SPATIAL MULTI-CRITERIA APPROACH FOR ASSESSING COVID-19 SPREAD IN NIGERIA AND LESSONS FOR FUTURE PANDEMIC MANAGEMENT

BY

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ABSTRACT

The novel Corona Virus Disease (COVID-19) quickly spread from Wuhan, China to many countries. This study aimed at examining the spread of COVID-19 in Nigeria using Geographic Information System technique and showing how the results derived can be used as decision-making tools for implementation of pandemic surveillance and control measures, thus contributing to its prevention, both now and for the future. Collected data were converted into Geographic Information System (GIS) format for processing and geospatial analyses using ArcGIS 10.0 software. A GIS-based Multi-Criteria Evaluation was also developed. Risk factors or criteria for COVID-19 spread, and their relative importance, were identified using expert-based knowledge. The criteria were each converted into map layers and combined based on a weighted linear combination to obtain COVID-19 pandemic risk map. The results show upward trends in the transmission, prevalence and mortality rate due to COVID-19 in Nigeria. During the period of 29 February, 2019 through 14 September, 2020, it has infected 56,388 people, resulting in 1,083 deaths. In terms of spread by states, Lagos remains the epicenter of the pandemic followed by Abuja, Oyo, Edo, Kano, Delta, Ogun, Rivers and Borno. The risk map show that generally Nigeria is at a high risk to the pandemic. Since COVID-19 is highly contagious and still spreading, there is need for proactive measures that will enhance public health mediations, good hygienic conditions, social distancing, and movement limitations to control the pandemic.

Key words: COVID-19, Geographic Information System, Multi-Criteria Analysis, Pandemic

INTRODUCTION

In December 2019, a novel corona virus (called COVID-19) was detected in Wuhan, China. By the end of February 2020, several countries globally, including many African countries, were experiencing sustained local transmission of corona virus disease. The European Centre for Disease Prevention and Control (ECDC) reported that as at 14 September, 2020, a total of 1,360,366 people have been infected in Europe. The five African countries with the most reported confirmed cases of the pandemic as at 14th of September, 2020 are: South Africa (650,749), Egypt (101,177), Morocco (88,203), Ethiopia (64,786) and Nigeria (56,388) while the five Africa countries with the most reported death cases as at 14th of September, 2020 are; South Africa (15,499) recording the highest number of fatality followed by Egypt (5,661), Algeria (1,620), Morocco (1,614) and Nigeria (1,083).

According to the Nigeria Centre for Disease Control (NCDC) 2020 situation reports on the spread of COVID-19 in Nigeria as at 14th of September, 2020, shows a total number of 56,388 confirmed cases across the 36 states including the Federal Capital Territory (FCT), Abuja. About 1,083 death cases were reported for the same period, since February 29th,

2020, when the process of data collection was initiated. The total number of people that have recovered from the pandemic as at 14 September, 2020 is 44,337. The most affected states in Nigeria in terms of confirmed cases and death respectively are; Lagos (18,663; 203), Federal Capital Territory, Abuja (5,447; 75), Oyo (3,221; 39), Plateau (3,115; 31) , Edo (2,610; 100), Kaduna (2,279; 33) Rivers (2,208; 59), Delta (1,791; 49), Ogun (1,748; 28), Kano (1,732; 54), Ondo (1,584;35) and Enugu (1,232;21).

The spread of disease, especially infectious disease, is unavoidably spatial; since majority of the data in public health have a spatial component, GIS can add a powerful graphic and analytic dimension by bringing together the fundamental epidemiological triad of person, time, and place (Gao, Rao, Kang, Liang and Kruse, 2020). A GIS is an integrated collection of computer software and data used to view and manage information connected with specific locations, analyze spatial relationships, and model spatial processes. It is a type of technology that integrates common database operations, such as query and statistical analysis, with the unique visualization and geographic analysis benefits offered by maps. Modernization of public health information systems to facilitate more efficient public health core functions, such as assessment, policy development, and assurance, requires geographically referenced information. The World Health Organization (WHO) and numerous other public health organizations have made the case for the importance of public health mapping and spatial analysis (Esri, 2007).

Today, using common types of GIS analysis, such as mapping where things are, mapping the "most" and "least," mapping disease density, finding "what's inside" or "what's nearby," and mapping change, public health authorities can prioritize interventions (Field, 2020). This study therefore attempts demonstrating how GIS techniques can be used to investigate the spread of COVID-19 in Nigeria since the first reported index case on the 29th of February to September 14th, 2020 and how it can be used as a decision-making tool for surveillance, response and prevention of an outbreak now and in the future. In achieving the above aim, the study will geo-visualize the pattern in the spatial distribution of COVID-19 cases in Nigeria and identify the diseases vulnerable and risk areas using GIS-based Multi-Criteria Evaluation.

THE STUDY AREA

Nigeria is situated between Latitudes 4° and 14° North of the Equator and Longitudes 3° and 14° East of Greenwich Meridian. The country is bordered on the west by the Republic of Benin; on the east by the Republic of Cameroon; on the north by Niger and Chad Republics and on the south by the Gulf of Guinea and Atlantic Ocean (see Figure 1). The land area is 909,890sqkm with an estimated population of over 200 million people. It is the most populous nation in Africa and contains more than 350 ethno-linguistic groups. The country as at today has evolved into a political structure that consists of 36 states and a Federal Capital Territory (Abuja), all constitutionally summarized into six geopolitical zones. There are also, 774 Local Government Areas in Nigeria (Ademiluyi, 2020).

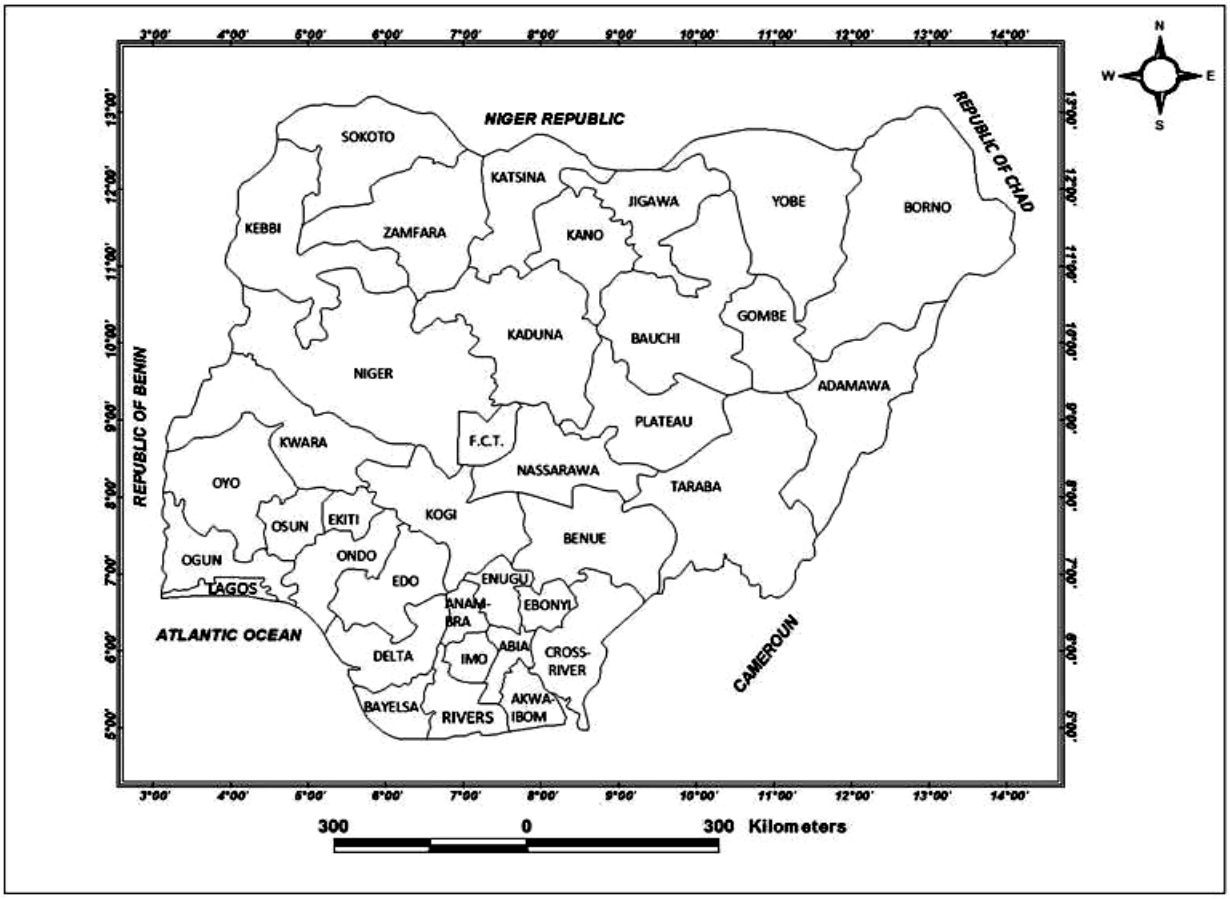


Figure 1: The Study Area (Nigeria)
Source: Oyo State Ministry of Lands, Survey and Urban Planning, Ibadan,2016

MATERIALS AND METHODS

Data Source and Types

Data used for this study include: (1) Analogue map of Nigeria sourced from the Oyo State Ministry of Lands, Survey and Urban Planning, Ibadan (2) situation reports on COVID 19 between 29 of February and September 14, 2020 by the Nigeria Centre for Disease Control (NCDC) and (3) the relative risk factors were selected based on Africa Center for Strategic Studies (ACSS) predisposing risk factors to COVID-19 and 4) the corresponding data for each factors was sourced from the National Bureau of Statistics (NBS) reports, National Population Commission and the Federal Ministry of Aviation. The software used is ArcGIS 10.2.

The methodology used in the study is presented in the flow chart diagram given in Figure 2.

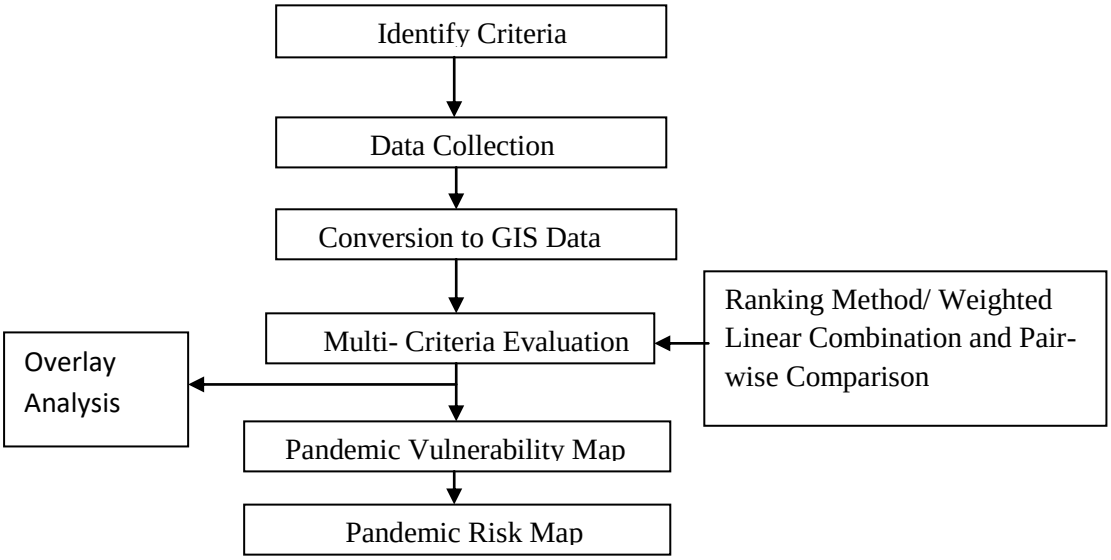


Figure 2: Methodology Flow Chart of the Study (Adapted from Saaty, 1980)

Identification of Factors or Criteria for COVID-19 Spread

Based on literature review and expert knowledge (ACSS, 2020a; Shannon, 2020; Wendy, 2020), the following factors were identified as potentially associated with the transmission and spread of COVID-19 in Nigeria: 1) International Exposure (travels from high risk countries), 2) Public Health System and Workers, 3) Urban Population, 4) Urban Density and 5) Displaced People.

Weighting/Ranking of the identified Factors

The identified risk factors (criterion) were ranked/weighted each, based on their significant contributions to the spread of COVID-19 in Nigeria through the Analytical Hierarchy Process (AHP) by specifying the degree of importance of factor 1 regarding factor 2 on a nine-point scale (factor 1 can be extremely more, very strongly more, strongly more, moderately more, equally important, moderately less, strongly, very strongly less or extremely less important than factor 2). The weighting/ ranking are presented in Table 1.

Table 1: Weighting/Ranking of the Identified Criteria for COVID-19 Spread in Nigeria

Risk Factors/Criteria (C)	Ranking (According to Importance)	Scores
International Exposure	Extremely more	1
Public Health System & Workers	Very strongly more	2
Urban Density	Strongly more	3
Urban Population	Moderately more	4
Displaced People	**Equally Important**	**5**

The ranking resulted in a pair-wise comparison matrix (Table 2). A numerical weight is derived for each risk factor from the pair-wise comparison matrix, and a consistency ratio (CR) is determined since individual judgment will never agree perfectly (Tables 3 & 4).

Table 2: Pair-Wise Comparison Matrix of the Ranked Criteria

Criteria	C1	C2	C3	C4	C5
C1	1	2	2	2	4
C2	0.5	1	2	2	4
C3	0.5	0.5	1	2	4
C4	0.5	0.5	0.5	1	4
C5	0.25	0.25	0.25	0.25	1
Total	**2.75**	**4.25**	**5.75**	**7.25**	**17**

Furthermore, the matrices derived were normalized by dividing each matrix by the sum of its column with their summations equal one (1) as shown in Table 3.

Table 3: Normalized Matrices

Criteria	C1	C2	C3	C4	C5	Priority Vector
C1	0.363	0.471	0.348	0.276	0.235	0.339
C2	0.182	0.235	0.348	0.276	0.235	0.255
C3	0.182	0.118	0.174	0.276	0.235	0.197
C4	0.182	0.118	0.087	0.138	0.235	0.152
C5	0.091	0.059	0.043	0.034	0.060	0.0574
Total	**1**	**1**	**1**	**1**	**1**	**1**

The adopted expression for calculating the consistency ratio in this study is stated below and results presented in Table 4.
CR=CI/RI, Where CI=λ max$^{-n/n-1}$, R1= Random consistency index, N=Number of criteria and $^{\lambda}$max is the priority vector multiplied by each column total.

Table 4: Random Indices for Matrices of various sizes (n)

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R1	**0**	**0**	**0.58**	**0.90**	**1.12**	**1.24**	**1.32**	**1.41**	**1.45**	**1.49**	**1.51**	**1.48**	**1.56**	**1.57**	**1.59**

CR= 0.0506.

The calculated Consistency Ratio (CR) value, 0.0506 falls below the threshold value of 0.1, showing a high level of consistency hence we can accept the weights.

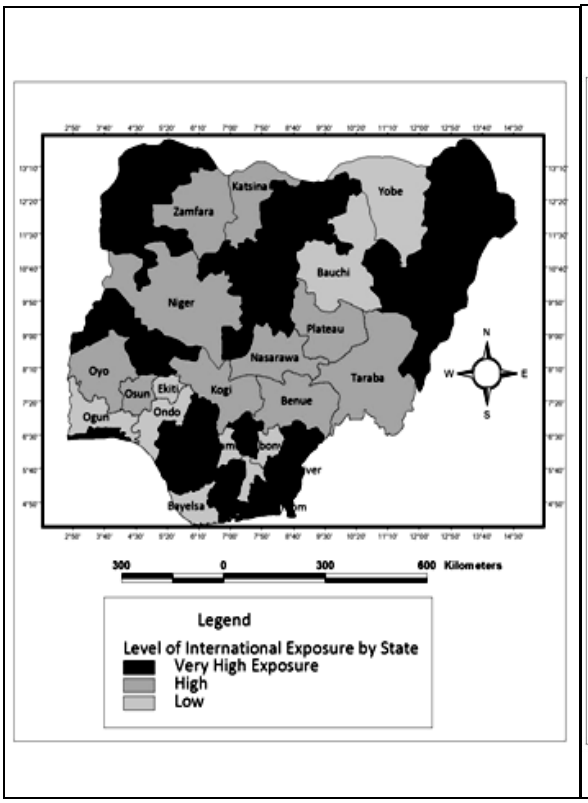
Creation of Each Criterion as a Map Layer in the GIS Environment

The selected criteria mentioned above were each created and converted into different map layers in the GIS Environment using ArcGIS10.0 software (Figures 3, 4, 5, 6 & 7). The Urban Population, Density and Displaced people criteria layers were derived from the Nigeria National Population Commission and National Bureau of Statistics Demographic Data. The International Exposure layer is derived from Federal Ministry of Aviation while the Public Health System and Workers layer is generated from Nigeria Centre for Disease Control Situation Reports (See Table 5).

Table 5: Corresponding Data for the Selected Criteria

	Selected Criteria (Corresponding Data)				
State	International Exposure	Public Health Facilities (Are there COVID-19 Care Centres?)	Urban Density/Sq.Km	Urban Population by State	Displacement of People
Lagos	Very High	Yes	62-77	12,550,598	None
FCT	Very High	Yes	17-31	3,564,126	None
Oyo	High	Yes	32-46	7,840,864	None
Edo	Very High	Yes	62-77	4,235,595	None
Delta	Very High	Yes	62-77	5,663,362	None
Rivers	Very High	Yes	62-77	7,303,924	None
Kano	Very High	Yes	2-16	13,076,892	Displaced
Ogun	High	Yes	32-46	5,217,716	None
Kaduna	Very High	Yes	17-31	8,252,366	Displaced
Ondo	Low	No	32-46	4,671,695	None
Borno	Very High	Yes	2-16	5,860,183	Displaced
Gombe	Very High	No	2-16	3,256,962	Displaced
Bauchi	Low	No	2-16	6,537,314	Displaced
Ebonyi	Low	Yes	47-61	2,880,383	Displaced
Plateau	High	Yes	17-31	4,200,442	Displaced
Enugu	Very High	No	62-77	4,411,119	None
Abia	Low	No	62-77	3,727,347	None
Imo	Very High	Yes	62-77	5,408,756	None
Jigawa	Very High	No	2-16	5,828,163	Displaced
Kwara	Very High	No	32-46	3,192,893	None
Bayelsa	High	No	62-77	2,277,961	None
Nasarawa	High	No	17-31	2,523,395	Displaced
Osun	High	Yes	32-46	4,705,589	None
Sokoto	Very High	Yes	2-16	4,998,090	Displaced
Niger	Very High	No	2-16	5,556,247	Displaced
Akwa-Ibom	Very High	No	62-77	5,482,177	None
Benue	High	No	17-31	5,741,815	Displaced
Adamawa	Very High	Yes	2-16	4,248,436	Displaced
Anambra	Low	Yes	62-77	5,527,809	None
Kebbi	Very High	No	2-16	4,440,050	Displaced
Zamfara	High	No	2-16	4,515,427	Displaced
Yobe	High	No	2-16	3,294,137	Displaced
Ekiti	Low	No	32-46	3,270,798	None
Taraba	High	No	2-16	3,066,834	Displaced
Cross-river	Very High	No	62-77	3,866,269	None
Kogi	High	No	32-46	4,473,490	None

Sources: National Bureau of Statistics Demographic Data (2017), Federal Ministry of Aviation (2020) and Nigeria Centre for Disease Control (2020)



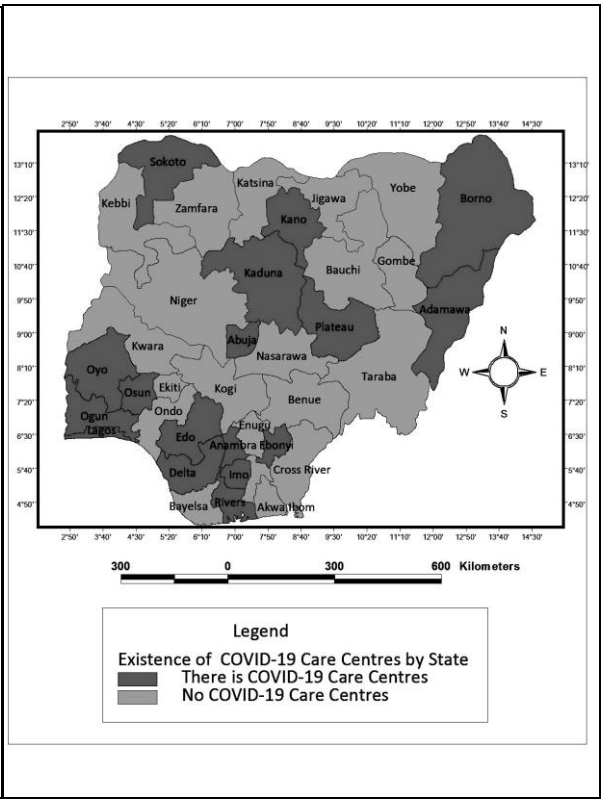
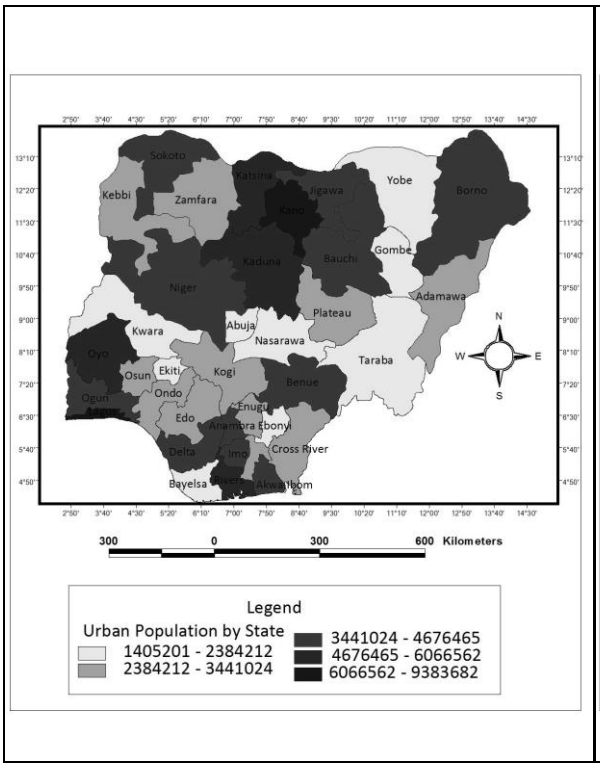


Fig. 3: International Exposure Layer **Fig. 4: Public Health System and Workers Layer**



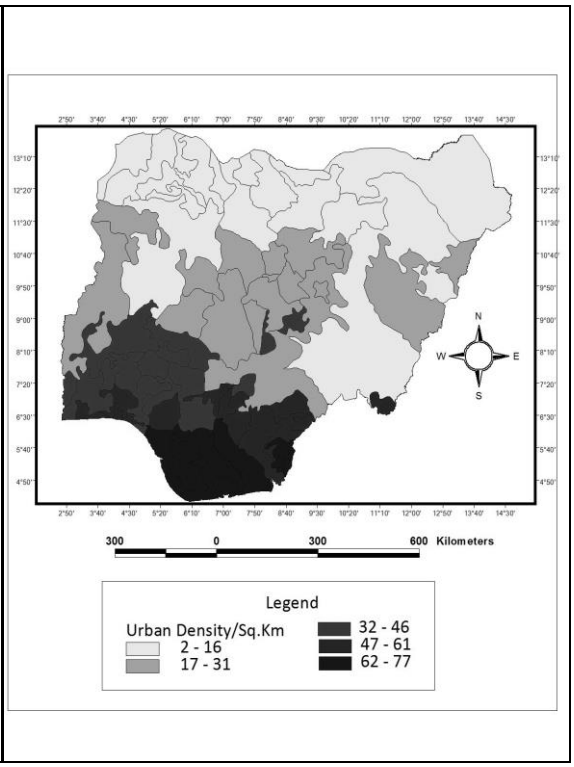


Figure 5: Urban Population Layer **Figure 6: Urban Density Layer**

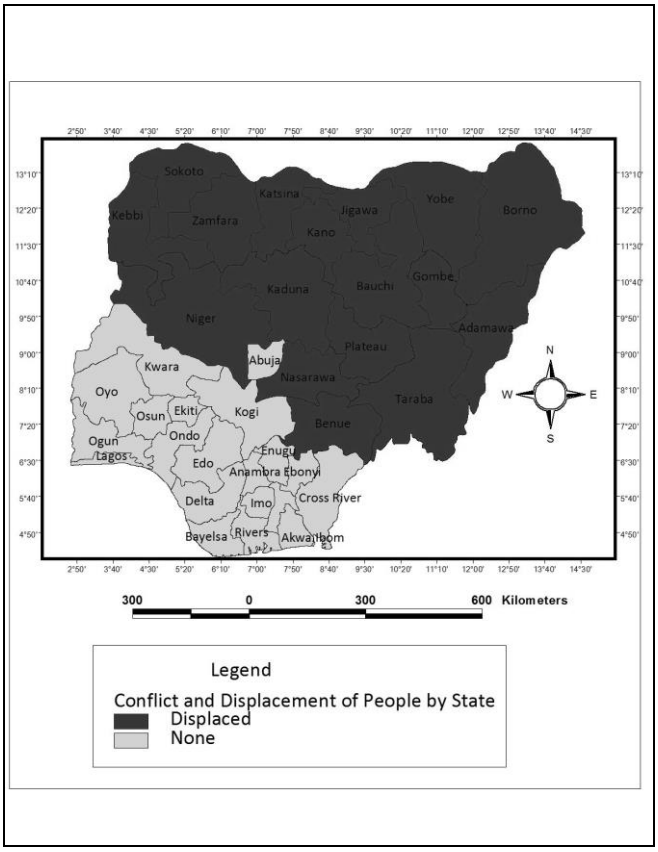


Figure 7: Displaced People Layer

Combination of all the Created Criteria Layers to produce the Pandemic Risk Map

All the created criteria layers were overlaid and combined in the ArcGIS 10.0 environment using the Analytic Hierarchy Process (AHP) extension to generate a single layer of both pandemic vulnerable and risk maps respectively as done by Adebayo (2018). The outputs (vulnerable and risk maps) were then re-classified and zoned into four (4) vulnerability and risk categories; very high, high, moderate, marginal (WHO, 2020) as shown in Figures 9 and 10 respectively.

RESULTS AND DISCUSSION

This section presents and discusses the results of this research. The first and second parts in this section are on the geo-visualization of the spreading pattern of COVID-19 between 29th of February and September 14, 2020 and the pandemic vulnerable and risk states in Nigeria respectively while the third part is on the implications of the findings in the first two parts for the surveillances, monitoring and prevention of COVID-19 pandemic in Nigeria now and after. Results of findings are presented in Tables 6, 7, 8 and 9 and maps (Figures 8a, b, c, d, e, f, g & h, 9, 10).

Geo-visualization of the Pattern in the Spread of COVID-19 Pandemic in Nigeria by States between 29th of February and 14th of September, 2020

Table 6; Figure 8a and b present the trend pattern of COVID-19 spread in Nigeria by states as at 29th of February and 31st of March, 2020. The table reveals that the first index case of the pandemic in Nigeria is recorded in Ogun state as at February 29, 2020.

Table 6: The Pattern of COVID-19 Spread in Nigeria by States as at 29th of February and 31st of March, 2020

State	As at February 29th, 2020 (Total Cases)				As at March 31st, 2020 (Total Cases)			
	Confirmed Cases	Discharged Cases	Deaths Cases	Active Cases	Confirmed Cases	Discharged Cases	Deaths Cases	Active Cases
Lagos	0	0	0	0	81	6	0	75
FCT	0	0	0	0	25	0	2	23
Oyo	0	0	0	0	8	0	0	8
Edo	0	0	0	0	2	0	0	2
Delta	0	0	0	0	0	0	0	0
Rivers	0	0	0	0	1	0	0	1
Kano	0	0	0	0	0	0	0	0
Ogun	1	0	0	0	3	2	0	1
Kaduna	0	0	0	0	3	0	0	3
Ondo	0	0	0	0	0	0	0	0
Borno	0	0	0	0	0	0	0	0
Gombe	0	0	0	0	0	0	0	0
Bauchi	0	0	0	0	2	0	0	2
Ebonyi	0	0	0	0	0	0	0	0
Plateau	0	0	0	0	0	0	0	0
Enugu	0	0	0	0	2	0	0	2
Abia	0	0	0	0	0	0	0	0
Imo	0	0	0	0	0	0	0	0
Jigawa	0	0	0	0	0	0	0	0
Kwara	0	0	0	0	0	0	0	0
Bayelsa	0	0	0	0	0	0	0	0
Nasarawa	0	0	0	0	0	0	0	0
Osun	0	0	0	0	2	0	0	2
Sokoto	0	0	0	0	0	0	0	0
Niger	0	0	0	0	0	0	0	0
Akwa-Ibom	0	0	0	0	0	0	0	0
Benue	0	0	0	0	1	0	0	1
Adamawa	0	0	0	0	0	0	0	0
Anambra	0	0	0	0	0	0	0	0
Kebbi	0	0	0	0	0	0	0	0
Zamfara	0	0	0	0	0	0	0	0
Yobe	0	0	0	0	0	0	0	0
Ekiti	0	0	0	0	1	0	0	1
Taraba	0	0	0	0	0	0	0	0
Cross-river	0	0	0	0	0	0	0	0
Kogi	0	0	0	0	0	0	0	0
Total	**1**	**0**	**0**	**0**	**131**	**121**	**8**	**2**

Source: Nigeria Centre for Disease Control (NCDC), 2020.

By the end of March, 2020, the pandemic had spread to 12 states of the country with Lagos state recording the highest number of confirmed cases (81), about 62% of the total confirmed cases recorded as at the end of March followed by the Federal Capital Territory, Abuja (25(19.1%) with 2 deaths cases, Oyo State (8), Ogun State (3), Kaduna State (3), Bauchi State (2), Enugu State (2). The states with only a case of COVID-19 as at 31st of March, 2020 are; Benue and Ekiti. The table further shows that the total number of the confirmed cases as at 31st of March is 131 with 121 discharged, 2 considered as active cases and 8 deaths cases (see Table 6).

Figures 8a and b further visualized the trend pattern of COVID-19 spread in Nigeria with the pandemic spreading from the two major important cities in Nigeria; Lagos and Abuja to the

adjacent or neighbouring states through inter-state travels and this has necessitated the human to human contact transmission of the pandemic (NCDC, 2020). The Nigeria Centre for Disease Control daily reports on COVID-19 shows that 27% of the pandemic transmission has been by travelling and contacts.

Table 7; Figures 8c and d show that by the end of the month of April 2020, the total number of confirmed cases has risen from 131 cases in the month of March 2020 to 1,932 representing 93.2% increase, with also significant increase in discharged cases from 121 to 319 with active cases moving from 2 to 1,555. Death cases also went up from 8 to 58. Out of the total number of confirmed cases recorded in the month of April 2020, Lagos State contributed the highest percentage (50.5%) followed by Kano (11.3%) and Federal Capital Territory, Abuja (9.3%). By the end of May 2020, the total number of confirmed cases has suddenly increased from 1,932 to 10,162 cases representing an increase of 81%. Lagos State is still leading other states in Nigeria in all the COVID-19 cases examined in this study. This is not far from the fact that Lagos is one of the most populous urban area and economic centre in Nigeria with a strong link to international exposure considering her proximity also to both International Air and Sea Ports respectively (WHO, 2020). Generally, these risk factors among others are responsible for the upward surge of this pandemic between the months of April and May, 2020 since the means of transmission of COVID-19 has been established as human to human contact (WHO, 2020).

The findings of this study corroborates with the fact that the first cases of the corona virus in Africa came from exposure to international contacts—travel, trade, tourism, or business (ACSS, 2020b; Shannon, 2020). Nigeria is one of the African countries with the greatest level of infections and also among the hardest hit in the early stage of the pandemic (ACSS, 2020c).

Figures 8c and d are thematic maps that further explained the trend pattern in the spread of the pandemic across the 36 states including FCT, Abuja between April 30th and May 31st, 2020. These figures show a wide spread of the pandemic nationwide except for Kogi and Cross-river states. Just within two (2) months (March-May, 2020), the pandemic has spread from 12 to 35 states including the FCT (Abuja). Lagos state remains the epicenter of the pandemic as at the 31st of May, 2020 followed by Kano and Abuja.

Table 7: The Pattern of COVID-19 Spread in Nigeria by States as at 30th of April and 31st of May, 2020

State	As at April 30th, 2020 (Total Cases)				As at May 31st, 2020 (Total Cases)			
	Confirmed Cases	Discharged Cases	Deaths Cases	Active Cases	Confirmed Cases	Discharged Cases	Deaths Cases	Active Cases
Lagos	976	199	21	756	4943	825	54	4064
FCT	178	36	3	139	660	182	19	459
Oyo	23	9	2	12	292	97	6	189
Edo	44	10	3	31	284	69	13	202
Delta	9	4	2	3	83	17	8	58
Rivers	13	2	2	9	206	59	14	133
Kano	219	0	3	216	954	240	45	669
Ogun	56	8	1	47	278	149	9	120
Kaduna	35	6	1	28	258	157	8	93
Ondo	9	3	0	6	25	20	2	3
Borno	66	0	6	60	271	167	26	78
Gombe	76	0	0	76	364	122	6	189
Bauchi	38	6	0	32	238	220	8	10
Ebonyi	2	0	0	2	40	8	0	32
Plateau	1	0	0	1	105	53	2	50
Enugu	3	2	0	1	18	12	0	6
Abia	2	0	0	2	10	3	0	7
Imo	1	0	0	1	36	14	0	22
Jigawa	7	0	1	6	270	135	5	130
Kwara	11	2	0	9	88	37	1	50
Bayelsa	5	0	0	5	21	7	1	13
Nasarawa	3	0	0	3	62	18	2	42
Osun	34	18	3	13	45	35	4	6
Sokoto	36	1	4	31	116	96	14	6
Niger	2	0	0	2	32	9	1	22
Akwa-Ibom	16	10	2	4	45	14	2	29
Benue	1	0	0	1	7	1	0	6
Adamawa	2	0	0	2	38	20	4	14
Anambra	1	1	0	0	11	3	1	7
Kebbi	2	0	0	2	33	29	4	0
Zamfara	4	0	1	3	76	71	5	0
Yobe	1	0	0	1	52	24	7	21
Ekiti	8	2	1	5	20	16	2	2
Taraba	8	0	0	8	18	10	0	8
Cross-river	0	0	0	0	0	0	0	0
Kogi	0	0	0	0	0	0	0	0
Total	**1,932**	**319**	**58**	**1,555**	**10,162**	**3,007**	**287**	**6868**

Source: Nigeria Centre for Disease Control (NCDC), 2020.

Table 8 and Figure 8e further show the trend in the spread of COVID-19 pandemic across the 37 states in Nigeria including Abuja. It can be deduced from the table that the total number of COVID-19 confirmed cases has increased from 10,162 in May 2020 to 25,694 cases by the end of June 2020, an increase of 60.4%. Major increases were also recorded for other cases; discharged cases from 3,007 to 9,746 (69.1%); deaths cases from 287 to 590 (51.4%) and active cases from 6,868 to 15,358 (55.3%). As at the end of the month of June, 2020, six (6) states recorded the highest number of confirmed cases with Lagos state badly hit (10,510 confirmed cases), 40.9% of the total confirmed cases for June followed by Abuja (1,870), Oyo (1,380), Kano (1,216), Edo (1,105) and Rivers (1,056).

Table 8 and Figure 8f also reveal that as at 31st of July, 2020, the total number of the confirmed cases for the 36 states including Abuja (Federal Capital Territory) in the month of June has increased from 25,694 to 43,151 confirmed cases, about 41% increase with Lagos state still the epicenter of the pandemic (see Table 8).

Table 8: The Pattern of COVID-19 Spread in Nigeria by States as at 30th of June and 31st July, 2020

State	As at 30th of June, 2020 (Total Cases)				As at July 31st, 2020 (Total Cases)			
	Confirmed Cases	Discharged Cases	Deaths Cases	Active Cases	Confirmed Cases	Discharged Cases	Deaths Cases	Active Cases
Lagos	10510	1603	128	8779	15121	2148	192	12781
FCT	1870	570	33	1267	3803	1122	42	2639
Oyo	1380	696	12	672	2760	1286	27	1447
Edo	1105	288	39	778	2292	1800	82	410
Delta	965	190	23	752	1510	1359	43	108
Rivers	1056	622	38	396	1791	1438	52	301
Kano	1216	931	52	233	1597	1258	53	286
Ogun	826	571	19	236	1394	1095	23	276
Kaduna	766	532	12	222	1457	1176	12	269
Ondo	292	102	19	171	1155	548	24	583
Borno	493	422	32	39	613	569	35	9
Gombe	503	352	19	132	607	524	23	60
Bauchi	503	449	12	34	560	520	13	27
Ebonyi	438	357	3	78	785	596	24	165
Plateau	382	197	10	175	1188	519	19	650
Enugu	261	73	6	182	807	425	18	364
Abia	310	207	3	100	545	426	5	114
Imo	332	40	6	286	468	119	9	340
Jigawa	318	307	6	5	322	308	11	3
Kwara	217	131	6	80	753	213	19	521
Bayelsa	205	100	14	91	328	279	21	28
Nasarawa	213	113	8	92	317	223	8	86
Osun	127	48	5	74	524	266	12	121
Sokoto	151	119	15	17	154	137	16	1
Niger	116	37	7	72	223	133	12	78
Akwa-Ibom	86	54	2	30	221	121	7	93
Benue	59	30	1	28	346	58	6	282
Adamawa	84	47	6	31	163	85	9	69
Anambra	73	57	9	7	135	75	12	48
Kebbi	79	58	7	14	90	79	7	4
Zamfara	76	71	5	0	77	71	5	1
Yobe	59	48	8	3	67	54	8	5
Ekiti	43	29	2	12	132	55	2	75
Taraba	19	10	0	9	54	11	0	43
Cross-river	0	0	0	0	45	9	3	33
Kogi	4	0	0	4	5	3	2	0
Total	**25,694**	**9746**	**590**	**15,358**	**43,151**	**19,565**	**879**	**22,707**

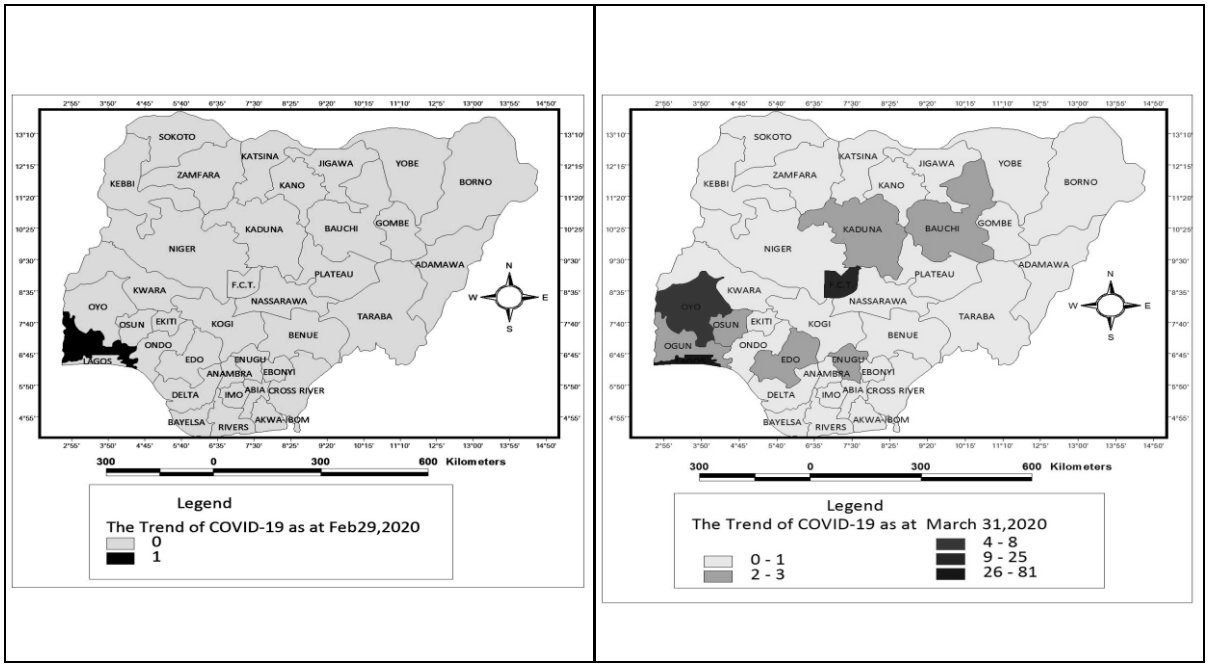
Source: Nigeria Centre for Disease Control (NCDC), 2020.

Table 9; Figure 8g and h show the spread pattern of COVID-19 cases in Nigeria as at 31st of August, 2020 and 14th of September, 2020. The total number of confirmed cases has increased by 20 %(from 43,151 to 54,008 confirmed cases) within a month (July to August, 2020). There is a slight increase in the total number of confirmed cases across the nation by 4% (from 54,008 to 56,388 confirmed cases) as at 14th September, 2020 with 44,337 discharged cases (see Table 9).

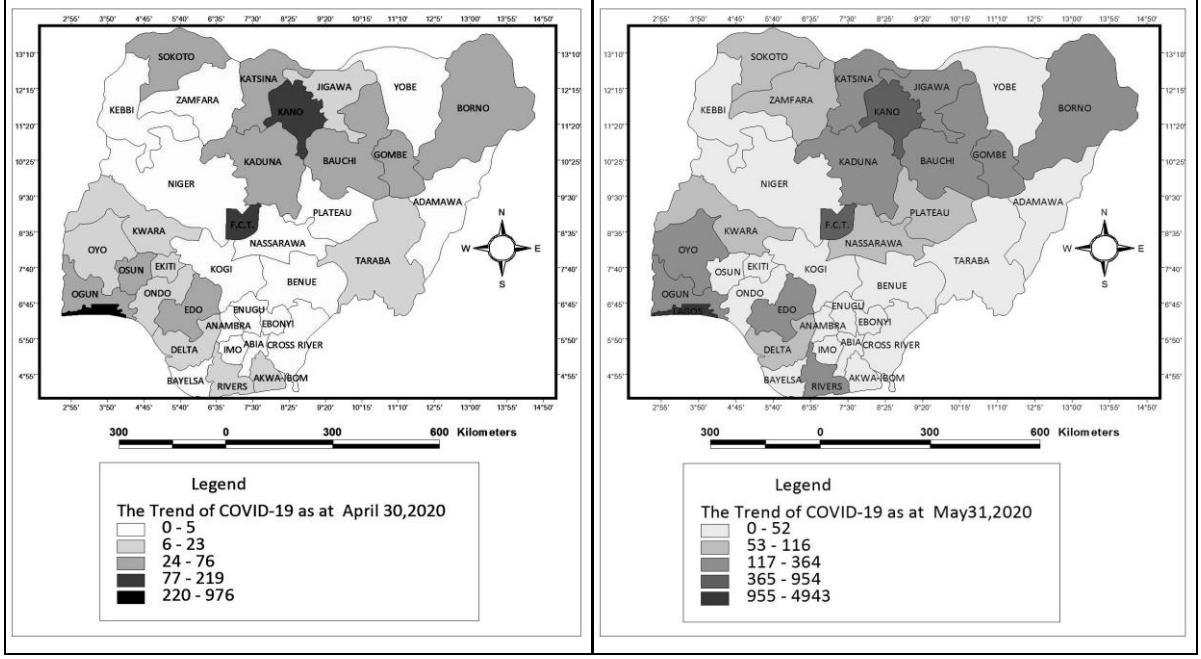
Table 9: The Pattern of COVID-19 Spread in Nigeria by States as at 31st of August and 14th September, 2020

State	As at 31st of August, 2020 (Total Cases)				As at September 14th, 2020 (Total Cases)			
	Confirmed Cases	Discharged Cases	Deaths Cases	Active Cases	Confirmed Cases	Discharged Cases	Deaths Cases	Active Cases
Lagos	18138	15231	202	2705	18663	15245	203	3215
FCT	5169	1536	50	3583	5447	1684	75	3688
Oyo	3118	1954	37	1127	3221	2102	39	1080
Edo	2584	2325	100	159	2610	2420	100	90
Delta	1744	1540	47	157	1791	1629	49	113
Rivers	2141	1971	57	113	2208	2118	59	31
Kano	1727	1537	54	136	1732	1626	54	52
Ogun	1648	1515	26	107	1748	1680	28	40
Kaduna	2141	1991	12	138	2279	2161	33	85
Ondo	1539	1380	31	128	1584	1490	35	59
Borno	741	671	36	34	741	703	36	2
Gombe	723	636	23	64	773	677	24	72
Bauchi	667	581	14	72	680	656	14	10
Ebonyi	993	931	27	35	1034	997	30	7
Plateau	2533	1395	29	1109	3115	2041	31	1043
Enugu	1162	907	21	234	1232	1088	21	123
Abia	771	697	8	66	828	792	8	28
Imo	527	193	11	323	546	216	12	318
Jigawa	322	308	11	3	322	308	11	3
Kwara	966	784	25	157	1002	794	25	183
Bayelsa	391	348	21	22	393	370	21	2
Nasarawa	434	298	12	124	446	298	12	136
Osun	782	734	17	31	805	763	17	25
Sokoto	159	140	16	3	159	142	17	0
Niger	243	216	12	15	244	216	12	16
Akwa-Ibom	278	232	8	38	286	251	8	27
Benue	453	216	9	228	467	401	9	57
Adamawa	228	180	15	33	230	196	15	19
Anambra	216	168	18	30	231	184	19	28
Kebbi	93	82	8	3	93	84	8	1
Zamfara	78	73	5	0	78	73	5	0
Yobe	67	59	8	0	72	59	8	5
Ekiti	262	203	4	55	302	267	5	30
Taraba	87	73	5	0	95	73	6	16
Cross-river	82	73	8	1	83	73	8	2
Kogi	5	3	2	0	5	3	2	0
Total	**54,008**	**41,638**	**1,013**	**11,357**	**56,388**	**44,337**	**1,083**	**10,968**

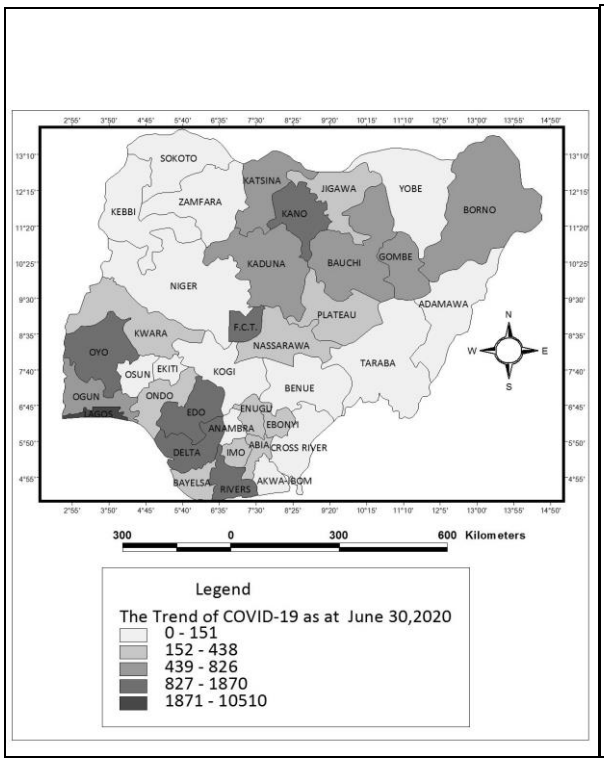
Source: Nigeria Centre for Disease Control (NCDC), 2020.



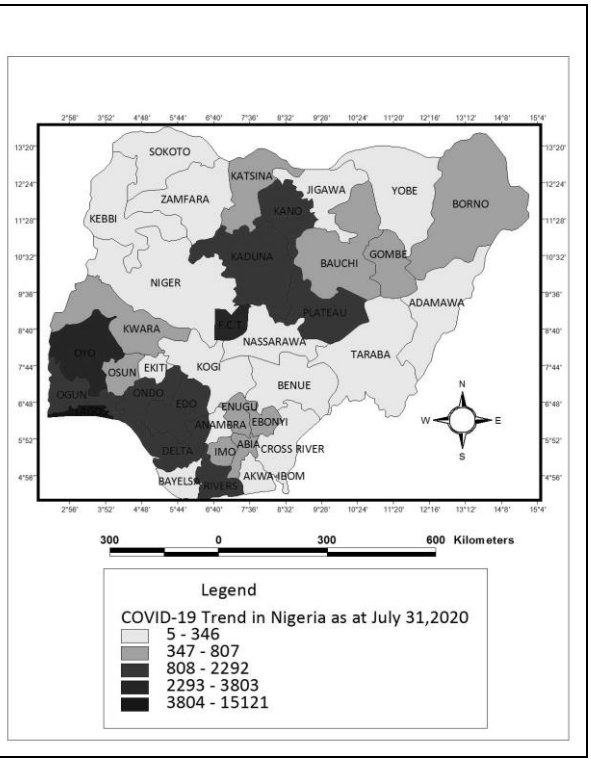
(a) February (b) March



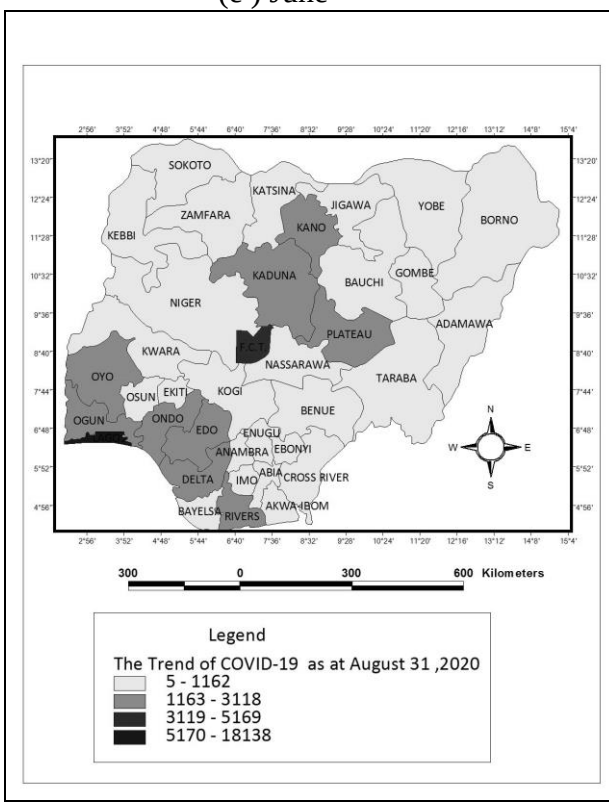
(c) April (d) May



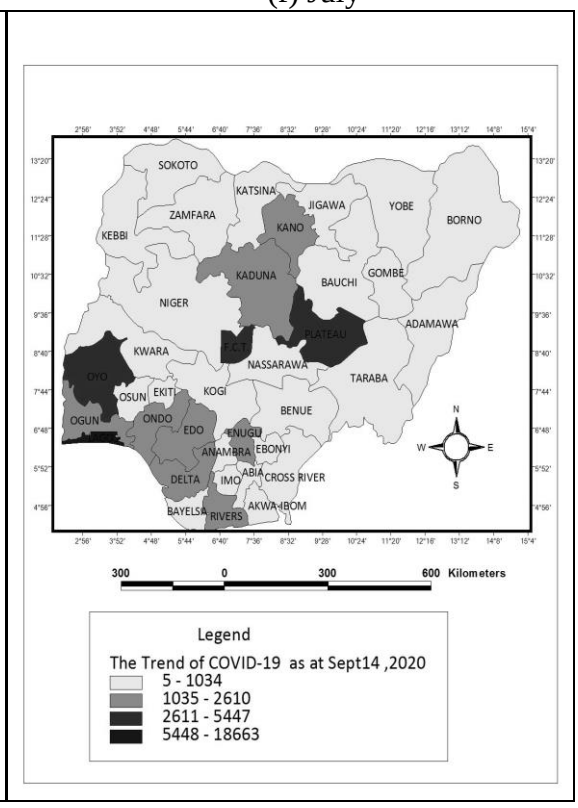
(e) June



(f) July



(g) August



(h) September

Figures 8a, b, c, d, e, f, g & h: The Pattern of COVID-19 Spread in Nigeria during the period of 29 February through September 14, 2020

Identification of States' Vulnerability Levels and at Risk to the Pandemic in Nigeria

Figure 9 shows graphically the vulnerability levels of states in Nigeria to the COVID-19 pandemic since February 29 and as at September 14, 2020. The states were classified into four (4) vulnerable zones; very high, high, moderate and marginal (Adebayo, 2018). The vulnerability map (Figure 9) reveals that Lagos state is the most highly vulnerable state to the pandemic due to international exposure (travels from high risk countries) and rapid urbanization followed by Oyo, Edo, Delta, Rivers, FCT (Abuja) and Kano.

The moderate and marginal vulnerable states to the pandemic due to rapid urbanization, lack of COVID-19 care centres and displacement of people include; Ogun, Ondo, Kwara, Imo, Enugu, Abia, Ebonyi, Kaduna, Katsina, Bauchi, Plateau, Gombe and Borno, Sokoto, Kebbi, Jigawa, Benue, Niger, Kogi, Osun, Ekiti, Zamfara, Nassarawa, Taraba, Adamawa, Cross-river, Akwa-Ibom, Bayelsa, Yobe, Jigawa and Anambra states. This shows that Nigeria is at a high risk. The vulnerability analysis was further subjected to risk assessment and result presented in Figure 10.

This result supports the view that COVID-19 appears to thrive in cities where it can be transmitted quickly at close range through the movement and frequent contact between people. Countries with higher urban populations are faced with the logistical and communication challenge of informing, monitoring, and possibly isolating a larger pool of at-risk people (ACSS, 2020b). Some of the African countries with the largest urban populations all have megacities: Lagos, Cairo, Addis Ababa, Kinshasa, and Johannesburg. All of these cities, except Addis Ababa, have peak population densities greater than New York City (56,000 people per square kilometer). Cairo's peak population density (175,000/km^2) easily tops the density of Wuhan, China (106,300/km2), where the novel corona virus originated (Shannon, 2020; Wendy, 2020).

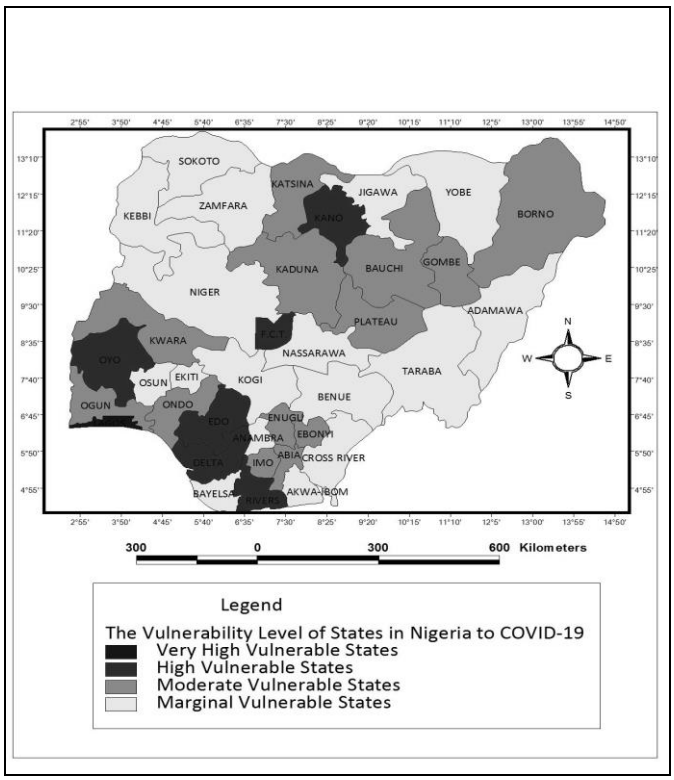


Figure 9 : The Vulnerability Levels of States in Nigeria to COVID-19 Pandemic

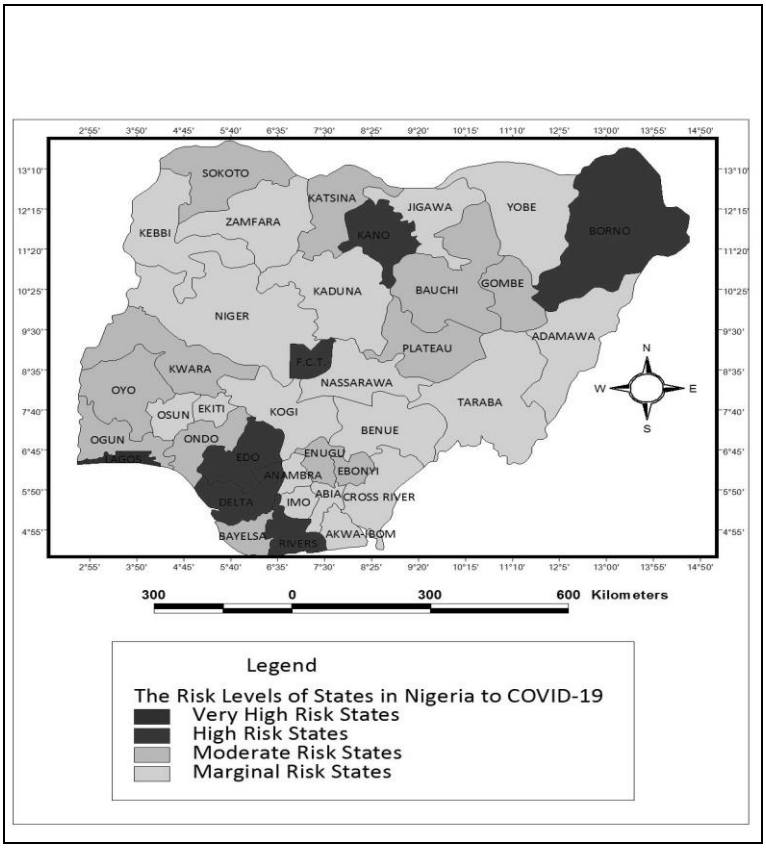


Figure 10: The Risks Levels of States in Nigeria to COVID-19 Pandemic

Figure 10 shows the levels of risk to COVID-19 in the 36 states of Nigeria including the Federal Capital Territory (FCT), Abuja as at 14th of September, 2020. From Figure 10, Lagos State is classified into the very high risk zone due to her exposure to international travels and rapid urban growth. It can also be deduced that the following states; Edo, Delta, Rivers, Kano, Borno states and Abuja fall under the category of high risk due to the following risk factors; international travels, urbanization and displacement of people.

Most of the states in Nigeria are moderately at risk (due to rapid urbanization but low exposure to foreign travelers) to the pandemic as at the 14th of September, 2020. They include; Oyo, Ogun, Kwara and Plateau (see Figure 10) while the states with marginal cases (due to low rate of exposure to travelers from high risk countries) of the pandemic are; Kebbi, Zamfara, Sokoto, Niger, Kaduna, Nassarawa, Benue and Ekiti (see Figure 10).

Implications of findings to the pandemic surveillances, monitoring and prevention

The findings of this study imply that the use of geospatial information technology to examine the spread of COVID-19 pandemic in Nigeria can help in rapid visualization of confirmed cases, distribution and pattern of spread. This makes it a vital tool when it comes to making decisions in the prevention and control of the pandemic both now and beyond. Decisions such as restrictions in movement, social distancing and human to human contacts can be quickly reached and implemented.

The maps (pattern, vulnerability and risk maps) generated in this study can play positive roles in;

- Educating the public with visual information to clarify pandemic concerns and enlist necessary action.
- Identification of vulnerable and risk areas and providing tools and techniques to capture and forecast future pandemic occurrences.
- The maps can also serve as major component/unit in the setting up of a Pandemic Early Warning System (PEWS) most especially in the high risk areas such as Lagos, Oyo, Ogun, Delta, Edo, Kano, Rivers, Borno states and Abuja (FCT).

CONCLUSION

This study attempted using GIS technology to examine the pattern of COVID-19 spread in Nigeria between 29th of February and 14th of September, 2020 (about seven months). From the first index case in February to 14th of September, 2020, there has been an upward trend in the spread of the pandemic nationwide and in each state including Abuja. Lagos State remains the epicenter of the pandemic. The study further shows that Nigeria is at a great risk to the pandemic, ranging from very high to marginal risk. It was also established in the study that assessment of COVID-19 spread using GIS coupled with MCE Approach could be a valuable tool in the prevention and control of its spread due to its ability to perform spatial analysis, manage large amounts of spatial data and produce cartographically appealing maps to aid in decision making. Therefore, it is suggested that policies aimed at mitigating the continuous spread of COVID-19 in Nigeria must include geospatial analysis in understanding the spatial-temporal dynamics of COVID-19 which is critical to forestalling its menaces.

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