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Gaps in Critical Care Infrastructure in Indian Hospitals: Disparities in ICU Bed Availability, Ventilator Access, and Trained Healthcare Workforce Across Urban and Rural Settings

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ABSTRACT: Access to life-saving services is uneven and critical care infrastructure is a vital component of an effective healthcare system in India. This review identifies the differences between urban and rural healthcare facilities, which include the availability of intensive care unit (ICU) beds, mechanical ventilators, oxygen systems and trained healthcare professionals. Published studies, hospital surveys, professional guidelines and health systems research were conducted to evaluate infrastructure availability, capacity of the workforce, financial accessibility and referral systems. The review reveals significant geographical inequalities in critical care capacity, with a common finding of a lack of available functional ICU beds, ventilators, intensivists and specialised nursing staff in the rural and district hospitals.

The COVID-19 pandemic also revealed the vulnerabilities of the oxygen supply chain, the availability of equipment and trained staff, and the level of preparedness for emergencies. The findings also suggest that the availability of infrastructure is not enough without proper staffing, infrastructure maintenance, vital supplies, and supporting services to provide effective critical-care facilities. Interventions like tele-intensive care, hub and spoke referral systems, simulation training, and standardized infrastructure evaluations could help to enhance access. To improve critical care, a specific infrastructure investment is needed, and sustainable workforce development, reliable oxygen systems, integrated referral networks and continuous quality monitoring are essential. There is a need to coordinate policy responses to guarantee access to quality critical care for all, in a timely and economically sustainable manner, all across urban and rural India.

1. INTRODUCTION

Critical care medicine is an essential component of the care of patients with life-threatening diseases such as serious infections, respiratory failure, cardiovascular emergencies, major trauma, postoperative disease, and multiple-organ dysfunction. Intensive care units (ICUs) offer round-the-clock monitoring, dedicated nursing, advanced respiratory care, and integrated care by multiple medical disciplines (Christensen & Liang, 2023). These services, therefore, are a vital part of the healthcare system's preparedness and resilience.

India has many difficulties in providing equal access to critical care due to its large population, geographical diversity, differences in healthcare financing, and an uneven distribution of specialized medical facilities (Barik & Thorat, 2015). In the metros, the tertiary health facilities have grown, and the intensive care facilities are more technologically equipped, whereas in the rural and semiurban areas, they still rely on district hospitals and referral centers that have less capacity to provide intensive care facilities.

Differences in the distribution of ICU beds, mechanical ventilators, trained intensivists, and specialized nursing resources result in significant disparities in the capacity of hospitals to care for the critically ill patient. These differences can lead to late presentation, long interhospital transfers, financial difficulties and potentially preventable deaths.

There was significant variation in the extent of critical care infrastructure availability and capacity within a geographical study of critical care infrastructure in central India, indicating the need for geographical mapping and standardised critical care facility assessment (Joshi et al., 2017).

A nationwide ICU needs-assessment survey was then conducted, which revealed that the national situation was lacking 24-hour intensivist coverage, nurse staffing, and digital infrastructure. Only 57% of ICUs that participated in the survey indicated that an intensivist was physically available at all times during the day and night (Kashyap et al., 2020).

The COVID-19 situation further highlighted the gaps in the critical care system in India. The surge in respiratory failure created an unprecedented demand for beds, ventilators, oxygen, and trained healthcare workers in the ICU. Equipment procurement, mobilization of staff, infection prevention, and surge-capacity planning were challenges that hospitals faced (Tempe et al., 2020).

There are many other factors besides just ICU beds to consider when infrastructure is limited. To operate an ICU, there must be a constant power supply, medical oxygen, well-maintained equipment, lab assistance, trained staff, systems in place for infection prevention, and timely availability of essential drugs.

Especially in resource-poor environments, it is crucial to differentiate between capacity and functional readiness. An intensive care bed may not be of any real use as a critical care bed if there are missing personnel, equipment, or supporting services.

This concern is further validated by recent research which has measured hospital preparedness in various strata of the healthcare system in India. District hospitals had less emergency and critical care preparedness than tertiary hospitals, and staffing gaps and shortages of supplies were significant factors (Bhaladhare & Rishipathak, 2026).

The study explores structural and operational aspects of critical care inequality in India, including the lack of availability of Intensive Care Unit (ICU) beds, lack of ventilators, lack of critical care workforce distribution, and the rural–urban disparity. It also analyzes the role of financing, referral systems, pandemic preparedness, telecritical care, and health policy in promoting equitable access to lifesaving services.

2. OVERVIEW OF CRITICAL CARE INFRASTRUCTURE IN INDIA

2.1 Structure of the Indian healthcare system

Indian health system is structured into three tiers. The health care delivery system in India comprises public and private health providers at primary, secondary, and tertiary levels (Chokshi et al., 2016). Primary healthcare centers mainly provide preventive services, treat outpatients, provide health services for children and mothers, and treat common diseases. The community health centers and district hospitals offer increasingly specialized services, whereas medical colleges and tertiary hospitals offer more equipped diagnostic, surgical, and intensive care facilities.

There is also significant contribution by private hospitals, especially in urban and economically developed areas, regarding critical care. But access to private intensive care may be limited due to treatment costs, insurance coverage, and geographic concentration.

One of the biggest problems is the disparity in critical care-capable facilities at various levels of healthcare delivery (Soto et al., 2013). District hospitals might contain intensive care beds, but they have limited capacity for extended periods of invasive mechanical ventilation and advanced hemodynamic monitoring, or renal replacement therapy. In such cases, it is common for medically fragile patients to need to be transported to more advanced hospitals.

2.2 Levels of intensive care

The capacity to treat patients and their organ-support needs varies among critical care facilities. Indian Society of Critical Care Medicine (ISCCM) has suggested a staged plan for ICU planning, with varying grades of critical care that depend on the infrastructure, equipment, staffing, and services available (Rungta et al., 2020).

While lower-level facilities can stabilize and monitor a patient and offer limited organ support, advanced ICUs can offer more complex management of multiorgan failure and specialized interventions. For healthcare planning purposes, this classification is helpful since not all hospitals need the same kinds of hospital facilities. However, the classification of the hospital's category in the ICU should not be the sole criterion.

2.3 Functional readiness versus nominal infrastructure

Having an ICU bed doesn't mean a patient can be treated safely in an intensive care unit. Multiple interacting components must make a system functional:

- Appropriate bed space and continuous patient monitoring.
- Reliable oxygen, suction, electricity, and backup systems.
- Availability of respiratory support equipment.
- Trained medical and nursing personnel.
- Essential medicines, diagnostics, and infection prevention resources.
- Established referral and emergency response arrangements.

The cross-sectional study in 2026, which included 50 Indian hospitals and 600 respondents, had a median overall emergency and critical care readiness score of 0.46 on a scale of 0-1. The median was 0.62 for tertiary hospitals, 0.50 for secondary hospitals, and 0.40 for district hospitals (Bhaladhare & Rishipathak, 2026). The results indicate significant differences in readiness of the facilities but should not be taken to represent a nationwide sample of hospitals.

3. DISPARITIES IN ICU BED AVAILABILITY

3.1 National ICU capacity and measurement challenges

It is hard to arrive at an accurate estimate of the total number of functional ICU beds in India, as information is available in various administrative reporting systems, professional associations, and public and private hospitals. Variations in definitions of intensive care capacity are also seen in different studies. Some have high dependency beds, neonatal intensive care units, temporary pandemic beds, or beds not equipped with all organ-support systems. For this reason, published national estimates should not be regarded as interchangeable.

As reported in a comparative study with international countries, India has around 8.1 critical care beds per 1,000 deaths in their study, and there is a significant variation across the states. The study also estimated that around half of critical care beds had ventilators (Jones, 2022). The numbers shown here are meant to be compared to earlier years and are not intended to be an accurate count of the number of functional ICU beds in 2026.

3.2 Urban concentration of intensive care services

Metropolitan areas typically offer advanced, critical care services, as tertiary hospitals, medical colleges, specialist doctors, and investments in critical care medicine are more likely to be found in urban areas (Chawla, 2023). Delhi, Mumbai, Chennai, Bengaluru and Hyderabad have a large tertiary health care network, with accessibility being significantly different between different hospitals and different socio-economic groups. Access to specialized treatment for nearby populations can be improved by urban concentration. It also generates dependency on referrals over long distances for people living outside major cities.

Overcrowding is possible at large urban hospitals due to the transfer of very sick patients from neighboring districts. The estimated requirement of ICUs, identification of dedicated hospitals, availability of ventilators, and trained manpower were some major issues faced by Delhi during the COVID-19 pandemic (Tempe et al., 2020). This experience shows that an adequate health care infrastructure is not guaranteed in urban areas even when there is a significant amount of it.

3.3 Rural and district-level deficiencies

Smaller hospitals may lack specialists and advanced diagnostics, which can be a challenge for rural communities. Lack of staffing, financial resources, poor equipment maintenance, and the challenge of providing around-the-clock specialist services have been limiting the growth of critical care services in rural parts of India (Vaughan & Edwards, 2020).

A recent study that compared the installation of equipment in the rural ICUs with the better-equipped urban ICUs showed significant variations in the availability of qualified intensivists and the infrastructure of ICUs (Sandal et al., 2026). The review

also highlighted professional isolation, poor career incentives, and insufficient institutional support as factors for rural workers to stay on the job.

All these challenges suggest that increasing the capacity of rural ICUs will not just be about acquiring beds and equipment. Investment in staffing, technical support, and referral coordination is also essential for the long run.

3.4 State-level disparities

The population density, fiscal capacity, spending on healthcare, medical education capability, and the ratio of public to private healthcare vary considerably across states in India. So, critical care facilities are geographically distributed differently.

More advanced tertiary care networks in states could lead to better access to specialized care, while areas that have lower incomes and are further from metropolitan areas could have a higher burden. But comparisons must be based on population-adjusted indicators and on a common definition. The number of available ICU beds can be low in a particular state even if the state has a high number of beds. There were significant gaps in critical care infrastructure and workforce that were noted during a public sector need analysis, creating the need for state-specific planning instead of a national allocation (Prabu et al., 2023).

3.5 Public–private differences

Private hospitals make a significant contribution to critical care capacity, but are not evenly distributed and are not as affordable as public hospitals (Kamath et al., 2024). Patients in public hospitals often have limited financial resources, and public hospitals can be busy, often have competing service demands, and have limited budgets. There is some flexibility for private hospitals in sourcing equipment and in the recruitment of specialists, though this can differ greatly based on hospital size and location.

Having private ICU beds does not mean that they are actually accessible in an equitable fashion if hospitals are unable to accept patients or insurance is inadequate. Hence, physical availability should be differentiated from financial accessibility in capacity assessments.

4. MECHANICAL VENTILATOR AVAILABILITY AND RESPIRATORY SUPPORT

4.1 Importance of mechanical ventilation

Selected patients with severe respiratory failure, impaired airway protection, or other conditions that demand assisted ventilation require mechanical ventilation (Mao & An, 2026). Depending on the patient's condition and clinical requirements, ventilatory support can be invasive or noninvasive. The artificial airway needs to be managed and opened with invasive ventilation, which involves continuous monitoring.

The delivery is safe because of trained clinicians, respiratory care, sedation, infection prevention, oxygen supply, and quick identification of complications. Ventilator availability should thus be evaluated as a functional service, and not just as a number of ventilators.

4.2 Distribution of ventilators

Each hospital may have different numbers of ventilators depending on the level of the ICU, the budget for purchasing ventilators, technical infrastructure, and the number of staff members available. Advanced tertiary ICUs are likely to have more invasive ventilators and monitoring systems than smaller district-level ICUs.

Analysis of the capacity of critical care, which took into account the entire period, estimated that only about half of the critical care beds in India were equipped with a ventilator (Jones, 2022). But this is only an estimate and will not provide an accurate picture of the current distribution of working ventilators. A better current assessment on the site needs to be verified at the hospital level for installed devices, working condition, consumables, maintenance plans, and trained operators.

4.3 Ventilator shortages during COVID-19

During the pandemic, it became increasingly clear how demand for respiratory support can explode and the impacts this has.

A recent 2020 Indian review noted the lack of trained human resources, and the possibility for alternative manufacturing technologies to be used in ventilator supply chains (Iyengar et al., 2020). A separate modelling study predicted that ventilators and specialists who could operate them were key limitations during the expected surges of the pandemic (Chatterjee et al., 2020). However, these estimates were scenario-specific and do not necessarily represent current national shortfalls.

An increase in equipment without a corresponding increase in staffing could lead to minimal gains in functional critical care access at best.

4.4 Equipment maintenance and usability

Infection control measures, availability of compatible accessories, as well as regular ventilator servicing and calibration, are required (Ministry of Health and Family Welfare, Government of India, 2024). Circuits can be missing, sensors can fail, batteries can run out, or technical support could be weak or nonexistent, potentially making equipment unusable. The issues may be particularly challenging in remote hospitals, where biomedical engineers and authorized service providers are less readily available.

Maintenance contracts, spare parts, training of maintenance personnel, and the long-term operating costs should therefore be included in procurement policies. The working inventory of ventilators should classify items as immediately available, temporarily unavailable, under repair, or permanently retired.

4.5 Appropriate respiratory support systems

Not all patients with respiratory failure need to have an invasive ventilator. Oxygen therapy/high flow nasal oxygen/noninvasive ventilation should be offered if clinically indicated. However, there are different equipment, monitoring and staffing needs for these interventions.

When clinically required, facilities should not provide less intense respiratory support in place of invasive ventilation. It is important that there are still safe pathways to escalate and that there is early referral, especially to district hospitals.

5. MEDICAL OXYGEN INFRASTRUCTURE AND SUPPLY CHAIN VULNERABILITIES

5.1 Oxygen as a foundational critical care resource

Medical oxygen is essential to treat the hypoxemia of pneumococcal infection, ARDS, sepsis, trauma, and other severe diseases. Oxygen therapy is necessary in many settings of care, such as in the emergency department, general ward, operating theater, and intensive care unit, as opposed to mechanical ventilation. Oxygen can be purchased from hospitals in a variety of ways, including: liquid oxygen storage system, pressure swing adsorption plant, cylinder storage, and concentrator.

There are benefits and drawbacks with each method in terms of production capacity, maintenance, electricity, transportation, and operating cost. During the COVID-19 pandemic, the significance of reliable production, storage, and distribution systems for medical oxygen was highlighted in a review of medical oxygen sources and distribution (Ismail & Bansal, 2022).

5.2 Urban–rural differences in oxygen access

In large urban hospitals, oxygen pipelines may be centralized; there might be bulk storage systems and technical maintenance teams to handle the oxygen. Smaller hospitals may rely more on cylinders or oxygen concentrators, and may be most dependent on the availability of transportation, electricity, or equipment maintenance to these sources. Distance can make it difficult to deliver goods in time and make emergency replacement goods less accessible.

However, even if there is oxygen-generating equipment in place, it must be available on a continuous basis, which requires electricity, trained operators, preventive maintenance, and appropriate back-up. Thus, the planning of oxygen infrastructure should be based on the entire oxygen supply chain, not just the production equipment.

5.3 Lessons from the second COVID-19 wave

The second wave of the COVID-19 pandemic in India exposed the serious flaws in the medical oxygen supply chain.

It was reported that the country had a multi-sectoral response that involved augmenting oxygen production, coordination of transport, strengthening storage facilities and training programmes (Verma et al., 2023). During the oxygen shortage that occurred in the state of Karnataka in May-June 2021, the report showed that there were significant differences between oxygen supply and demand. It also highlighted failures in the supply chain and their significant clinical impact (Bhat et al., 2023). The experiences show that despite an increase in production capacity for the aggregates, oxygen shortages can occur if there are problems in the logistics and distribution process.

5.4 Oxygen system resilience

Demand forecasting, reserve capacity, emergency transportation plan, and preventive maintenance are all future oxygen preparedness elements. Hospitals should have policies in place to monitor oxygen consumption, detect leaks, establish backup policies, and act on equipment failures.

A recent study that analyzed the oxygen management challenges in Indiarevealed interlinked operational and organizational factors affecting oxygen availability (Singh et al., 2025). Rural facilities need to be given added priority if things happen to go wrong with their oxygen supplies, as there may be a delay in emergency oxygen being brought in.

6. SHORTAGES OF TRAINED CRITICAL CARE HEALTHCARE PROFESSIONALS

6.1 Intensivist availability

The intensivist is a trained and expert doctor in the care of the most seriously ill patients. Intensivists are responsible for making complex decisions about organ support, hemodynamic stabilization, managing infection, sedation, and multidisciplinary care.

Over the past few decades, the formal education of critical care has been expanded in India. However, the distribution of trained intensivists is not homogeneous. According to the ININ2018 survey, there were 135 ICUs, and only 77 of them had an intensivist around the clock (Kashyap et al., 2020). This finding suggests an important staffing deficit in the surveyed facilities, but does not directly apply to all Indian ICUs.

There are further recruitment difficulties rural hospitals encounter, including lack of professional development opportunities, smaller teams of specialists, inadequate infrastructure, and family or personal factors.

6.2 Critical care nursing shortages

Critical care nurses play a vital role in monitoring, administering medications, caring for the ventilator, preventing infections, and identifying patient deterioration quickly. Staffing of nurses is determined by the level of acuity of the patients being cared for, the complexity of their treatments, and the availability of other staff to support.

Historically, intensive care services were found in large urban hospitals, and the need for expanded intensive care nursing education remains (Gnanadurai, 2021). The ININ2018 survey showed that around 50% of the ICUs that participated indicated that their patient-to-nurse ratio was 2 or higher (Kashyap et al., 2020). This finding presents a challenge to staffing levels, especially for patients needing ongoing organ support.

Staffing ratios must be correlated, however, with severity of patients, shift patterns and institutional care models.

6.3 Burnout and workforce retention

A critical care environment can be defined as one with high clinical acuity, complex decision-making, emotional stress, and demanding schedules for the critical care professional.

In a tertiary hospital in South India, 204 health care professionals participated in a cross-sectional study which showed high burnout rates, but the results were not nationally representative (Saravanabavan et al., 2019). A study conducted among the nurses in the ICU revealed that 37.6% of the respondents had high burnout. Increased risk of burnout was associated with lack of specialized ICU training and additional duty hours (Sinha et al., 2021). The results show that psychological well-being, staffing, professional recognition, and working conditions are areas that need to be addressed to ensure workforce sustainability.

Increasing the number of training opportunities without an increase in retention may have limited long-term effects.

6.4 Respiratory therapists and allied health professionals

Respiratory therapists, physiotherapists, clinical pharmacists, biomedical engineers, laboratory workers, and infection prevention workers are all essential to critical care delivery (Rungta et al., 2020). Depending on their qualifications and institutional responsibilities, respiratory care practitioners can take part in ventilator management, airway clearance, respiratory monitoring, and weaning protocols.

Biomedical Engineers assist in equipment maintenance and technical safety. Clinical pharmacists provide support for optimising medicines, and physiotherapists support with mobilising and rehabilitating. These jobs are especially significant in

technologically sophisticated ICUs. Smaller hospitals, on the other hand, might only be able to employ a few allied health workers and thus burden doctors and nurses even further.

6.5 Workforce education and competency development

The healthcare professional needs to be equipped with skills that will enable them to manage the airway, monitor the heart and blood vessels, prevent infections, respond to emergencies, and communicate effectively. Simulations can offer an opportunity to rehearse high-risk procedures and multi-disciplinary responses without putting patients at risk. In order to allow for the implementation of competence-based education, there needs to be initial assessment, supervised practice, refresher training, and periodic reassessment.

In the ISCCM position paper on basic critical care in the COVID-19 pandemic, it was advocated that there is a need for standardized approaches that are suitable for resource-limited environments (Juneja et al., 2020). These can be used to guide training for district hospitals, but should be more than just clinical protocols for pandemics.

7. RURAL–URBAN INEQUITIES IN CRITICAL CARE ACCESS

7.1 Geographical barriers

Access to emergency treatment is heavily impacted by geographic distribution of healthcare facilities. Invasive ventilation and/or advanced organ support may be required in hospitals located far away from rural and remote areas. Mountain areas, tribal areas, flood-prone districts, and areas of low road access can be important travel barriers. A delay in referring the patient may lead to worsening clinical status until definitive care is offered. Thus, critical care access ought not to be determined solely on the basis of the number of beds available in an administrative district but also on the basis of travel time and the capability for referral.

7.2 Differences in Hospital Readiness

A recent nationwide cross-sectional study evaluated emergency and critical care readiness in 50 hospitals spread throughout India. The results showed that there was a significant difference in the level of operational preparedness between tertiary, secondary, and district-level healthcare facilities.

On a scale of 0-1, tertiary hospitals reported a median readiness score of 0.62, secondary hospitals scored a median of 0.50, and district hospitals scored a median of 0.40. 72% of the hospitals that participated reported that they had personnel shortages, 68% reported essential supplies stock-outs, 66% reported insufficient training, and 56% reported infrastructure limitations (Bhaladhare & Rishipathak, 2026). The results show significant differences in the level of critical care readiness present throughout the health care system. Targeted infrastructure development, workforce development, and better resource allocation were highlighted in the district hospitals, which showed comparatively low readiness.

Importantly, these scores do not report the intensity of emergency critical care or the number of deaths in the ICU, but are rather an indicator of preparedness for emergency critical care. The study also compared the levels of the hospitals instead of measuring the difference between rural and urban.

7.3 Referral pathways and emergency transportation

Good referral systems link facilities to higher-level facilities that offer advanced treatment. An effective referral pathway involves early identification of critical illness, stabilisation prior to transport, liaison with the receiving hospital, and having the right ambulance resources. Transfer delays can occur due to insufficient beds at referral hospitals, lack of necessary equipment on the ambulance, or poor communication with the hospital.

India has fragmented emergency care, which is spread across multiple levels of healthcare. The implementation research protocol for INDIA-EMS suggests a hub-and-spoke model with hospitals in tertiary and peripheral facilities in selected districts (Ayyan S et al., 2025). The protocol doesn't define effectiveness, but rather a methodology for the assessment of integrated emergency care systems.

7.4 Financial barriers

High cost of interventions, hospitalisation, medication, diagnostics, and post-discharge rehabilitation is common in critical illness. The cost of treatment can be a major financial burden or can mean that a household is not admitted to the hospital even when they are needed.

Financial difficulties can remain even if a hospital is accessible. Eligibility, coverage of services, hospital participation, and administrative implementation of public insurance and government-funded health insurance programs can enhance access. Therefore, in planning for critical care, affordability is also a factor of critical care planning that needs to be addressed in an equitable way.

7.5 Social and demographic inequalities

Access to intensive care may also differ by socioeconomic position, disability, gender, age, and social marginalization. Those with limited knowledge of health or financial means might not notice when they are having serious health problems or get a proper referral. But definitive measures of these differences await representative patient-level studies. However, future research needs to explore the interplay between geographical barriers, income and social disadvantage, as well as insurance coverage.

8. LESSONS FROM THE COVID-19 PANDEMIC

8.1 Sudden increases in critical care demand

Suddenly, the COVID-19 pandemic has created an unprecedented need for respiratory support, oxygen, Intensive Care Units (ICUs), and trained healthcare personnel. Healthcare systems struggled to anticipate surges in patient numbers and their severity.

India faced a deficiency of resources in critical care delivery during the pandemic, as highlighted in a review of the critical care delivery challenges in India (Tirupakuzhi Vijayaraghavan et al., 2021). The experience highlighted the need to plan for a demand that has a significant deviation from the normal occupancy of hospitals.

8.2 Surge capacity and temporary infrastructure

Hospitals increased their critical care capacity, mobilizing wards, creating makeshift intensive care units, and redistributing critical care equipment. However, increased bed numbers didn't always mean increased high-quality intensive care bed numbers. To set up temporary facilities, oxygen pipelines, monitoring devices, infection prevention programs, and trained personnel were needed.

A review articulating the preparation of the ICU in low-resource environments highlighted the need for space, equipment, staff protection, and training to be coordinated (Kajal et al., 2020). These lessons continue to be applicable in preparation for future outbreaks of infectious diseases and other mass-casualty situations.

8.3 Resource allocation and ethical considerations

In times of extreme scarcity, tough choices will have to be made about access to lifesaving interventions. Ethical allocation frameworks need to focus on clinical need, clear criteria, fairness, and uniformity. Decisions must be made without considering things like social status, wealth, disability stereotypes, or other irrelevant facts. The pandemic also demonstrated the need to ensure healthcare workers' safety and the provision of essential non-COVID services during emergencies.

8.4 Sustainable preparedness

Preparing for a pandemic should not be seen as a special procurement. Pandemic preparedness is to be integrated into the process of strengthening routine health care, not left to a special procurement. Equipment bought in the crisis needs continuous maintenance and integration into clinical services.

Training must also be ongoing following the end of the emergency. Assessment of ability to safely expand capacity, monitoring of the supply chain, and regular drills should be part of preparedness planning.

9. EMERGING STRATEGIES FOR STRENGTHENING CRITICAL CARE INFRASTRUCTURE

9.1 Tele-intensive care services

Tele-intensive care (tele-ICU) involves using telecommunications and digital monitoring to assist healthcare teams at remote hospitals with intensive care services. Some possible services are remote patient assessment, physiological data interpretation, clinical decision support, staff mentoring, and escalation decision support. This may be especially useful in rural hospitals where maintaining continuous intensivist coverage may be challenging.

A study of the implementation of tele-ICU in rural hospitals around the globe confirmed perceived benefits related to expert consultation, consistency in care, and the possible reduction in transfers to tertiary care (Goedken et al., 2017). The study was not done in India, but the lessons learnt are relevant to implementation in India.

Tele-ICU should not be considered a substitute for competent bedside clinicians. Airway procedures, emergency medications and equipment failures may not be performed by a remote specialist without assistance. Reliability of connectivity, training of local staff, clinical governance and clear responsibilities are essential elements to successful implementation.

9.2 Hub-and-spoke critical care networks

A hub-and-spoke system links tertiary and district/periphery hospitals. In such a system, more complex specialist care can be done at larger facilities, and more basic care can be done at smaller facilities that have the capacity to stabilize, provide some more complex care, and then refer patients on for appropriate follow-up.

Possible benefits are better referral coordination, sharing of training materials, and the more effective use of specialist services. But, too much centralization in a hub-and-spoke arrangement may be detrimental because peripheral hospitals may not be able to handle common emergencies. The model should have a strong focus on building district-level capacity and access to tertiary expertise.

9.3 Modular critical care infrastructure

In an emergency, modular ICUs could give the hospital the space it needs. These can include standardized monitoring systems, medical gas infrastructure, infection prevention systems, and adaptable clinical areas.

Modular construction, however, isn't necessarily economically viable or clinically adequate. Hospitals need to have trained staff, the right equipment, and support services in place in expanded facilities. A flexible infrastructure that can be used for routine clinical requirements and can be expanded during emergency situations may be the most sustainable option.

9.4 Simulation-based workforce development

Training in airway management, cardiopulmonary resuscitation, sepsis recognition, and multidisciplinary communication can be enhanced with simulation, as can training in ventilator emergencies. There is the possibility of imparting hands-on training to doctors, nurses, and other health professionals in district hospitals at regional training centers. Mobile simulation teams and blended learning can be used to help with getting to remote facilities. Attendance should not be the only way to assess training programs. Attendance should not be the only criteria for assessing training programs.

9.5 Strengthening neonatal and pediatric critical care

Another factor which needs to be considered in critical care planning is the need for different equipment and different staffing needs when dealing with newborns and children. While the provision of good equipment and training of specialists were identified in a nationwide survey of neonatal intensive care units in India, poor capacity and staffing were still a concern (Sundaram et al., 2014).

The monitoring, respiratory, and medication systems, and skills needed in neonatal and pediatric critical care must be age-appropriate. The service disparities between rural and urban areas are in need of specific evaluation, as the level of adult ICU care cannot be directly substituted.

10. POLICY AND HEALTH SYSTEM INTERVENTIONS

10.1 Standardized ICU infrastructure requirements

Clear definitions of the capacity and functional readiness of ICUs at the national and state level should be adopted. Standardized assessments should be able to differentiate physical beds, staffed beds, operating ventilators, and beds that are able to deliver specific organ-support services.

An important framework to define ICU levels and plan infrastructure is presented in the ISCCM consensus statement (Rungta et al., 2020). But to make the standards effective, there has to be monitoring, funding, and technical assistance.

10.2 Targeted investment in underserved districts

Infrastructure investment needs to be proportionate to the population size, disease burden, travel time, existing services, and referral capacity. Improving the distribution of equipment could not necessarily help to reduce geographical inequities.

Local planning should recognise the district-level facilities that would yield the best improvement in time to access critical care. Funds invested in capital should be correlated to sustainable operating budgets for staffing, consumables, maintenance, and quality assurance.

10.3 Workforce recruitment and retention

The policies that can be used to increase the availability of rural workers include financial incentives, career ladders, housing assistance, continuing education, and professional mentoring. Typical deployment of specialists should be backed up with effective equipment and multidisciplinary teams.

Rural hospitals may find it difficult to keep the professionals if they cannot practice safely or keep up their clinical skills because of infrastructure issues. Working conditions and professional development, then, should be the focus of retention policies, not salary.

10.4 Public–private coordination

Public-Private Partnerships can help in supporting the availability, training, and coordination of specialists and preparedness for emergencies. But these agreements must be price transparent, involve quality requirements, be accountable, and avoid unfair patient selection.

Agreements should specify services rendered, how to be reimbursed, clinical roles, and measures of success. The goal is not to simply boost the number of hospitals participating; it is to greatly enhance the population's access to the hospitals involved.

10.5 Critical care information systems

A national or interoperable state-level critical care information system can improve visibility into functional capacity. Relevant data that should be included would be the number of beds in operation, number of ventilators available, staffing, amount of oxygen on hand, and the referrals. These systems could be used to assist with planning during normal operations and emergencies. Digital registries, however, need to be accurate to enter, validated, secure in the privacy of the data, and have a clear description of responsibilities when operating them.

11. MEASURING CRITICAL CARE EQUITY AND SYSTEM PERFORMANCE

Measuring critical care inequality will need indicators measuring capacity, accessibility, readiness, and patient outcomes.

Table 1. Indicators for measuring critical care inequality

Domain	Proposed indicator	Relevance
ICU infrastructure	Functional ICU beds per 100,000 population	Population-adjusted capacity

Ventilator access	Operational invasive ventilators per 100,000 population	Respiratory support availability
Workforce	Intensivists per 100 staffed ICU beds	Specialist staffing
Nursing	Patient-to-nurse ratio by acuity and shift	Bedside care capacity
Geography	Travel time to the nearest functioning ICU	Physical accessibility
Affordability	Patient out-of-pocket expenditure for critical care	Financial access
Oxygen	Duration of available oxygen reserve at projected demand	Supply resilience
Referral	Time from referral decision to definitive critical care	System coordination
Quality	Risk-adjusted ICU mortality and complications	Clinical performance
Readiness	Standardized facility readiness score	Operational capability

11.1 Geographic accessibility analysis

GIS can be used to calculate the travel time for communities to reach operational critical care facilities (Haynes et al., 2006). This can be a more accurate way of identifying underserved areas than counting the number of beds in a district alone. Road conditions, ambulance availability, seasonal disruptions, and referral hospital capacity should be considered when modeling travel times.

11.2 Workforce-adjusted capacity

The number of available beds in an ICU can be significantly lower than the actual number of physically occupied beds in a hospital if the bed is not staffed. There are workforce-adjusted indicators that can be used to differentiate between installed infrastructure and operational services (Wang et al., 2026). No one staffing formula is suitable for all ICUs; however, due to the variation in the acuity of patients and the complexity of services offered.

11.3 Quality and patient outcomes

In the end, expansion of infrastructure should positively impact clinically meaningful outcomes. These measures are all related to the risk of dying, complications that could have been prevented, time between diagnosis and treatment, rate of infection, and functional outcomes at discharge. Comparisons between hospitals should consider the differences in case mix, referral patterns, and the level of severity of patients. Otherwise, hospitals treating the sickest patients may appear to perform poorly despite delivering high-quality care.

11.4 Surge-capacity assessment

Rapidly expanding safe critical care services in hospitals is an essential part of emergency preparedness.

In India, pandemic modelling studies showed that if a certain transmission scenario is assumed, the number of patients will outnumber the number of beds and ventilators available (V. R. Verma et al., 2020). These estimates were based on the assumption that took place during 2020, and are not to be understood as current nationwide deficit. However, they show how vital scenario-based preparedness planning is.

12. COMPARATIVE ANALYSIS OF URBAN AND RURAL CRITICAL CARE INFRASTRUCTURE

Table 2. Comparison of Urban and Rural Critical Care Infrastructure

Critical care component	**Common advantages in major urban centers**	**Common challenges in rural and peripheral settings**
ICU beds	Greater concentration of tertiary and specialty facilities	Limited availability of advanced intensive care
Mechanical ventilators	More specialized equipment and technical support	Equipment shortages, servicing difficulties
Intensivists	Greater specialist workforce concentration	Recruitment and retention barriers
Critical care nurses	More opportunities for specialized training	Limited access to dedicated critical care education
Medical oxygen	Greater access to centralized storage and pipelines	Dependence on cylinders, concentrators, and transport
Advanced diagnostics	Greater availability of laboratory and imaging services	Delays and dependence on referrals
Emergency transport	More developed networks in many urban areas	Longer distances and variable ambulance availability
Telecritical care	Better connectivity and specialist networks	Connectivity, staffing, and infrastructure limitations
Affordability	More provider options but potentially high private costs	Fewer alternatives and substantial referral expenses
Surge preparedness	Greater potential for resource mobilization	Limited reserve capacity and technical support

These are general trends and not common traits. There can be significant barriers to use, including cost, overcrowding, and service availability, for urban patients and, conversely, rural hospitals may perform better than less well-resourced urban hospitals.

12.1 Prioritizing investments according to local need

When designing a practical investment strategy, one needs to take into account the existing level of critical care capacity, the population served by the critical care and the sustainability of critical care services (Nandy, 2025). Instead of investing in complex machines, for some district hospitals, providing a reliable oxygen supply, trained emergency teams, and effective referral arrangements can provide more immediate benefits.

For larger secondary hospitals, the next step might be to increase the number of monitored beds, respiratory care, and 24-hour nursing services. Tertiary hospitals might need to enhance their advanced organ support, improve the availability of specialists and the quality of care, as well as coordinate with peripheral hospital care units. This layering system may help to eliminate the duplication of unnecessary infrastructure and enhance the continuity of care.

12.2 Procurement and equipment lifecycle management

Purchase equipment that meets clinical needs and is likely to be used for a long time.

A scoping review of the procurement and distribution of ventilators during COVID-19 identified challenges in the supply chain and strategies employed during periods of severe shortage (D. Wang et al., 2025). The lessons from the review are applicable to Indian hospital procurement systems, despite the fact that it is based on evidence from around the world.

The true cost of ownership should be considered at the hospital level, and should comprise installation, training, consumables, servicing, calibration and replacement. The number of devices acquired should not be the sole focus of procurement success; rather, functional availability and clinical utility should be used as the metric.

13. LIMITATIONS AND CHALLENGES

Although research related to critical care infrastructure in India has gained momentum over the past few years, various methodological, structural, and operational limitations limit the assessment of critical care infrastructure, particularly for rural-urban disparities. One of the most serious difficulties is the lack of a regularly updated, nationally representative database of the number of functional ICU beds, ventilators, oxygen systems, and trained critical care personnel in public and private hospitals throughout the country. Current studies often take place during a pandemic or use hospital surveys, administrative records, professional networks, or surveys, and may not accurately reflect current capacity.

In addition, there is variation in the definition, which further complicates comparisons. Some investigations include intensive care beds as well as high dependency, temporary critical care beds; others don't separate installed from operational resources. This can lead to an overestimate of the number of patients that can safely receive advanced organ support, as reported capacity.

Another weakness is that the representations are geographical. Published research often disproportionately represents urban tertiary hospitals, while geographically remote, rural and tribal hospitals are underrepresented. There are also differences in the quality of clinical outcomes, as well as in the degree of severity of patients and referral patterns between hospitals, which further restrict direct comparisons.

The same issues arise with workforce assessments where professional registration does not necessarily reflect current critical care activity and/or location. Furthermore, there is a lack of information regarding shift coverage, nursing competency, and allied health staffing, which impedes assessment of functional readiness.

There is additional complexity due to financial and unofficial referral systems, and different insurance plans. There are numerous existing studies available, but few are longitudinal in nature and can make causal inferences between lack of infrastructure and death.

Standardised definitions, representative facility surveys, long-term monitoring of the workforce, geographical access analyses and patient outcome registers are needed to address these limitations. These enhancements are vital to support the creation of fair and valid evidence to inform critical care planning and allocation of resources.

14. FUTURE PERSPECTIVES

To build the critical care infrastructure in India in the future, the following aspects should be kept in mind: Geographical distribution, functional preparedness, sustainability of the critical care workforce, and integrated emergency healthcare delivery. A national critical care registry would be a significant step forward, as it would allow for ongoing data collection on the state of critical care facilities, including the number of beds available, the availability of ventilators and oxygen, the number of specialists on call, and the capability for referrals. This data could be used to inform resource allocation decisions and to identify areas where resources are not being fully utilized.

The provision of district-level critical care services should be supported by investments in the provision of reliable electricity, medical oxygen systems, biomedical maintenance, essential diagnostic systems, and multidisciplinary staffing. Future planning should not attempt to duplicate tertiary hospital infrastructure across the board, but rather develop tiered service networks which can stabilize, support organ function, and refer promptly to appropriate tertiary hospitals.

Tele-intensive care gives a chance to share special expertise in remote hospitals. The use of EMRs, remote monitoring, and structured clinical communication can enhance coordination, but efficacy needs to be assessed by patient outcomes and cost-effectiveness studies.

Workforce development will continue to be a key priority. Train intensivists, nurses, and allied health professionals more extensively in critical care, use simulation education, incentivize critical care professionals to stay in rural areas, and provide professional support programs to enhance the supply of these providers. Special emphasis should be placed on burnout prevention and ongoing competency development.

Longitudinal and nationally representative datasets should be used to explore geographical accessibility, financial protection, treatment delays, and risk-adjusted clinical outcomes in future research. Predictive modeling can also be used to assist with surge preparedness and equipment planning.

Sustainable improvement will take place through the coordination of several actors such as government agencies, professional societies, educational institutions, hospitals, and communities. Policies should focus on tangible improvements in timely, affordable, and safe critical care, not just on the expansion of infrastructure.

15. CONCLUSION

The health system in India has grown significantly, and there is significant disparity in the availability of and access to critical care services. ICU bed distribution, access to mechanical ventilators, medical oxygen infrastructure, and trained healthcare workforce are some of the factors that cause unequal treatment opportunities between urban and rural areas. Geographical concentration of tertiary hospitals, inequitable public investment, staffing shortages, financial outliers, and disorganized referral systems are key factors that affect these disparities.

The evidence that has been reviewed suggests that physical infrastructure is not enough to ensure effective delivery of critical care. Properly trained physicians and nurses, reliable respiratory support, continuous monitoring, essential diagnostics, equipment maintenance, and coordinated clinical management are essential for a functional and well-equipped ICU. District hospitals and peripheral hospitals often experience problems maintaining these synergistic resources, thus requiring greater reliance on higher-level referral hospitals.

COVID-19 has exposed gaps in surge preparedness, oxygen supply, ventilator procurement, and staffing. It also highlighted the need for collaborative resource management, flexible infrastructure, and swift training efforts.

To overcome these challenges, geographically specific investments, uniform infrastructure evaluation, better recruitment and retention of workers, and better emergency transportation systems are needed. Tele-intensive care, or hub-and-spoke models, can provide specialist assistance to facilities that lack it, but with sufficient bedside staffing and infrastructure.

Health system changes after that should include a strong critical care registry, population-based planning metrics, quality tracking, and financial safeguards. Special attention should be paid to service readiness as opposed to the number of beds available.

In summary, access to critical care in an equitable manner needs to be an integral part of India's mainstream policy to strengthen healthcare. Coordinated policies will also be necessary for sustainable progress, and will need to be responsive across the levels of healthcare delivery to the needs of infrastructure, workforce development, affordability and clinical quality.

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AUTHOR CONTRIBUTIONS

Taraka Nandmuri: Conceptualization, Investigation.

Taraka Nandmuri: Literature review and analysis

Taraka Nandmuri: Manuscript Drafting

Taraka Nandmuri: Supervision, Writing—Review & Editing

CONFLICT OF INTEREST

The author declares no conflicts of interest to disclose.

Ethics Statement

This manuscript is a literature-based review of previously published research and does not involve the recruitment of human participants, collection of primary patient data, or experimentation on animals. Therefore, institutional ethics committee approval and informed consent were not required for the preparation of this review.

Data Availability Statement

Data supporting the findings of this study are available from the corresponding author upon reasonable request.

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