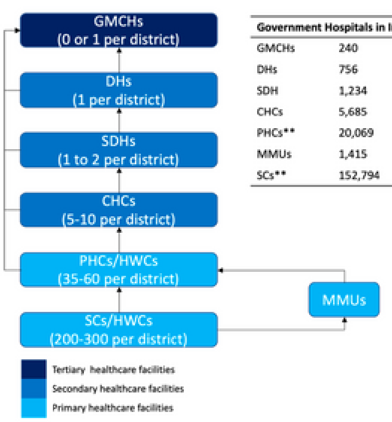
Public sector health services in India are organized as a three-tier hierarchical system, comprising of the following levels: primary - subcenters and primary health centers (PHCs); secondary - community health centers (CHCs), sub-divisional hospitals (SDHs), and district hospitals (DHs); tertiary - medical colleges and teaching hospitals.(8) The number of functioning government health facilities in 2019 can be found in Figure 3.

The private sector in India also plays a major role in providing inpatient and outpatient services, diagnostic services, and human resources for health, and in the pharmaceutical sector. It was reported that India had 43,486 private hospitals in 2020, of which 344 were private medical college hospitals.(8,9) The organization of the private sector in India is diverse, including for-profit, not-for-profit, charitable and religious organizations. About 70% of all outpatient visits and 58% of hospitalization visits occur in private facilities.



Government Hospitals in India in 2019*	
GMCHs	240
DHs	756
SDH	1,234
CHCs	5,685
PHCs**	20,069
MMUs	1,415
SCs**	152,794

Figure 3: Government healthcare facilities in India in 2019.[8] GMCHs: Government Medical College Hospitals; DHs: District Hospitals; SDHs: Sub-Divisional Hospitals; CHCs: Community Health Centres; PHCs: Primary Health Centres; MMUs: Mobile Medical Units; SCs: Sub-health centres. * In addition, Indian Railways and Employees' State Insurance Corporation (ESIC) run 128 and 155 hospitals, respectively. ** Some are being converted into Health and Wellness Centres (HWCs).

The healthcare workforce in India was estimated to be over six million in 2019 (Figure 4). To make it easier to regulate and implement standard practices in private healthcare facilities, they are regulated by the Clinical Establishments (Registration and Regulation) Act, 2010 along with government healthcare facilities – the one exception are hospitals owned, controlled, or managed by the Armed Forces.(8)

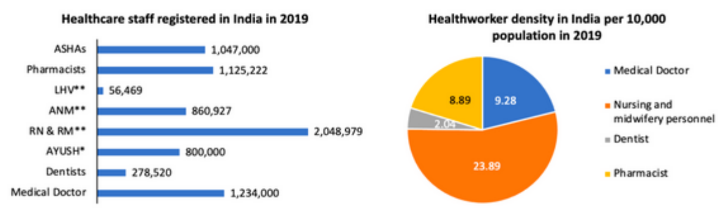


Figure 4: Healthcare workforce in India in 2019.[8] AYUSH: Ayurveda, Yoga and Naturopathy, Unani, Siddha, and Homeopathy; RN & RM: Registered Nurse and Registered Midwife; ANM: Auxiliary Nurse Midwife; LHV: Lady Health Visitor; ASHAS: Accredited Social Health Activists. * Data from 2018; ** Data from 2017

Due to human resource challenges within the public health sector (e.g., absenteeism, low motivation, corruption), alongside shortages or unavailability of essential medicines and diagnostic services, patients switch to private providers despite higher out-of-pocket (OOP) costs or insurance financing. Insurance schemes (privately purchased or publicly funded) provide partial or complete coverage for hospitalization at empaneled hospitals (i.e., those where people can seek medical care for free of cost with governments supporting costs); however, outpatient care at private hospitals is mostly paid for out of pocket.

To tackle rising OOP expenditure for the care-seekers, several tax-funded health insurance programmes have been initiated since the mid-2000s. In 2018, a new national scheme, Pradhan Mantri Jan Arogya Yojana (PM-JAY),

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that integrated the health insurance schemes of several state governments under one umbrella was launched. The PM-JAY , with a focus on inpatient services, seeks to cover 500 million people from poor, and economically and socially disadvantaged groups, with an annual benefit package entitlement of INR 500,000 ($US 6,100) to households, including over 1,500 treatment packages provided free to patients in need.(8,10–12)

COVID-19

The first case of COVID-19 in India was reported on January 27, 2020 in Kerala.(13) As of May 2023, over 45 million cases had been reported, with a mortality rate of 1.2%, with Maharashtra having the highest infections. However, reports based on excess mortality indicate far more cases and deaths than have been officially reported.(14) The peak of the first COVID-19 wave was observed around mid-September 2020, with a peak daily oxygen demand of around 3,095 metric tonnes (MT). The second wave of infections peaked around early May 2021, with peak daily demand reaching over 11,000 MT - over threefold higher than the first wave, and the struggle to meet this oxygen demand become a defining moment in the pandemic globally.

Over 927 million samples have been tested for COVID-19, and over 2.2 billion vaccination doses have been administered since 16 January 2021.(15) To effectively manage the pandemic, the Government of India took steps to swiftly strengthen various aspects of healthcare services, such as surveillance and diagnostics, immunization and vaccinations, hospital bed capacity and equipment infrastructure, medical oxygen supply chain, data systems, and policies, guidelines and capacity building (Figure 5).(16–19) In addition, during the COVID-19 pandemic, US$ 1.1 billion (₹ 8257.88 crores) and US$2.8 billion (₹ 23,123 crores) were released by the Central government to the States as financial assistance under the Emergency COVID Response Plan (ECRP) in Phase 1 and Phase 2, respectively.

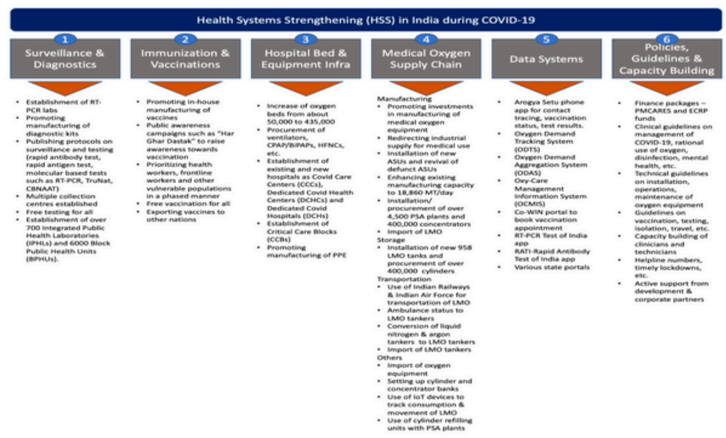

Figure 5: Strengthening of healthcare systems in India during COVID-19.[16–19] RT-PCR: Reverse Transcription – Polymerase Chain Reaction; CBNAAT: Cartridge Based Nucleic Acid Amplification Test; ICU: Intensive Care Unit; CPAP: Continuous Positive Airway Pressure; BiPAP: Bilevel Positive Airway Pressure; HFNC: High Flow Nasal Cannula; ASU: Air Separation Unit; PSA: Pressure Swing Adsorption; LMO: Liquid Medical Oxygen; IoT: Internet of Things; PMCARES: Prime Minister's Citizen Assistance & Relief in Emergency Situation; ECRP: Emergency COVID Response Plan.

Under the Prime Minister's Citizen Assistance & Relief in Emergency Situation (PMCARES) fund, a sum of US$115 million (₹ 933.63 crores) was allocated between June 2020 and June 2021 to procure 1,222 pressure swing adsorption (PSA) plants with a total oxygen manufacturing capacity of 1,750 metric tonnes.(16,18) Finally, the Central government and State governments received financial and technical support from a range of private, non-profit, multilateral and bilateral organizations, including: World Health Organization (WHO), United Nations Children's Fund (UNICEF),

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World Bank, United States Agency for International Development (USAID), Gates Foundation (GF), Clinton Health Access Initiative (CHAI), PATH, Jhpiego, Oxygen for India - a global initiative convened by the One Health Trust, Give India, and the Swasth Alliance, and finally support from many other corporate social responsibility partners.

Given India's size and large global diaspora, it played a large role in the fate of the pandemic. India's pandemic preparedness plan was largely abandoned in the face of a real pandemic and to an extent, the response was driven by political priorities and lockdowns.(20) There were several challenges in implementing the International Critical Care Guidelines for COVID-19 on infection control and using respirator masks.(21) Despite the significant health and economic impact, the pandemic offered an opportunity to invest in the public health infrastructure such as capacity building, public health research, and surveillance, which have been neglected over the past few decades. For instance, the increase in usage of non-invasive ventilation (NIV) using high flow nasal cannula (HFNC) as the initial mode for hypoxic respiratory failure when compared with other methods of NIV was highlighted.(22,23) The quality and regulation standards for the use of ventilators were also defined.(24)

Various strategies and principles were adopted by hospitals to mitigate challenges in administration, hospital space organization, management of staff and supplies, maintenance of standard of care, and specific COVID-19 care and ethics during the pandemic.(25,26) Additionally, substantial growth was observed for e-pharmacy businesses during the pandemic which have the potential to improve access to medicines, but come with public health challenges such as the sale of prescription-only medicines without prescription, the sale of substandard and falsified medicines, and risks of consumer fraud and data privacy.(27)

Mathematical modelling was developed to support optimal management of immunisation, diagnostic testing, patient caseload and medical oxygen supply. Examples of this include a model to ensure quick sample transport at minimum cost and to support optimal utilisation of testing laboratories;(28) a 10-day forecasts of the number of daily confirmed cases;(29) and a prediction equation using weight and height to estimate oxygen demand in the Asian-Indian population.(30) Furthermore, a pandemic management strategy comprising integrated satellite remote sensing, geographic information system (GIS), and local knowledge-based approach to effectively tackle the contagion of this disease was used in some areas.(31)

However, on the other side, an increase in the incidence of fires in Indian hospitals was reported during COVID-19 due to increased use of oxygen and alcohol-based disinfectants, high-power demand, increase in inflammable material in wards and limited fire safety infrastructure. Therefore, several changes in the equipment maintenance and management practices in Indian hospitals is required along with conformity with the Indian fire safety regulations.(32,33)

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Oxygen supply and clinical use landscape in India

Before COVID-19, India's daily liquid oxygen manufacturing capacity was about 9,000-10,000 MT/day, of which about 10% was utilized for medical purposes. Considering future surges in oxygen demand, the capacity was enhanced to 18,860 MT/day by December 2021 by increasing production from existing liquid oxygen plants, repairing defunct liquid oxygen plants, commissioning of PSA plants and procurement of oxygen concentrators.

Since September 2020, over 4500 PSA plants have been installed, and if functional, would have a combined manufacturing capacity of about 4,000 MT/day. The central and state funds, as well as donations from development partners, international agencies, and corporates, helped to install these 4,500 PSA plants across various public health facilities ranging from government medical colleges, district hospitals, civil hospital and some community health centres. In addition, the estimated 100,000 concentrators in the country would contribute to about 1,000 MT/day.

In India, INOX Air Products and Linde Gases have a combined market share of 60% in liquid oxygen manufacturing. Most of the liquid oxygen manufactured in the country is utilized by large-scale industries, such as the steel and electronics industry (25-35%). There are 1,600 liquid oxygen tankers owned by private manufacturers for transporting liquid oxygen.(34)

With a single-day COVID-19 peak of active cases of 3.6 million people, the demand for oxygen in India in May 2021 was about 11,200 MT/day. The manufacturing capacity at the time was 9,446 MT/day, leading to a considerable deficit of 1750 MT.(18,35) The country faced multiple challenges in the constituent parts of the oxygen supply chain linked to: 1) production; 2) transportation; 3) storage - Figure 6.

The regulation of medical oxygen in India involves multiple different actors and government departments. The Petroleum and Explosives Safety Organization (PESO), under the Department of Promotion of Industry and Internal Trade, Ministry of Commerce and Industry, regulates and monitors the installation and commissioning of liquid oxygen manufacturing units. PESO serves as the nodal agency for regulating the safety of hazardous substances such as explosives, compressed gas, and petroleum. Using the Gas Cylinder Rules 2016 and Static and Mobile Pressure Vessels (Unfired) Rules 2016, it regulates the installation and commissioning of LMO tanks, booster units to refill cylinders with PSA plants and the use of liquid oxygen cylinders and gaseous cylinders in a hospital setting.(36,37)

Oxygen concentrators being medical devices, their registration and use is overseen by Central Drugs Standard Control Organization (CDSCO) under the Directorate General of Health Services, MoHFW.(38)

Moreover, oxygen being an essential medicine, medical oxygen suppliers require a license based on the Drugs and Cosmetics Act of 1940, which gives the Indian Pharmacopoeia legal status to regulate purity requirements for medical oxygen. The National Accreditation Board for Testing and Calibration Laboratories

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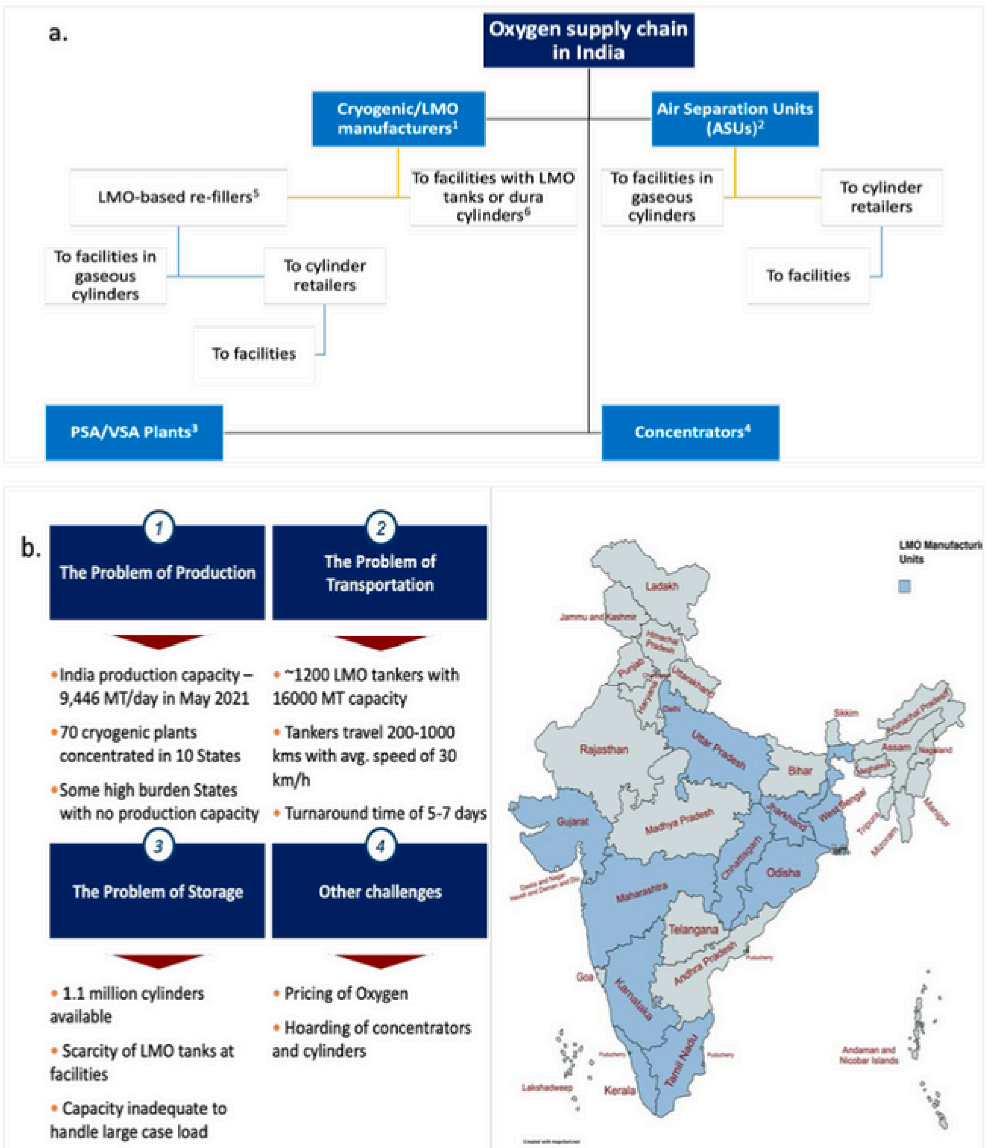

Figure 6: (a) Medical oxygen supply chain and (b) the challenges associated with it in India[34]

[1]Cryogenic/LMO manufacturers: Using a cryogenic air separation unit, oxygen is stored in liquid form with a purity of >99%.
[2]ASUs: Using a cryogenic air separation unit, oxygen is stored in gaseous form with a purity of >99%.
[3]PSA/VSA plants: Using pressure or vacuum swing adsorption technology operating at ambient temperatures, generates oxygen with a purity of 93±3%.
[4]Concentrators: Using PSA technology operating at ambient temperatures, generates oxygen with a purity of >82%, connected directly to patients.
[5]LMO-based re-fillers: They receive oxygen in liquid form from cryogenic/LMO manufacturers, convert it into gaseous form, and fill it into cylinders
[6]Dura cylinders: Mobile LMO tanks that are connected directly to MGPS and may be refilled on or off-site.

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(NABL) is a Constituent Board of the Quality Council of India that approves laboratories to test the quality of medical oxygen delivered to patients, primarily through PSA plants.(34) During the pandemic, cylinder and LMO refilling costs fluctuated based on the demand, and so the National Pharmaceutical Pricing Authority capped the price of medical oxygen. But this did not cover transportation costs levied by the vendors.(39) The sites for PSA plant installation across the hospitals were prepared mostly by either the National Highways Authority of India (NHAI) under the Ministry of Road Transport and Highways or Central Public Works Department (CPWD) under the Ministry of Urban Development. On the other hand, PSA plants were installed by Defence Research and Development Organisation (DRDO) under the Ministry of Defence, Ministry of Petroleum & Natural Gas, Ministry of Power, Ministry of Coal, Ministry of Railways or Central Medical Services Society (CMSS) under MoHFW.(40)

In India, the most common storage sources of medical oxygen in healthcare facilities are compressed gas cylinders and LMO tanks, while oxygen concentrators and PSA plants are the most common forms of production. In tertiary care hospitals, LMO tanks and PSA plants typically act as primary sources of oxygen by providing oxygen through the medical gas pipeline system, whereas gaseous cylinders and concentrators act as secondary and reserve supplies, respectively.

PSA plants and cylinders are the primary sources of oxygen in secondary care hospitals, whereas only cylinders are the primary source in primary care hospitals. An ideal hospital journey for a patient in India requiring oxygen therapy can be seen in Figure 7.(41)

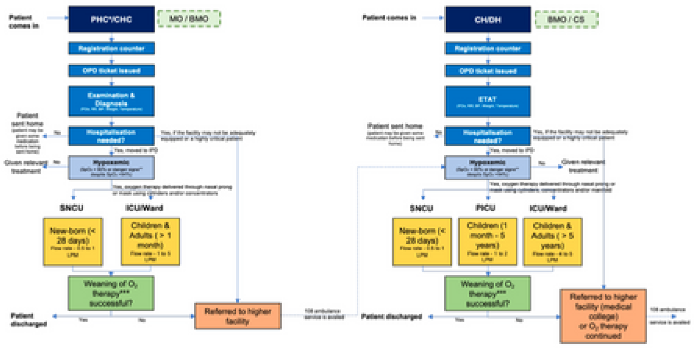

Figure 7: Hospital journey of a patient requiring oxygen therapy in India.
BMO: Block Medical Officer; BP: Blood Pressure; CH: Civil Hospital/Sub-divisional Hospital (SDH); CHC: Community Health Centre; CMHO: Chief Medical & Health Officer; CS: Civil Surgeon; DH: District Hospital; ETAT: Emergency Triage Assessment and Treatment; HR: Human Resource; ICU: Intensive Care Unit; IPD: In Patient Department; LPM: Litres Per Minute; MO: Medical Officer; OPD: Out Patient Department; PHC: Primary Health Centre; PICU: Paediatric Intensive Care Unit; POx: Pulse Oximetry; RR: Respiratory Rate; SNCU: Special Newborn Care Unit. * PHCs are mostly delivery points where new-borns and mothers are primary receivers of oxygen therapy. ** Danger signs are lethargy, unconsciousness, nasal flaring, vomiting, or convulsion. *** Weaning is successful if SpO_2 is within desired range after stopping therapy for 15 mins and rechecked after 1h

During the COVID-19 pandemic, MoHFW regulated the use of oxygen for COVID-19 management and issued guidelines for management of COVID-19 in adults and children. It categorized patients into three groups: 1) 80% of cases are mild and do not require oxygen; 2) 17% of cases are moderate and can be managed on non-ICU beds, and 50% of these may require oxygen at 10 LPM; 3) 3% of cases are severe ICU cases requiring oxygen at 24 LPM.(42,43)

In addition, various State health departments published their own guidelines for medical oxygen use.(44,45) After the COVID-19 pandemic, returning to routine service delivery (i.e., lower oxygen demand), has thrown up a new challenge for hospitals and State administrators. Many State governments and other stakeholders have expressed concerns over the 'high costs' incurred by keeping PSA plants operational, including electricity bills, costs of fuel for diesel generators

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and technically qualified and trained HR to operate them safely. Due to lower utilisation, they are now also being referred to as “white elephants.” Allowing them to lie idle could mean letting these plants become defunct over time, which would be a waste of the estimated US$730 million (₹ 6000 crore) investment that had gone into installing and commissioning them.

To ensure the maximum utilisation of PSA plants as a source of medical oxygen, an Oxygen Technical Advisory Committee (TAC) has been formed under the stewardship of the National Health Systems Resource Centre (NHSRC). Their mandate is to provide: guidelines on the purity of oxygen being delivered by PSA plants and their regular testing, the requirement of medical gas pipeline system (MGPS) infrastructure with PSA plants, mixing of PSA plant generated oxygen with LMO and their usage in ICUs, refilling cylinders with PSA plants, operational cost comparison with other sources of oxygen, use of solar power as a source of energy for their operations, audits and mock drills.

The TAC consists of experts from various domains within the oxygen ecosystem, including representatives from the NHSRC, health commissioners, oxygen nodal officers from state health departments, medical experts, professors, industry experts (PSA plant and LMO manufacturers), oxygen quality testing experts, and engineers.

The need for a national medical oxygen grid (NMOG)

The COVID-19 pandemic highlighted the impact of mHealth and Industry 4.0 technologies (such as the Internet-of-Things (IoT), big data and artificial intelligence) based-applications in pandemic responses especially in LMICs. With minimum human interface, they make the healthcare system more resilient and provide significant benefits to underserved populations.(1)

During COVID-19, these digital applications augmented accessibility, communication, and public health practices through telemedicine, automated GPS and Bluetooth-based contact and quarantine tracing, and real-time information dissemination; however, it also raised questions on maintaining personal privacy. The uptake of these applications was enhanced due to high smart phone penetration and digital literacy, and availability of free or subsidized internet data; thus, promoting greater flow of information without significant financial implications.(28,46–50)

As the Indian subcontinent is highly susceptible to natural disasters, a disaster supply chain structure was proposed that integrates information and digital technologies for multi-agency information sharing, coordination and decision making for implementation of better response practices.(51) The list of digital solutions used in the Indian State of Kerala during the COVID-19 pandemic response can be found in Appendix 1.(47,52)

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The Indian Central Government took multiple steps to strengthen the oxygen supply chain to tackle the health crisis and prevent the deaths of many COVID-19 patients (Figure 5). These included efforts for improving oxygen production, enhancing tanker availability to optimize logistics, improving oxygen storage at the last mile, and easing procurement norms. In addition, anticipating the challenges in medical oxygen management during the second wave of the pandemic, the MoHFW expedited the development and deployment of the Oxygen Demand Aggregation System (ODAS) as well as the Oxy-Care Management Information System (OCMIS) as comprehensive IT solutions to aggregate the estimated demand of oxygen from health facilities across the country. They have proven to be invaluable assets that allowed the district, state, and national authorities to make meaningful decisions based on the aggregated data to optimize faster delivery of oxygen.

However, these systems also have several limitations (Figure 8), as follows:

- Need for a computer or laptop to enter the data.
- Realtime access to internet to submit the data.
- High data entry burden on a single nodal person through one user ID per facility.
- No demand-based predictive and decision analytics available at the facility level.

In the post COVID-19 scenario, always ensuring the availability of oxygen in adequate quantities regardless of demand fluctuations is critical. In a vast and densely populated country such as India, ensuring oxygen availability is even more significant as the health system is expanding rapidly, but is fragmented. The supply chain challenges in India are not unique to medical oxygen as other industries such as electricity and oil and gas, also have very different points of production and consumption with significantly varying demand. The risks associated with such a setup could be mitigated by establishing interconnected grids which comprises of networks of producers and consumers to facilitate efficient and timely delivery of a product. (34)

Figure 8: (a) Oxygen Demand Aggregation System (ODAS). (b) Oxy-Care Management Information System (OCMIS)
ICU: Intensive Care Unit; HDU: High Dependency Unit; PMCARES: Prime Minister's Citizen Assistance & Relief in Emergency Situations; ECRP: Emergency COVID Response Plan; PSA: Pressure Swing Adsorption; IoT: Internet of Things. *IoT devices: They are pieces of hardware, such as sensors that are programmed for certain applications and can transmit data over the internet or other networks.

A National Medical Oxygen Grid (NMOG) could solve this need, and is be based on four principles:

1. preference for creating large storage capacity.
2. preference for creating an interconnected network to allow asset reallocation based on demand.
3. preference for public–private partnerships.
4. working towards achieving oxygen self-sufficiency.

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The grid mechanism would be enabled by a robust IT platform, which would include both traditional manual and technology-enabled (IoT device-based) automatic data collection.(34) The technology-enabled data inputs may be captured through specific sensors for pressure, quality, level, and flow rate. They may also involve other technologies such as GPS coordination and QR code scanning to overcome the challenges associated with laborious manual data entry.

A detailed comparison between the NMOG IT platform and the oxygen management systems used during COVID-19 in India are presented in Table 3. The IT platform would ensure coordination between different stakeholders and help monitor resource prioritization and allocation during a crisis.(34) Moreover, with a governance framework at the facility, district, state, and national levels, the IT grid would provide the following functions and features (Figure 9):

- 7-day demand prediction tool to estimate the demand for medical oxygen and different types of hospital beds (low flow vs high flow) based on the CAGR of data of the recent past. This could also notably act as an outbreak early warning system if demand considerably exceeds predicted trends.
- Cost comparison tool for optimal utilization of oxygen sources such as LMO, PSA plants, and cylinders.
- Oxygen metric unit conversion tool to report demand/supply/consumption in metric tonnes (MT) or any other desired metric system.
- Differences in estimated vs actual consumption tool to promote rational use of oxygen.
- Global capacity building repository tool on clinical and technical aspects of medical oxygen.
- Decision analytics tool to support asset allocation and patient management.

In addition, to further improve data entry on the NMOG portal, the following features have been included:

- Accessibility from desktop or laptop, and also from a phone app (both android and iOS version).
- Supports data entry in offline mode through a phone app when internet connection may not be temporarily available; however, would need internet connection before the end of the day for submission to the main server else the data for the day would be marked as blank.
- Concept of Master-Satellite data entry operator has been implemented: Master data entry operator: Would review, validate and submit the data to the main server. Can also enter the data. Can create and delete multiple satellite data entry operators each of whom would be tasked to manage an oxygen asset(s) or a ward(s) in the hospital. Satellite data entry operator: Would enter and submit data for asset(s) being managed by them.

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Metrics	ODAS	OCMIS	NMOG
Technology			
Intuitive user interface			✓
Master-satellite users			✓
Personalised GUI			✓
Web portal	✓	✓	✓
Phone app		✓	✓
Features & Functions			
Facility profile creation	✓	✓	✓
Oxygen infrastructure management	✓	✓	✓
Bed infrastructure management	✓		✓
Disease-wise patient management			✓
Mock drill management		✓	✓
Supplier management		✓	✓
Order placing & management (demand side)	✓	✓	✓
Order placing & management (supply side)			✓
Predictive analysis of oxygen demand, bed demand and disease-specific patient caseload			✓
Decision analytics on asset allocation and patient management			✓
Oxygen source operational cost analysis tool			✓
Rational use of oxygen tool			✓
Oxygen unit conversion tool			✓
Oxygen knowledge products repository			✓
Map based data visualisation			✓
Help & support			
User manual	✓	✓	✓
Video tutorial			✓
Accessible technical support/ grievance redressal mechanism		✓	✓

Table 3: Comparison of NMOG IT platform with the oxygen management systems used during COVID-19 in India

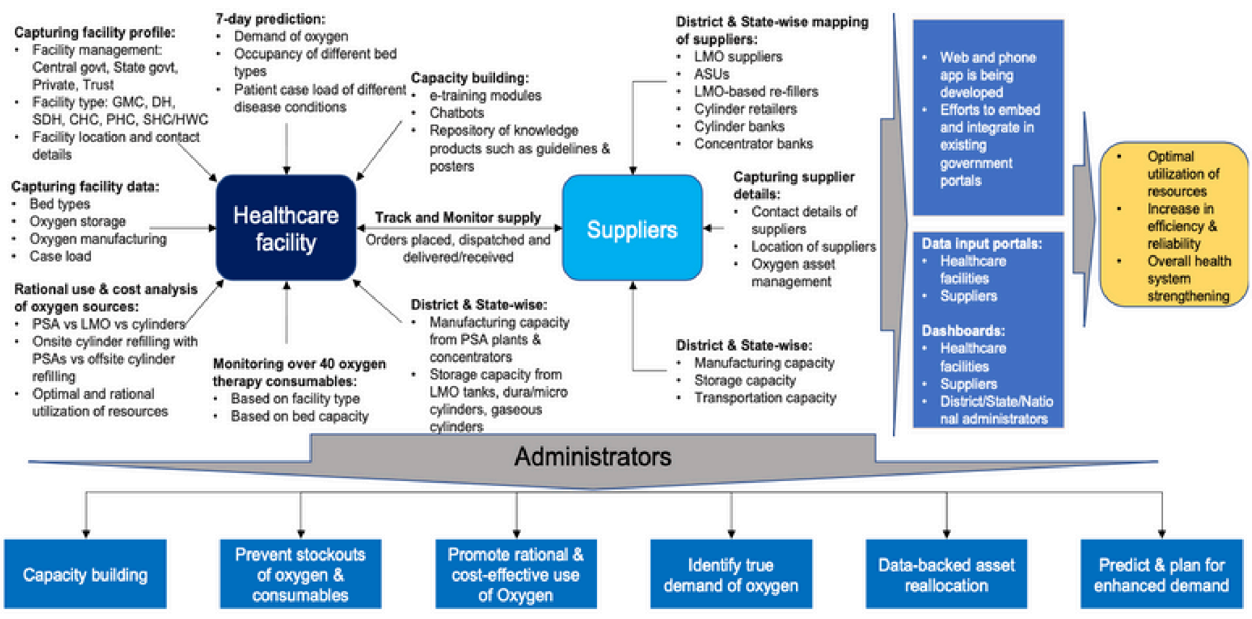

Figure 9: NMOG's functions and features

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Additional methods information

Academic and grey literature were screened. The grey literature sources searched were: Government of India circulars, notifications, press releases, advisories, public orders, regulations and guidelines, reports (or data) from MoHFW website, World Bank, UNICEF, WHO, and other development organisations.

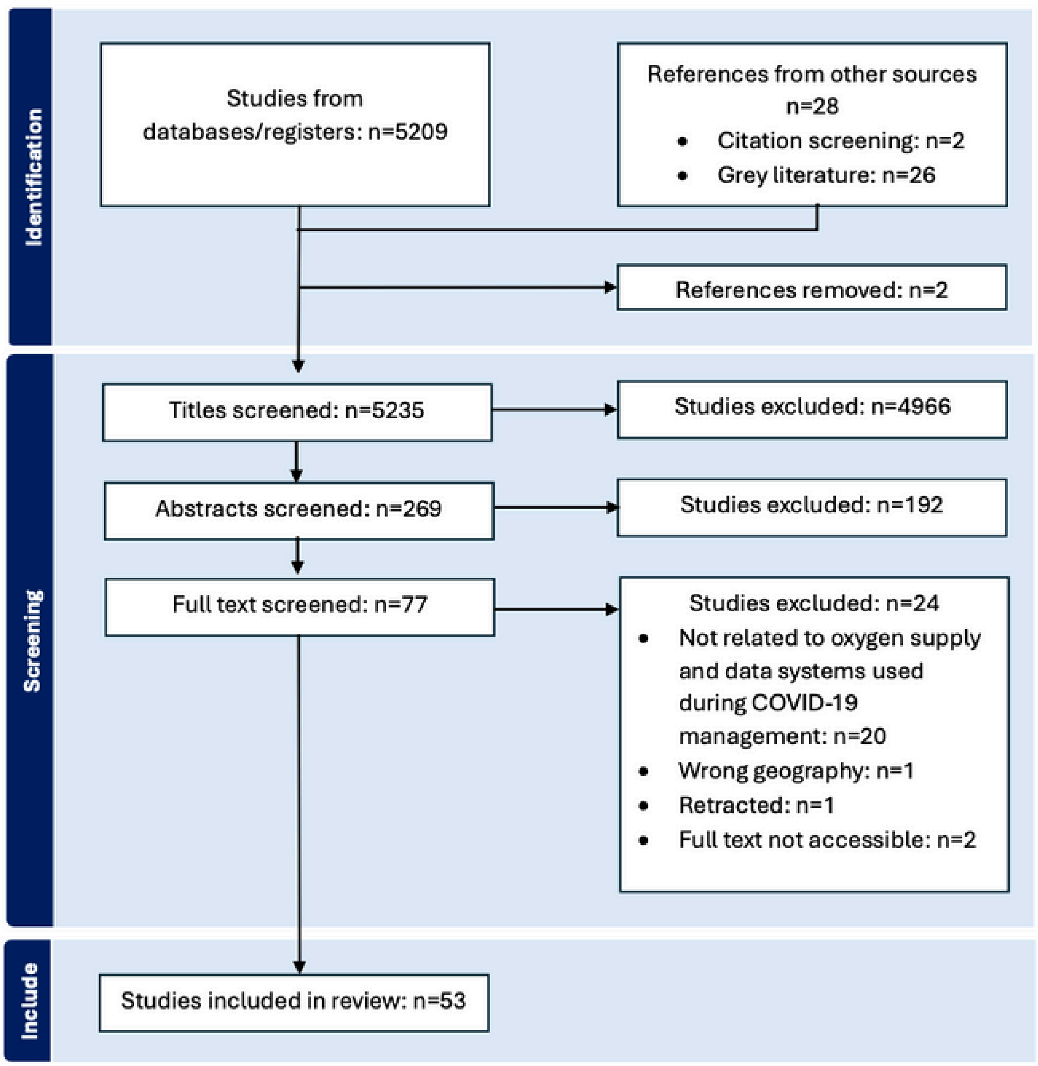

Figure 10: Academic and grey literature inclusion

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Appendix I: Digital solutions used in Kerala for COVID-19 management

#	Solution name	Description	Solution type
1.	Arogya Mitra	Provides information on Kerala's COVID-19 response activities	Web portal
2.	Arogya Setu	Provides information on risks, best practices and relevant COVID-19 advisories	Mobile app
3.	Arogyakeralam	Kerala's National Health Mission (NHM) portal, which includes COVID19 related information	Web portal
4.	BeSafe Tracking	Tracks an individual by device/phone Global Positioning System (GPS)	Mobile app
5.	BlueTeleMed	Tele-counselling and telemedicine	Mobile app
6.	Break the Chain campaign	Conveying important COVID-19 containment messages through animation	Online campaign
7.	Break the Chain diary	Presents a route map of places visited	Mobile app
8.	Chiri (smile) telecall	Tele-counselling for children's mental health involving frontline health workers (ASHAs, Anganwadi workers)	Helpline/tele-call
9.	CoronaSafe Network—quiz	A multilingual quiz on COVID-19 myths and protective measures	Web portal
10.	CoronaSafe Network	An open-source disaster management platform	Web portal
11.	Covid Safety	Bluetooth and GPS-enabled tracker to track proximity to a COVID-19 positive person	Mobile app
12.	COVID-19 Jagratha	Real-time surveillance, care and support for people affected or quarantined by COVID-19	Mobile app/ web portal
13.	Department of Health & Family Welfare	Information on state health department activities, data visualisation on COVID-19 status, online training modules and communication material	Web portal
14.	DISHA-1056	A toll-free 24/7 telehealth helpline providing physical and mental health guidance, counselling, and information	Web portal/helpline
15.	Doctor just a phone call away	Tele-counselling and telemedicine for police personnel	Helpline, WhatsApp or video consultation
16.	Emergency Response Support System 112 Service	Provides rapid assistance in response to citizen 'distress signals' in the form of voice calls, SMSs, email, and web requests	Helpline
17.	eSanjeevani OPD	National tele-consultation service	Mobile app/web portal
18.	GoK Dashboard	Government of Kerala dashboard visualising COVID-19 status including daily reporting, quarantine report, test results and hot spots	Web portal
19.	GoK- Direct Kerala	Shares announcements, updated guidelines, and safety tips for visitors to Kerala	Mobile app
20.	Kerala Battles COVID	Consolidation of COVID-19 management updates for public accessibility	Web portal

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21.	Kerala Health Disease Surveillance	Disease surveillance app using phone location; also provides awareness on COVID-19	Mobile app
22.	Kerala Police Home Quarantine Assistance	Coordinates the delivery of non-clinical services to people	Mobile app
23.	Kerala Sannadha Sena (volunteers)	Enrols and coordinates community volunteers	Mobile app/web portal
24.	Kerala Superhero app	Tracks the near real-time location of volunteer assets like ambulance drivers, delivery crews and medical personnel	Mobile app
25.	Koode	Enables people under home quarantine to self-report and collate health details daily	Mobile app
26.	Koode helpline	Tele-counselling by Ayurveda doctors	Helpline
27.	Local self-government Kerala pandemic dashboard	Provides information on local government COVID-19 activities and services	Web portal
28.	Ottakkalla Oppamundu ('not alone with you')	Provides psychosocial support to children	Helpline
29.	People Move	Tracks and delivers non-clinical services to people	Mobile app
30.	Pol-App	Kerala police information programme	Mobile app
31.	PRASANTHI	Free service provision or directory	Helpline
32.	Project Eagle Eye	Drone tracking of lockdown violations	Drones
33.	Shops app	Online shopping	Mobile app
34.	WhatsApp chatbot	Provision of COVID-19 information and directory to services	Mobile app
35.	Kerala health online training	Educational videos about COVID-19 on YouTubes	Mobile app/web portal

ASHAs: accredited social health activists; SMSs: short message services.

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THE LANCET Global Health

COMMISSION ON MEDICAL OXYGEN SECURITY

ABOUT THE COMMISSION

Announced in September 2022, *The Lancet Global Health* Commission on Medical Oxygen Security provides a thorough exploration of medical oxygen coverage gaps, with recommendations to ensure that no patient dies for lack of access to this essential medicine, including during public health emergencies like COVID-19.

The Commission was led by 18 Commissioners - multi-disciplinary academics with clinical, economic, engineering, epidemiological, and public policy expertise - representing all regions of the world. Forty Advisors representing United Nations and global health agencies, donors, academic institutions, and non-governmental organizations provided guidance. A large global network of Oxygen Access Collaborators provided constant input to the Commission and included representatives from industry and Ministries of Health. Special consultations were conducted with patients, caregivers, and clinicians to ensure that their voices and experiences shaped the Commission's recommendations.

An Executive Committee coordinated the work of the Commission and included representatives from **Makerere University**, Uganda; **International Centre for Diarrheal Disease Research** (icddr,b), Bangladesh; **Murdoch Children's Research Institute** (MCRI), Australia; **Karolinska Institutet**, Sweden; and **Every Breath Counts Coalition**, USA.

You can find the Commission report here and the advocacy package here, including:

- ***Report with Comments***
- ***Policy Brief (English, French, Spanish, Arabic, Chinese, and Russian)***
- ***Spotlight Brief: Access to Medical Oxygen Scorecard ($ATMO_2S$)***
- ***Spotlight Brief: Patient and Caregiver Testimonials***
- ***Spotlight Brief: 10 Oxygen Coverage Indicators***
- ***Spotlight Brief: 20 Priority Areas for Oxygen Innovation***
- ***Country Case Studies***

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