Research Article

Enhancing Healthcare Access: Drone-based Delivery of Medicines and Vaccines in hard-to-Reach Terrains of Northeastern India

Abstract

Background: Ensuring efficient healthcare access in a geographically diverse country like India poses significant challenges, particularly in challenging terrains. Conventional transportation methods often encounter difficulties due to inadequate infrastructure and adverse climatic conditions, resulting in delays in medical supplies. This study aimed to assess the viability of drones for transporting various types of medical supplies across diverse geographical landscapes, also evaluating their impact on transportation time, covered distance, weight carrying capacities and safety of medical supplies.

Materials and Methods: The study spanned 4 months across 19 healthcare centres across Manipur and Nagaland. Different types of drones were used for the transportation of vaccines, medications and surgical items across these centres covering terrains such as flatlands, valleys, foothills, islands and hills.

Results: Drones were able to successfully transport the medical supplies maintaining the essential temperatures and integrity of the samples. Further, drone-based supplies significantly reduce the delivery time compared to conventional road-based delivery mechanisms.

Conclusion: The present study demonstrates the potential application of drones for the delivery of healthcare supplies in remote areas. Despite the logistical challenges, drones offer a time-efficient alternative for medical supply delivery. However, there is a need for further research and logistical infrastructure development in the current field.

Keywords: Difficult terrain, drone, healthcare delivery, India, unmanned aerial vehicles

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Introduction

A robust healthcare system must ensure universal access, affordability, accountability, quality care and attention to vulnerable groups. Timely delivery of medical supplies is crucial for effective healthcare delivery.[1] However, challenges such as difficult terrain, poor transportation infrastructure, limited cellular network coverage and adverse environmental conditions often lead to delays in the supply chain, potentially compromising the quality of healthcare deliveries.[2] In response to these challenges, researchers have begun exploring alternative delivery methods to complement existing supply chain mechanisms. Unmanned aerial vehicles (UAVs), commonly known as drones, have emerged as a promising technology to enhance healthcare logistics and transportation. With proven success in various sectors such as military operations, agriculture and food distribution, drones may offer a transformative solution for healthcare delivery.[3-8]

Experience from countries such as Nepal, Haiti and certain Caribbean islands has demonstrated the effectiveness of drones in delivering critical medical supplies during disasters and emergencies.[9-12] In resource-constrained settings such as Malawi and Rwanda, drones have expedited the delivery of essential medical items to remote areas, thereby reducing response times and saving lives.[13,14]

Despite the documented benefits of drone technology in healthcare delivery, there has been a notable absence of comprehensive scientific

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studies conducted in India to evaluate its utility across diverse climatic, operational and geographical conditions. Therefore, this study aimed to assess the feasibility of drones for transporting various types of medical supplies across different landscapes. It evaluated factors such as transportation time, distance covered, weight-carrying capacities and the safety of medical products, with the objective of informing future healthcare logistics strategies.

Materials and Methods

Study setting

The study was conducted in the challenging and remote areas of the Northeastern region, specifically focusing on Manipur and Nagaland. Commencing in September 2021, the study concluded in July 2022. It was implemented as part of the ICMR's *i*-DRONE initiative (ICMR's Drone Response and Outreach for North East).

This investigation utilised drones as a means of transporting medical supplies and facilitating connectivity amongst various healthcare facilities including district hospitals (DHs), community health centres (CHCs) and primary health centres (PHCs) situated in diverse geographical terrains. These terrains encompassed land, foothills, islands, valleys and mountains, each presenting unique logistical challenges. To address these challenges effectively, a variety of drone models were employed, selected based on the specific geographical features and distances between the health centres. These drones were utilised for the delivery of a range of medical supplies, including vaccines, medicines and surgical equipment, ensuring timely and efficient healthcare service delivery.

Study site and their selection

The present study focused on Manipur and Nagaland states in the North-Eastern region of India, chosen for their challenging geographical terrains that pose obstacles to medical supply distribution. Only government centres that got medical supplies from DHs were chosen.

The study involved three take-off centres (population as per Census 2011): two from Manipur included DH, Bishnupur (located in plain land, serving a population of 67,783), DH, Churachandpur (in a valley, serving a population of 82,576), and one from Nagaland includes DH, Mokokchung (in a mountainous area, serving a population of 35,913). DH Tuensang served as a landing point in a mountainous area, catering to a population of 36,774. Medical supplies were transported to 16 landing points, which included various PHCs and CHCs across different terrains.

Medical supplies transported through drone

The study involved delivering different types of medical supplies. These included vaccines, Universal Immunization Programme and COVID-19 vaccines, routine medications needed at CHCs, PHCs such as syrups (such as levocetirizine and iron folic acid), tablets (including ranitidine, cetirizine, multivitamins, calcium with Vitamin D3, paracetamol, zinc sulphate and iron folic acid), and surgical items such as gloves and syringes.

Various types of drones used for medical supply

Different types of drones with beyond visual line of sight capability were utilised in the study. Four distinct drone models, each with specific capacities and specifications, were employed based on the terrains being covered. These included single-rotor helicopters, multirotor quadcopters, vertical take-off and landing (VTOL) type 1 drones, and Hybrid VTOL drones. All drones fell within the small (2 kg to 25 kg weight of drone) category as defined by the Drone Rules of India (2021). They were equipped with Global Positioning System GPS technology and operated under the no permission, no flight protocol, ensuring coordination with nearby air traffic control (ATC) and obtaining necessary permissions before flights. The Keyhole Markup Language (KML) file and route map between three take-off sites and 16 landing sites were developed using Google Earth.

For this study, drone services were hired through an expression of interest. After a careful evaluation and as per the study's requirements and the service provider's past experience in similar work, a suitable UAV service provider was selected to fulfil the study's needs.

Collaboration with the stakeholders

Coordination and necessary approvals from multiple stakeholders, including the Airports Authority of India, Directorate General of Civil Aviation, state health authorities, district administration and district health departments in both states and districts, were secured well in advance of the study.

Implementation plan for drone-based medical supply delivery

Identification of site and command centre

A dedicated command centre was established to oversee drone operations, staffed with a pilot, co-pilot and engineer near the landing site. This centre, equipped with essential infrastructure, ensured efficient coordination and management of all ground activities. Further, for drone take-off and landing, clear flat land areas were identified, measuring around 5 × 5 m at each of the 19 health centres. These areas were identified and chosen both in accordance with the drone pilots and located nearest to health centres.

Training and coordination with healthcare workers

Healthcare workers (HCWs) from each site underwent basic training in packaging and transporting medical supplies. Initially, 3–4 HCWs were selected and trained for this purpose. They were responsible for loading, unloading, and conducting quality checks to ensure the proper integrity of transported supplies was maintained post-drone sorties.

Coordination with air traffic control

Before each flight, coordination with ATC was paramount. Flight paths were submitted for approval, and necessary clearances were obtained to ensure safe and uninterrupted drone operations.

Preimplementation dry run and piloting

Before actual implementation, a series of preimplementation dry runs and piloting exercises were conducted. These tests allowed for the identification of any operational challenges or technical issues, ensuring that all systems were functioning optimally before full-scale deployment.

Development and execution of sortie plan

The Sortie Plan, along with KML files, was carefully developed to make sure the drone operations went smoothly. A KML file is a markup language used to represent geographical data and visualise it on both two-dimensional maps and three-dimensional Earth browsers with the help of the Google Earth platform. This included getting everything ready for the flight, like preparing the boxes and checking everything was working properly before take-off. We sent the flight plans to ATC for approval and found good spots near the health centres for the drones to land.

Continuous monitoring

Throughout the implementation phase, continuous monitoring was conducted to identify any operational challenges or issues. Feedback from HCWs, technical teams, and ATC was incorporated to enhance efficiency and effectiveness.

Data collection

Various datasets such as site details, weather conditions, carrier box information and flight specifics such as time taken for carrier box preparation, transportation to the take-off site, distance covered, landscape details, flight altitude, speed and take-off time, were recorded through Case recorded forms (available at https://www.icmr.gov.in/idrone/index.html). In addition, medicine data were collected, encompassing information such as name, quality, lot number, expiry date and carrier box weight. During flight, vibration and dynamics data were recorded for analysis.

Before each flight, a thorough assessment of weather conditions, including wind speed, temperature, precipitation and humidity, was conducted using data from the Indian Meteorological Department's official website.

Data analysis

The present study comprehended a wide-ranging data gathering from various sources, their compilation, performing data cleaning and extracting relevant data for further analysis. Further, the statistical analysis was performed using one-way analysis of variance (ANOVA) using GraphPad Software, LLC (California, USA) for examining the variance between various data groups. This analysis was required to identify the disparities and correlations for a better understanding of the obtained results.

Ethics approval

The study ethics approval was obtained from the Central Ethics Committee on Human Research (CECHR), Ref No. CECHR-007/2021 of ICMR.

Results

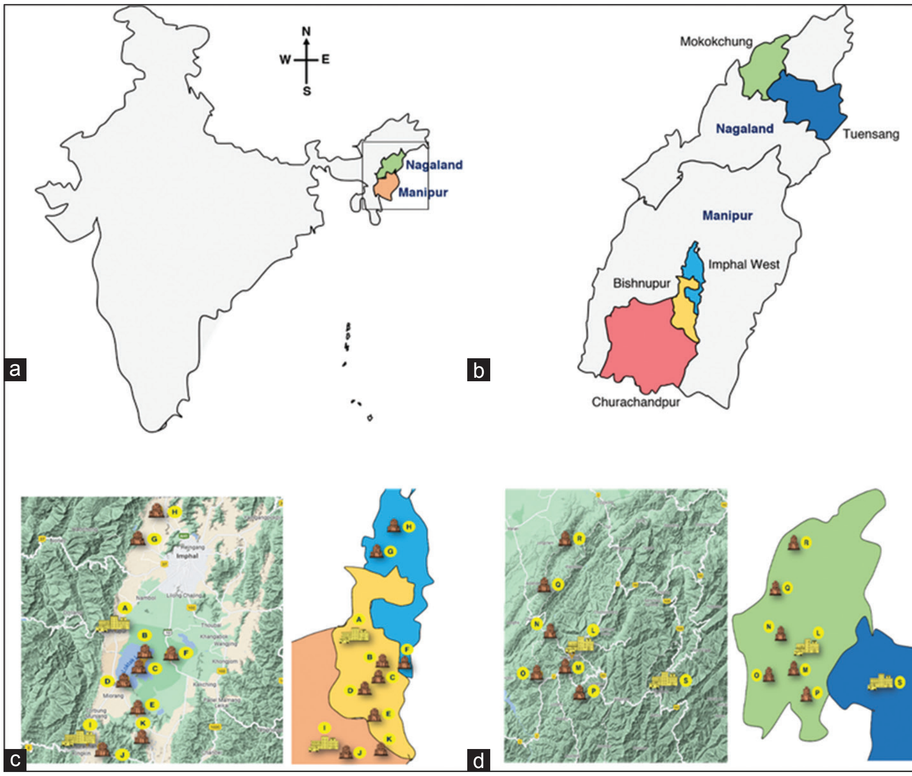
A total of 19 sites were selected, with three designated as take-off points for efficiently distributing medical supplies to the remaining 16 sites, all in close collaboration with state health authorities. Across five districts in Manipur and Nagaland, 73 HCWs underwent comprehensive training to handle carrier boxes and facilitate loading and unloading operations from drones. Simultaneously, drone operators also received nine trainings to learn about the transportation of medical supplies, ensuring both teams could proficiently execute their tasks. In total, 11 centres in Manipur and eight in Nagaland were identified as study sites in coordination with the respective states. Across the 19 centres, a total of 73 HCWs received training, with varying numbers trained at each centre: DH Bishnupur (7), PHC Karang (3), PHC Thanga (4), CHC Moirang (3), PHC Kumbi (4), PHC Sekmaijin (3), PHC Phayeng (4), PHC Khurkhul (3), DH Churachandpur (7), PHC Saikot (3), PHC Sagang (3), DH Mokokchung (4), PHC Ungma (3), PHC Sabangya (4), PHC Longkhum (4), PHC Longsa (3), CHC Mangkolemba (4), PHC Alongkima (4), DH Tuensang (3) [Figure 1].

In total, 32 sorties without payloads and 30 sorties with payloads were conducted during the study. These sorties have validated the drone-based delivery of medical supplies across various landscapes, such as land to land, land to island, land to foothill, foothill to land, land to valley, valley to land, mountain to mountain and mountain to land [Supplementary Tables 1 and 2].

In the present study, approximately 20,736 medical supplies, comprising medicines, vaccines and surgical supplies, were transported from the three take-off sites to their respective landing sites. These items included various supplies such as routine Universal Immunization Program vaccines (~4.22%), Covishield COVID-19 vaccines (~20.09%), syrup levocetirizine (~0.06%), syrup iron folic acid (~0.62%), tablet ranitidine (~0.9%), tablet cetirizine (~0.95%), tablet multivitamin (~3%), tablet calcium with D3 (~3.21%), tablet paracetamol (3.78%), tablet zinc sulphate (~18.6%), tablet iron folic acid (~23.7%), surgical gloves (0.36%) and syringes (20.51%).

The minimum aerial distance covered in our study was 6 km from DH, Mokokchung to PHC-Ungma (conventional road distance span around 6–8 km), and the maximum distance covered was 40 km from DH, Mokokchung to DH Tuensang (conventional road distance span over 86 km). Notably, the longest sortie, as mentioned earlier, comprised various medical supplies. The average speeds of quadcopters, single-rotor helicopters, VTOL, and Hybrid VTOL Type 2 were 7.17, 12.66, 15.98 and 25.96 m/s, respectively. In totality, the drones flew around 773 km in our study, equivalent to roughly 1400 km by road. It took them approximately 862 min to cover the aerial distance between centres, whereas the same journey by road could take over 5000 min under typical conditions in that terrain (based on the factors such as traffic congestion, weather conditions and other pertinent variables.

The aerial distance between the sites was significantly less than the road distance (one-way ANOVA; $P > 0.05$*). For instance, if we talk specifically in Manipur, the aerial distance that the drone traveled from "takeoff site DH Bishnupur" to all of their respective landing sites was significantly lesser than the corresponding road distances (One-way ANOVA; $P > 0.05$*), except "takeoff site DH Bishnupur" to "landing site PHC Kumbi" (Aerial distance of 24.5 km compared to 28 km of road distance). Similarly, the air distance from "takeoff site DH Churanchandpur" to all of their landing sites was significantly lesser than the corresponding road distances (One-way ANOVA; $P > 0.05$*), except from "takeoff site DH Churanchandpur" to "landing site PHC Saikot" (aerial distance and road distance equidistant of 6 km). In Nagaland, (one-way ANOVA; $P > 0.05$*), except for "the takeoff site "DH Mokokchung" to the "landing site PHC Longkhum (aerial distance of 12 km compared to road distance of 17 km) and PHC Longsa (aerial distance of 11 km compared to road distance of 19 km)," all other air routes were statistically significant. Out of the stated 16 centres, it was found that drones were able to reduce travel time significantly (statistically significant) for the 13 routes whereas, for the remaining three routes (DH Churanchandpur to PHC Saikot, DH Mokokchung to PHC Longkhum and DH Mokokchung to PHC Longsa), the travel time was reduced by drones but was not found to be statistically significant.



Codes (A-S) and Health centres (DH, CHC and PHCs)			
A	DH Bishnupur *(plain land)*	K	PHC Sagang *(plain land)*
B	PHC Karang *(island)*	L	DH Mokokchung *(mountain)*
C	PHC Thanga *(island)*	M	PHC Ungma *(mountain)*
D	CHC Moirang *(plain land)*	N	PHC Sabangya *(mountain)*
E	PHC Kumbi *(plain land)*	O	PHC Longkhum *(mountain)*
F	PHC Sekmaijin *(plain land)*	P	PHC Longsa *(mountain)*
G	PHC Phayeng *(foothill)*	Q	CHC Mangkolemba *(valley)*
H	PHC Khurkhul *(plain land)*	R	PHC Alongkima *(mountain)*
I	DH Churachandpur *(valley)*	S	DH, Tuensang *(mountain)*
J	PHC Saikot *(foothill)*		Manipur state
			Nagaland state

Figure 1: India map indicating the States (a) and Districts (b) chosen for the drone-based delivery of medical supplies. Map showing the terrains of health centres involved in the drone-based delivery of medical supplies in Manipur (c) and Nagaland (d). The schematic diagram shows the district-wise distribution of health centres in both states

In order to estimate the transportation time for drone-based medicine delivery, the time required for loading the carrier box into the drone at the take-off site and unloading the same from the drone at the landing site were calculated and reported in Figure 2. While the average time required for loading the carrier box was 8.5 min, unloading the carried box took around 5.5 min. It shows that the unloading time was significantly lesser than the loading time (One-way ANOVA; $P > 0.05$*), except for sorties conducted in Nagaland. It is important to note that the longest sortie of 40 km between DH, Mokokchung to DH Tuensang took around 28 min, which is way less than the conventional road transportation mode spanning over 6–8 h.

Similarly, the time required to cover air distances in both states was significantly lesser than road distances (one-way ANOVA; $P > 0.0001$***), except from "takeoff site DH Chauranchandpur" to "landing site DH Bishnupur" [Figure 3].

Certain atmospheric elements such as temperature, precipitation, wind speed and cloud cover influence drone operations. Therefore, these weather conditions were monitored before and during every sortie. In Manipur, daytime temperatures ranged from 20 to 30°C, while in Nagaland, they ranged between 16 and 20°C. Although no precipitation occurred during drone operations in Manipur, there were 4–5 days of rainfall in Nagaland, leading to grounded drone flights. Throughout the study, wind speeds remained between 1 and 4 m/s. Cloud cover ranged from 5% to 28% during the observation period.

The inner temperature of the carrier box was observed during take-off and after landing, as our study delivered temperature-sensitive medical supplies, i.e. vaccines and the medicines and surgicals. The study findings showed that despite the outside day temperature exceeding up to 35°C, the inside temperature of the carrier box was maintained within the required range to keep the cold chain intact for the supplies [Figure Supplementary 1]. The results showed that transportation of medicines and surgical items without the cold chain resulted in an average outer box temperature of 23.3°C before the take-off, which further rose to 24.1°C post landing; however, this increase was not deemed statistically significant (one-way ANOVA; $P > 0.05$*). In the sorties conducted under cold chain maintenance, the average temperature of the carrier box was 5.6°C before take-off, which was increased to 6.9°C which is statistically insignificant (one-way ANOVA; $P > 0.05$*).

Discussion

This study was conducted in the northeastern part of India, where medical supplies were successfully delivered to 19 healthcare facilities. Another crucial element involved the training of 73 HCWs and 8 pilots to oversee the drone-based delivery of medical supplies. These trainings boosted the confidence and proficiency of both HCWs and pilots in managing drone missions. Similar findings were reported by De Silvestri *et al*., highlighting the importance of training healthcare personnel for the safe and successful execution of drone operations in healthcare delivery.[15] In addition, Connor *et al*. showed a rise in satisfaction amongst HCWs with the integration of drones in healthcare supply chains, a finding consistent with our study.[16]

Moreover, the present study also involved the assessment of various environmental factors that may often influence drone sorties, such as atmospheric temperature, precipitation, wind

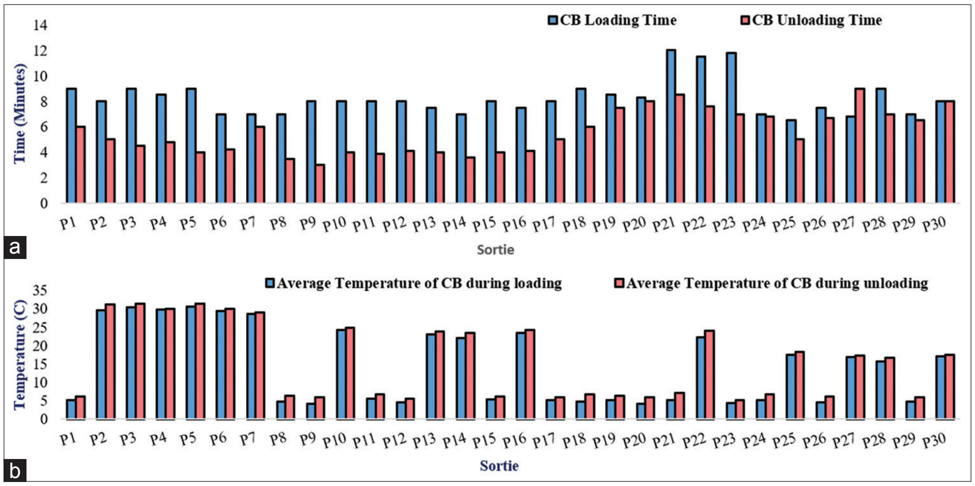


Figure 2: (a) Time required for loading and unloading carrier box from the drone during each sortie, and (b) the internal temperature of the carrier box before and after the drone flight during each sortie. The sortie details (P1-P30) are mentioned in Table 1

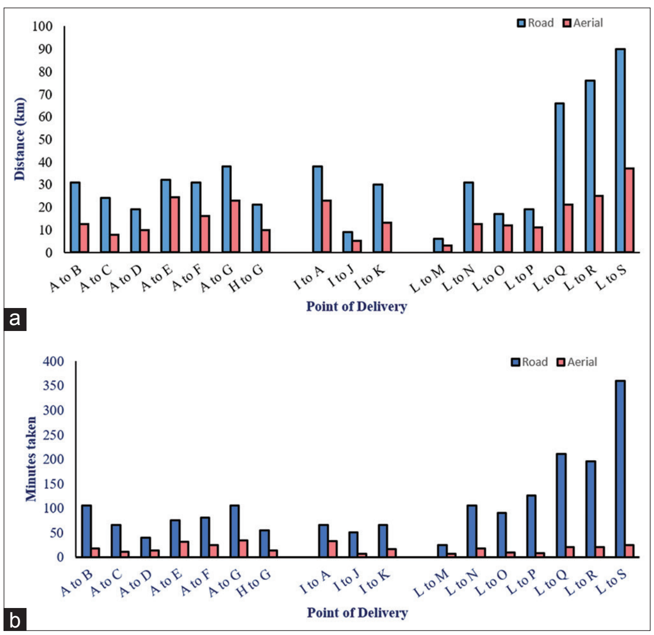


Figure 3: Comparison of road and aerial transportation between the points for (a) distance to be covered, and (b) time required. The codes of each centre are the same as given in Figure 1

velocity, and cloud cover, to ascertain operational feasibility. Throughout the study period in both states, environmental factors were mostly conducive to drone operations, except for a few rainy days in Nagaland. It highlights the need for an alternative for emergency conditions to avoid some or such use cases.[17] Further, in the present study, it was also recorded that cloud cover and permissible wind velocity have negligible impact on drone operations, affirming the use of drones as a transportation alternative across such areas and terrains to complement existing systems. There have been multiple studies in the past decade, that various developing and low-income countries have used drones to supply medical items as per their specific local needs.[18,19] In a study reported in *Nature Medicine*, in Malawi, a drone company has been delivering a variety of medical supplies for various diseases such as bacterial (tuberculosis), viral (rotavirus, polio and COVID-19), etc., Not only this, but a global organisation also named Village Reach has partnered with various entities in African countries such as Mozambique, Congo and Malawi for the delivery of essential healthcare supplies.[20-25] These studies were in agreement with our study findings that the potential use of drones may vary based on the local needs for time-effective and resource-specific supplies.

Besides these, the present study also highlights the adaptability of drone-based delivery operations for temperature-sensitive medical supplies. The samples were transported in their specified temperature range to keep their quality and integrity intact. For instance, vaccine transportation requires the use of pre-cooled-gel/ice packs for maintaining the requisite temperature range of 4–8°C for the samples, notwithstanding varying atmospheric temperatures. On the contrary, the medications and surgical items have no such prerequisite for maintaining cold chains and temperature, simply ensuring the integrity of the delivered medical supplies.[26] It was important to note that out of all sorties conducted, 15 sorties carried various vaccines (P1, P8, P9, P11, P12, P15, P17, P18, P19, P20, P21, P23, P24, P26 and P29) thus requiring maintenance of 4–8°C temperatures. This finding suggested the use of drones with adequate packaging can serve as a potential alternative to conventional road-based transportation of temperature-sensitive medical supplies. In a study by Amukele *et al*., the explanation for the delivery of haematological samples over long distances is explained in terms of statistical correlation, keeping time and temperature as variables.[26] Such studies are important for understanding how the change in temperature of payload (interior and outside) with respect to time affects the quality of the transported samples.

Additionally, the current study significantly highlights the time-efficiency of drone-based delivery of medical supplies, particularly in comparison with the conventional road-based mode of transportation. It was quite interesting to observe the contrast in travel times when comparing various permutations and combinations of transportation methods. In scenarios where conventional road-based transportation required over 100 min, drone-based transportation completed the journey in less than 50 min. For instance, the transportation route from DH Bishnupur on plain land to island PHC Karang and foothill PHC Phayeng, as well as from mountainous DH Mokakchung to mountainous PHCs Longsa and Alongkima, along with CHC Mangkolemba (in the valley), all took over 100 min via conventional road transport, whereas drone delivery connected these locations in under 50 min. This prominent finding is evident that the drone-based delivery of medical supplies emerged as a promising alternative, especially in hard-to-reach areas or during emergencies where the conventional mode takes a longer time to deliver the supplies. A study first time reported in Sweden by Claesson *et al*., did an explorative feasibility study for the delivery of automated external defibrillators (AED) and reported that drones were time-efficient in rural settings as compared to emergency medical services in 93% of cases with mean time saved of 19 min which plays crucial during emergency cardiac situations.[27] A similar time-efficient delivery of healthcare logistics was reported by Rosamond *et al*., during the delivery of AEDs in remote areas in emergency conditions also, it was acceptable to 89% of the study participants.[28,29] Both studies were in agreement with our research suggesting drones as a time-efficient alternative delivery medium for medical supplies.

It is essential to underscore certain limitations associated with using drone technology for healthcare deliveries. Drone operations are significantly affected by weather conditions, especially by the rains and high-speed winds. Sometimes, proper coordination with stakeholders and obtaining necessary approvals can also pose limitations on drone utilisation. In our study as well, there were certain limitations while performing the actual operations, such as limited payload capacity (which was highly restricted based on the size and type of drone), restricted operation range (in terms of altitude and battery life), dependency on optimal weather conditions (such as rain showers and/or wind speeds), restrictions in the transportation of drone and equipment via rail/road/air network which often leads to high costs, etc., However, the operations went mostly smoothly and the laid objectives were completed for the study.

India has along and creditable history of vaccines and vaccine service delivery for more than a two centuries.[30] This is one of the many innovations that have been done to improve service delivery for the COVID-19 vaccination response in India. Other being the use of the COWIN platform and then transforming it into U-WIN platform for routine immunisation expansion.[31] Clearly, there is a need for the expansion of all these learnings for strengthened health service delivery and improved access to general health services in the country.

Conclusion

It is imperative to establish effective collaboration with stakeholders, especially state health departments. In addition, adequately training healthcare personnel to integrate new technologies, such as drones, into the existing healthcare framework and acquire the necessary skills is essential. Our study highlights the significant potential of drones as valuable additions to the healthcare delivery system, particularly in navigating challenging terrains and addressing emergencies. However, it is essential to acknowledge certain limitations associated with drone technology, such as weather dependence, the need for healthcare staff training, pilot availability and coordination with stakeholders. Despite these challenges, drones offer considerable benefits in overcoming geographical barriers and ensuring timely medical supply deliveries. To fully leverage the advantages of drone-based healthcare delivery, further research, regulatory frameworks and infrastructure development are essential.

Relevance to preventive medicine:
This study on drone-based delivery of medicines and vaccines in Northeastern India highlights the importance of technology in improving access to essential healthcare services in remote areas, thereby reducing health disparities and ensuring timely preventive and curative interventions. This innovative approach addresses critical logistical challenges and strengthens public health response capabilities, making it highly relevant and fully aligned with the journal's objectives.

Implications for clinical practice:
The timely access to essential medications and vaccines in remote areas, contributes to improving patient outcomes and continuity of care. Integrating this technology into clinical practice enhances healthcare delivery and supports public health infrastructure.

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Conflicts of interest

There are no conflicts of interest.

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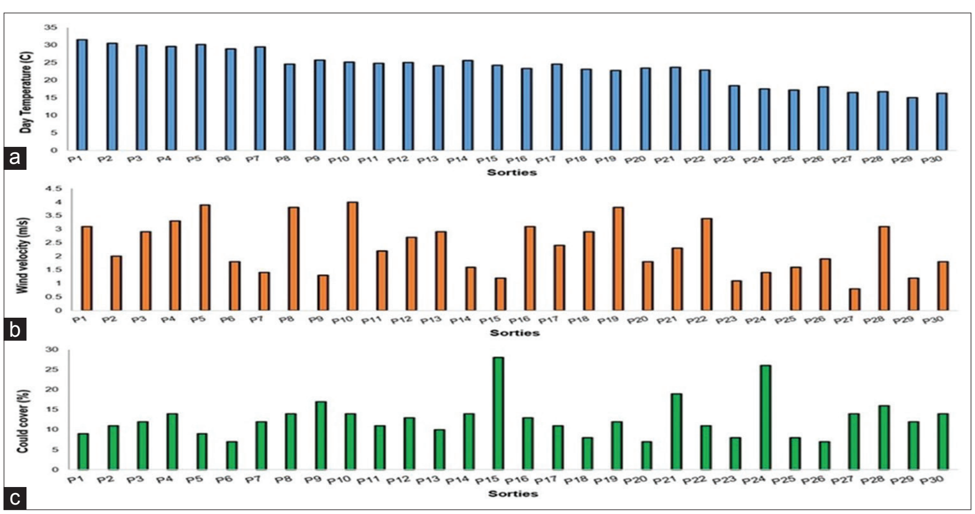
Supplementary Table 1: List of sorties conducted in Manipur and Nagaland with payload

Sortie code	Takeoff site	Landing site	Type of drone	Aerial distance (km)	Time travelled (min)	Drone speed (m/s)	Weight (kg)	Payload details
P1	DH-Bishnupur	PHC-Karang	Single rotor helicopter	12.5	17	12.25	2.10	Covishield vaccine
P2	DH-Churachandpur	DH-Bishnupur	Single rotor helicopter	23	33	11.62	1.03	IFA tablets
P3	DH-Bishnupur	PHC-Phayeng	Single rotor helicopter	23	34	11.27	1.03	IFA tablets
P4	PHC Khurkhul	PHC, Phayeng	Single rotor helicopter	10	13	12.82	1.20	IFA and paracetamol tablets
P5	PHC Khurkhul	PHC, Phayeng	Single rotor helicopter	10	12	13.89	0.80	Vitamin D3 capsules
P6	PHC Khurkhul	PHC, Phayeng	Single rotor helicopter	10	14	11.90	2.40	IFA syrup bottles
P7	DH-Bishnupur	PHC, Sekmaijin	Single rotor helicopter	16	25	10.67	0.50	IFA syrup bottles
P8	DH-Churachandpur	PHC, Saikot	Single rotor helicopter	6	7	14.29	1.20	Covishield vaccines
P9	DH-Churachandpur	PHC, Saikot	Single rotor helicopter	6	7	14.29	1.20	Covishield vaccines
P10	DH-Churachandpur	PHC, Saikot	Single rotor helicopter	6	7.5	13.33	1.40	Syringes
P11	DH-Churachandpur	PHC, Saikot	Single rotor helicopter	6	7.5	13.33	1.35	Covishield vaccines
P12	DH-Churachandpur	PHC, Saikot	Single rotor helicopter	6	7.5	13.33	1.35	Covishield vaccines
P13	DH-Churachandpur	PHC, Saikot	Single rotor helicopter	6	8.2	12.19	1.75	Syringes
P14	DH-Churachandpur	PHC, Saikot	Single rotor helicopter	6	8	12.50	1.60	Syringes
P15	DH-Churachandpur	PHC, Saikot	Single rotor helicopter	6	8	12.50	1.65	JE vaccines, PCV, and Covishield
P16	DH-Churachandpur	PHC, Saikot	Single rotor helicopter	6	8	12.50	1.64	Syringes
P17	DH-Bishnupur	CHC Moirang	Single rotor helicopter	15.77	22	11.95	2.40	Covishield vaccines, JE vaccines, and syringes
P18	DH-Bishnupur	PHC Kumbi	Single rotor helicopter	24.5	31	13.17	1.20	Covishield vaccines and JE vaccines
P19	DH-Bishnupur	PHC Thanga	Single rotor helicopter	12.38	16	12.89	1.90	Covishield vaccines, JE vaccines and syringes
P20	DH-Churachandpur	PHC Sagang	Hybrid VTOL	13	16	13.54	1.45	JE vaccine
P21	DH-Churachandpur	PHC Sagang	Hybrid VTOL	13	16.5	13.13	1.65	Covishield vaccines
P22	DH-Churachandpur	PHC Sagang	Hybrid VTOL	13	16.5	13.13	1.80	Syringes
P23	DH-Mokokchung	PHC Sabangya	Hybrid VTOL	12.5	17	12.25	1.01	OPV, MR, and diluents
P24	DH-Mokokchung	PHC Longsa	Hybrid VTOL	11	8	17.18	0.99	RVV, RVV dropper, Covishield, FIPV and PCV
P25	DH-Mokokchung	PHC Ungma	Multirotor quadcopter	3	7	7.143	0.80	Paracetamol (tablet), cetirizine (tablet), zentac, and bottles of levocetirizine
P26	DH-Mokokchung	PHC Mangkolema	Hybrid VTOL	21	20	17.5	1.24	PCV, Hep B, surgical gloves and syringes
P27	DH-Mokokchung	PHC Longkhum	Hybrid VTOL	12	9	22.22	1.40	Paracetamol, zentac, bottles of levocetirizine, IFA, zinc-sulphate
P28	DH-Mokokchung	PHC Alongkema	Hybrid VTOL	25	20	20.83	1.03	IFA tablets and bottles of IFA (50 mL)
P29	DH-Mokokchung	PHC Longsa	Hybrid VTOL	11	7.5	24.44	0.50	Covishield vaccine
P30	DH-Mokokchung	DH-Tuensang	Hybrid VTOL	37	25	24.67	2.13	Zinc-sulphate, paracetamol, B- complex, IFA, calcium + Vitamin D3

DH: District Hospital, PHC: Primary Health Centre, IFA: Iron folic acid, VTOL: Vertical takeoff and landing, RVV: Rotavirus vaccine, OPV: Oral polio vaccine, Hep B: Hepatitis B, JE: Japanese encephalitis vaccine, PCV: Pneumococcal conjugate vaccine, MR: Measles Rubella vaccine, FIPV: Intradermal fractional-dose inactivated polio vaccine

Supplementary Table 2: List of sorties conducted in Manipur and Nagaland without payload								
Sortie code	**Take-off site**	**Landing site**	**Type of drone**	**Aerial distance (km)**	**Time travelled (min)**	**Drone speed (m/s)**	**Road distance (km)**	**Time travelled (min)**
D1	DH-Bishnupur	PHC-Karang	Single rotor helicopter	12.5	16.5	12.63	31	105
D2	DH-Bishnupur	PHC-Karang	Single rotor helicopter	12.5	16.5	12.63	31	105
D3	PHC-Karang	DH-Bishnupur	Single rotor helicopter	12.5	17	12.25	31	105
D4	DH-Bishnupur	PHC Phayeng	Single rotor helicopter	23	33	11.62	38	105
D5	PHC Khurkhul	PHC Phayeng	Single rotor helicopter	10	12	13.89	21	55
D6	PHC Khurkhul	PHC Phayeng	Single rotor helicopter	10	12	13.89	21	55
D7	PHC Khurkhul	PHC Phayeng	Single rotor helicopter	10	12	13.89	21	55
D8	PHC, Saikot	DH-Churachandpur	Single rotor helicopter	6	7	14.28	6	50
D9	PHC, Saikot	DH-Churachandpur	Single rotor helicopter	6	7	14.28	6	50
D10	PHC, Saikot	DH-Churachandpur	Single rotor helicopter	6	7	14.28	6	50
D11	PHC, Saikot	DH-Churachandpur	Single rotor helicopter	6	7	14.28	6	50
D12	PHC, Saikot	DH-Churachandpur	Single rotor helicopter	6	7	14.28	6	50
D13	PHC, Saikot	DH-Churachandpur	Single rotor helicopter	6	7	14.28	6	50
D14	PHC, Saikot	DH-Churachandpur	Single rotor helicopter	6	7	14.28	6	50
D15	PHC, Saikot	DH-Churachandpur	Single rotor helicopter	6	7	14.28	6	50
D16	PHC, Saikot	DH-Churachandpur	Single rotor helicopter	6	7	14.28	6	50
D17	DH-Bishnupur	CHC Moirang	Single rotor helicopter	15.77	21	12.52	19	40
D18	DH-Bishnupur	PHC Kumbi	Single rotor helicopter	24.5	31	13.17	28	75
D19	DH-Bishnupur	PHC Thanga	Single rotor helicopter	12.38	16	12.89	24	65
D20	PHC Sagang	DH-Churachandpur	Hybrid VTOL	13	16	13.54	30	65
D21	PHC Sagang	DH-Churachandpur	Hybrid VTOL	13	16	13.54	30	65
D22	PHC Sagang	DH-Churachandpur	Hybrid VTOL	13	16	13.54	30	65
D23	PHC Sabangya	DH-Mokokchung	Hybrid VTOL	12.5	8	26.04	31	105
D24	PHC Longsa	DH-Mokokchung	Hybrid VTOL	11	7.5	24.44	19	125
D25	PHC Ungma	DH-Mokokchung	Multirotor quadcopter	3	6	8.33	6	25
D26	PHC Mangkolema	DH-Mokokchung	Hybrid VTOL	21	20	17.5	66	210
D27	PHC Longkhum	DH-Mokokchung	Hybrid VTOL	12	8.5	23.53	17	90
D28	PHC Alongkema	DH-Mokokchung	Hybrid VTOL	25	20	20.83	76	195
D29	DH-Mokokchung	PHC Longsa	Hybrid VTOL	11	7.5	24.44	19	125
D30	PHC Longsa	DH-Mokokchung	Hybrid VTOL	11	7.5	24.44	19	125
D31	PHC Longsa	DH-Mokokchung	Hybrid VTOL	11	7.5	24.44	19	125
D32	DH-Tuensang	DH-Mokokchung	Hybrid VTOL	37	24	25.69	90	360

DH: District Hospital, PHC: Primary Health Centre, VTOL: Vertical take-off and landing



Supplementary Figure 1: Weather conditions were recorded on the days of sorties conducted. (a) Ambient temperature, (b) wind speed and (c) cloud cover. The sortie details (P1-P30) are given in Table 1