



Spatial Distribution of COVID-19 Vaccination Across India

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ABSTRACT

The COVID-19 pandemic is the most devastating public health emergency spreading globally. India was one of the world's worst-affected countries due to the COVID-19 pandemic. As per World Health Organization (WHO), there is no effective treatment for COVID-19. Therefore, after almost a year from the initial outbreak of the COVID-19 (in the early of 2021), several vaccines were approved and administered in most countries including India. The present study aims to assess the spatial distribution of COVID-19 vaccine using the geospatial tools. The spatial distribution maps for selected vaccination categories are generated using Quantum-Geographical Information System (Q-GIS) application. After processing and combining vaccination data and geospatial data, state-wise graduated thematic maps of India is generated based on age group, vaccine doses and total vaccination in all over India till July, 2022. Results of the study show that the maximum vaccination is recorded in highly populated states of India including Uttar Pradesh, Madhya Pradesh, Bihar, Maharashtra etc. respectively as compared to Union territories. The methods and database used in the present study can be useful for administration, strategy makers and researchers for future public health emergencies and other vaccination campaigns.

Keywords: Covid-19, Covid-19 Vaccination, Geographical Information System, Health GIS.

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INTRODUCTION

The current global pandemic of COVID-19 is an international threat. COVID-19, or Coronavirus, was the most highlighted term in the year 2020, and it was believed to be originated in Wuhan, Hubei province of China. The fast-spreading variant of coronavirus was highly contagious and caused by Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2). On January 30, 2020, an outbreak of a public health emergency was declared by the World Health Organization (WHO) at the international level due to the rapid transmission of the virus from human to human, causing a pandemic in many countries (1). As of April 28, 2021, COVID-19 has rapidly spread globally with high morbidity and mortality, currently affecting over 149 million people and claiming over 3 million lives. India is presently the second most affected country after the United States. Ever since the coronavirus outbreak, almost 200 countries have been affected globally. As of date, more than 100 million people have been infected, and more than 2 million people are deceased globally (2). In India, the number is more than 10 million and 150 thousand, respectively. The pandemic outbreak resulted in many fatalities and has become a significant concern for the administrative units of respective countries (3).

India has experienced health threats due to the COVID-19 pandemic ever in its history. By August 2021, more than 30 million Indians were infected, and almost half a million died of COVID-19 infections (4,5). Similar to many other countries, COVID-19 vaccines were granted emergency use authorization in India in early 2021. However, vaccine rollout in India faced a complicated path with political polarization, vaccine shortage, misinformation and rumors, and challenges with registration and appointments, just to name a few (6). Beside effective treatment, vaccination is a crucial preventive strategy in mitigating the pandemic. A safe and effective vaccine for COVID-19 infection has been on the wish list of healthcare agencies across the globe since the onset of the pandemic. As the development process of a vaccine demands clinical trials across various phases for multiple checks about its safety, potency, and efficacy, there is an inherent delay in its launch. The vaccine must be trialed among all groups of individuals, particularly in high-risk individuals such as the elderly, pregnant women, and people with co-morbidities, and immunodeficiencies.

India started the administration of vaccines for COVID-19 on 16 January 2021 with a focus on India's healthcare workers and frontline workers. Later, in a phased manner, the vaccination drive extended to

senior citizens and those ≥ 45 years with co-morbidities. From 1 May 2021 onwards, those aged >18 years were eligible. India is currently administering two vaccines – one developed by AstraZeneca with Oxford University (Covishield) and other by the Indian firm Bharat Biotech (Covaxin) – both approved in January 2021, ahead of the vaccine rollout. In April 2021, a third vaccine – Russia's Sputnik V – was approved for use (7,8). Usually, it takes years to develop a safe and effective vaccine. Considering the immediate need for vaccination, the currently administered vaccines have been developed with a short period of testing and hence is a matter of concern among the population. This concern over safety and efficacy, resulting in vaccine hesitancy, is a potential barrier to the effective implementation of vaccination programs. Initially, Due to adverse effects reported in a few cases (Adverse Events Following Immunization - AEFI), it was natural for people to become skeptical about the effectiveness of the COVID-19 vaccine, which led to hesitancy. People wanted to observe and learn from the experience of healthcare workers who have taken the shots. Pfizer and Moderna vaccines were also made available to Indians (9). Currently available covid 19 vaccines in India are shown in Table 1.

Table 1: Status of Covid Vaccines in India (10)

Vaccine	Status	Production Capacity (Million)	Planned Capacity (Million)	Doses ordered (Million)	Approval	Deployment
Covishield	In use	840	-	750	01 January 2021	16 January 2021
Covaxin	In use	700	-	550	03 January 2021	16 January 2021
Sputnik V	In use	140	-	156	12 April 2021	14 May 2021
Corbevax	In use	-	960	300	28 December 2021	16 March 2022
Moderna	Approved	Import	-	-	29 June 2021	Order Cancelled
Johnson & Johnson	Approved	-	8	-	7 Aug 2021	Not yet
ZyCoV-D	Approved	-	240	10	20 August 2021	Not yet
Covovax	Approved	-	-	200	28 December 2021	Not yet
Sputnik Light	Approved	-	-	-	6 February 2022	Not yet

Geographical Information System (GIS) can contribute to public health by providing information on many pandemic issues and properly supporting the decision-making process. They can provide information regarding the distribution of health services (11). Thus, any growing disparities might be eliminated. Also, policy-makers would make the right decisions. Health professionals can quickly identify the difficulties and disparities regarding the accessibility to health services to cope with the current situation. GIS have been vital to the assessment and treatment of health problems related to different areas of land. Epidemiology was one of the fields in which maps were first used in health research. The GIS can play an important role in disease surveillance, management, and analysis (12). It can provide tremendous convenience for healthcare providers as regards the organization and the management of these services. Hence, managing and coordinating various services would be easier with high efficiency. Healthcare can provide direct, quick, and efficient healthcare services to patients. It provides us with the exact location of specific medical equipment and how somebody may gain the fastest access to it (13). The study aims to investigate the state-wise spatial distribution of the COVID-19 vaccination across India. To precise, the study aims to examine vaccination category-wise in all states and Union Territories (UTs) of India using GIS tools and methods to provide proper accessibility and coverage.

MATERIAL AND METHODS

Analysis Methods: Total vaccination data was obtained from the websites of Ministry of Health and Family Welfare, India (14) and COVID-19 India (15). The vaccination data, including the 12 to 14 years age group, 15 to 18 age group, 18+ age group, and precaution dose, was collected from January 1, 2021, to June 20, 2022 (Table 2). After collecting data, it was processed and organized in a delimited file in MS Excel. The spatial distribution of vaccination data was presented through maps generated by Quantum-GIS (QGIS). QGIS functions as geographic information system software, allowing users to analyze and edit spatial information and compose and export graphical maps (16). QGIS 3.26.0 'Buenos Aires' was used to analyze the spatial distribution of covid-19 vaccination data. The boundary or shapefile of Indian administrative was downloaded from diva-gis.org (17). India is a federal union comprised of 28 states and 8 union territories, total 36 separate entities. Districts and smaller administrative units are

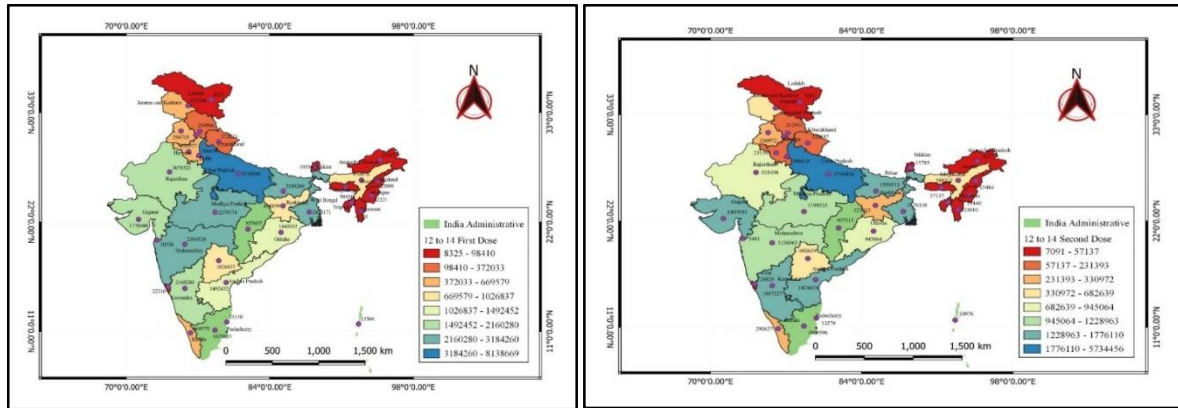
subdivided further inside the states and union territories. COVID-19 vaccination data and geographical data were integrated into the software to get possible results. The symbology is the essential tool to represent the data with spatial aspects in GIS, so graduate symbology was used to classify and visualize vaccination data by various groups, i.e., 12 to 14 years age group, 15 to 18 age group, 18+ age group, and precaution dose.

Table 2: Covid-19 vaccination by different age groups in all States and UT of India.

Name of State / UT	12 to 14 years age group		15 to 18 years age group		18+ years age group		Precaution Dose	
	I st Dose	II nd Dose	I st Dose	II nd Dose	I st Dose	II nd Dose	18 to 59	60+ years
A & N Islands	13304	10976	19030	16370	311403	314096	1737	25690
Andhra Pradesh	1492452	1474474	2533733	2525820	40605966	43500581	17482	4653187
Arunachal Pradesh	22427	8227	51222	33776	854353	733963	106	37522
Assam	858076	389217	1190074	852879	22509329	20093793	37408	625644
Bihar	3184260	1598513	5761044	3973243	62261923	56060120	1575134	1588824
Chandigarh	34800	19090	56422	38083	1087104	909097	6295	46720
Chhattisgarh	855655	407315	1175133	883899	18739796	17435650	18814	679947
Dadar Nagar Haveli	10536	5461	19332	13594	428486	328405	13224	7372
Delhi	596196	380419	992512	839630	16529637	14048011	764086	807278
Goa	32316	24828	51406	43668	1351331	1215528	5912	61091
Gujarat	1770480	1407095	3096636	2793010	49211378	49001522	182379	3797480
Haryana	505977	231393	1144384	723241	21918679	18484570	427800	545699
Himachal Pradesh	254966	212931	329079	298653	6018087	5718045	5668	417354
Jammu & Kashmir	517206	436846	874291	792202	9933162	10228125	6774	462685
Jharkhand	825859	322922	1470438	874884	21196582	15524312	39153	378384
Karnataka	2160280	1487327	2726917	2430192	49913567	49664847	318448	2956321
Kerala	669579	290627	1294543	884047	26982681	23660898	121484	1913269
Ladakh	8325	7091	9962	8807	219029	184545	30700	44972
Madhya Pradesh	2279174	1198525	4173246	3283177	53969513	53512707	42872	1805702
Maharashtra	2364536	1228963	3962556	2836057	84474800	70580664	648181	3036949
Manipur	42221	13440	98741	50266	1450514	1192735	12	108732
Meghalaya	30020	11038	70863	34229	1327380	1014960	260	46533
Mizoram	41201	23010	57797	41089	781979	652969	291	50981
Nagaland	22008	15484	57729	36521	834494	675570	467	34687
Odisha	1445035	945064	2143930	1691544	31266363	29179730	116515	1513222
Puducherry	25150	13578	49146	39327	897176	685230	153	30932
Punjab	594735	330972	1085445	757023	22251980	18872232	9663	721752
Rajasthan	2078521	935498	3484020	2647294	50943299	45538093	40944	2119053
Sikkim	19556	15785	29375	24745	538403	503406	601	39547
Tamil Nadu	1629853	1000996	2485155	1969070	55427125	49189685	80434	1184590
Telangana	1026837	682639	1697296	1505467	29510652	28611399	129195	850421
Tripura	98410	57137	141261	103666	2649871	2288532	307	147455
Uttar Pradesh	8138669	5734456	13963145	12172492	153431463	142737918	186762	3355890
Uttarakhand	372033	220447	525142	422419	8151994	7864509	18059	663186
West Bengal	2428171	1776110	3522899	2902364	67100490	60295642	377248	3322858

RESULTS AND DISCUSSION

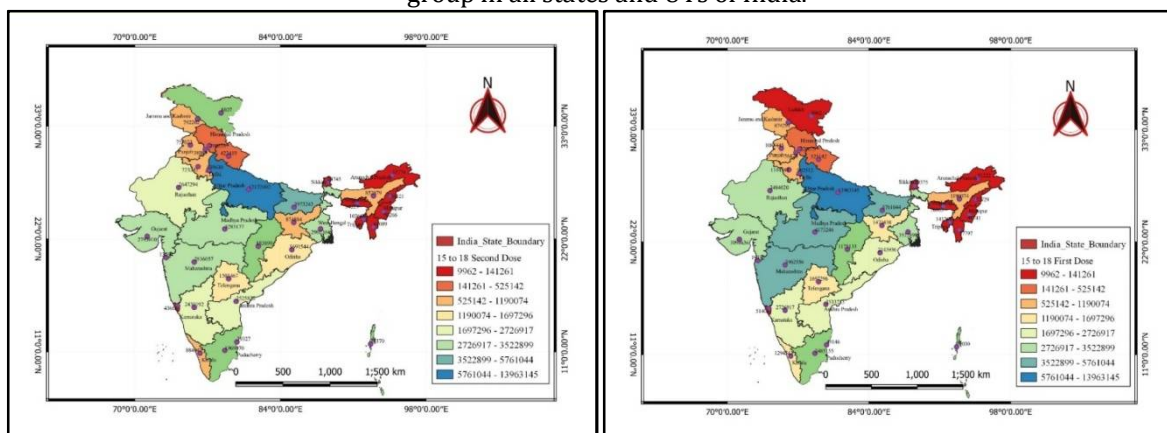
India began the administration of COVID-19 vaccines on 16 January 2021. It has administered over 1.9 billion doses of the currently approved vaccines, including first, second, and precautionary (booster) doses till 17 June, 2022. Here, 93% of the eligible population (12+) has received at least one shot, and 83% of the eligible population (12+) is fully vaccinated. Spatial distribution of Covid-19 vaccination, including 12 to 14 years, 15 to 18 years, 18+ years, and precaution dose, has been presented through maps generated by QGIS (Figure 1 to Figure 4). It was noticed that the maximum dose of Covishield was given, followed by Covaxin and Sputnik V. Vaccinations in India by different vaccine brands is shown in Table 3.



(A) First dose

(B) Second dose

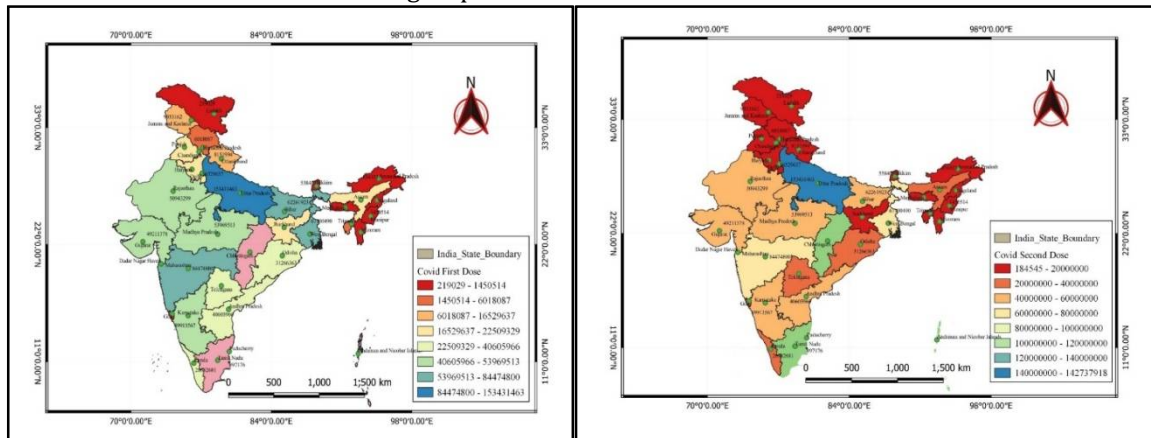
Figure 1: Spatial distribution of Covid-19 vaccination first dose and second dose in 12 to 14 years age group in all states and UTs of India.



(A) First dose

(B) Second dose

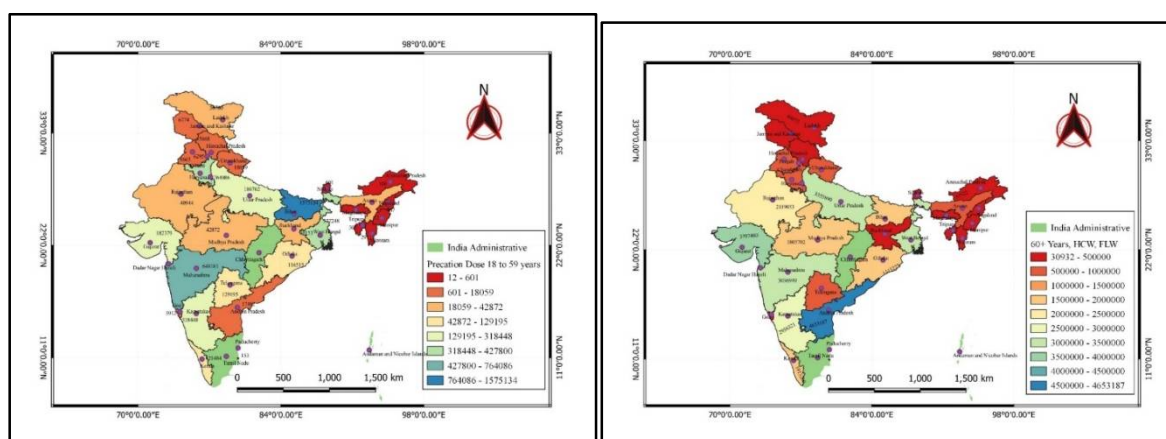
Figure 2: Spatial distribution of Covid-19 vaccination first dose and second dose in 15 to 18+ years age group in all states and UTs of India.



(A) First dose

(B) Second dose

Figure 3: Spatial distribution of Covid-19 vaccination first dose and second dose in 18+ years age group in all states and UTs of India.



(A) 18+ years

(B) Dose 60+ year, HCW and FLW

Figure 4: Spatial distribution of Covid-19 vaccination precaution dose in all states and UTs of India.

Table 3: Vaccinations in India by different vaccine brands.

S.N.	Brand	Vaccination
1.	Covishield	1,56,80,95,059
2.	Covaxin	32,78,19,340
3.	Sputnik V	12,24,641
4.	Corbevax	5,60,57,093
5.	Covovax	5,581

Results of the study indicate that maximum vaccination in the 18+ year age group has been observed in Uttar Pradesh, followed by Maharashtra, West Bengal, and Bihar (Figure 3). In contrast, minimum vaccination has been recorded in Ladakh, Andaman & Nicobar, and Dadar Nagar Haveli (Table 2). Higher vaccination in mentioned states may be due to the availability of both doses of vaccines, awareness about vaccination drives as well as the consequences of not being vaccinated because the death rate and spreading rate were at their peak during the second wave of Covid-19. Similarly, lower vaccination in mentioned states and UTs may be due to a lack of proper awareness and a shortage of required doses per population. It can also be a significant reason for the difference in vaccination in states and UTs. Initially, the government of India wanted to cover up those states where death rate was high and the spreading rate was at its peak.

However, the trend was not followed in the 12-to-14-year age group vaccination. Maximum vaccination in this age group has been recorded in Uttar Pradesh, followed by Bihar, West Bengal, and Maharashtra (Figure 1). Slightly decline in vaccination has been observed in Maharashtra and West Bengal as compared to the 18+ population vaccination, whereas the lower number of vaccinations was recorded in Ladakh, followed by Dadar Nagar Haveli, Andaman and Nicobar Islands (Table 2). It was interestingly noticed that Rajasthan and Madhya Pradesh showed tremendous growth in vaccination in the 15 to 18 age group population.

Figure 1 to Figure 4 shows the spatial distribution of cumulative vaccination of COVID-19 in all States and Union Territories of India. Spatial maps of vaccination have presented that the range of vaccination was categorized into eight parts, and it varied from 219029 to 153431463 of the first dose in the 18+ age group population. It has been revealed that lower vaccination was found in some parts of North India and East India, including Ladakh, Sikkim, Meghalaya, Mizoram, Nagaland, Arunachal Pradesh, Dadar Nagar Haveli, etc. In contrast, the second dose ranged from 9962 to 13963145. So, a fall in the second dose in Jammu & Kashmir, Chandigarh, Himachal Pradesh, and Uttarakhand have been observed. This decline may be due to the unavailability of enough doses in a short time. It has been interestingly observed that higher vaccination was recorded in Uttar Pradesh in both First and Second doses, (i.e., 153431463 and 153431463), whereas it ranged between 4000000 to 6000000 in Bihar, Madhya Pradesh, Rajasthan, Gujarat, Andhra Pradesh and Karnataka (Figure 3 A and B).

COVID-19 vaccination in the 15 to 18 age group population has been presented through spatial maps for both doses generated by QGIS in Figures 2. The first dose of COVID-19 has ranged from 9962 to 13963145, whereas the second dose has ranged between 8807 to 12172492. A similar trend was followed in this category, and the results of the study have revealed that a slight decline in vaccination has been observed

in many states of North India, including Sikkim, Meghalaya, Manipur, Arunachal Pradesh, Tripura, and Nagaland. Similarly, a slight decline has been recorded in both doses of COVID-19 vaccines as compared to the 18+ population in Rajasthan Gujrat and West Bengal. The first dose of COVID-19 has ranged from 9962 to 13963145, whereas the second dose has ranged between 8807 to 12172492.

In India, a vaccination drive for the 12 to 14-year population was initiated after the 15 to 18 and 18+ population. The spatial distribution of vaccination in the 12 to 14 age group categories has been presented in Figure 1 (A and B). The first dose of COVID-19 has ranged from 8325 to 8138669, whereas the second dose has ranged between 7091 to 5734456. The outcome of the study revealed that a tremendous increase of first dose of vaccination has been observed and has ranged between 2160280 to 3184260 in Maharashtra, Madhya Pradesh, Bihar, and West Bengal, while a similar trend in the second dose of the vaccination has been found in Karnataka, Andhra Pradesh, Gujarat, Bihar, and West Bengal and it has been ranged from 1228963 to 1776110. However, most of the population of India varies between 18 to 60 years and live in Uttar Pradesh, Maharashtra, Bihar, West Bengal, Rajasthan, etc. which can be another reason for the increasing number of vaccinations in above states. It could be seen from the study that the participants from the age group 18-30 years and older people were more inclined toward the acceptance of the vaccine than the other age groups (18, 19, 20). The precaution dose results are different from the other three categories, i.e., 12 to 14 years, 15 to 18 years, and 18+ years. Maximum precaution dose vaccination was done by Andhra Pradesh, followed by Maharashtra, Delhi, and Haryana, while minimum precaution dose was recorded in Manipur, Arunachal Pradesh, Pondicherry, and Meghalaya. Similarly, a slight drop has also been observed in the precaution dose Figures 4 (A and B). This trend may be because initially, people were not ready for the vaccine. They were hesitating and unaware of the consequences of different variants of Covid-19. Later, Administration, health workers, and policymakers convinced people to vaccinate themselves. Vaccination awareness programs, free vaccine drives, online registration, spot registration, and mobile vaccine van, were executed to vaccinate the maximum population and resulted as administered over 1.9 billion doses overall, including first, second, and precautionary (booster) doses of the currently approved vaccines by India (21, 22, 23).

Table 4 shows cumulative vaccinations in India and according to the data it has been noticed that about 74% population has been vaccinated with dose and about 68% people are fully vaccinated. Figure 5 represents vaccinations in India by age group and it shows that 18-44 years population has been highly vaccinated followed by 45-60 years population. According to the government, based on the projected mid-year count for 2021, the country's total population aged 12 years and above is approximately 108 crores. Around 94.37% of the 12+ population of the country have received at least one dose of the COVID-19 vaccine since the vaccination drive began. In addition to this, 86.99% of the eligible population has been fully vaccinated. In term off cumulative vaccination as compared to population of states and UTs, 90% citizens of Andhra Pradesh has been recorded fully vaccinated followed by Andhra Pradesh (88%), Andaman and Nicobar Islands (88%), Lakshadweep (87%), Jammu and Kashmir (85%), and Himachal Pradesh (84%) whereas lower vaccination has been recorded in Meghalaya (33%), Nagaland (34%) and Manipur (41%).

Table 4: Cumulative Vaccinations in India.

S.N.	Beneficiaries Vaccinated	First Dose	Second Dose	Total
1.	12 to 14 Years	36448824	22917894	59366718
2.	15 to 18 Years	60343904	48542748	108886652
3.	18+ Years	915079989	840502089	1755582078
4.	Precaution Dose	5224568 (18-59)	38081929 (60+ Years, HCW, FLW)	43306497

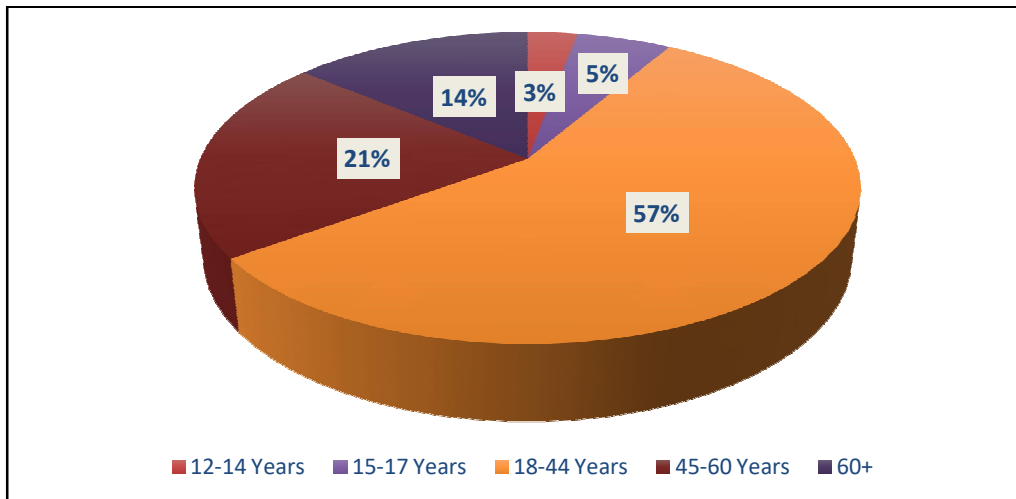


Figure 5: Vaccinations in India by Age Group

CONCLUSION

The prime aim of the prospective study was to highlight the overall vaccination status and strategies implemented during corona pandemic in India. It is also well known that India is the world's largest manufacturer and worldwide distributor of vaccines. COVID-19 vaccination was under government control in the initial phase. Impactful coordination at national, state, and district levels has been established for effective cooperation and collaboration among the key departments involved in COVID-19 vaccination. Twenty-three ministries/departments and numerous developmental partners were involved in planning for the COVID-19 vaccine. The study's outcome can be stored and viewed as baseline data for future pandemic preparedness and to effectively tailor and refine the strategies that will help the population at large.

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