Geo-Visualization of Multi-State Covid-19 and Vaccination Patterns in Nigeria

U. W. Ibor, Ph.D
Department of Geography, Federal University Lokoja, Nigeria
Author's Email: uguru.ibor@fulokoja.edu.ng

ABSTRACT

COVID-19 vaccination is an ongoing global response to mitigate the impact of COVID-19 with different levels of coverage across countries. This study addresses the paucity of information on how vaccine coverage relates to cases of COVID-19 across geo-political zones in Nigeria. Secondary data from Nigeria Center for Disease Control and National Bureau of Statistics on COVID-19 cases and vaccination were analyzed using the Geographic Information System (GIS). The map of Nigeria was produced in ArcGIS using the data of the reported cases for each state. The map was colour coded to show zones of low to high prevalence. Rank order and multiple regression techniques were used to ascertain significant relationships. The results showed that South West had the highest confirmed cases of COVID-19 (49%), followed by North Central (19%) and South South zone with 39,126 cases which accounted for 15% of the total number of confirmed cases. The geopolitical zones with the lowest confirmed cases of COVID-19 were Northwest (8.0%), Southeast (5.0%) and North East (4.0%). Similarly, the south-western (13.7%) and north-western (12.8%) zones had high vaccine coverage, while the south-southern (-6.38), south-eastern (-10.2), north-central (-0.86) and north-eastern (-9.01) zones had low vaccine coverage. South West showed high incidences of confirmed COVID-19 cases and high coverage of vaccine. Meanwhile, the North West in which the confirmed cases of COVID-19 showed low incidences had high composite variates of vaccination. Population size was significantly responsible for the 40.4% changes in the total number of persons vaccinated in Nigeria ($t = 3.084$, $p<0.05$). The study concludes that confirmed cases of COVID-19 and vaccine uptake vary across the states of Nigeria. Concerted efforts are required to scale up vaccine uptake in low coverage areas.The study concludes that confirmed cases of COVID-19 and vaccine uptake vary across the states of Nigeria. Concerted efforts are required to scale up vaccine uptake in low coverage areas.

Keywords: Vaccination, Spatial Pattern, Global response, Geopolitical, Nigeria.

1. Introduction

COVID-19 vaccination is an ongoing global response to mitigate the impact of COVID-19 pandemic with different levels of compliance across countries. As at November 2023, seven hundred and seventy-two million confirmed cases of COVID-19 had been reported globally, with over six million associated deaths (World Health Organization, 2023). In Nigeria, over two million and sixty-six thousand cases with over three thousand deaths have been reported in February, 2023 (National Center for Disease Control, 2023). The pandemic also led to severe psychological, and socio-economic crises across the world and Nigeria in particular. Unfortunately, many Nigerians do not believe in the existence of the virus (Olu-Abiodun, 2022). At the peak of the pandemic in 2020, far-reaching measures such as travel restrictions, extensive testing, nationwide lockdown, social distancing, use of face masks, and isolation of infected persons were put in place to curb the further spread of COVID-19 (Presidential Steering Committee on COVID-19, 2022; Olu-Abiodun et al., 2023; Jacobs and Okeke, 2022). However, these measures were not enough to contain the spread of the virus and it was not easy to enforce among the general populace (Olu-Abiodun et al., 2023).

At present, there is no specific treatment for COVID-19. However, vaccination is still one of the most effective ways of preventing the virus. Despite the potentials of COVID-19 vaccine in viral prevention, Nigeria is one of the countries in Sub-Saharan Africa where vaccine hesitancy is high. Yet, it is a known fact that the novel virus, though under control, is still very much around and humanity might have to learn to live with it for a long time like some developed nations are already doing. The Africa Center for Disease Control (CDC)…estimated that at least 60 percent of the continent's population needs to be vaccinated to create community immunity that will protect Africans…' (Africa Center for Disease Control, 2021; Seydou, 2021). In spite of the public health importance of COVID-19 vaccination, vaccine refusal has now become a public health concern, most especially in Sub-Saharan Africa (SSA) (Motumbo, et al., 2021; Oyekale, 2022). Vaccine hesitancy occurs against a colonial backdrop of inequalities in global health research, socio-cultural complexities, poor community involvement and public distrust (Ochola, 2023). To overcome vaccine hesitancy, almost all countries at some point provided the vaccine to people free of charge and enacted mandatory vaccination policies (Cameron-Blake et al., 2023). The legality of compulsory vaccination as attempted in some states of Nigeria and elsewhere is also replete with controversies.

Empirical review has shown that existing studies on COVID-19 are based on spatial and temporal patterns of outbreaks as well as associated socio-economic and environmental risk factors (Osayomi et al., 2021; Okafor & Ibor, 2021). Relatively, few geographic studies have established the correspondence between spatial pattern and vaccine situation of the pandemic in Nigeria (Oyekale, 2022). The very few available literatures on vaccination have at best highlighted the problem of vaccine hesitancy. There is less evidence on how acceptance of the vaccines relates to cases of COVID-19 across geo-political zones in Nigeria.

Apparently, studies on COVID-19 vaccination, and more importantly, the spatial and geographic factors influencing COVID-19 vaccination in Nigeria are rare. This limitation has implications in health planning and policy formulation. Hence, it is critical to undertake the study on spatial patterns of COVID-19 and vaccination in order to address disparities in vaccine coverage in relation to COVID-19 cases. The study could provide insights on vaccine coverage and disparities in access in order to guide interventions and promote access to COVID-19 vaccines and vaccination. Expectedly, the study can be beneficial to planning authorities in promoting geographical access, in the consumption of vaccines of other diseases of public health importance.

2. Study Area and Methodology

Study Area

Physical Characteristics

Nigeria is located between Latitudes 4° and 14°N of the Equator and Longitudes 2° and 15°E of the Prime Meridian with a total land area of 923,768 km2, and borders with Republics of Benin and Niger, Chad, and Cameroon (Philips, 2004). It is a sub-Saharan West African country on the Gulf of Guinea, east of the Greenwich and north of the equator. The country is made up of 36 states including the Federal Capital Territory (FCT), Abuja (Figure 1). It maintains a large expanse of coastline, over 853 km in length, with hydrological features which includes the major rivers Niger and Benue, both of which confluence at Lokoja, and flows further southwards through the Niger Delta into the Atlantic Ocean (Philips, 2004).

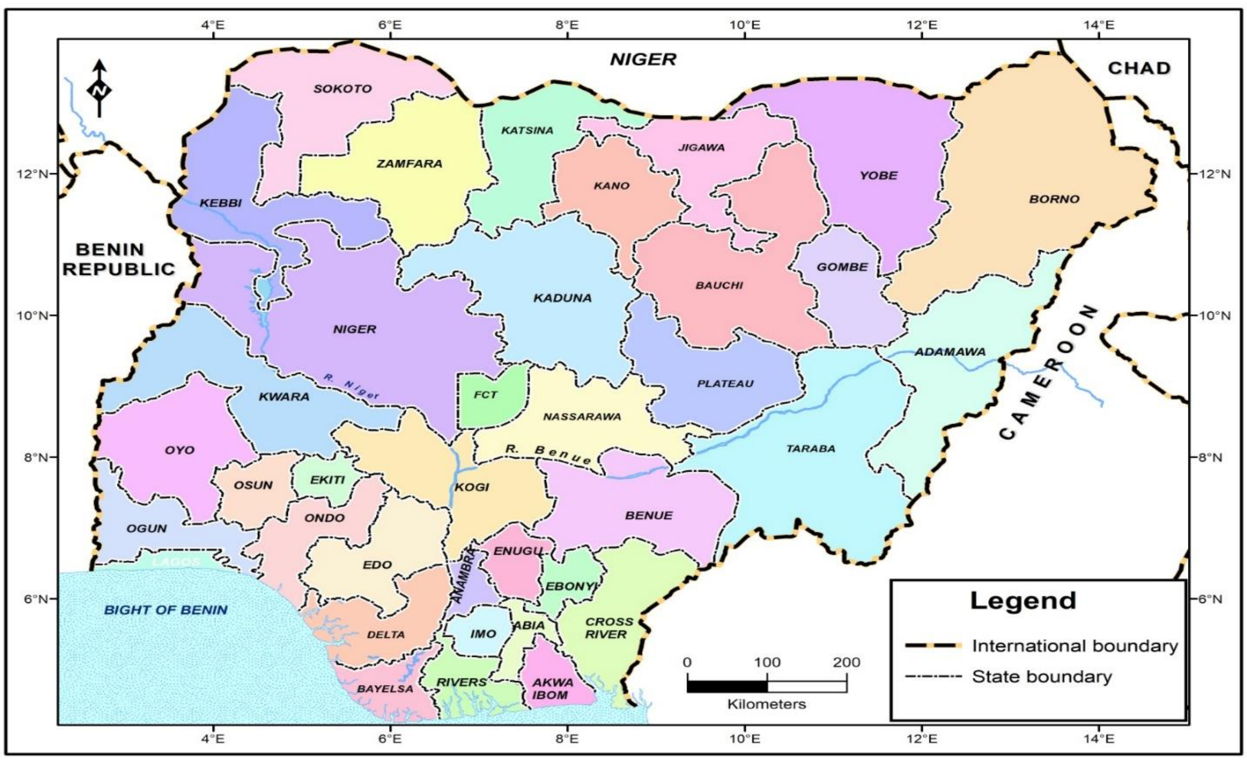

Figure 1: Nigeria – Study Area

Source: Kogi State Ministry of Lands and Urban Development, 2023.

The climate of Nigeria is dominated by West African monsoon circulation and the prevailing winds transport moisture from the Gulf of Guinea in the low levels of the atmosphere. There are three major climatic regions in Nigeria: a tropical monsoon climate in the south, a tropical savanna climate for most of the central regions and a Sahelian hot and Semi-arid climate in the north of the country (World Bank Group, 2021). These regions are characterized by variant climatic patterns (Nnamchi and Li, 2011). Nigeria's climate is influenced by its geographical location, topography, and the interactions of various air masses. The climate has a significant impact on the country's health, economy, and society. The high temperature and humidity can also be uncomfortable and can lead to health problems (Nnamdi, Lin, Wang & Nnamchi, 2019). In fact, several studies in Africa and elsewhere indicate that the transmission of COVID-19 is affected by temperature (Kassem, 2020; Ayodele, Jimoh, Fagbamigbe & Onakpoya, 2021; Chen, Prettner & Kuhn, 2021; Gansmeier, 2022).

Population and Economic Characteristics

Nigeria is the most populous country in Africa. The 2006 census confirmed over 140 million people in Nigeria, but this population has grown steadily, and is presently estimated at more than 170 million people, making the country the seventh most populous country in the world (Population Reference Bureau, 2007; World Bank 2013). High fertility rate along with urbanization which appear not to be accompanied by corresponding strategies for birth control partly explains rapid population growth in Nigeria (Ibor, 2019). Currently, Nigeria has the largest economy in Africa with an estimated 2015 gross domestic product (GDP) of $521.8 billion (NBS, 2015). The country is classified as a lower-middle-income country with 62 percent of its citizens living in extreme poverty (World Bank, 2021) and the resultant illiteracy and ignorance and its impact on health outcomes.

In Nigeria, healthcare is organized into Primary HealthCare (PHC), Secondary HealthCare (SHC) and Tertiary HealthCare (THC). The PHCs handles primary illnesses; and are located at the grassroot, while THCs are located in urban centers and responsible for the treatment of higher order illnesses including COVID-19 (Monye, 2006). This suggests that health facilities for the prevention, diagnosis and treatment of COVID-19 are not evenly distributed in Nigeria. However, effective medical and adequate pharmaceutical and non-pharmaceutical measures are prerequisite to successfully combat COVID-19. As a result, healthcare delivery has experienced progressive deterioration due to weakened political will on the part of successive governments to effectively solve several problems that have existed in the sector over many years (Monye, 2006). This negatively impacts the productivity of citizens and Nigeria's economic growth by extension. The poverty level is high as a result they can hardly afford healthcare. As of February 2018, the country was ranked 187 out of 191 countries in the world in assessing the level of compliance with Universal Health Coverage (UHC), as very little of the populace is health insured, whereas even government provision for health is insignificant (Awosusi & Temitope, 2015).

The COVID-19 pandemic in Nigeria was a part of the worldwide pandemic of coronavirus disease 2019 (COVID-19) caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). In order to flatten the COVID-19 curve through a persistent reduction in confirmed cases, and ensuring that infected persons quickly recover from the virus, the Nigeria Government introduced a number of interventional measures including vaccination. As a result, a nationwide immunization campaign has been ongoing in the country. As of 28 February 2022, 17,914,944 people have received their first dose of COVID-19 vaccine, and 8,197,832 have received their second dose (National Center for Disease Control, 2022). In spite of efforts to expand vaccine uptake and increase the awareness on vaccination and general sanitation, there are still inherent attitudes, belief and practices promoting vaccine hesitancy in different parts of the country, leading to low vaccination rates.

METHODOLOGY

The study area (Nigeria) was divided into 36 states and the Federal Capital Territory. All the 36 states including FCT were selected for the study. Epidemiological data set for COVID-19 were created from 27 February 2020 at the Nigeria Centre for Disease Control, Abuja. These data on the daily number of COVID-19 cases in Nigeria are collected and updated every 24 hours digitally. This dataset contains confirmed COVID-19 cases, active, deaths, tests, and recovered number of COVID-19 in each of the 36 states of Nigeria. However, the last observation of the final data set that were used in the analysis was in February, 2023. Similarly, the dataset for COVID-19 vaccination was obtained from the National Center for Disease Control. The explanatory variables (population size, literacy rate and number of air passenger traffic) were gathered from National Bureau of Statistics, Abuja Office.

Secondary data on Covid-19 doses administered to persons as at February 2022 was obtained from website of Nigeria Centre for Disease Control (NCDC). The number of first and second doses administered to clients was summed up to arrive at the total for the thirty-six states of Nigeria and the FCT and prepared and formatted as database file in Microsoft Excel. COVID-19 data used in this study was also collated to the Geopolitical zone level. ArcMap 10.8 version software was used for the mapping and analysis of COVID-19 data. The ArcMap was used to explore the datasets in order to assign symbols and create map layouts for visualization. In doing so, vector shapefiles of Nigeria by states as well as at the Geo-political zones were obtained from OpenStreetMap and added to the table of content of ArcMap 10.8. These shapefiles through the field attribute, was also joined to the formatted Excel database in ArcMap 10.8 software using '*join and relate'* tool for the two shapefiles, using *common field* containing the names of the thirty-six states. The resultant database in the new attribute was further exported as shapefile ready for spatial analysis and mapping.

Spatial distribution of COVID-19 cases, in terms of Confirmed, Recoveries, Deaths, Active, and Tests) and vaccine doses were mapped using choropleth technique (graduated colour) to quantify the magnitude of COVID-19 data both at the states and geopolitical zones. Analyzing the spatial pattern of COVID-19 cases as well as first and second doses, Global Moran's I statistics extension in Spatial analyst tool of ArcMap 10.8 was used. Shapefile containing COVID-19 cases and doses in the attribute table were used as input Feature class, while actual data was used as *input field* ble to establish the spatial pattern. Result on spatial pattern was generated as report file from the Results window of the software. Final mapping of the spatial distribution of COVID-19 was done in the Layout view window and exported as Raster in picture format for inclusion in the research.

Descriptive and inferential statistics were used in analyzing the data collected from the field. Descriptive statistics such as frequencies, tables and simple percentages were used to analyze COVID-19 and vaccination rates. In order to analyze and determine the spatial pattern of vaccination against COVID-19, Global Moran's I statistics in Spatial analyst tool of ArcMap extension was used. The technique was applied in order to know if values of vaccination correlate in geographic space. A positive Moran's I index value indicates tendency towards clustering while a negative Moran's I index value indicates tendency toward dispersion. The Moran's I index varies between -1 (negative spatial autocorrelation) and + 1 (positive spatial autocorrelation). If it is close to zero, zero spatial autocorrelation is present. A positive spatial autocorrelation in this instance would mean states with similar vaccination rates are spatially clustered while a negative autocorrelation suggests states are surrounded by neighbours with contrasting values.

The second hypothesis which states that ‘’there is a significant relationship between number of confirmed cases and number of persons vaccinated in Nigeria’’ was tested using the Pearson’s Product Moment correlation (PPMC). In this hypothesis, population size is the independent variable and number of persons vaccinated is the dependent variable.

While the Multiple Regression Analysis (MRA) was employed to test the hypothesis that ‘’ the number of persons vaccinated of COVID-19 is not significantly influenced by number of deaths, number of confirmed cases, population size, literacy rate and number of air passenger traffic. For this analysis, the independent variables were number of deaths (x_1), number of confirmed cases (x_2), population size (x_3) literacy rate (x_4) number of air passenger traffic, while total number of persons vaccinated of COVID-19 was the dependent variable (Y). MRA was used to determine the most important factor(s) influencing COVID-19 vaccination in Nigeria. A large part of the data was analyzed using Statistical Product and Service Solutions (SPSS) version 22.0

Rank order technique was used to derive standard deviates that were used to rank the states into high and low vaccine coverage. For the method, the raw data was weighted by the number variable for each indicator give the weighted score for each year and state in each measure (Njar, 2018; Ibor et al., 2015). The standard scores (Z) for each state and year were then summed up to get an composite score and by so doing indexing the position of that state in the whole distribution of values. The method is given by the equation:

$$Z = \frac{X - \bar{x}}{S}$$

Where:

x = score for a variable

$\bar{x}$ = mean value

S = standard deviation for the

The model involves the computation of series of standard scores for the COVID-19 vaccination variables. These provide a mean to classify and rank the states on a common measure/scale. The classification and ranking of states are to show the relative position of each of the states and how each fared in the COVID-19 vaccination in Nigeria. With these computations, the aim of using Rank order technique was to determine the magnitude of differences that exist among the states in terms of COVID-19 vaccination in Nigeria as well as to ascertain high and low coverage areas in the overall vaccine distribution. Also, the composite measures of inequalities in which all indicators and their variables have contributed is shown. This method has been widely used (Anjorin et al., 2022; Njar, 2018; Ibor et al., 2015; Aderamo & Aina, 2011). The technique has the advantage of simplicity in calculation (it can be calculated manually) and the merit of providing a base level (i.e. the zero mean) against which the magnitude of coverage can be measured and categorized. Therefore, in the scores obtained from this standard deviate technique, states with positive scores were regarded as high coverage areas while those with negative scores were considered low coverage areas (Njar, 2018; Ita et al., 2012; Aderamo & Aina, 2011).

3. Results and Discussion

COVID-19 Distribution by Geo Political zones in Nigeria

The pattern of COVID-19 across geopolitical zones, in terms of confirmed cases, recoveries, deaths, active cases, and tests is as shown in table 1. Result from table 1 indicates that, out of the total number of 266,213 confirmed cases in Nigeria, South West zone has the highest value of 131,261 which accounts for 49%. North Central zone came a distant second with 50,773 accounting for 19%, followed by South South zone with 39,126 cases which accounts for 15% of the total number of confirmed cases. Northwest (21827) ranked fourth in the burden of COVID-19 in Nigeria and Southeast occupied fifth position in the severity of COVID-19 with 12792 cases. North East zone recorded the lowest confirmed cases (10,434) which accounts for only 4% of the total burden of the disease. Southwest has the highest confirmed cases of COVID-19 and Northeast has the lowest. This pattern of may have been influenced by differences in demographic, socioecpnomic and genetic risk factors. Dense population agglomeration, intense urbanization and high air passengers' traffic have combined to sustain the disease in the Southwest. Whereas. endemic poverty could be a lessening factor of the disease in Northeast.

The result agrees with the work of Fasona et al., (2021) that patterns of vulnerability of COVID-19 is influenced by variations in social, economic, environmental and cultural conditions or processes in Nigeria.

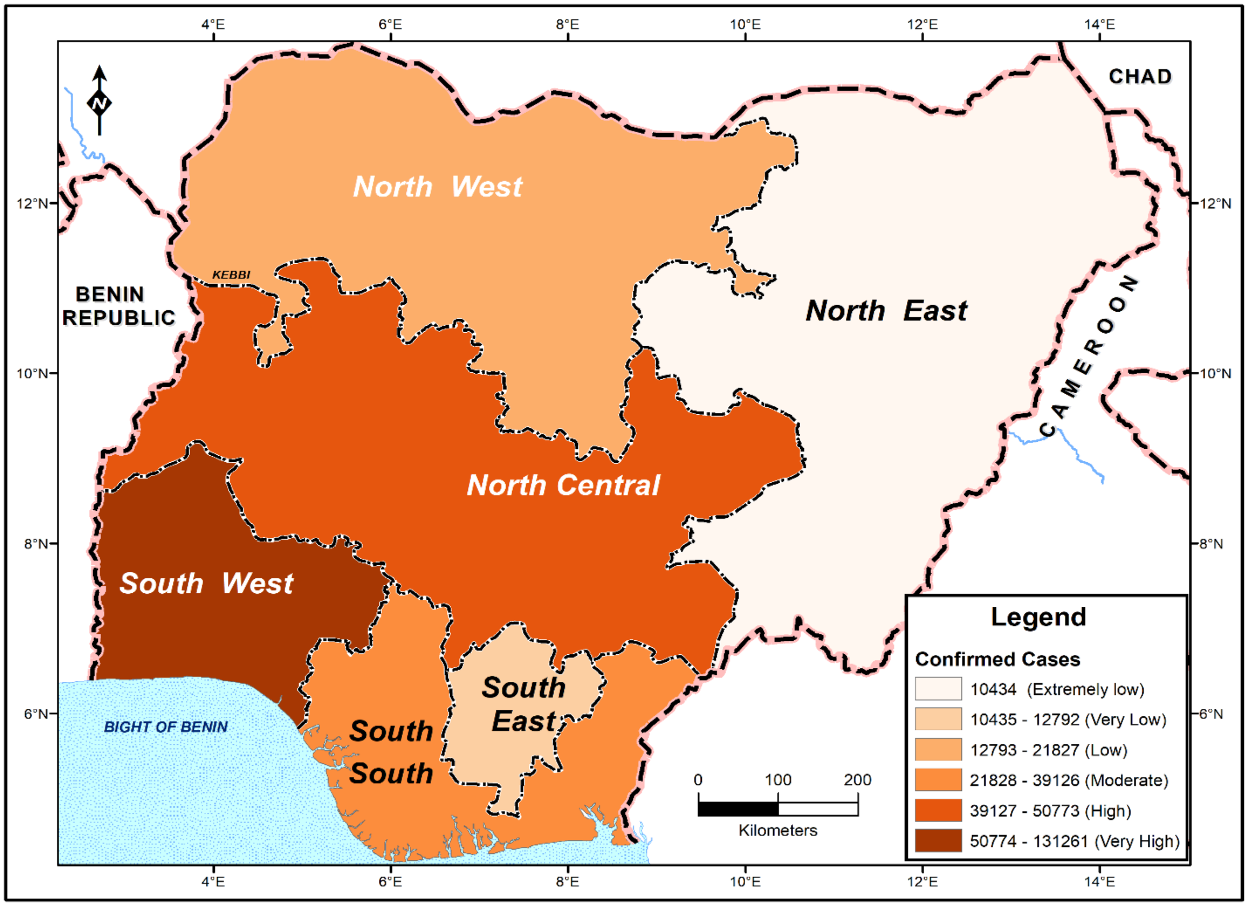

Figure 2: distribution of confirmed cases by Geo-political zones in Nigeria as at February 2023.

Out of the total recoveries of 259,027, South West zone further maintained the lead with 128159 accounting for 49%, while North Central, and South-south zones maintained second and third positions with 49033, and 37901 recoveries, accounting for 18% and 15% respectively. Northwest recorded 21827 recoveries, occupying the fourth position, while the Southeast maintained fifth position with 12792 recoveries. The lowest number of recoveries was also recorded in North East zone with 10027 recoveries accounting for 4%. This result indicates that the highest recoveries were recorded in Southwest and the lowest in Northeast. The high recoveries in Southwest could be attributed to increase the number of COVID-19 diagnostic and isolation centers/facilities, particularly in Lagos State. This assertion has been noted by Okafor and Osayomi, (2021). Low confirmed cases of COVID-19 in Northeast may be the reason for low recoveries.

In terms of COVID-19 deaths, Southwest recorded the highest deaths with 1284 deaths accounting for 41% out of the total of 3145 deaths. This time around, South-south zone overtook North Central to attain the second position with 686 deaths, accounting for 22%, while North Central recorded 474 deaths accounting for 15% of the total. Northwest and Northeast recorded 324 and 205 deaths accounting for 10% and 7% respectively. The lowest number of deaths was recorded in Southeast with 172 deaths accounting for 5%. This result indicates that the Southwest had the highest deaths and southeast recorded the lowest deaths from COVID-19. The high numbers of deaths in Southwest may be due to disease severity, while low death rate in Southeast could be attributed to recoveries occasioned by prompt diagnosis. This fact has been supported by Adejumo et al, (2022) in their study on factors associated with death among hospitalized COVID-19 patients in Lagos State, Nigeria.

Out of the 4131 active cases, Southwest zone recorded the highest occurrence with 1918 active cases accounting for 46%. This is closely followed by Northcentral zone with 1266 active cases accounting for 31%. The South-south is the third geopolitical zone in the lead of active cases (539), accounting for 13%. Northeast has the fourth highest active cases of 192 incidences, representing 5%; and Southeast accounts for the fifth position with 146 active cases. The lowest active cases of 70 was recorded in North West accounting for just 2%. This result suggests that the Southwest had the highest active cases and the Northwest recorded the lowest. Differences in disease outcomes in infected persons is likely the reason for variations in active cases in the regions. This observation has been made by Adejumo et al, (2022).

Considering the total test conducted of 5915126, South West zone has the highest number of these tests (2050500) accounting for 35%. 1200775 and 1094765 tests were recorded in North Central and South South zones accounting for 20% and 19% respectively. On the lower end, North East and South East zones recorded the lowest tests with 440613 and 337034 tests accounting for 7% and 6% respectively. It is evident from the result that three zones: South West, North Central, and South South, clearly top the zones with high occurrence of confirmed cases, recoveries, deaths, active cases, and number of tests in Nigeria.

Table 1: Summarised Covid 19 cases by Geo political zones in Nigeria as at February, 2023.

Geo Political	Confirmed Cases	%	Recoveries	%	Death	%	Active Cases	%	Testing	%
North West	21827	8	21433	8	324	10	70	2	791439	13
North East	10434	4	10027	4	205	7	192	5	337034	6
North Central	50773	19	49033	19	474	15	1266	31	1200775	20
South West	131261	49	128159	49	1284	41	1918	46	2050500	35
South East	12792	5	12474	5	172	5	146	4	440613	7
South South	39126	15	37901	15	686	22	539	13	1094765	19
Total	**266213**	**100**	**259027**	**100**	**3145**	**100**	**4131**	**100**	5915126	100.0

SOURCE: Author's computation from NCDC COVID-19 Situation Report, February 2023.

Spatial Variations in COVID-19 vaccination in Nigeria

The weighted raw values of states on COVID-19 vaccination variable were transformed into standard scores. The transformation gives scores that form the matrix represented in Table 2. The summation of the scores for standard deviate in each state results in the composite score in COVID-19 vaccination in Nigeria. The result shows the (summed) deviates. Focusing on the signs of the composite deviates, only nine (9) states were found to be high in COVID-19 vaccine coverage, while twenty-eight(28) states had low vaccine coverage rates. The high vaccine coverage states were Delta, FCT, Jigawa, Kano, Lagos, Nassarawa, Ogun, Osun and Oyo. It is important to note the primacy of Jigawa, Lagos and Kano states. These states have the highest standard positive deviate of +9.42,+8.33 and +7.30 respectively accounting for thrice as much as the scores of some states in the low coverage category put together. This pattern signifies a highly distinctive spatial structure in COVID-19 vaccination in Nigeria. The scores of the twenty-eight (28) low vaccine coverage states ranged from -0.05 for Zamfara State which was the lowest to -2.62 for Bayelsa state which was the least of all the low vaccine coverage states. A closer look at the scores in Table 2 revealed that states such as Delta, Jigawa, Kano, Lagos, Oyo, Osun, Ogun and Nasarawa had positive scores across the periods of COVID-19 vaccination in Nigeria. Therefore, states with negetive scores in varying degrees are indicative of the low coverage in COVID-19 vaccination in Nigeria. From the pattern displayed, it is apparent that there exists haphazard distribution of vaccination across the states in Nigeria.

Table 2: Standard deviates or scores in COVID-19 vaccination in Nigeria

State	Total clients vaccinated (1st dose)	Total clients vaccinated (2nd dose)	Total of 1st and 2nd dose	Composite score
Abia	-0.61	-0.52	-0.59	-1.72
Adamawa	-0.32	-0.37	-0.34	-1.03
Akwa Ibom	-0.63	-0.64	-0.64	-1.91
Anambra	-0.69	-0.72	-0.71	-2.12
Bauchi	-0.32	-0.42	-0.36	-1.1
Bayelsa	-0.85	-0.89	-0.88	-2.62
Benue	-0.39	-0.53	-0.44	-1.36
Borno	-0.57	-0.67	-0.61	-1.85
Cross River	-0.26	-0.22	-0.25	-0.73
Delta	0.12	0.60	0.27	0.99
Ebonyi	-0.78	-0.83	-0.81	-2.42
Edo	-0.55	-0.56	-0.56	-1.67
Ekiti	-0.37	-0.23	-0.33	-0.93
Enugu	-0.57	-0.68	-0.61	-1.86
FCT	-0.06	0.14	0.00	0.08
Gombe	-0.49	-0.38	-0.47	-1.34
Imo	-0.70	-0.67	-0.70	-2.07
Jigawa	3.81	2.23	3.38	9.42
Kaduna	-0.16	-0.05	-0.13	-0.34
Kano	2.63	2.15	2.52	7.3
Katsina	-0.08	-0.32	-0.15	-0.55
Kebbi	-0.43	-0.43	-0.44	-1.3
Kogi	-0.51	-0.65	-0.56	-1.72
Kwara	-0.06	-0.05	-0.06	-0.17
Lagos	2.15	3.55	2.63	8.33
Nassarawa	1.32	1.76	1.48	4.56
Niger	-0.24	-0.37	-0.29	-0.9
Ogun	0.92	1.25	1.04	3.21
Ondo	-0.14	-0.08	-0.13	-0.35
Osun	0.16	0.16	0.16	0.48
Oyo	0.88	1.07	0.96	2.91
Plateau	-0.47	-0.42	-0.46	-1.35
Rivers	-0.16	-0.13	-0.15	-0.44
Sokoto	-0.50	-0.65	-0.56	-1.71
Taraba	-0.55	-0.68	-0.60	-1.83
Yobe	-0.57	-0.68	-0.61	-1.86
Zamfara	0.04	-0.09	0.00	-0.05

Author's Analysis, 2023

Disparities in COVID-19 vaccination across geopolitical zones

In this section, the magnitude of spatial idisparity that exist among geopolitical zones is assessed. The six geopolitical zones in Nigeria are: southeast (Anambra, Enugu, Ebonyi, Imo and Abia states; south-south (Edo, Delta, Rivers, Bayelsa, Cross-River and Akwa-Ibom states); south-west (Lagos, Ogun, Oyo, Osun, Ondo and Ekiti states); north-central (Kwara, Kogi, Plateau, Nassarawa, Benue, Niger and F.C.T); north-east (Taraba, Adamawa, Borno, Yobe, Bauchi and Gombe states) and north-west (Sokoto, Zamfara, Kebbi, Kaduna, Katsina, Kano and Jigawa states). The composite scores which is the summation of standard score values (Z-score) were used to display disparity in COVID-19 vaccination across geopolitical zones (Table 3). A cursory look at the signs of the composite deviates revealed that the south-western and north-western geopolitical zones were advantaged or privileged to have more persons or total persons vaccinated (first and second dose), an indicative of high vaccine coverage, while the south-southern, south-eastern, north-central, and north-eastern geopolitical zones had low numbers of persons vaccinated. The geopolitical zone with the highest vaccine coverage was the southwest, while the southeast geopolitical zone was the least in the distribution of persons vaccinated (first and second dose) as at 28 February, 2022. The result therefore shows a high level of disparity in the total number of persons vaccinated (first and second dose).

Table 3: Composite scores in COVID-19 vaccination

Geopolitical Zones	Composite scores
South-east	-10.19
South-west	13.65
South-south	-6.38
North-central	-0.86
North-east	-9.01
North-west	12.77

Source: Author’s Analysis, 2023

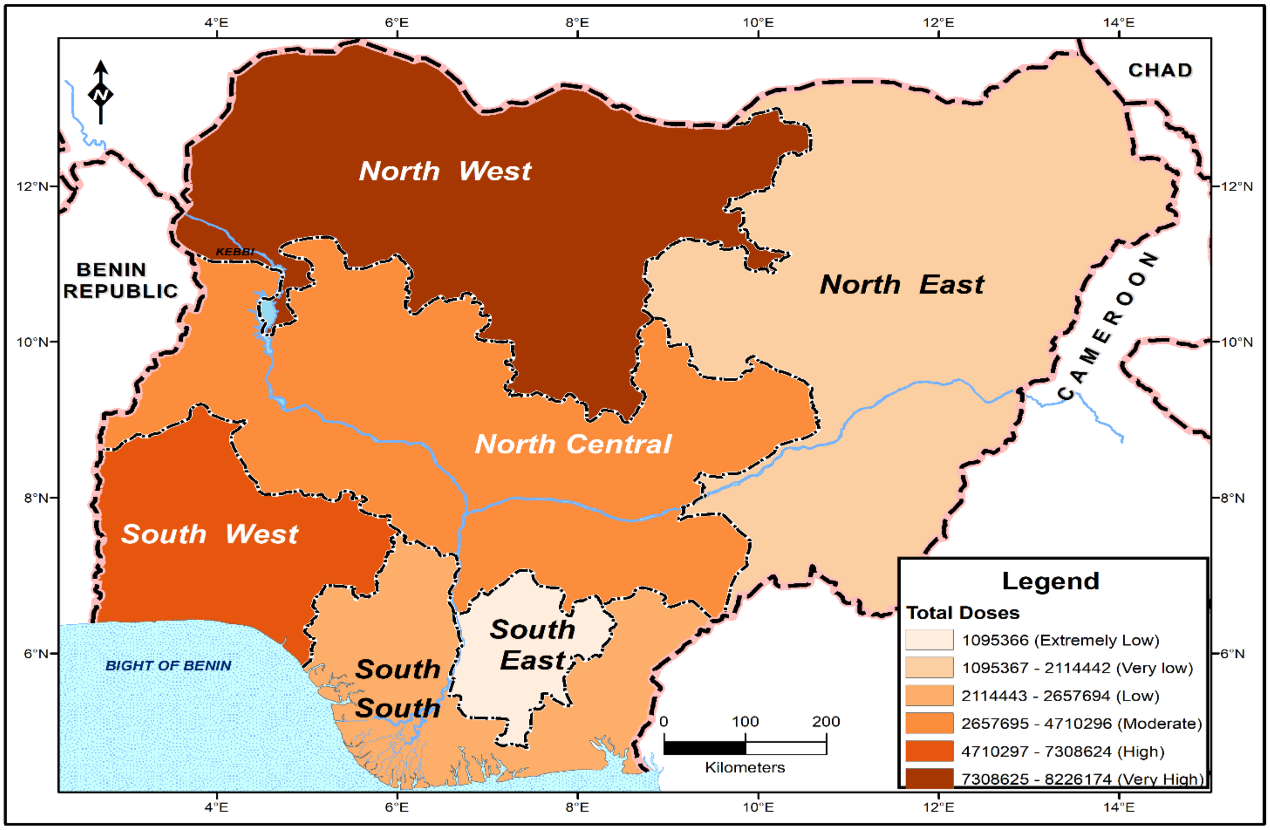

Figure 3: Distribution of Total number of Covid-19 Vaccines administered in Geo-political zones of Nigeria .

The information presented in Figures 3 & 4 shows most advantaged and most disadvantaged geopolitical zones in relation to COVID-19 vaccination. As displayed, the most advantageous zone was the south-western geopolitical zones closely followed by the north-western geopolitical zone. On the disadvantaged zones, the south-eastern geopolitical zone was most disadvantageous, closely followed by the north-eastern geopolitical zone. The less disadvantageous was the north-central geopolitical zone. The information shows a noticeable pattern of disparity in the distribution of COVID-19 vaccination in Nigeria.

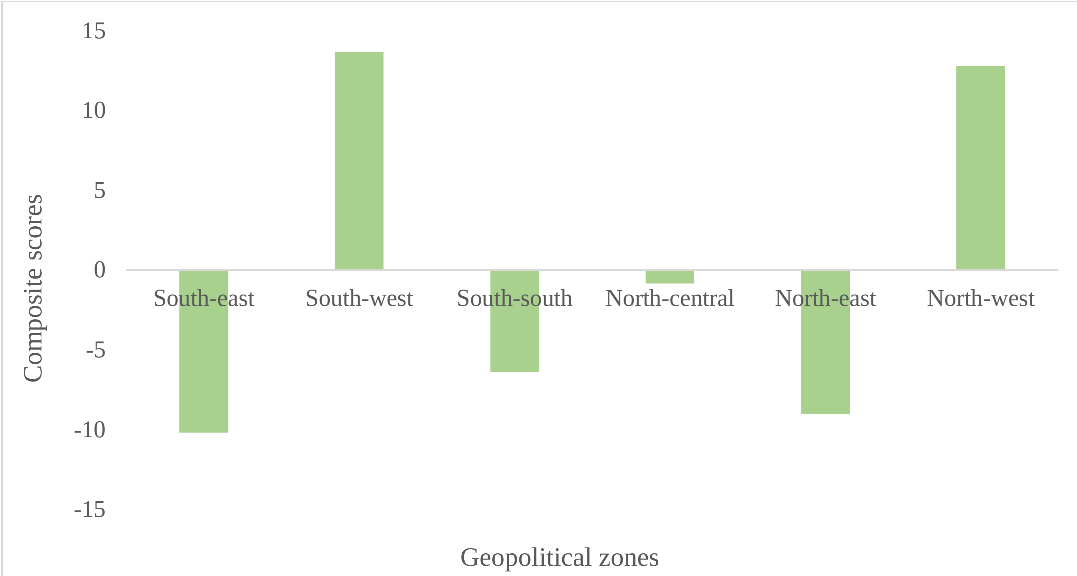

Figure 4: Disparities in COVID-19 vaccination across geopolitical zones

Source: Author's Analysis, 2023

Table 4 shows the result of Spatio-autocorrelation of first and second doses of Covid-19 as well as the total doses in Nigeria. On the one hand, Result from table 3 shows that spatial pattern of first dose of Covid-19 across the Geo-political zones is random. In other words, the result indicates that given the z-score of -0.927985153889, the pattern does not appear to be significantly different than random. Similarly, the Spatial pattern for the second dose also exhibit random pattern given the z-score of 0.656036294254, the pattern does not appear to be significantly different from random. The spatial pattern of the overall doses (first and second) interestingly exhibits a random pattern given the z-score of 0.833944361719 significant at 0.01 level of significant, the pattern does not appear to be different from random pattern. The result of test of significance to arrive at the observed pattern is as shown in figures 5a – c. Overall, these results suggest that the distribution of COVID-19 vaccination is not evenly distributed in Nigeria. This pattern may be due to inequalities in the supply and administration of COVID-19 vaccines.

Table 4: Spatial Pattern of first and second doses of Covid-19 Vaccine by Geo-political zone

Doses	Z-Score	P-Value	Variance	Expected Index	Moran's Index	Pattern
1st dose	0.927985	0.353415	0.140539	-0.200000	0.147888	Random
2nd dose	0.656036	0.511801	0.145627	-0.200000	0.050350	Random
1st & 2nd Dose	0.833944	0.404312	0.147809	-0.200000	0.120618	Random

Source: Author’s Analysis, 2023

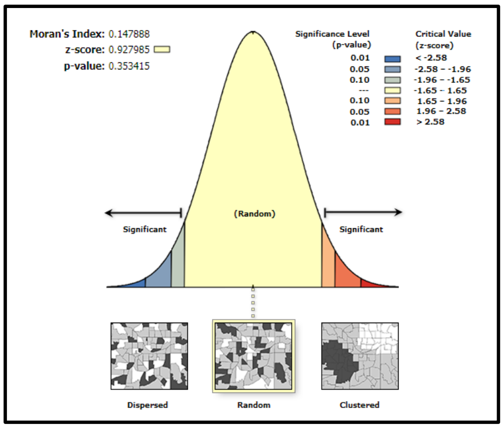

Figure 5a: Global Morans I 1st dose

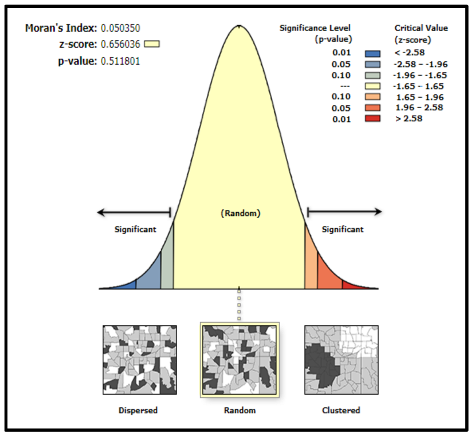

Fig. 5b : Global Morans I 2nd dose

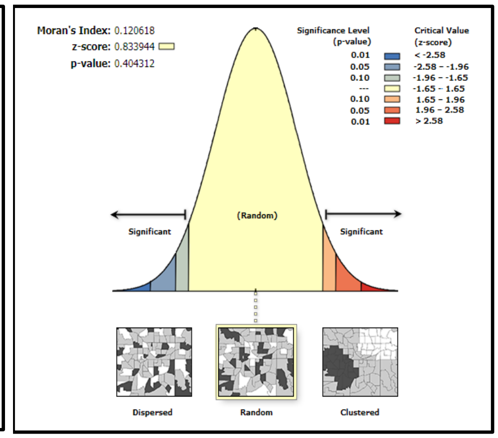

Fig. 5c: Global Morans I 1st & 2nd dose total

Explanatory Factors of COVID-19 Vaccination in Nigeria

In attempt to examine the relationship between confirmed cases of covid-19 and total number of vaccines administered as at February, 2023, figure 6 helps to visualize these results. It could be inferred from figure 6 on the one hand that, Lagos with the highest number of confirmed cases of covid-19, recorded high (but not the highest) number of vaccines. Similarly, FCT which also recorded high confirmed cases after Lagos, did not record a corresponding high number of vaccines. Rather, Kano state which had moderate confirmed cases of convid-19, received higher vaccines, even more that the FCT. On the other hand, and more remarkably, Nasarawa state which can be categorized as having very low confirmed cases of covid-19, surprisingly received the highest total vaccines alongside with Kano state (moderate confirmed cases). This is also the case in Zamfara state. The result further shows that, while some states (Kebbi, Zamfara, Jigawa, Katsina, Abia, Cross Rive, Osun, Gombe, and Adamawa) with very low confirmed cases of covid-19, moderate and low vaccines were received in the same states. States such as Bauchi, Yobe, Sokoto, Niger, Benue, Taraba, Kogi, Enugu, Ebonyi, Imo, Ekiti, Bayelsa, and Borno, all recorded very low confirmed cases of covid-19 as well and very low total number of vaccines.

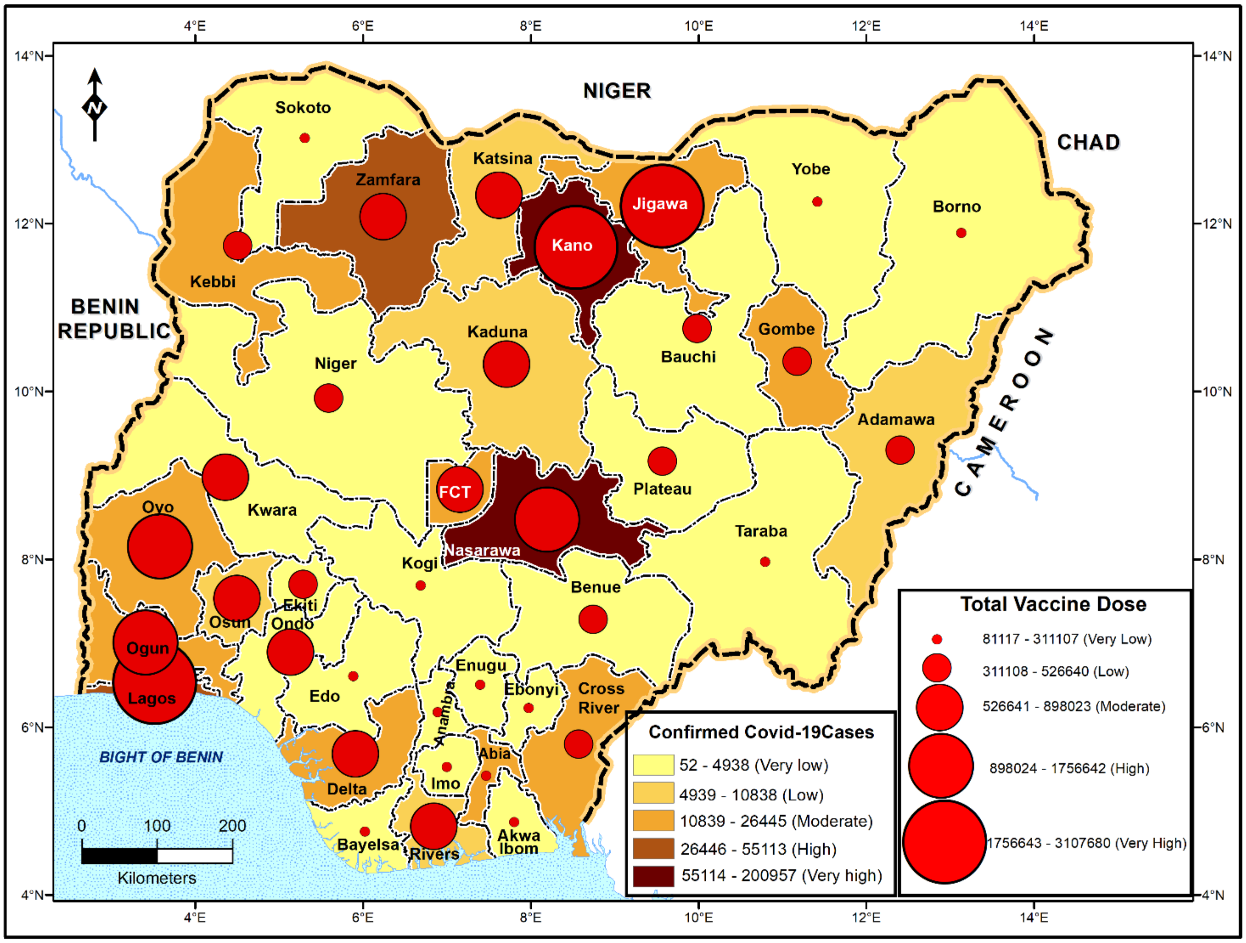

Figure 6: Spatial distribution of Covid-19 confirmed cases and total dose of vaccines as at February 2023.
Source: Author's analysis, 2023.

The Pearson's correlation was used to determine the relationship between number of confirmed cases of CIVID-19 and total number of persons vaccinated. The result obtained is contained in Table 5. The result reveals a positive and significant relationship between the number of confirmed cases of COVID-19 and the total number of persons vaccinated against the virus in Nigeria ($r = 0.442$, $p<0.05$). This decision is taken because the probability value of 0.006 is lower that 5% significance level. The positive correlation coefficient therefore implies increase in the number of confirmed cases would result in a corresponding increase in the total number of persons vaccinated. The result obtained implies that the number of confirmed cases has a direct association with the total number of persons vaccinated. The result in Table 5 therefore indicates that the increase in the number of confirmed cases of COVID-19 substantially increases the total number of persons vaccinated of the virus.

Table 5: Pearson's Correlation between the Number of Confirmed Cases of COVID-19 and the Total Number of Persons Vaccinated

Variable	Number of confirmed cases	
	r-value	Probability value
Number of persons vaccinated	0.442*	0.006

*Correlation is significant at 0.05 level (2-tailed); N = 37

Source: Author's Analysis, 2023.

Also, Pearson's correlation was employed to test if there is no positive relationship between number of tests and number of persons vaccinated against COVID-19. The result obtained is shown in Table 6. The result reveals a positive relationship between number of tests and number of persons vaccinated against COVID-19 ($r = 0.293$, $p>0.05$). The positive correlation coefficient simply indicates that increase in number of tests will result in a corresponding increase in the number of persons vaccinated. This result implies that as people do test to know their status of COVID-19, they try to protect themselves from infection by receiving the vaccine. Thus, states with more tests are more likely to have more persons vaccinated against COVID-19. The result obtained implies that the number of persons vaccinated is a function of the number of tests carried out.

Table 6: Pearson's Correlation between Number of Tests and Number of Persons Vaccinated Against COVID-19

Variable	Number of persons vaccinated	
	r-value	Probability value
Number of tests	0.293 ns	0.079

ns = Correlation is insignificant at 0.05 level (2-tailed)

Source: Author's Analysis, 2023

Further attempt was made to determine the influence number of deaths from COVID-19, number of confirmed cases, population size, number of air passenger traffic and literacy rate on the total number of persons vaccinated. This was achieved using multiple regression analysis to analyze and the result obtained is presented in Table 7. However, to correctly carry out the analysis**,** the logarithmic conversion method was employed to transform the variables to make them appropriate for regression analysis. The results in Table 7 revealed that out of the five independent variables simultaneously entered into the model, only population size was retained and significantly responsible for the changes in the total number of persons vaccinated. Population size was able to cause 40.4% of the changes in the total number of persons vaccinated in Nigeria. The result further indicated that population size (t = 3.084, $p<0.05$) exercised significant influence on the total number of persons vaccinated. The result simply shows that population is an important determinant of the total number of persons vaccinated across Nigeria. Also, a significant regression equation was found ($F = 9.508$, $p< 0.05$) implying the model is ideal in predicting the total number of persons vaccinated. The positive regression coefficient between population size and the total number of persons vaccinated simply suggests increase in the total number of persons vaccinated with the increase in population. Similar result was reported by Wehenkel (2020) who observed a positive association between COVID-19 deaths and influenza vaccination rates among elderly people worldwide. In addition, the strength of the predictor variable using the unstandardized regression coefficients suggests that population size is able to predict 63.6% of the increase in the total number of persons vaccinated.

Table 7: Summary of stepwise multiple regression analysis of the influence of population size on the total number of persons vaccinated

Predictor	**Coefficients**		
	b	**β**	**t-value**
Population size	1.005	0.636	3.084*
Test results			
F- value	9.508*		
R	0.636		
R^2	0.404		
Constant	1.055		
Std error	0.25		

*Significant at 5% significance level
Source: Author’s Analysis, 2023

Table 8: Factors influencing COVID-19 Vaccination in Nigeria using multiple regression

States	Deaths from COVID-19	number of confirmed cases	population size	literacy rate	air passenger traffic
Abia	34	2260	4138343	69.1	0
Adamawa	38	1309	4890180	43.6	175699
Akwa Ibom	44	4976	5089919	56.0	0
Anambra	19	2825	6006037	69.0	0
Bauchi	24	2032	8177929	18.3	0
Bayelsa	28	1373	2566229	54.9	0
Benue	25	2311	6201034	59.1	0
Borno	44	1629	6169245	33.6	197898
Cross River	25	948	4466383	46.4	197,998
Delta	112	5812	5687575	59.4	0
Ebonyi	32	2064	3238425	-	0
Edo	322	7928	4795888	64.4	433017
Ekiti	28	2451	3603329	54.5	0
Enugu	29	2952	4731224	75.9	508513
FCT	249	29403	2961274	55.7	4,758843
Gombe	56	3313	3919755	38.9	0
Imo	58	2691	5528336	75.4	322464
Jigawa	18	669	7357683	16.7	0
Kaduna	90	11662	8976519	44.7	73110
Kano	126	5401	15388077	45.4	545749
Katsina	37	2418	10121012	30.4	30313
Kebbi	16	480	5437029	16.4	0
Kogi	2	5	4466040	50.0	0
Kwara	64	4691	3519306	46.9	148109
Lagos	771	104266	13663620	81.2	4093712
Nassarawa	39	2831	2847966	28.4	0
Niger	20	1183	6727946	36.2	0
Ogun	82	5810	6395277	48.5	0
Ondo	109	5173	5338547	51.3	113625
Osun	92	3311	4518534	57.3	0
Oyo	202	10250	8050684	51.7	51172
Plateau	75	10349	4729486	47.4	57020
Rivers	155	18089	7542647	61.0	900728
Sokoto	28	822	6341253	18.0	132551
Taraba	34	1513	3592586	36.1	0
Yobe	9	638	3655645	22.6	0
Zamfara	9	375	5756544	27.4	0

Source: National Bureau of Statistics, 2023.

Conclusion and Recommendations

There are geopolitical variations of COVID-19 incidences and the distribution of COVID-19 vaccination in Nigeria. This study has established the fact that the spatial pattern of COVID-19 can provide better understanding of COVID-19 epicenters; and areas of high and low COVID-19 vaccination. This knowledge can guide in identifying high-risk areas and the deployment of vaccines and other interventional measures aimed at preventing the disease through herd immunity. The findings are useful for monitoring for future epidemiological outbreaks and response against biological threats in the country. The random pattern of COVID-19 vaccine coverage means that the administration of vaccination is not evenly distributed. South West showed high incidences of confirmed COVID-19 cases and high coverage of vaccine. Meanwhile, the North West in which the confirmed cases of COVID-19 showed low incidences had high vaccination rate. The maps produced have highlighted the spatial pattern of COVID-19 and vaccination, pointing to the fact that GIS technique can be useful in the geographic studies of diseases and spatial epidemiological investigations. Based on these findings, it has been recommended that concerted efforts are required to scale up vaccine uptake in low coverage areas, especially in the southern part of Nigeria. Surveillance and other interventional measures should be more concentrated in geopolitical zones and states that have been most affected by the pandemic, but with very low-to-moderate vaccine coverage.

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