MAPPING THE RISK AND DISTRIBUTION PATTERN OF COVID-19 PREVALENCE IN NIGERIA: GIS APPROACH

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ABSTRACT

The novel corona virus (COVID-19) outbreak is a public health global disaster. This study explored the techniques of Geographic Information System (GIS) in assessing the risk and spread of COVID-19 across the 36 states in Nigeria and Abuja, the Federal Capital Territory (FCT) with the main objective of showing how maps can be employed in explaining pandemic situations for easy interpretation and quick decision-making. The study relies on publicly available data on COVID-19 cases in Nigeria, sourced from the website of Nigeria Centre for Diseases Control (NCDC). Geo-visualization analysis technique was adopted for this study with results presented in form of maps. Results show that Lagos, Oyo, Edo, Rivers, Kano, Delta, Kaduna, Ogun, Plateau states and Abuja (FCT) are hardly hit by the pandemic in terms of the total number of both confirmed cases and deaths respectively as at Thursday 13th of August, 2020. Findings also revealed that Lagos, Oyo, Ogun, Ondo, Edo, Delta, Rivers, Kaduna, Kano, Plateau states and Abuja (FCT) were classified as the very high risk states to the pandemic. The use of maps for easy explanations, effective planning, preparedness and response to pandemic phenomena was equally established by this study. Since the virus spreads easily through human to human contact, it is recommended that restrictions of movements should be the priority of every concern stakeholder.

Keywords: COVID-19, Risk, Pattern, Mapping, Geographic Information System (GIS), Nigeria

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Introduction

Viral infections are infectious in nature and usually constitute a major treat to both health and socio-economic of any society (Meo *et al.,* 2020). In late December 2019, corona virus (COVID-19) emerged from Wuhan, China and currently spreading globally, causing a great public health apprehension. It can be transmitted easily from the following ways; animal to animal, animal to human, and human to human (Li *et al.*, 2020; World Health Organization, 2020a, 2020b). More than 21millioncases of COVID-19 have been reported in 214 countries and regions as at August 13th, 2020 with 755,786 deaths.The number of reported COVID-19 cases is rapidly increasing in major Africa countries as at August 13th, 2020, bringing the total number of confirmed cases to 936,062 and 18,286 deaths (John Hopkins University, 2020).

The Nigeria Centre for Disease Control (NCDC) daily reports on the COVID-19 pandemic (in accordance to case definitions and testing strategies of various countries) show that, a total number of 48,116 confirmed cases were recorded in Nigeria as at August13th, 2020 with 34,309 discharged. About 966 deaths were reported for the same duration, since February 29th, 2020, when this process of

data collection was initiated.

One of the important features of epidemics such as COVID-19 is their spatial distribution, which depends mainly on the mechanism, human mobility and control strategy of the epidemic (Gross et al., 2020).The integration of Geographic Information System (GIS) techniques with spatial statistics can play a major role in geospatial analysis and how to mitigate the epidemic. It can further be enhance to provide scientific deductions, find spatial correlations with other parameters, and identify transmission dynamics (Xiong *et al.,* 2020).Review of literatures shows that, one of the most cited researched work that makes use of GIS for the spatial analysis of COVID-19 is that of Guan et al. (2020). Guan *et al.* (2020) involves the extraction of data on 1099 patients with laboratory-confirmed COVID-19 cases from Chinese hospitals between the 29th of December and January 29th, 2020, and proceeded to characterize their profile. The distribution pattern of the rapid spread of the disease throughout mainland China, by province, characteristics between residents of Wuhan and non-residents, history of direct contact with wildlife and non-residents of Wuhan who visited the city or who had contact with citizens there were performed. Their findings revealed thatthe clinical characteristics of the affected patients are more precisely defined using GIS.

Jella *et al*. (2020) also carried out a study on the geographical distribution of orthopaedic surgeons aged 65 years or more (age-group considered more vulnerable to the disease) by comparing their distribution with other specialties and with those diagnosed with COVID-19 to determine the potential risk of orthopaedic surgeons during the pandemic of COVID-19. Their results revealed that the following states; New York, New Jersey, California and Florida are the epicenter of the pandemic. Furthermore, De Kadt *et al.* (2020) used GIS techniques to produced two maps for the city of Gauteng. One is the risk factor index map that can be use to enhance social distance and preventive hygiene in curbing the spread of the pandemic while the second map is to responds to the concern about how the social distancing measures taken and its reaction to an outbreak will impact poorer communities. Gibson and Rush (2020), following their GIS study, later discovered that social distancing is not realistic in certain informal settlements of more than 146,000 households located in Cape Town, which are densely populated, with houses in close proximity to each other, and lacking sanitation infrastructures.

Since COVID-19 pandemic is of spatial dimension, this makes it a geographical phenomenon and mappable. For this reason, the use of geospatial and statistical tools has become particularly relevant with the declaration of COVID-19 as a global pandemic, making it a thematic polyhedron where geographical variables can be presented graphically.

Although valuable works on examine COVID-19 spread using GIS techniques have been carried out in some major part of the world; Africa (Gibson and Rush, 2020; Kuupiel *et al.,* 2020), Latin America and the Caribbean (De Ángel Solá *et al.,* 2020; Buzai, 2020) and in South Asian countries (Sarwar et al., 2020) but insufficient. Health geography that makes use of GIS techniques to respond to needs at all levels is effective, reliable and applicable. COVID-19 studies couple with GIS could be valuable tools in decision making and, most essentially for social mobilization and community responses. GIS can also play a major role in imagery evaluation of disease growth, concentrations, or threats across time (Tosepu *et al.,* 2020). This imagery evaluation could be in form of static map series, animations, and linked interactive micro maps. This is time for Nigerian states to focus on preparing general referenced epidemic maps and sampling plans that will educate the populace about the spread of COVID-19 at all levels- National, States and Local. The resultant map can be helpful to delineate the boundaries of area of concern.

Therefore, the purpose of this paper is to visualize the risk and spread pattern of COVID-19 pandemic in Nigeria using Geographic Information System (GIS) techniques. The objective of this work among others is to develop a geo-visualization system to analyze epidemic data and equally highlight the implications of findings. In view of this, the paper is divided into three (3) sections; section two is on the research methodology used for the study while section three discusses the results of findings. Section four concludes the study.

1.1. Study Area

Nigeria is located at the region of longitude 3^0 and 14^0 East of Greenwich meridian and latitude 4^0 and 14^0 North of the Equator. The country is bordered

by the Republic of Benin on the west; the Republic of Cameroon on the east; Niger and Chad Republics on the north and on the south by the Gulf of Guinea and Atlantic Ocean respectively (see figure 1).The land area is 909,890sqkm while water is 13,879sq km. Compared with other West African countries; Nigeria is third in area size, with a projected population of over 200 million people 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 new Federal Capital Territory (Abuja), all summarized into six Geopolitical zones. There are also, 774 Local Government Areas in the country, each with its own administrative headquarters (Ademiluyi, 2020).

Agriculture is the largest sector of the economy and employs about 70% of the labour force and accounting for more than one-third of the GDP. Nigeria has commercial quantities of over forty-four (44) minerals spread across more than 500 locations across the country. Most of these resources remain untapped till today (Ademiluyi, 2020).

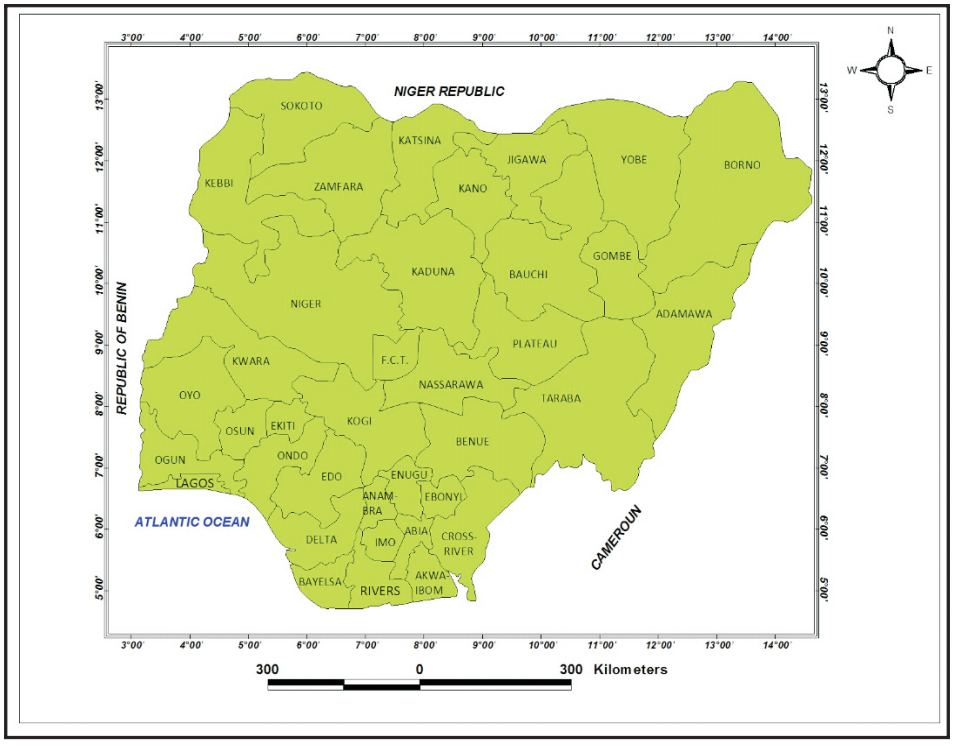

Figure 1: Map of the Study Area (Nigeria)
Source: Federal Ministry of Works,Housing and Power,Ibadan (2016)

1.0. Materials and Methods

1.1. Data Source and Types

The data used for this study include; 1) the daily reports on COVID-19 cases (between 29th of February and 13th of August,2020) in Nigeria, obtained from the Nigeria Centre for Disease Control (NCDC) 2020 and 2) map of Nigeria acquired from the Federal Ministry of Works, Housing and Power, Abuja (2016).

1.2. Data Analysis

Descriptive statistics and Geographical Information System (GIS) techniques were the two methods of analysis employed for this study (Park et al., 2016). The descriptive statistics method includes the use of percentages and graph. The Geographical Information System (GIS) techniques used to examine visually the trend pattern in the spread of COVID-19 across the 36 states and Abuja (FCT) in Nigeria include; scanning, geo-referencing, digitization, attribute database creation and spatial analysis (Adebayo, 2018). The GIS software used is ArcGIS10.0.

The acquired map was scanned using Corel draw 12 and exported into theArcGIS environment, and then it was geo-referenced using the tie-points method. On- screen digitization was performed on the geo-referenced map through the application of

Arc GIS 10.0 software to create states boundaries of the study area as polygon features. Likewise, Microsoft Excel was used to process the daily reports on COVID-19 cases in Nigeria (between 29th of February and 13th August, 2020) obtained from the Nigeria Centre for Disease Control and exported via the spatial analyst tool of Arc GIS 10.0 into the GIS environment (Adebayo, 2015). The results of analysis are presented in tables (Tables 1, 2, 3&4) and maps (Figures 2, 3, 4, 5, 6, 7, 8 &9).

2.0. Results and Discussions

This section presents and discusses the results of this research. The discussion is in three (3) parts; mapping of (1) the distribution pattern of COVID-19 cases in Nigeria (2) COVID-19 pandemic risk zones in Nigeria and (3) Implications of findings.

2.1. Mapping the Distribution Pattern of COVID-19 Pandemic in Nigeria (between 29th of February and 13th of August, 2020).

Table 1-4; figure 2 to 9 present the spatial spread or distribution pattern of COVID-19 pandemic in Nigeria. It was discovered from table 1; figure 2&3 that the pandemic (COVID-19) as at the 31st of March, 2020,hasspread from one (1) state to nine (9) states in Nigeria with Lagos state (81) recording the highest number of COVID-19 confirmed cases followed by Abuja (FCT) (25) and Oyo state (8). Figure 4&5 further show that the pandemic has spread tremendously from nine(9) to thirty-four (34) states by the end of April, 2020 except for Cross river and Kogi states with zero cases. It also reveal that as at 31st of May,2020, the spread of COVID-19 is still within the 34 states including the FCT, Abuja with Lagos state the epicenter of the pandemic (see Table 2 and Figure 5).

The GIS analysis presented in Figure 6 &7 shows the pattern of COVID-19 prevalence in Nigeria as at 30th of June and 31st of July, 2020. From figure 6, it can be deduced that the spread of the COVID-19 had gotten to 35 states including FCT, Abuja except for Cross river with zero cases as at 30th of June, 2020 with very high incidence of COVID-19 confirmed cases recorded in Lagos, Kano, Oyo, Edo, Delta, Kaduna, Rivers, Ogun states and Abuja (FCT). By the 31st of July, 2020, the pandemic had already spread to the 36 states including the FCT, Abuja and found out that Lagos, Ogun Oyo, Edo, Delta, Rivers, Kano, Kaduna, Ondo, Plateau and FCT, Abuja are the states with significant number of infected people certified positive (see Figure 7).

The Geo-visualization of confirmed cases distribution as a result of this pandemic across the states in Nigeria as at 13th of August, 2020 was also presented in Figure 8. COVID-19 confirmed cases are found to be very high in Lagos, Oyo, Edo, Delta, Rivers, Kano, Kaduna states and FCT, Abuja with Kogi state (5) recording the least.

Table 1: The Distribution Pattern of COVID-19 Cases 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.

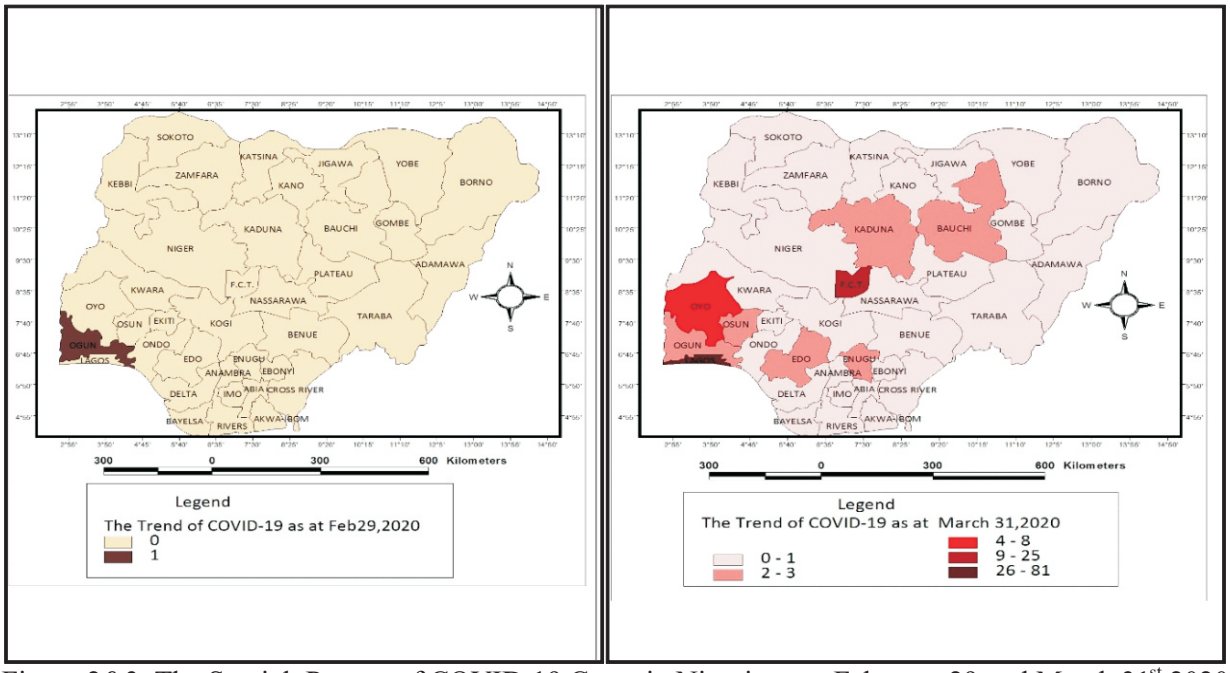

Figure 2&3: The Spatial Pattern of COVID-19 Cases in Nigeria as at February 29 and March 31st,2020

Table 2: The Distribution Pattern of COVID-19 Cases 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.

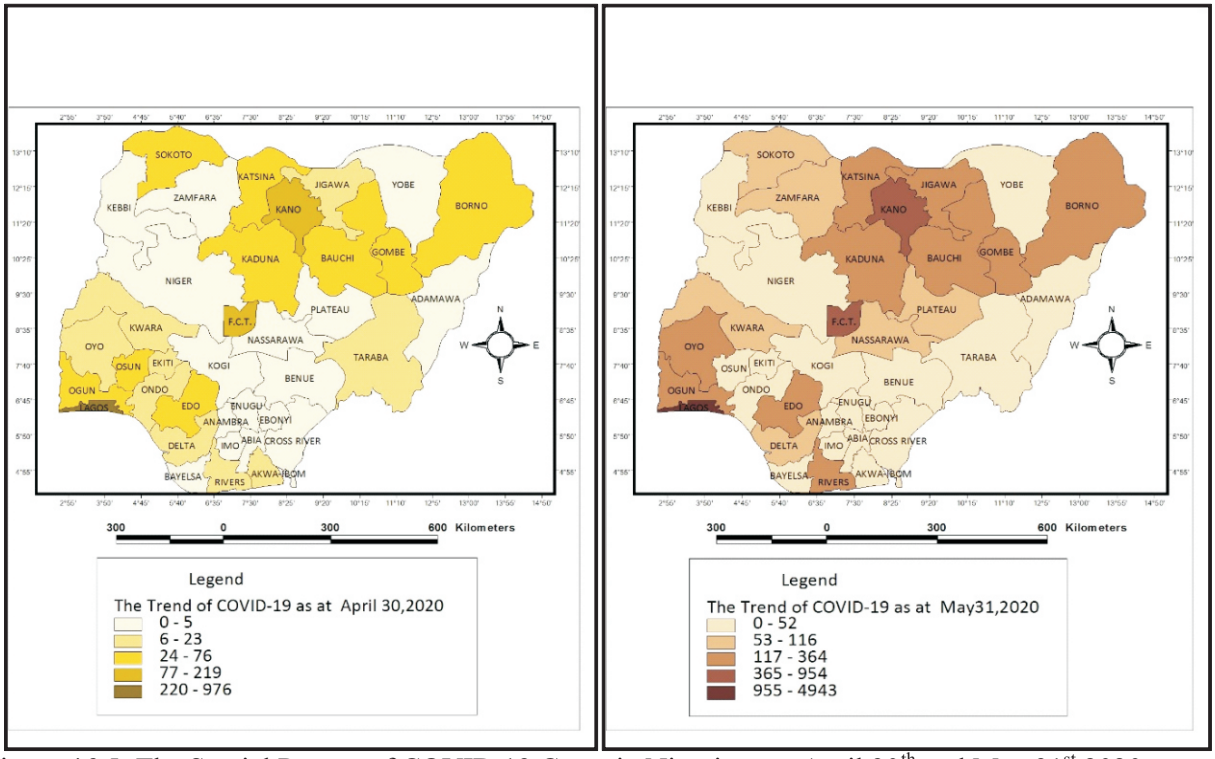

Figure 4&5: The Spatial Pattern of COVID-19 Cases in Nigeria as at April 30th and May 31st,2020

Table 3: The Distribution Pattern of COVID-19 Cases in Nigeria by States as at 30th of June and 31stJuly, 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.

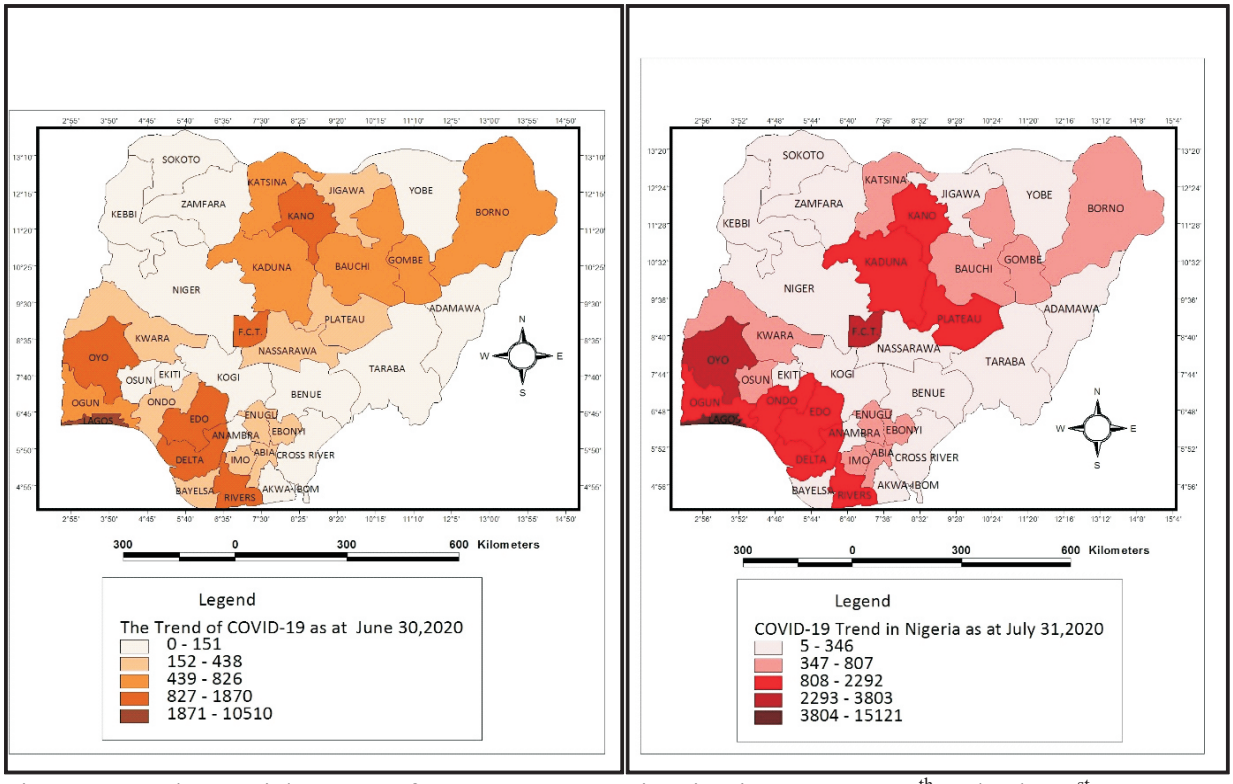

Figure 6&7: The Spatial Pattern of COVID-19 Cases in Nigeria as at June 30th and July 31st,2020

Table 4: The Distribution Pattern of COVID-19 Cases in Nigeria by States as at 13th August, 2020

	As at August 13th,2020(Total Cases)			
State	**Confirmed Cases**	**Discharged Cases**	**Death Cases**	**Active Cases**
Lagos	16256	13132	201	2923
FCT	4632	1325	46	3261
Oyo	2935	1504	31	1400
Edo	2399	2121	100	178
Delta	1665	736	24	905
Rivers	1991	1775	56	160
Kano	1706	1493	12	201
Ogun	1626	1430	44	152
Kaduna	1661	1320	54	287
Ondo	1373	770	28	575
Borno	719	341	13	365
Gombe	698	576	36	86
Bauchi	677	546	5	126
Ebonyi	908	852	26	30
Plateau	1521	1288	24	209
Enugu	976	650	19	307
Abia	647	576	23	48
Imo	494	168	10	316
Jigawa	346	316	21	9
Kwara	888	591	23	274
Bayelsa	372	233	8	141
Nasarawa	322	308	11	3
Osun	580	533	14	33
Sokoto	185	104	12	69
Niger	241	207	8	26
Akwa-Ibom	228	168	12	48
Benue	430	139	9	282
Adamawa	194	81	3	110
Anambra	156	131	18	7
Kebbi	90	82	8	0
Zamfara	78	55	4	19
Yobe	77	71	5	1
Ekiti	154	138	16	0
Taraba	73	42	8	23
Cross-river	67	57	8	2
Kogi	5	3	2	0
Total	**48,116**	**34,309**	**966**	**12,841**

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

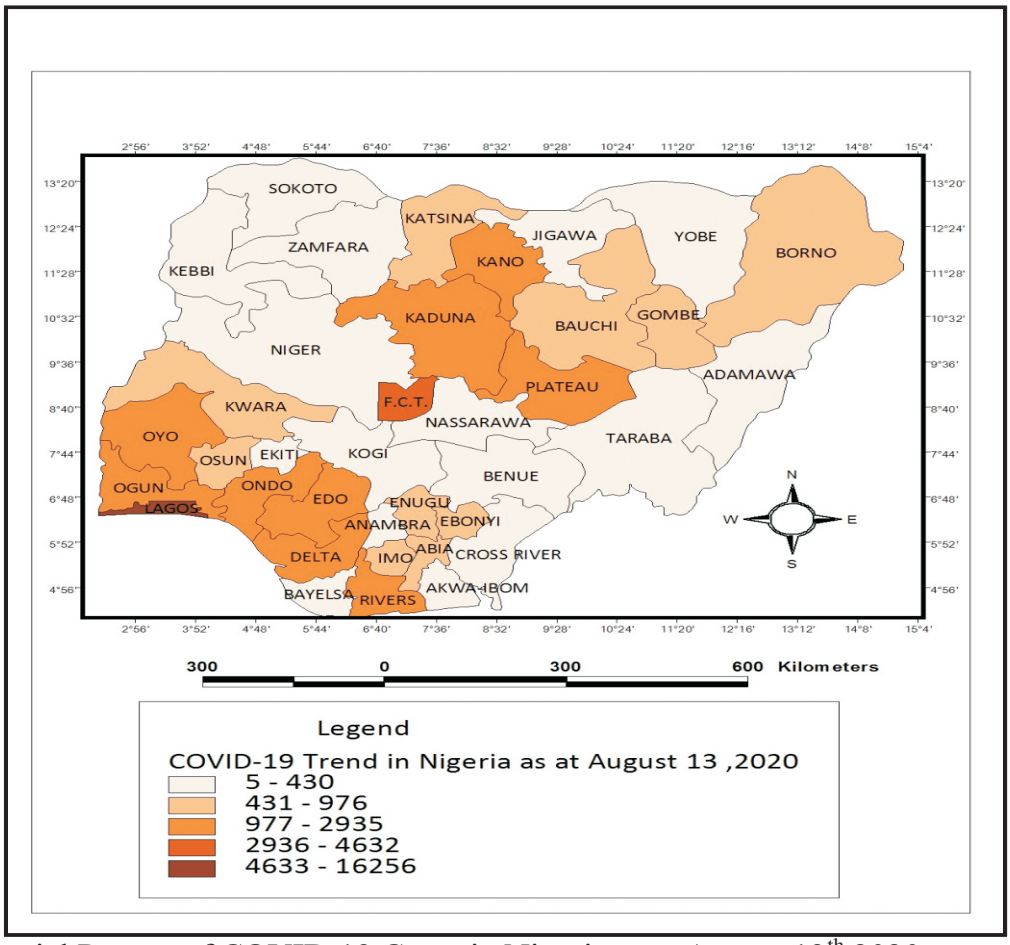

Figure 8: The Spatial Pattern of COVID-19 Cases in Nigeria as at August 13th,2020

1.1. Mapping COVID-19Pandemic Risk Zones in Nigeria (between 29th of February and 13th of August, 2020).

The resultant risk analysis using GIS (UNISDR, 2013a; Whanda *et al.,* 2015) in Figure 9 revealed that Lagos state as at August 13, 2020, is at a very high risk to the spread of COVID-19 pandemic in Nigeria. The result of finding also revealed that the following states; Oyo, Ogun, Edo, Delta, Rivers, Kano and Abuja, the Federal Capital Territory (FCT) are classified as high risk zone.States at moderate risk to the pandemic include; Ondo, Enugu, Ebonyi, Abia, Imo, Kaduna, Katsina, Bauchi, Gombe, Plateau and Borno. The risk analysis presented in Figure 9, further show that the following states are at marginal pandemic risk. These states are; Osun, Ekiti, Bayelsa, Anambra, Cross-river,Akwa-Ibom,Benue,Kogi, Kwara, Niger, Nassarawa, Taraba, Adamawa, Kebbi, Zamfara, Sokoto, Jigawa and Yobe.

For each state in Nigeria to be at one level of the pandemic risk, it shows that the entire country is at a high risk with Lagos state the epicenter of the pandemic. If care is not taken, rapid communities' transmission is inevitable.

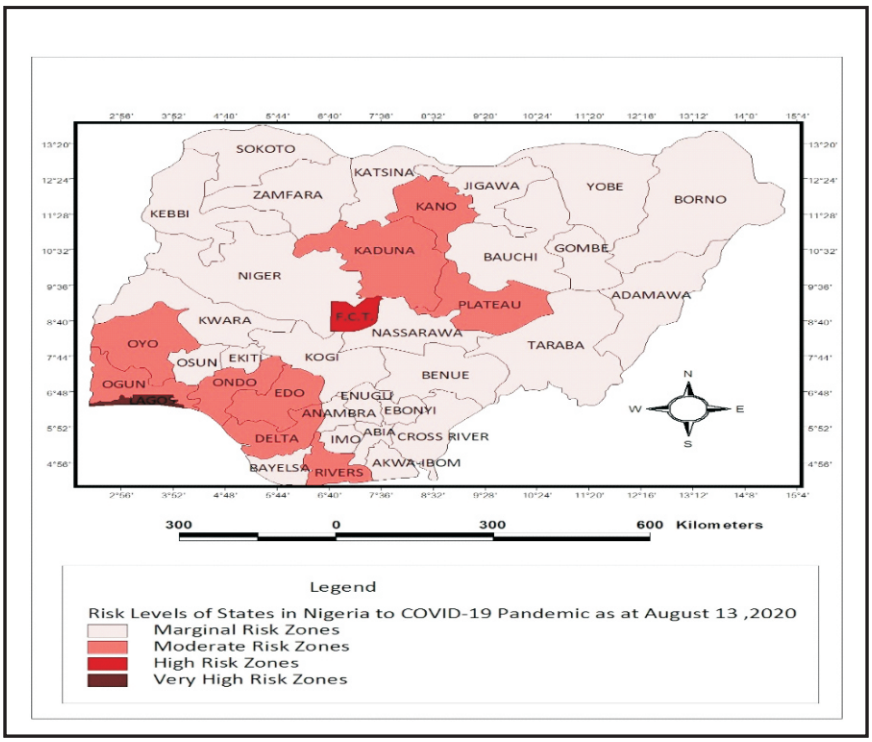

Figure 9: Risk Levels of States in Nigeria to COVID-19 Pandemic as at August 13,2020

Implications of Findings

Since human to human contact is still the major factor for the spread of this deadly virus, maps like the ones generated and presented visually in this study can be employed by all relevant stakeholders for quick decision making concerning its spread such as restrictions of movements from and into hotspot states (intra and inter-state movement), whether to have total or partial lockdown, in having effective responses in terms of medical facilities and palliative measures that will help in reducing the effects. These maps put together can also serve the purpose of early warning now and in the future.

These maps can further be used to control community and neighborhood spread in Nigeria and globally. Generally, geo-visualization analysis of health events through the use of Geographic Information System techniques has the capacities of storing, analyzing and displaying such in a simple graphic form for quick understanding and interpretation.

Conclusion and Recommendations

This study attempted using the techniques of Geographic Information System to visualize the riskand spatial distribution COVID-19 across the 36 states and FCT, Abuja in Nigeria. It equally presented how geo-visualization analysis could be used to explain public health phenomenon for quick decision and intervention. Lagos, Oyo, Ogun, Edo, Delta, Rivers, Kano, and Kaduna states together with Abuja were found to be the most hardly hit areas in Nigeria with the entire country at a very high risk to the pandemic. It also established how maps like the ones generated in this study can be used to checkmate the spread of diseases across the space. The study concludes by recommending a proactive involvement of geo- visualization analysis among other numerous methods for explaining public health phenomena by all relevant stakeholders for quick planning, preparedness and responses.

References

Adebayo, O.H. (2018). Geospatial Assessment of Flood Risk Areas in Lower and Upper Benue River Basins of Nigeria. Journal of Disaster Risk Reduction. 1(1): 49-57.

Ademiluyi, I.A., (2020). Human Geography and the Search for a New Nigeria. *95th Inaugural Lecture.* Olabisi Onabanjo University, Ago Iwoye, Ogun State.

Buzai, G.D., (2020). De Wuhan a Luján. Evolución espacial del COVID-19. *Posición* 3,

2683–8915.

De Ángel Solá, D.E., Wang, L., Vázquez, M., and Méndez Lázaro, P.A., (2020). Weathering the pandemic: how the Caribbean Basin can use viral and environmental patterns to predict, prepare and respond to COVID-19. *Journal of Medical Virology.* 1–9.

De Kadt, J., Gotz, G., Hamann, C., Maree, G.and Parker, A., (2020). Mapping Vulnerability toCOVID-19 in Gauteng. GCRO Map of the Month. Gauteng City-Region Observatory.

Gibson, L. and Rush, D., 2020. Novel coronavirus in Cape Town informal settlements: feasibility of using informal dwelling outlines to identify high risk areas for COVID-19 transmission from a social distancing perspective. *JMIR Public Health Surveillance.* 6(2), e18844. https://doi.org/10.2196/18844.

Gross, B., Zheng, Z., Liu, S., Chen, X., Sela, A., Li, J. and Havlin, S., (2020). Spatio-temporal propagation of COVID-19 pandemics. *Medical Review*xiv 2020.03.23.20041517.

Guan,W.J., Ni, Z.Y., Hu, Y., Liang,W.H., Ou, C.Q., He, J.X. and Du, B.,(2020). Clinical characteristics of coronavirus disease 2019 in China. *New England Journal of Medicine.* 382 (18): 1708–1720.

Jella, T.K., Acuña, A.J., Samuel, L.T., Jella, T.K., Mroz, T.E. and Kamath, A.F., (2020). Geospatial mapping of orthopaedic surgeons age 60 and over and confirmed cases of COVID- 19. *Journal of Bone Joint Surgery. Am.* https://doi.org/10.2106/JBJS.20.00577.

John Hopkins University (2020). Africa COVID-19 Update: 14:00 WAT on Friday 10 July. https://www.africanews.com.

Kuupiel, D., Adu, K.M., Bawontuo, V., Adogboba, D.A., Drain, P.K., Moshabela, M. and Mashamba-Thompson, T.P., (2020). Geographical accessibility to glucose-6-phosphate dioxygenase deficiency point-of-care testing for antenatal care in Ghana. *Diagnostics*. 10 (4), 229.

Liu, J., Zhou, J., Yao, J., Zhang, X., Li, L. and Zhang, K., 2020. Impact of meteorological factors on the COVID-19 transmission: A multicity study in China. *Science of the Total Environment*. 726, 138513.

Sarwar, S.,Waheedab, R., Sarwar, S. and Khand, A. (2020). COVID-19 challenges to Pakistan: is GIS analysis useful to draw solutions Science of Total Environment. https://doi.org/10.1016/j. scitotenv.2020.139089.

Tosepu, R., Gunawan, J., Effendy, D.S., Ahmad, L., Lestari, H., Bahar, H. and Asfian, P., (2020) .Correlation between weather and Covid-19 pandemic in Jakarta, *Indonesia Science of. Total Environment.* 138436 https://doi.org/10.1016/j.scitotenv.2020.138436.

UNISDR (2013a). Global Assessment Report on Disaster Risk Reduction: From Shared Risk to Share Value: the Business Case for Disaster Risk Reduction. United Nations Office of Disaster Risk Reduction (UNISDR).

Whanda, S., Sani, Y. and Bulus, G. (2015). Modelling of Potential Pipeline Impact Radius and High Consequence Area in a Wetland Sub-Region of Nigeria. *Journal of Geographic Information System.* 7,692-709.

World Health Organization, 2020a. Considerations for Quarantine of Individuals in the Context of Containment for Coronavirus Disease (COVID-19): Interim Guidance, 19 March 2020 (No. WHO/2019-nCoV/IHR Quarantine/2020.2). World Health Organization.

World Health Organization, 2020b. Critical Preparedness, Readiness and Response Actions for COVID-19-7 March 2020.

Xiong, Y., Guang, Y., Chen, F. and Zhu, F., (2020). Spatial statistics and influencing factors of the novel coronavirus pneumonia 2019 epidemic in Hubei Province, China. *Research Square* https://doi.org/10.21203/rs.3.rs-16858/v2 Preprint.