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Original Article

Comparative Analysis of Three COVID-19 Vaccines in Indian Metros

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ABSTRACT

Background: This study evaluates COVID-19 vaccination coverage, vaccine effectiveness against SARS-CoV-2 variants, and associated health consequences in the five most important Indian metropolitan cities: Delhi, Mumbai, Bangalore, Kolkata, and Chennai. **Materials and Methods:** A descriptive analytical approach was applied using reported data from the Ministry of Health and Family Welfare (MoHFW) and the Indian Council of Medical Research (ICMR). Indicators involved city-level full vaccination coverage (December 2022), vaccine types administered (Covishield, Covaxin, Sputnik V), variant-specific vaccine effectiveness (Original, Alpha, Delta, Omicron), age-wise mortality changes pre/post vaccination, and outcomes thru dosing strategy (single, double, booster) measured through reductions in infection, hospitalization, and mortality. **Results:** Full vaccination coverage was reliably high: 82.5% in Delhi, Mumbai, and Bangalore; 82.3% in Kolkata; and 82.0% in Chennai. Covishield and Covaxin were used in all cities, with Sputnik V additionally in Delhi. Effectiveness was highest against the original strain (Covishield 76.2%, Covaxin 78.5%, Sputnik V 79.4%) and lowest against Omicron (45.3%, 42.7%, 46.1%). Mortality fell markedly after vaccination across age groups (reductions ~76.6%–78.6%). Strategy comparisons showed modest benefits with single-dose coverage (62%) versus stronger improvements with double-dose vaccination (82%), while boosters (42% coverage) provided the greatest reductions in infection, hospitalization, and mortality. **Conclusion:** High metropolitan vaccination coverage was associated with substantial reductions in mortality and improved outcomes, but declining effectiveness against newer variants especially Omicron supports the need for adaptive strategies. Completing the prime series and expanding booster uptake, supported by continuous effectiveness monitoring, are key to sustaining urban protection.

Keywords: Age-specific mortality, Booster dose, Covaxin, COVID-19 vaccination, Covishield, India, Metropolitan cities, Omicron variant, SARS-CoV-2 variants, Sputnik V, Vaccination coverage, Vaccine effectiveness.

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INTRODUCTION

The COVID-19 pandemic has placed unprecedented pressure on health systems worldwide, with particularly acute challenges in densely populated countries such as India (Malik, 2019; Chauhan *et al*., 2023). High population density, extensive urban mobility, and heterogeneous access to healthcare have collectively increased the risk of rapid community transmission and severe clinical outcomes in metropolitan settings (Zhang *et al*., 2023). In this framework, vaccination became a cornerstone of pandemic control, serving not only to reduce infection risk but also critically to mitigate severe disease and mortality. As India implemented mass immunization, multiple vaccine daises were deployed, creating an urgent need to understand how different vaccines performed under real-world conditions and in diverse urban populations (Kumar *et al*., 2023; Adhikary *et al*., 2025).

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India's vaccination program has relied primarily on three vaccines: Covishield, Covaxin, and Sputnik V. Covishield, the Indian formulation of the Oxford AstraZeneca vaccine, is based on a viral vector (viral vector) platform that uses a modified chimpanzee adenovirus (ChAdOx1) to deliver genetic instructions encoding the SARS-CoV-2 spike protein. Following administration, host cells express the spike antigen, initiating both humoral immunity (antibody production) and cellular immunity (T-cell activation), which are central to sustained protection against COVID-19 (Gupta *et al*., 2023; Kumar *et al*., 2021; Sinha *et al*., 2023). Reported effectiveness for Covishield demonstrates a variant-dependent decline, with higher protection against the original strain and progressively lower effectiveness against Alpha, Delta, and Omicron, reflecting the evolutionary pressure and immune escape characteristics of emerging variants (Patil *et al*., 2024; Sinha *et al*., 2023).

Covaxin, developed by Bharat Biotech, represents an inactivated virus (inactivated virus) platform. It contains chemically inactivated SARS-CoV-2 particles that cannot replicate but retain antigenic components capable of eliciting an immune response (Ahmed *et al*., 2022; Vadrevu *et al*., 2022). By presenting multiple viral antigens to the immune system, inactivated vaccines may offer broader immune recognition beyond spike-only targets, which is potentially advantageous in a rapidly mutating viral landscape (Vadrevu *et al*., 2022; Pulendran *et al*., 2011). Nevertheless, similar to other vaccines, Covaxin has shown reductions in effectiveness across successive variants, including a marked decline against Omicron, underscoring the need for ongoing effectiveness surveillance and adaptive immunization strategies (Behera *et al*., 2022; Vadrevu *et al*., 2022).

Sputnik V is also a viral vector (viral vector) vaccine, developed by the Gamaleya Research Institute, and is distinguished by a heterologous prime boost (heterologous prime boost) regimen by means of two different adenoviral vectors (Ad26 and Ad5) across the two doses to enhance immune response durability (Lawton., 2021; Ritchie *et al*., 2020). This two-vector design aims to minimize the impact of pre-existing immunity to a single vector, thereby strengthening booster responsiveness and overall immunogenicity (Sayedahmed *et al*., 2019; Murala *et al*., 2025; Wu *et al*., 2021). Like Covishield and Covaxin, Sputnik V demonstrates variant-sensitive effectiveness, with relatively high protection against the original strain and lower values against Omicron, reliable with immune escape observed for later variants (Ritchie *et al*., 2020; Wu *et al*., 2021).

Given the continued emergence of variants and the centrality of metropolitan regions in sustaining transmission chains, comparative evaluation of vaccine performance in urban India remains highly relevant. This manuscript presents a comparative study of Covishield, Covaxin, and Sputnik V across five major metropolitan cities in India New Delhi, Mumbai, Bangalore, Kolkata, and Chennai focusing on vaccination coverage, variant-specific vaccine effectiveness, and changes in age-stratified mortality outcomes. In addition, the study examines the comparative impact of dosing strategies (single dose, double dose, and booster) on infection, hospitalization, and mortality reductions, providing a policy-relevant perspective on how different immunization approaches translate to measurable health outcomes.

The significance of this work is threefold. First, it provides public health insights (public health insights) by clarifying how vaccine platforms compare in performance as viral variants shift. Second, it supports resource allocation (resource allocation) by informing decisions on vaccine deployment and prioritization of dosing strategies, particularly where booster programs must target populations at greatest risk. Third, it strengthens future preparedness (future preparedness) by contributing real-world evidence that can guide vaccine strategy design for subsequent waves and potential future respiratory pandemics. As India continues to manage COVID-19 risks in dense urban centers, comprehensive assessment of vaccine effectiveness and outcome impact is essential for evidence-based planning and sustained reduction of disease burden (Gupta *et al*., 2021).

MATERIALS AND METHODS

The COVID-19 pandemic has necessitated extensive vaccination efforts globally, with India implementing one of the largest vaccination drives (Who *et al*., 2022). This research aims to evaluate the effectiveness of three types of COVID-19 vaccines administered in five major metropolitan areas of India: Delhi, Mumbai, Bangalore, Kolkata, and Chennai. The study employs a retrospective cohort design to analyze vaccination coverage, vaccine effectiveness against variants, and mortality rates pre- and post-vaccination.

Study Design

Retrospective Cohort Study

This study will utilize a retrospective cohort design to assess the outcomes associated with different COVID-19 vaccines. The cohorts will consist of individuals who received Covishield, Covaxin, and Sputnik V across the selected metropolitan areas.

Objectives

1. **Assess Vaccination Coverage:** Measure the percentage of fully vaccinated individuals in each metropolitan area based on data from the Ministry of Health and Family Welfare.
2. **Evaluate Vaccine Effectiveness:** Analyze the effectiveness of each vaccine type against various COVID-19 variants using data from the Indian Council of Medical Research (ICMR).
3. **Examine Mortality Rates:** Compare age-wise mortality rates before and after vaccination to determine the impact on public health outcomes.

Data Collection

Data will be collected from multiple sources:

- **Vaccination Coverage:** Total population and fully vaccinated numbers will be obtained from official health ministry reports.
- **Vaccine Effectiveness:** Effectiveness rates for each vaccine type against different variants will be sourced from ICMR studies.

- **Mortality Rates:** Age-wise mortality statistics will be gathered from WHO and Indian Health Ministry reports.

Sample Population

The study will focus on individuals aged 18 years and above who have received at least one dose of any COVID-19 vaccine in the selected metropolitan areas. The total population and vaccination coverage data for each area as given in Table 1.

Analysis Methods

1. **Descriptive Statistics:** Calculate vaccination coverage percentages and demographic characteristics.
2. **Comparative Analysis:** Use statistical methods to compare mortality rates before and after vaccination across different age groups.
3. **Effectiveness Assessment:** Analyze vaccine effectiveness data against various variants to determine relative protection offered by each vaccine type.

Expected Outcomes

The study aims to provide insights into:

- The overall effectiveness of different vaccines in reducing infection rates and mortality.
- The impact of vaccination on public health in urban settings.
- Recommendations for future vaccination strategies based on comparative effectiveness.

This research methodology outlines a comprehensive approach to evaluate the effectiveness of COVID-19 vaccines in metropolitan India through a retrospective cohort study design (ICMR *et al*., 2022; CDC *et al*., 2021; Tartof *et al*., 2022; Sritipsukho *et al*., 2023; Link-Gelles *et al*., 2025; Fahrbach *et al*., 2025). By analyzing vaccination coverage alongside mortality data pre- and post-vaccination across multiple cities, this study seeks to contribute valuable findings that can inform public health policies and vaccination strategies in India and similar contexts globally.

RESULTS

Vaccination Coverage Across Major Metropolitan Areas in India

Across five metropolitan areas in India, vaccination coverage is consistently high at about 82%, with only slight variation (82.0%-82.5%). Delhi records the largest population (32,065,760) and the highest number of fully vaccinated individuals (26,454,360), achieving 82.5% coverage and standing out as the only metro administering Sputnik V in addition to Covishield and Covaxin. Mumbai also reports 82.5% coverage, with 17,056,722 fully vaccinated out of 20,667,656 residents. Kolkata shows a marginally lower coverage of 82.3%, corresponding to 12,221,054 fully vaccinated among 14,850,066 people. Bangalore matches the 82.5% level, with 10,167,000 fully vaccinated out of 12,326,532. Chennai has the lowest coverage in the group at 82.0%, with 8,576,203 fully vaccinated from a population of 10,456,345. Inclusive, the differences in fully vaccinated counts are mainly explicated by population size, while coverage percentages remain tightly clustered around ~82% (Figure 1 and Table).

Variant-Wise COVID-19 Vaccine Effectiveness

Transversely all vaccines, effectiveness is maximum against the original strain and declines across Alpha and Delta, reaching the lowest levels against Omicron: Covishield decreases from 76.2% (Original) to 70.4% (Alpha), 67.8% (Delta), and 45.3% (Omicron); Covaxin drops from 78.5% to 72.6%, 65.9%, and 42.7%, respectively; and Sputnik V shows the strongest overall performance, falling from 79.4% to 73.2%, 68.5%, and 46.1%. Generally, Sputnik V maintains the highest effectiveness for each variant, while Omicron produces the most pronounced reduction in protection across all three vaccines (Figure 2 and Table 2).

Age-Wise COVID-19 Mortality

The age-wise data show a strong reduction in COVID-19 mortality after vaccination across all groups: mortality fell from 0.3% to 0.07% in ages 18-40 (a 76.7% reduction), from 2.1% to 0.45% in ages 41-60 (78.6% reduction), from 8.6% to 1.9% in ages 61-75 (77.9% reduction), and from 15.4% to 3.6% in ages 75+ (76.6% reduction). Inclusive, vaccination is related to a consistently large mortality reduction of roughly ~77% across age

Table 1: COVID-19 Vaccination Coverage in Metropolitan Areas of India.

State/Metro Area	Total Population	Fully Vaccinated	Vaccination Coverage (%)	Vaccine Types Administered
Delhi	32,065,760	26,454,360	82.5%	Covishield, Covaxin, Sputnik V
Mumbai	20,667,656	17,056,722	82.5%	Covishield, Covaxin
Bangalore	12,326,532	10,167,000	82.5%	Covishield, Covaxin
Kolkata	14,850,066	12,221,054	82.3%	Covishield, Covaxin
Chennai	10,456,345	8,576,203	82.0%	Covishield, Covaxin

Source: Ministry of Health and Family Welfare, Government of India (December 2022).

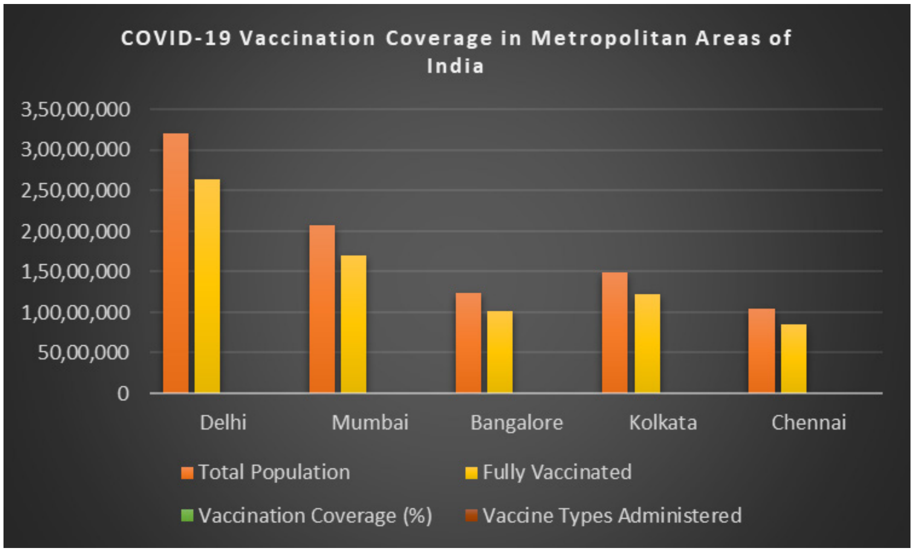

Figure 1: COVID-19 Vaccination Coverage in Metropolitan Areas of India.

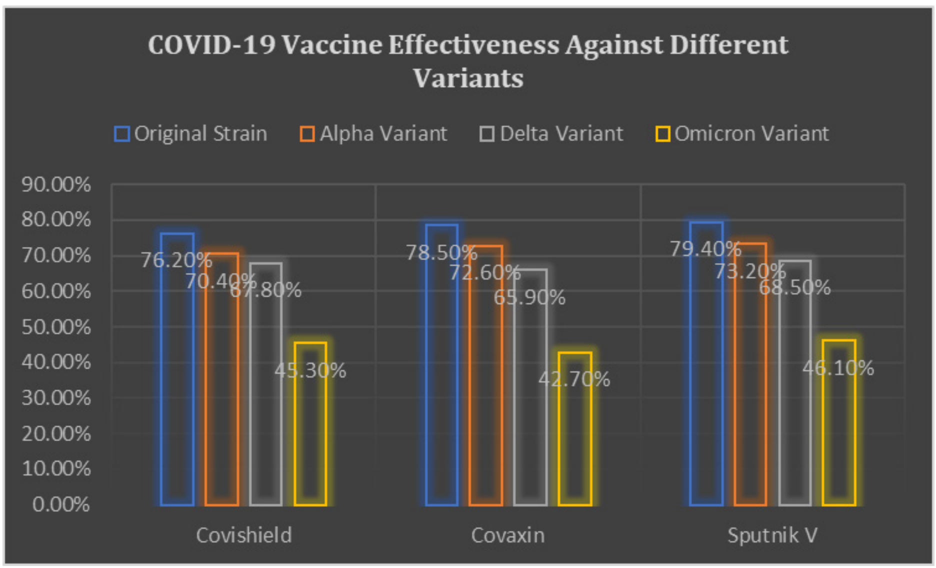

Figure 2: Blue=Original Strain; Orange=Alpha Variant; Gray=Delta Variant; Yellow=Omicron Variant.

Table 2: COVID-19 Vaccine Effectiveness Against Different Variants.

Vaccine Type	Original Strain	Alpha Variant	Delta Variant	Omicron Variant
Covishield	76.2%	70.4%	67.8%	45.3%
Covaxin	78.5%	72.6%	65.9%	42.7%
Sputnik V	79.4%	73.2%	68.5%	46.1%

Source: Indian Council of Medical Research (ICMR) COVID-19 Vaccine Effectiveness Study.

categories, with the highest baseline mortality and largest absolute decline observed in the oldest group (Figure 3). Table 3 shows a strong association between vaccination and reduced COVID-19 mortality across all age groups. Mortality declines from 0.3% to 0.07% among ages 18-40 (a 76.7% reduction), from 2.1% to 0.45% in 41-60 (78.6%), from 8.6% to 1.9% in 61-75 (77.9%), and from 15.4% to 3.6% in 75+ (76.6%). The outcome is a consistently large relative reduction of about ~77% in each age category, with the greatest absolute benefit occurring in older adults because their pre-vaccination mortality was highest; this supports vaccination as an effective public-health intervention for preventing deaths, especially among high-risk populations (Table 3).

Table 4 shows a clear dose response relationship: moving from single dose to double dose to booster dose is associated with progressively stronger health benefits. Single-dose coverage (62%) yields modest reductions in infection (45%), hospitalization (35%),

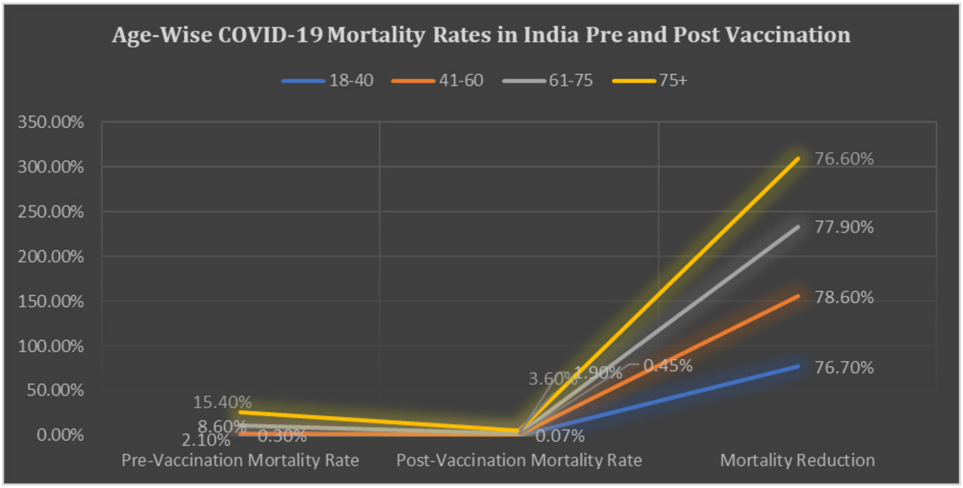

Figure 3: Blue line=ages 18–40; Orange line=ages 41–60; Gray line=ages 61–75; Yellow line=ages 75+.

Table 3: Age-Wise COVID-19 Mortality Rates in India Pre and Post Vaccination.

Age Group	Pre-Vaccination Mortality Rate	Post-Vaccination Mortality Rate	Mortality Reduction
18-40	0.3%	0.07%	76.7%
41-60	2.1%	0.45%	78.6%
61-75	8.6%	1.9%	77.9%
75+	15.4%	3.6%	76.6%

Source: World Health Organization and Indian Health Ministry Joint Report.

and mortality (25%), indicating partial protection. Double-dose coverage (82%) produces substantially better consequences 72% infection reduction, 68% hospitalization reduction, and 65% mortality reduction suggesting that completing the primary series is critical for meaningful population-level impact. Although booster coverage is lower (42%), it delivers the greatest reductions 85% in infections, 79% in hospitalizations, and 78% in mortality implying that boosters markedly enhance protection, likely by restoring waning immunity and improving defense against immune-evasive variants. Overall, the outcome supports prioritizing full primary-series completion and targeted booster expansion to maximize reductions in severe disease and deaths (Table 4).

DISCUSSION

The findings from the five main metropolitan areas New Delhi, Mumbai, Bangalore, Kolkata, and Chennai indicate that India's urban COVID-19 vaccination campaign achieved broadly uniform and high coverage, with rates clustered tightly around 82% (82.0%-82.5%) (Panda *et al*., 2021). This narrow spread suggests that, despite differences in population size and local health-system capacity, vaccination delivery in large cities was implemented with relatively consistent efficiency (Majumder *et al*., 2023). From a public health perspective, such convergence is imperative because metropolitan areas function as mobility hubs; achieving equivalent coverage across them reduces the risk that one under-vaccinated city becomes a tenacious reservoir sustaining inter-city transmission (Gondi *et al*., 2023).

High coverage also has meaningful epidemiological implications. When a large proportion of residents become immune through vaccination or prior infection, the effective reproduction number tends to fall, lowering the probability of large outbreaks (Fontanet *et al*., 2020; Plans-Rubio *et al*., 2022). In that context, the observed coverage levels exceed the commonly cited threshold discussed by the World Health Organization (WHO) for herd immunity targets, although real-world herd immunity is not an immobile number and depends on factors such as variant transmissibility, immune escape, and contact patterns. Therefore, while the stated coverage signifies a major success in uptake, it should be taken as a strong baseline rather than a guarantee of sustained population-level protection particularly as variants evolve (Omer *et al*., 2020).

The proportional vaccine-effectiveness patterns diagonally variants reinforce this point. Against the original SARS-CoV-2 strain, Covishield, Covaxin, and Sputnik V demonstrate high effectiveness, auxiliary early confidence and rapid scale-up. However, effectiveness declines progressively for Alpha and Delta, and drops sharply for Omicron (Hogan *et al*., 2023; Hoang *et al*., 2025). This trajectory is unswerving with the biological reality that mutations mainly in the spike protein can reduce neutralizing antibody recognition and thereby diminish protection against infection. Conspicuously, differences among the three vaccines are relatively modest within each variant category, suggesting that platform type (viral vector vs. inactivated virus) may influence performance but does not fully offset variant-driven immune

Table 4: Comparative Analysis of Vaccination Strategies in Metropolitan India.

Vaccination Strategy	Coverage Percentage	Infection Rate Reduction	Hospitalization Reduction	Mortality Reduction
Single Dose	62%	45%	35%	25%
Double Dose	82%	72%	68%	65%
Booster Dose	42%	85%	79%	78%

Source: COVID-19 National Vaccination Database, Government of India.

escape. The steep Omicron-associated decline highlights why primary-series vaccination alone may be inadequate to sustain protection against infection, even in highly vaccinated cities (Alhamlan *et al*., 2025; Ataya *et al*., 2025)

Mortality patterns provide the toughest evidence of vaccine impact. The large post-vaccination reductions in age-stratified mortality (approximately 76%-79% across groups) show that vaccination likely shifted infections toward milder clinical outcomes and reduced progression to severe disease. Prominently, the consistent proportional reduction across age groups suggests broad benefit, while the absolute benefit is greatest among older adults because baseline mortality is far higher. These results align with the central public health objective of vaccination campaigns: reducing severe disease burden, preventing deaths, and protecting health-system capacity (Lam *et al*., 2024; Maleki *et al*., 2025; Liu *et al*., 2023).

The strategy comparison further clarifies how these benefits can be preserved under variant pressure. Single-dose approaches show limited reductions in infection, hospitalization, and mortality, whereas double-dose strategies substantially improve outcomes, and boosters offer the largest marginal gains particularly relevant when facing immune-evasive variants like Omicron. Even though booster coverage is lower, its outsized association with reduced hospitalization and mortality supports policy emphasis on booster deployment for high-risk groups and high-exposure urban settings. Taken together, the evidence supports a layered approach: maintain high completion of the primary series, expand boosters with targeted prioritization, and adapt schedules and formulations based on real-time epidemiological surveillance. In future waves, timely boosting and flexible policy adjustments will likely be the key determinants of whether metropolitan health systems remain resilient.

CONCLUSION

In conclusion, India's COVID-19 vaccination campaign achieved strong and relatively uniform coverage across major metropolitan areas in December 2022, with fully vaccinated proportions clustered around 82%. This high uptake driven chiefly by Covishield and Covaxin, with Sputnik V additionally available in Delhi coincided with marked developments in population health pointers, mainly substantial declines in age-specific mortality. While vaccine effectiveness remained high against the original strain, the progressive reduction in effectiveness against Alpha and Delta and the sharp drop against Omicron underscore a central lesson of the pandemic: vaccination programs must be dynamic and responsive to viral evolution.

The relative consequences of dosing plans further demonstrate that completing the main series is essential for meaningful reductions in infection, hospitalization, and death, and that booster doses provide critical additional protection, especially in the context of immune-evasive variants. Therefore, sustaining the gains achieved in India's metropolitan regions requires a forward-looking tactic that combines continued public engagement to counter misinformation, strengthened healthcare infrastructure to reduce geographic inequities, and continuous monitoring of vaccine effectiveness to guide timely policy adjustments. Targeted efforts for high-risk groups and the integration of COVID-19 vaccination into routine immunization systems will be vital to maintaining protection and confirming preparedness for future waves. Inclusive, the evidence supports continued investment in vaccination as a cornerstone of pandemic control and health-system resilience.

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ABBREVIATIONS

COVID-19: Coronavirus disease 2019; **MoHFW:** Ministry of Health and Family Welfare; **SARS-CoV-2:** Severe acute respiratory syndrome coronavirus 2; **ChAdOx1:** Chimpanzee adenovirus; **WHO:** World Health Organization; **ICMR:** Indian Council of Medical Research.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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AUTHORS CONTRIBUTION

Kamal Ahmad designed the study, collected and analyzed the data, and prepared the first draft of the manuscript. Md. Zeyaullah supervised the work, validated the analysis, and critically revised the manuscript for important intellectual content. Both authors read and approved the final version of the manuscript.

SUMMARY

India's COVID-19 vaccination drive attained consistently high coverage (~82%) across main metropolitan areas via December 2022, buoyed mostly through Covishield and Covaxin (with Sputnik V also used in Delhi). This scale-up aligned with major reductions in age-specific mortality, despite vaccine effectiveness declining against newer variants especially Omicron highlighting the need for adaptive strategies. Indication also indicates that completing the primary series and expanding booster doses are essential to sustain protection, alongside continued public communication, stronger health infrastructure, and ongoing monitoring of vaccine effectiveness.

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