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Post-Vaccine Spatial Patterns and Associated Risk Factors of COVID-19 Infections, Recoveries, and Deaths in West Africa

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Abstract: COVID-19, declared a public health emergency by the World Health Organization in March 2020, came to an end on May 5, 2023. The pandemic affected every part of the world including West Africa. Previous studies on this subregion examined the distribution and drivers of COVID-19 with a view to identifying its epicentres during the first wave of the pandemic long before a COVID-19 vaccine was found. After several rollouts, questions on the post vaccine spatial patterns of the pandemic and the degree to which vaccination influenced morbidity and mortality outcomes surfaced. The focus of this paper therefore was to examine the spatial patterns and associated risk factors of COVID-19 infections, recoveries and deaths in the post vaccine period. The study relied on public data sources. Pearson Correlation and Stepwise regression method were used to identify the drivers of the spatial patterns. Findings show that Nigeria and Cape Verde were the pandemic's hotspots in West Africa. In addition, population size, elderly population, air traffic, access to WASH, and some socioeconomic indicators were significant in the explanation of the spatial patterns of the disease. In conclusion, the geography of the pandemic in West Africa did not significantly change on account of vaccination.

Keywords: Coronavirus, Vaccines, Pandemic, Spatial Analysis, Global Health, West Africa

1. Introduction

In December 2019, a rare pneumonia "…of an unknown cause", later named asCOVID19, broke out in Wuhan city of China and evolved into a pandemic on March 11, 2020 [1]. As of August 9, 2023, over 760 million cases and 6.9 million deaths of COVID-19 worldwide have been reported, and more than 7 million lives have been claimed globally [2]. On May 5, 2023, the World Health Organization declared the official end of COVID-19 as a public health emergency [3]. However, some scholars have observed that there is no consensus on when and how epidemics/pandemics truly end [4].

Before its 'end', it had caused a substantial impact on work-life regimes, healthcare systems, and the global economy. The pandemic clearly affected every part of the world, however, with varying degrees of severity. For instance, Africa, the last continent to report COVID-19 [1, 5-6] was the least affected by the virus with relatively few confirmed morbidity and mortality [7-9]. The continent's first confirmed case was reported in Egypt on February 14, 2020. West Africa's first case was reported in Nigeria on February 27, 2020, brought in from Italy [6].

Since then, the sub-region has come into focus because of its highly perceived vulnerability. It was believed that "many West African countries have poorly resourced health systems rendering them unable to quickly scale up an epidemic response" [10], especially in light of the 2014 Ebola outbreak. Countries of this region have historically been faced with numerous health challenges, including healthcare worker shortages due to brain drain, poorly equipped and managed primary healthcare facilities, poverty, and low standard of living [11]. These inadequacies, as some have thought, would place the subcontinent in a precarious state and would be grossly unprepared for the COVID-19 outbreak [12].

Besides these anxieties, the World Health Organization at the onset of the pandemic had identified Nigeria, West Africa's most populous country, as one of the thirteen potential COVID-19 transmission hotspots in the world. Thereafter, a number of studies examined the first wave of COVID-19 in West Africa in order to discern the patterns, trends, and correlates of its diffusion [13-15]. The findings collectively showed that population size and volume of international air traffic were major influences on the health crisis in the subregion, with a special focus on Nigeria as the pandemic's epicentre. However, these studies were limited to the pandemic's first wave prior to the development of the first COVID-19 vaccine. Since the roll-out of the first COVID-19 vaccine in 2021, the resumption of air travel and easing of restrictions, has the geographical distribution of COVID-19 significantly changed in West Africa? Although [14] examined the coverage and drivers of the COVID-19 vaccination in West Africa, it did not consider their potential impact on the pandemic.

While these foundational studies successfully mapped the initial spread and drivers of COVID-19 in West Africa, they were confined to the pre-vaccination era. A critical gap exists in understanding how the geographical patterns of the pandemic evolved after the widespread rollout of vaccines. Did the introduction of vaccines, coupled with the resumption of mobility, significantly alter the spatial epidemiology of infections, recoveries, and deaths in the region? This study directly addresses this gap by providing the first comprehensive spatial analysis of COVID-19 in West Africa, specifically focused on the post-vaccine period. This allowed us to assess the extent to which vaccination campaigns influenced the pandemic's geography.

In light of the above, the paper's key objective is to analyze more recent spatial patterns of retrospective COVID-19 infections, recoveries, and deaths in West Africa since the rollout of a COVID-19 vaccine. To achieve this, the following sub-objectives have been set out: First, analyze the geographical distribution of COVID-19 infections, recoveries, and deaths in West Africa. Second, identify the risk factors influencing these patterns. Lastly, determine the extent to which COVID-19 vaccination distribution shaped COVID-19 outcomes across West Africa.

2. Materials and Methods

Secondary data were obtained from the World Population Data Sheet 2022, World Health Statistics 2022; 2021 African Statistical Yearbook of the African Development Bank (AfDB), Human Development Report 2021/2022, International Civil Aviation Organization (ICAO) 2020, and the Economic Community of West African States Centers for Disease Control and Prevention (ECOWAS CDC), 2022.

Specifically, cases of COVID-19 Infections, Recovery and Deaths, and vaccination coverage in fifteen countries of West Africa were collected from ECOWAS CDC as of December 4, 2022. Since then, the ECOWAS CDC has ceased reporting COVID-19 incidence and vaccination coverage. In light of the circumstance, the data on COVID-19 vaccination used in the study was the only available and the most recent information. Other variables such as population size, population density, urban population, air traffic volume, number of international airports, net migration, percent population 65 years and above, number of doctors per 10000 persons, Human Poverty Index, Human Development Index, diabetes, obesity, hypertension, human immunodeficiency virus per 1000 persons, tuberculosis, access to wash facilities, access to safe water, COVID-19 vaccination, life expectancy index, gross domestic product per capita, gross national income per capita, and fine particulate matter were extracted from these published sources (see Table 1).

Table 2: Study variables, Theoretical basis, and Sources

Variable	Data Sources	Year
Population (m)	World Population Data Sheet	2022
Population Density	World Population Data Sheet	2022
Urban Population	World Population Data Sheet	2022
Percentage of Population (Ages 65+)	World Population Data Sheet	2022
Net Migration	World Population Data Sheet	2022
Air Traffic	International Civil Aviation Organization (ICAO)	2020

International Airports	International Civil Aviation Organization (ICAO)	2020
Population Fully Vaccinated Against COVID-19	ECOWAS CDC	2022
Life Expectancy at Birth	World Population Data Sheet	2022
Human Development Index	Human Development Report	2021/2022
Human Poverty Index	Human Development Report	2021
Gross Domestic Product	World Population Data Sheet	2022
Gross National Income Per Capita ($)	World Population Data Sheet	2022
Doctors per 10,000 Persons	World Health Statistics	2022
Prevalence of Hypertension among Adults (30-79 yrs.)	World Health Statistics	2022
Prevalence of Obesity among Adults (18yrs+)	World Health Statistics	2022
New HIV infections (per 1,000 uninfected population)	World Health Statistics	2022
Tuberculosis Incidences (per 100,000 population)	World Health Statistics	2022
Access to WASH Facilities	World Health Statistics	2022
Access to Safe Water	World Health Statistics	2022
Fine Particulate Matter in Urban Areas	African Statistical Yearbook of the African Development Bank (AfDB)	2021

Source: Compiled by authors

The variables selected for this study were chosen based on the existing literature on ecological associations with COVID-19 infections, recoveries, and deaths in West Africa.

Table 2: Study variables, Theoretical basis, and Sources

Variable	Theoretical Basis	Source
Population size	Large population size increases the degree of susceptibility to COVID-19 and facilitates rapid transmission of the virus among people.	[13-14; 17-18]
Population Density	A higher degree of population concentration facilitates the diffusion of COVID-19	[16, 18-19]
Urban population	Urban characteristics such as large population living in urban settlements, housing conditions, public transportation, poor air quality and facility-sharing	[21, 22-24]

	influence the transmission of the virus.	
Air traffic and international airports	Global connectivity, particularly through frequent air travel, facilitates the rapid spread of COVID-19.	[13, 24-28]
Net migration	Migration aids the diffusion of the virus from source regions to destination areas.	[29, 30-32]
Percent Population 65 years and above	Elderly people are at great risk of infection and death associated with COVID-19 due to age and pre-existing medical conditions.	[17, 33-35]
Doctors per 1000 persons	Higher patient-to-provider ratio leads to delayed detection of the virus and longer wait times for intervention and delayed response in treatment and care.	[36-38]
Human Poverty Index	Poverty limits access to basic needs, including healthcare and proper living conditions, which in turn increases the risk of infection.	[17, 39-40]
Human Development Index	Countries with higher levels of development are more responsive to the pandemic	[41, 42-43]
Pre-existing medical conditions (Diabetes, Obesity and Hypertension, HIV, and TB)	Non-communicable and co-morbidities can increase the risk of COVID-19 infection and death.	[8, 44-45]
Access to WASH facilities and safe water	Limited access to safe water and WASH facilities compromises prevention measures and creates multiple pathways for the transmission of the virus.	[46,47-48]
COVID-19 Vaccination	COVID-19 vaccination confers immunity and reduces the risk of infection and possibly death	[49,50-51]

Life Expectancy Index	Countries with lower life expectancy often have younger populations who may be asymptomatic carriers of COVID-19, while countries with higher life expectancy often have older populations who are more susceptible to severe illness and death from the virus.	[26, 52-54]
Gross Domestic Product and Gross National Income	Countries with strong indicators of economic prosperity are more likely to effectively contain the pandemic	[26, 39, 52]
Fine Particulate Matter	Fine particulate matter pollution facilitates an unhindered entry of the virus and later causing breathing difficulty.	[55, 56-57]

Counts and rates were used to allow for a comparative spatial analysis of the pandemic in West Africa because they are often known to reveal distinct geographies of a phenomenon. Two dimensional (2D) proportional circle and choropleth maps showing the spatial pattern of COVID-19 in West Africa were designed with the aid of ArcGIS software version 10.2 was employed for this purpose.

The formula for calculating the COVID-19 rate is:

COVID-19 rate = (number of confirmed COVID-19 cases / Total population for each country) x 100,000

The same applied to the computation of rates for recovery and deaths.

The stepwise simple linear regression technique was used to examine the individual and joint contributions of explanatory factors to COVID-19 infections, recoveries, and deaths in West Africa. Before that, Pearson's correlation analysis was done to decipher the strength and nature of the association between COVID-19 and the possible risk or otherwise protective factors.

Lastly, scatter plots, designed with Data Wrapper, graphically illustrate the associations between the COVID-19 infection rate and the explanatory variables.

3. Results

3.1. *Spatial Pattern of COVID-19 Infections*

There was a total of 883,352 COVID-19 infections in West Africa as of December 4, 2022. The country with the largest number of infections was Nigeria (266,283) followed by Ghana (171,023) and Senegal (88,887). However, Sierra Leone (7,757) was the one with the lowest COVID-19 infections, followed by Liberia (8,022) and Guinea-Bissau (8,505) (Fig.1).

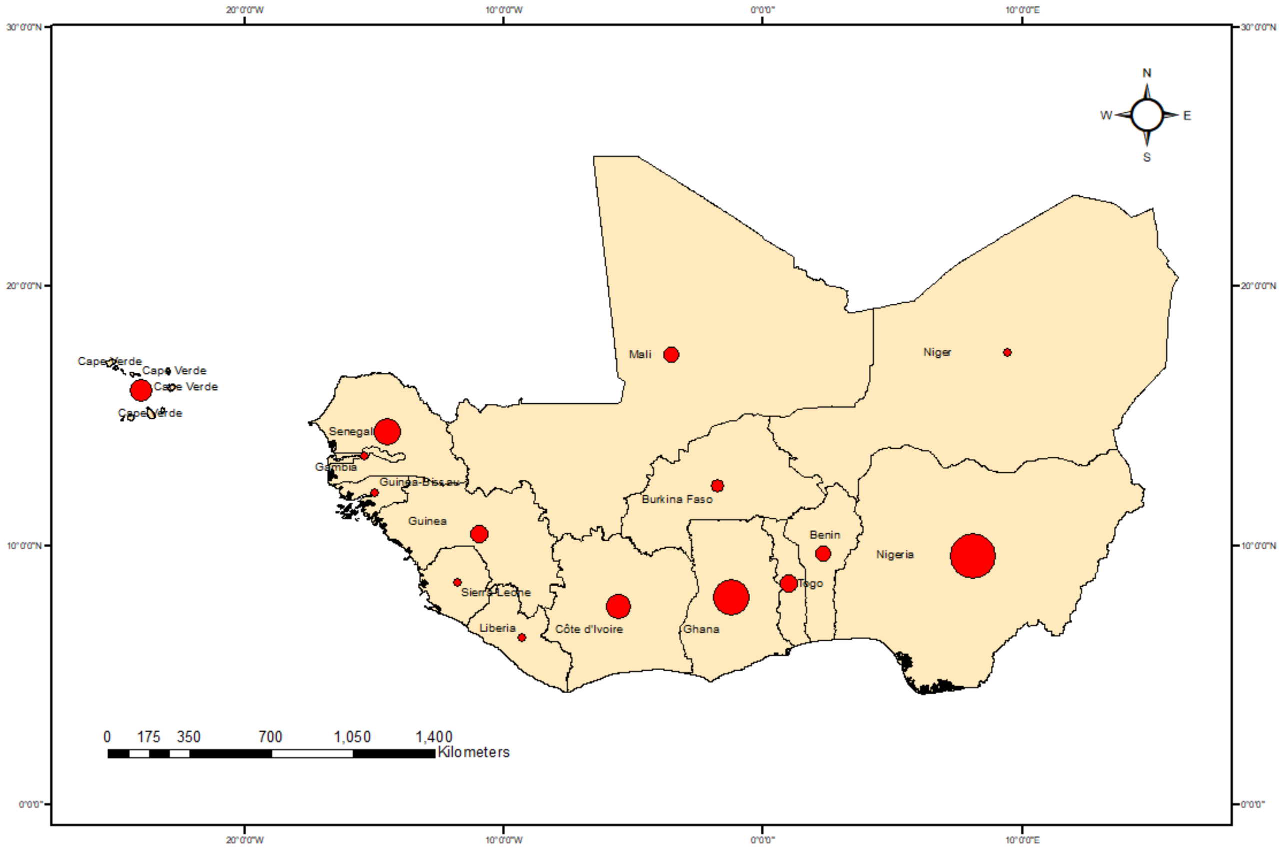

Fig. 1: Spatial Pattern of COVID-19 Infections in West Africa (December 4, 2022)

3.2 *Spatial Pattern of COVID-19 Recoveries*

West Africa had a total of 864,383 recoveries. Nigeria had the largest number of COVID-19 recoveries (259,640), followed by Ghana (169,553) and Côte d'Ivoire (87,051). Similarly, Sierra Leone had the lowest number of recoveries (4,819), followed by Liberia (7,715) and Guinea-Bissau (8,322) (Fig. 2).

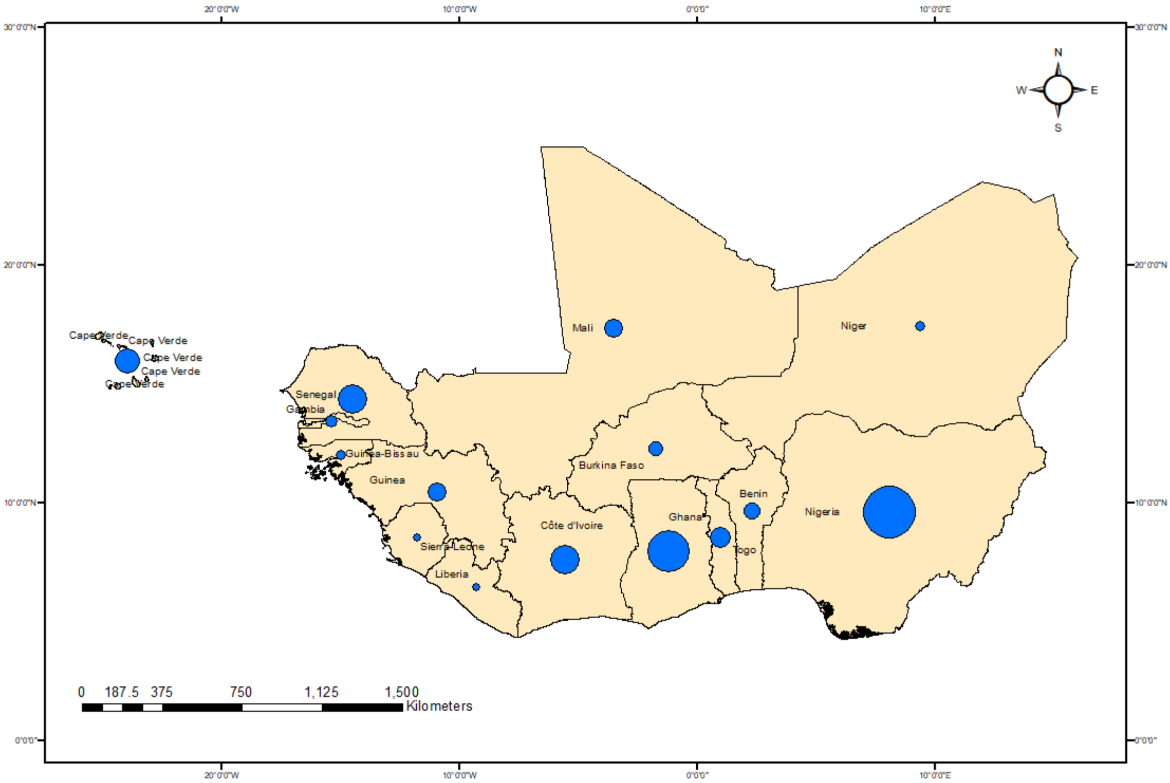

Fig. 2: Spatial Pattern of COVID-19 Recoveries in West Africa (December 4, 2022)

3.3 *Spatial Pattern of COVID-19 Deaths*

There were 11,400 COVID-19-related deaths in West Africa. On one hand, Nigeria recorded 3,155 deaths, followed by Senegal (1,968) and Ghana (1,416). On the other hand, Sierra Leone (125), followed by Benin (163) and Guinea-Bissau (176) had the lowest COVID-19 deaths in the region (Fig.3).

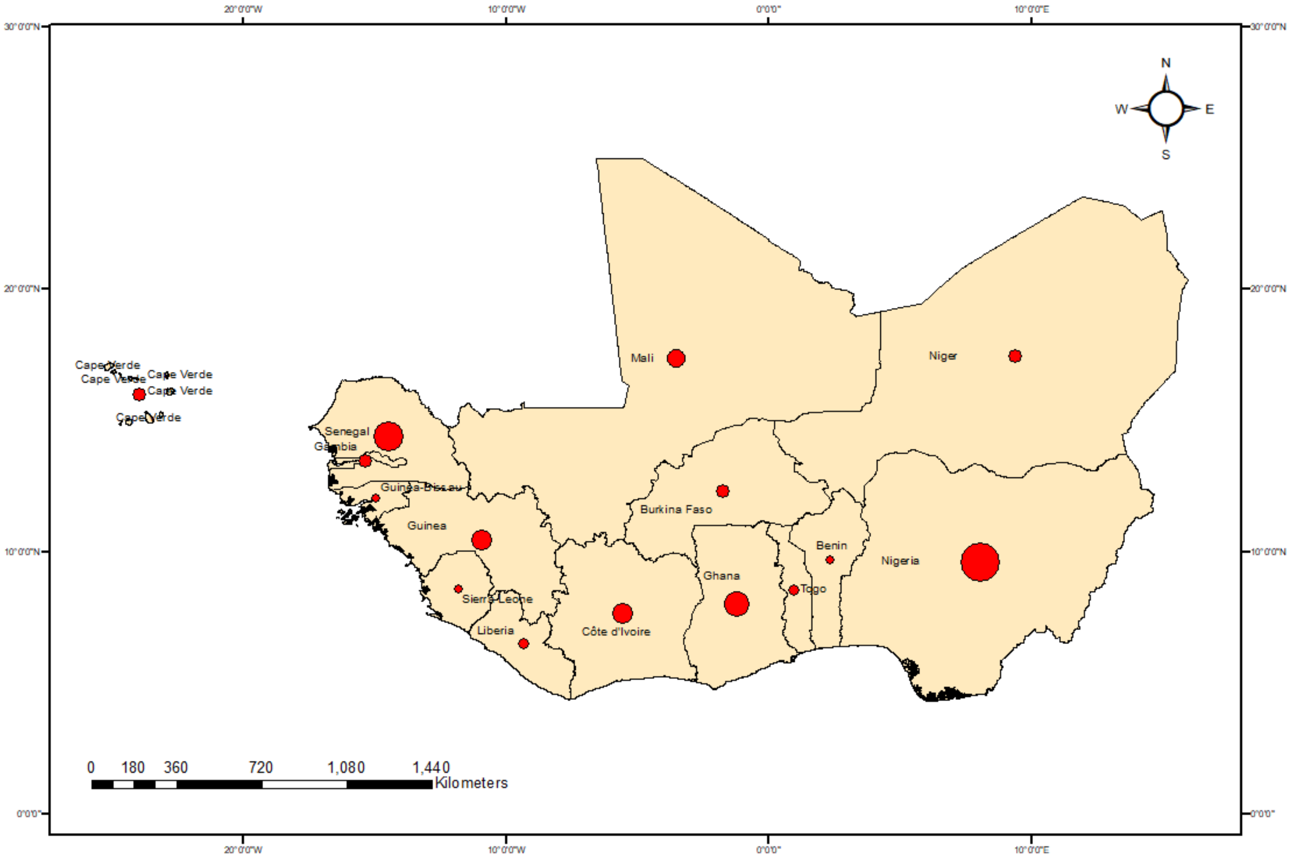

Fig. 3 Spatial Pattern of COVID-19 Deaths in West Africa (December 4, 2022)

3.4 *Spatial Pattern of COVID-19 Infection Rate*

COVID-19 Infection Rate (CIR) in West Africa was 14,272 per 100,000. However, with noticeable substantial variation, Cape Verde (10,513/100,000) had the highest incidence rate, followed by Ghana (510.52/100,000) and Senegal (496.58/100,000). Niger (36.06/100,000) had the lowest COVID-19 infection rate, followed by Sierra Leone (89.16/100,000) and Burkina Faso (95.29/100,000) in West Africa (Fig. 4.2.1).

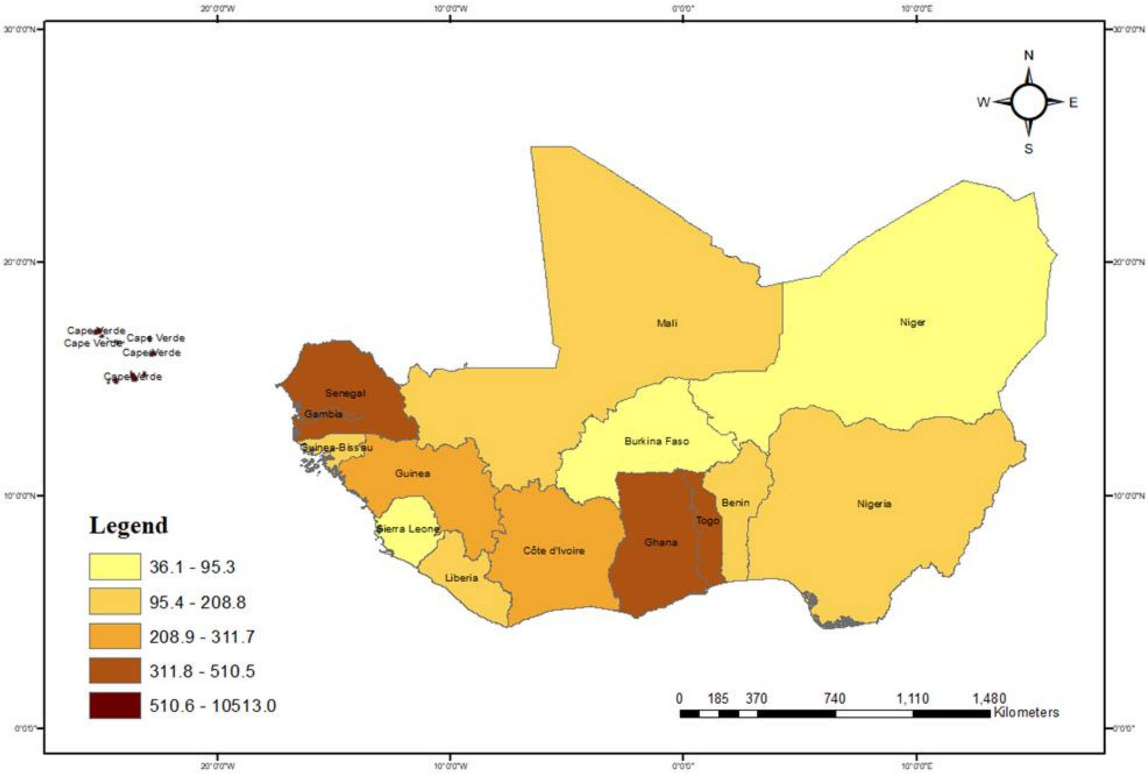

Fig. 4: Spatial Pattern of COVID-19 Infection Rate in West Africa (December 4, 2022)

Notably, when population size is accounted for, Cape Verde emerges as the clear outlier with an infection rate an order of magnitude higher than other countries, revealing a distinct risk profile driven by factors beyond sheer population.

3.5 *Spatial Pattern of COVID-19 Recovery Rate*

COVID-19 Recovery Rate (CRR) for West Africa was 14,067.62 per 100,000. Cape Verde (10,415.17/100,000) had the highest CRR, followed by Ghana (506.13/100,000) and Senegal (485.4/100,000) in the region. However, Niger (34.21/100,000) had the lowest CRR, followed by Sierra Leone (55.39/100,000) and Burkina Faso (93.14/100,000) in the West Africa region (Fig. 2).

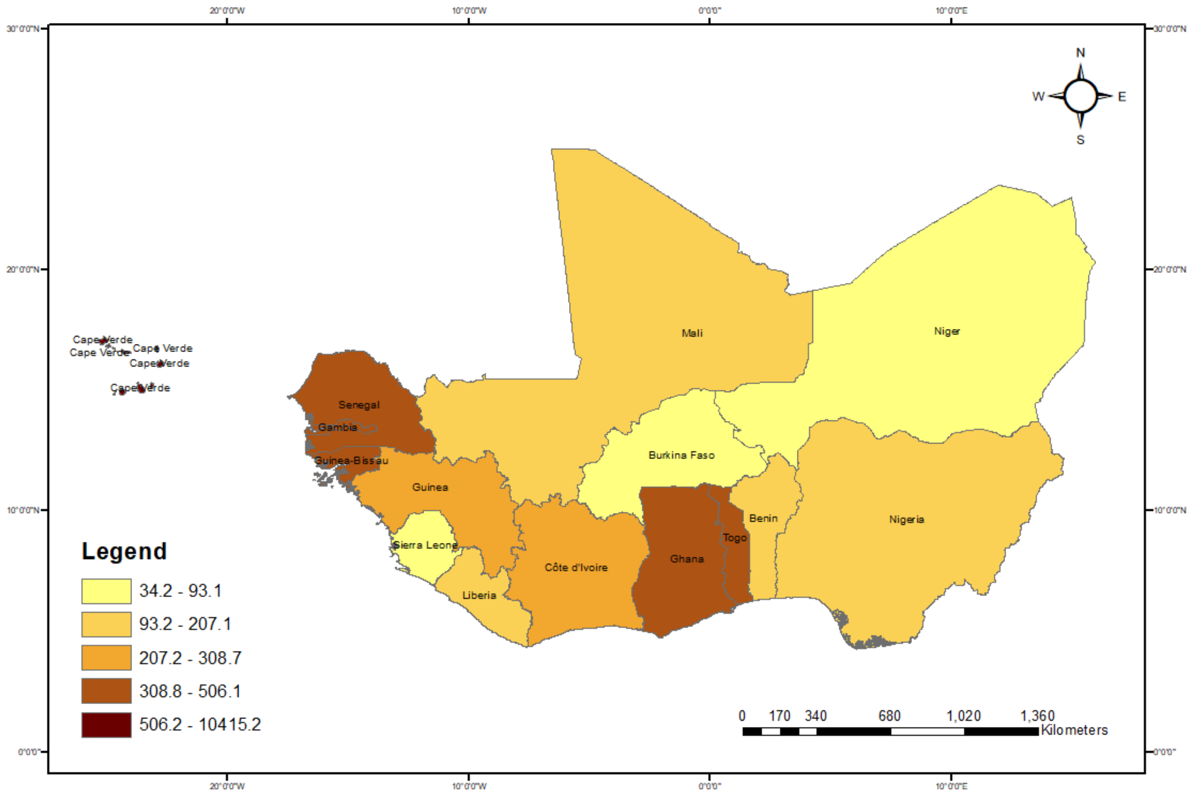

Fig. 5: Spatial Pattern of COVID-19 Recovery Rate in West Africa (December 4, 2022)

3.6 *Spatial Pattern of COVID-19 Death Rate*

COVID-19 Death Rate (CDR) was 133.85 per 100,000 for West Africa. Like infections and recoveries, Cape Verde (68.67/100,000) had the highest CDR in the region, followed by Gambia (13.78/100,000) and Senegal (10.99/100,000). However, Niger (1.20/100,000) had the lowest CDR in the region, followed by Benin (1.22/100,000) and Sierra Leone (1.44/100,000).

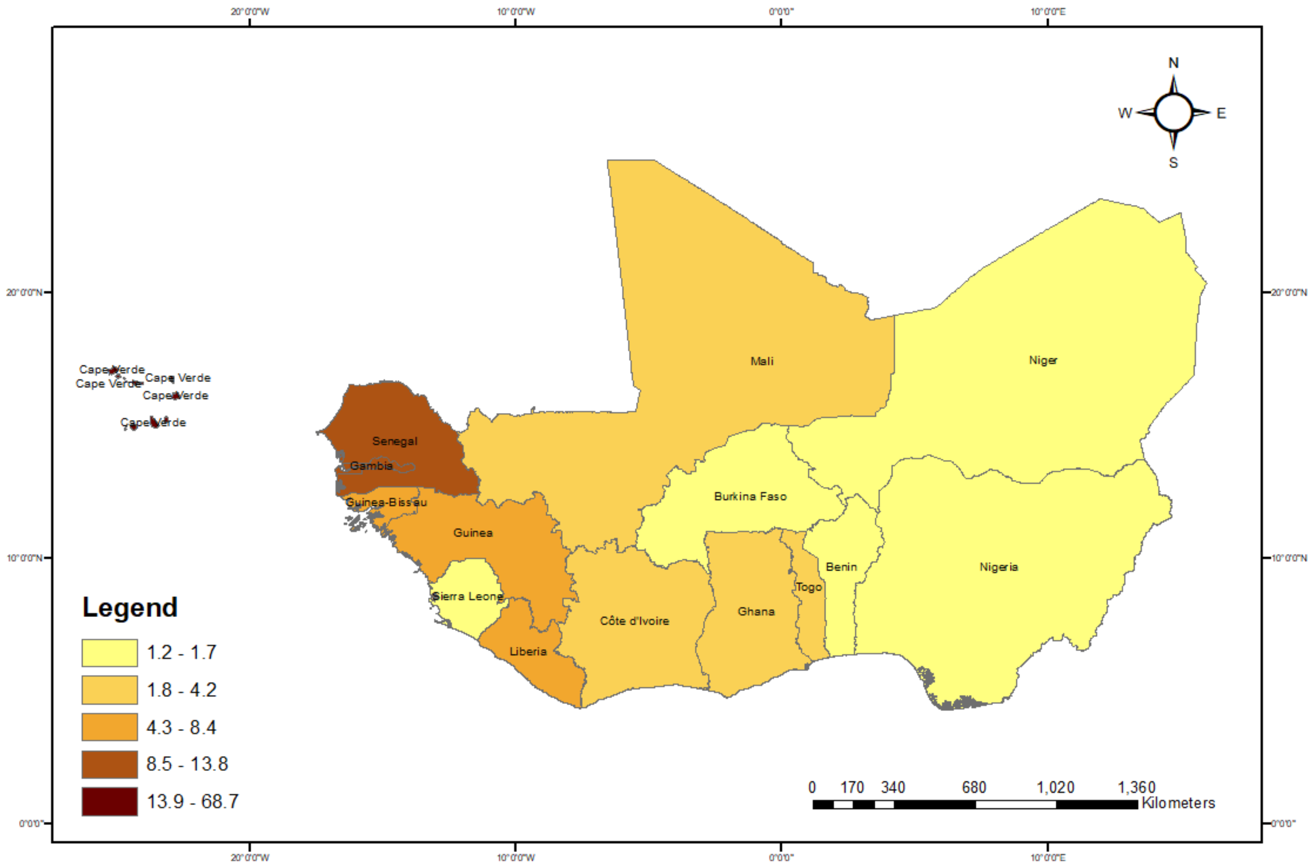

Fig. 6: Spatial Pattern of COVID-19 Death Rate in West Africa (December 4, 2022)

3.7 *Association between COVID-19 and Explanatory Variables*

The results of the Pearson correlation analysis are set in Tables 3 and 4. Table 3 presents the correlation with COVID-19 infection, recovery, and deaths (counts). With respect to infections, COVID-19 was positively associated with population size (r=0.844), air traffic (r= 0.872), number of international airports (r= 0.591), gross domestic product (r=0.650), gross national income per capita (r=0.689), and access to WASH facilities (r=0.769).

Like infections, COVID-19 recoveries were positively related to the same set of variables: population size (r=0.838), air traffic (r=0.872), number of international airports (r=0.592), gross domestic product (r=0.656), gross national income per capita (r=0.695) and access to WASH facilities (r=0.770). Lastly, COVID-19 deaths are directly related with population size (r=0.837), air traffic (r=0.919), and access to WASH facilities (r=0.638) (see Table 3).

Table 4 displays the association with the COVID-19 standardized rates. COVID-19 incidence rate was positively correlated with urban population (r=0.577), elderly population (r=0.838), life expectancy at birth (r=0.732), human development index (r=0.634), doctors per 10,000 persons (r=0.897), while inversely associated with human poverty index (r=-0.692).

Correlations with recovery rates are very similar to incidence rates. Recovery rates are also positively related to urban population (r=0.577), elderly (r=0.838), life expectancy at birth (r=0.732), gross domestic product (r=0.654), gross national income (r=0.563), doctors per 100,000 persons (r=-0.693), while it was negatively related to human poverty index (r=-0.693).

COVID-19 death rate was directly related to urban population (r=0.623), elderly population (r=0.796), life expectancy at birth (r=0.775), human development index (r=0.603), gross domestic product (r=0.602), doctors per 100,000 persons (r=0.868), and hypertension (r=0.524), and was negatively associated with human poverty index (r=-0.692).

In both tables 3 and 4, COVID-19 has a weak and insignificant relationship with vaccination. This shows that, at the ecological level and by the study cut-off date, national vaccination coverage rates were not a primary statistical driver of the observed spatial patterns in cumulative cases, recoveries, or deaths.

Table 3: Associations between COVID-19 and Explanatory Variables

Variable	Infection	Recovery	Death
Population (m)	**0.844****	**0.838****	**0.837****
Population Density	0.346	0.352	0.137
Urban Population	0.325	0.329	0.188
Percentage of Population (Ages 65+)	0.214	0.218	0.034
Net Migration	0.378	0.381	0.333
Air Traffic	**0.872****	**0.872****	**0.919****
Number of International Airports	**0.591***	**0.592***	0.45
Population Fully Vaccinated Against COVID-19	-0.186	-0.184	-0.346
Life Expectancy at Birth	-0.122	-0.115	-0.114
Human Development Index (HDI)	0.499	0.506	0.237
Human Poverty Index	-0.367	-0.373	-0.141
Gross Domestic Product	**0.650****	**0.656****	0.458
Gross National Income Per Capita ($)	**0.689****	**0.695****	0.48
Doctors per 10000 Persons	0.355	0.356	0.218
Prevalence of Hypertension among Adults (30-79 yrs.)	-0.149	-0.153	-0.05
Prevalence of Obesity among Adults (18yrs+)	-0.014	-0.011	-0.168
New HIV infections (per 1000 uninfected population)	-0.021	-0.022	-0.141
Tuberculosis Incidence (per 100,000 population)	-0.008	-0.015	0.035
Access to WASH Facilities	**0.769****	**0.770****	**0.638***
Access to Safe Water	0.109	0.12	0.058
Fine Particulate Matter in Urban Areas	-0.225	-0.225	-0.13

** Correlation is significant at the 0.01 level.

* Correlation is significant at the 0.05 level

Table 4: Associations Between COVID-19 Rates and Explanatory Variables

Variable	**Infection Rate**	**Recovery Rate**	**Death Rate**
Population (m)	-0.159	-0.158	-0.208
Population Density	0.477	0.477	0.485
Urban Population	**0.577***	**0.577***	**0.623***
Percentage of Population (Ages 65+)	**0.838****	**0.838****	**0.796****
Net Migration	-0.418	-0.416	-0.464
Air Traffic	-0.172	-0.171	-0.21
Number of International Airports	0.272	0.272	0.178
Population Fully Vaccinated Against COVID-19	0.238	0.226	0.053
Life Expectancy at Birth	**0.732****	**0.732****	**0.775****
Human Development Index (HDI)	**0.634***	**0.635***	**.603***
Human Poverty Index	**-0.692****	**-0.693****	**-0.692****
Gross Domestic Product	**0.653****	**0.654****	**0.602***
Gross National Income Per Capital ($)	**0.562***	**0.563***	0.51
Doctors per 10000 Persons	**0.897****	**0.897****	**0.868****
Hypertension among Adults (30-79 yrs.)	0.472	0.471	**0.524***
Obesity among Adults (18yrs+)	0.397	0.397	0.408
New HIV infections (per 1000 uninfected population)	0.433	0.406	0.451
Tuberculosis Incidence (per 100,000 population)	-0.285	-0.287	-0.226
Access to WASH Facilities	0.256	0.256	-0.029
Access to Safe Water	0.689	0.694	0.621
Fine Particulate Matter in Urban Areas	0.118	0.118	0.135

** Correlation is significant at the 0.01 level.

* Correlation is significant at the 0.05 level

Source: Author's Computation

3.8 *Determinants of Spatial Patterns of COVID-19 Infection, Recovery and Death Rate*

Tables 5 and 6 shows the results of the stepwise regression analysis for counts and rates respectively. With regard to infection counts, access to WASH facilities, gross national income, population and air traffic collectively accounted for nearly 97 percent of the variance in the geographical distribution of COVID-19 infections (R^2=0.969). Similarly, these same set of factors contributed nearly 97 percent of the variation in COVID-19 recoveries (R^2=0.968). Population size emerged as the only significant factor explaining sixty nine percent of the variation in COVID-19 deaths (R^2=0.692) (see Table 5 and Figures 7-15)

With regard to rates, human poverty index was the only significant predictor of COVID-19 infection rates (R^2=0.479) while human development index only explains sixty three percent of the variation in recovery rates. Lastly, elderly population was the only significant variable of COVID-19 death rates (R^2= 0.639) (see Table 6 and Figures 16 to 18)

Table 5: Stepwise Regression Result (COVID-19 Counts)

COVID-19 Infection	Variable	R Square	F	Sig
	Access to WASH Facilities	0.969	97.798	0.000
	Gross National Income Per Capital ($)			
	Population (m)			
	Air Traffic			
COVID-19 Recovery	**Variable**	**R Square**	**F**	**Sig**
	Access to WASH Facilities	0.968	90.827	0.000
	Gross National Income Per Capital ($)			
	Population (m)			
	Air Traffic			
COVID-19 Death	**Variable**	**R Square**	**F**	**Sig**
	Population	0.692	24.683	0.000

Table 6 Stepwise Regression Result (COVID-19 Rates)

COVID-19 Infection Rate	Variable	Coefficient	R Square	Adjusted R Square	F	Sig
	Human Poverty Index	0.692	0.479	0.439	11.975	0.004
COVID-19 Recovery Rate	**Variable**	**Coefficient**	**R Square**	**Adjusted R Square**	**F**	**Sig**
	Human Development Index (HDI)	0.635	0.634	0.606	22.554	0.011
COVID-19 Death Rate	**Variable**	**Coefficient**	**R Square**	**Adjusted R Square**	**F**	**Sig**
	Percentage of Population (Ages 65+)	0.796	0.634	0.606	22.554	0.000

Source: Author's Computation

Note: Figures 7-10 illustrate the strong positive associations between infection counts and key infrastructure/socio-economic variables (WASH, GNI, Population, Air Traffic), which together explained 97% of the variance (Table 5).

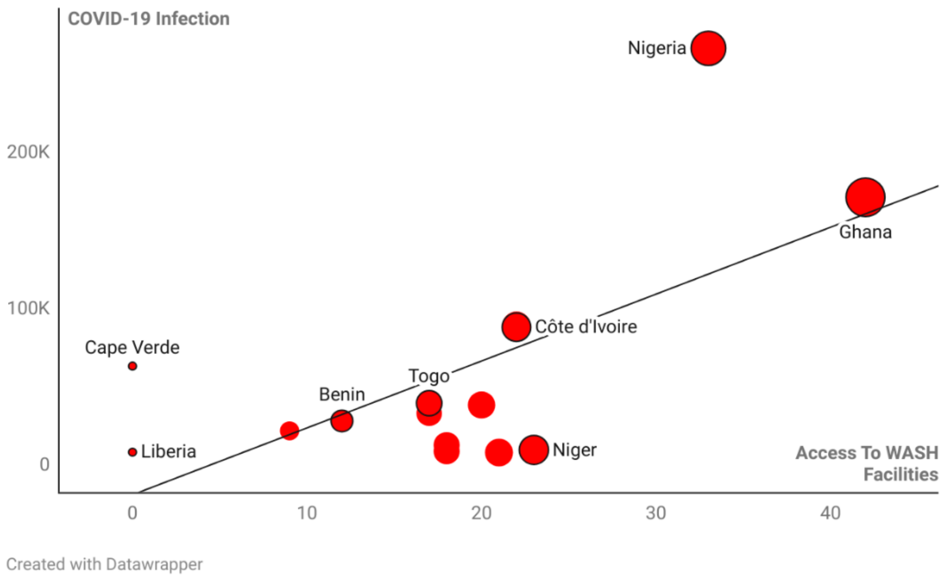

Fig. 7: Relationship between COVID-19 Infection and Access to WASH Facilities

The strong positive correlation shows that higher reported infections are associated with greater WASH access, likely reflecting better healthcare infrastructure and case detection rather than a causal risk factor.

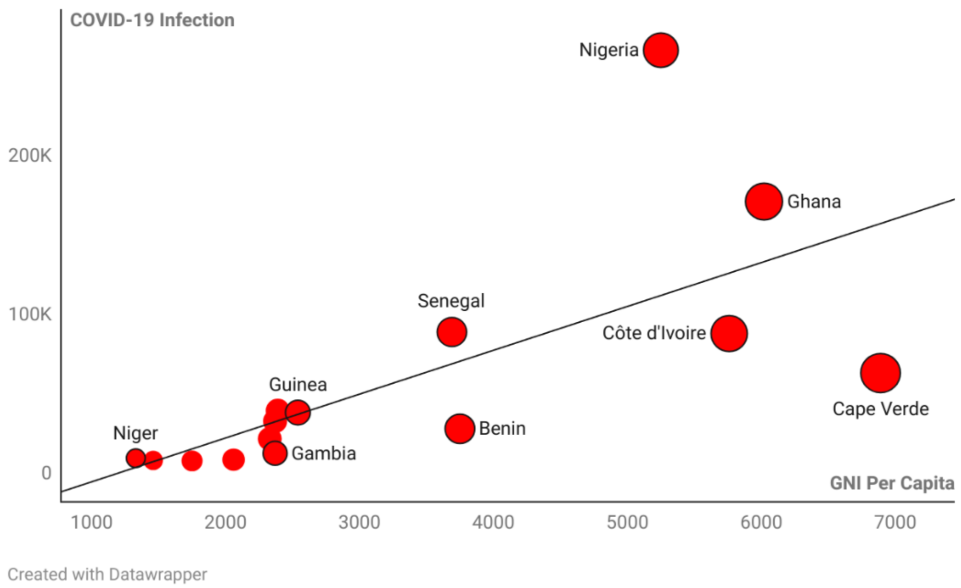

Fig. 8: Relationship between COVID-19 Infection and GNI Per Capita

The positive relationship with GNI per capita shows that economic capacity, linked to testing and reporting, is a stronger predictor of reported infection counts than direct transmission risk.

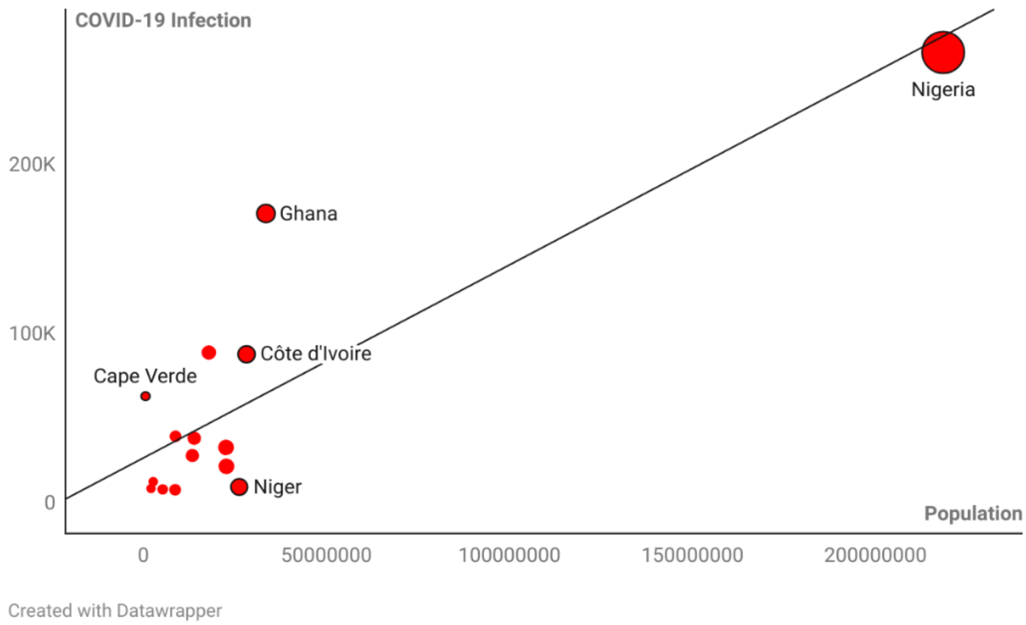

Fig. 9: Relationship between COVID-19 Infection and Population Size

Population size comes up as the most fundamental demographic driver, directly scaling the absolute number of infections across West African nations.

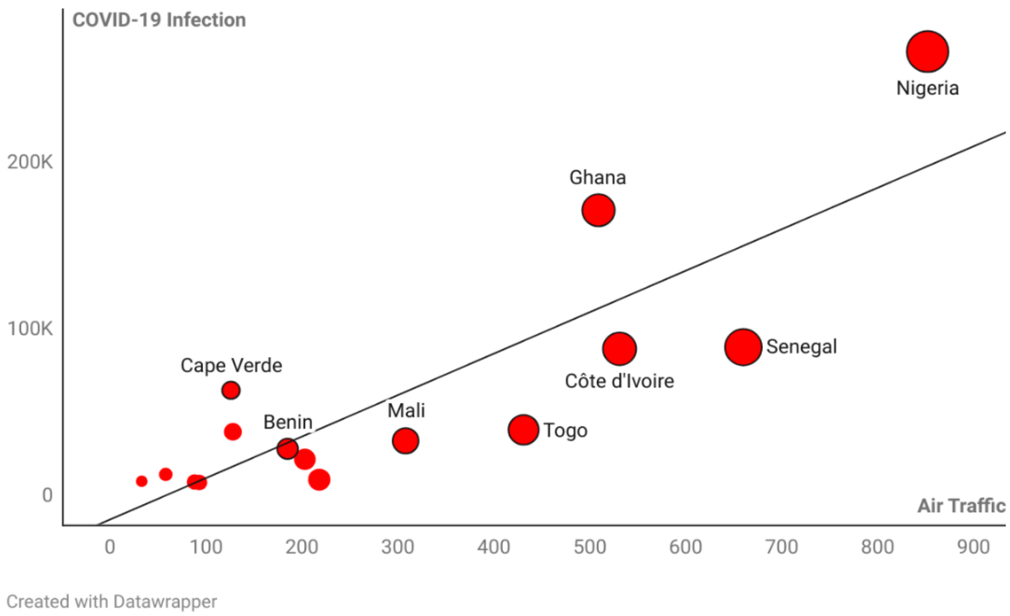

Fig.10: Relationship between COVID-19 Infection and Air Traffic

Air traffic volume confirms international connectivity as a critical vector for the importation and sustained transmission of the virus.

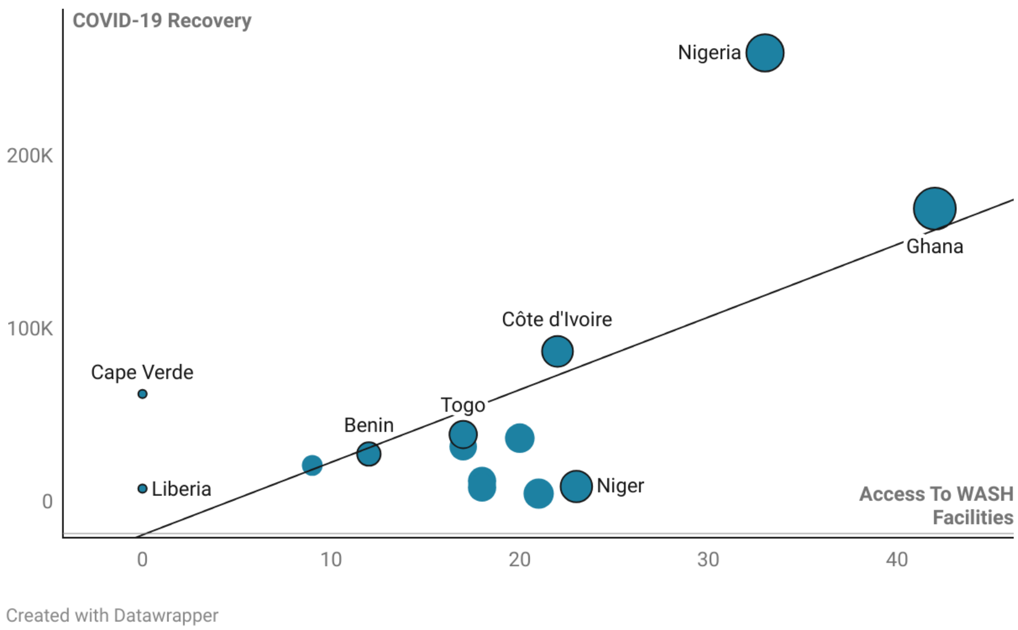

Fig 11: Relationship between COVID-19 Recovery and Access to WASH Facilities

The relationship here is near-identical with WASH facilities for recoveries, and it mirrors that of infections, reinforcing the role of reporting and healthcare system capacity.

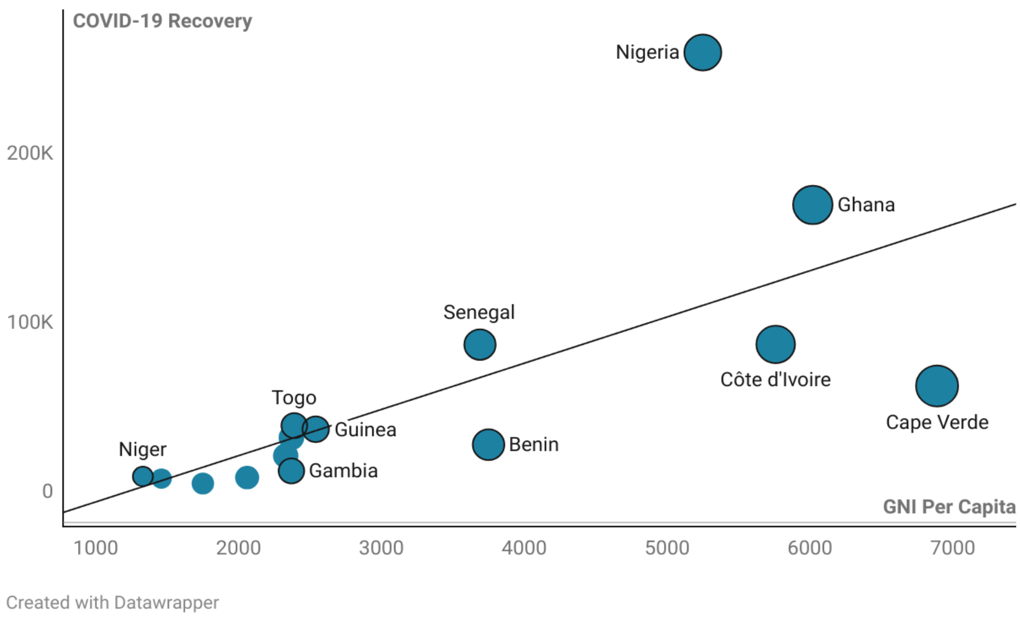

Fig 12: Relationship between COVID-19 Recovery and GNI Per Capita

The parallel trend for GNI and recoveries suggests that economic resources facilitated both case identification and subsequent recovery tracking.

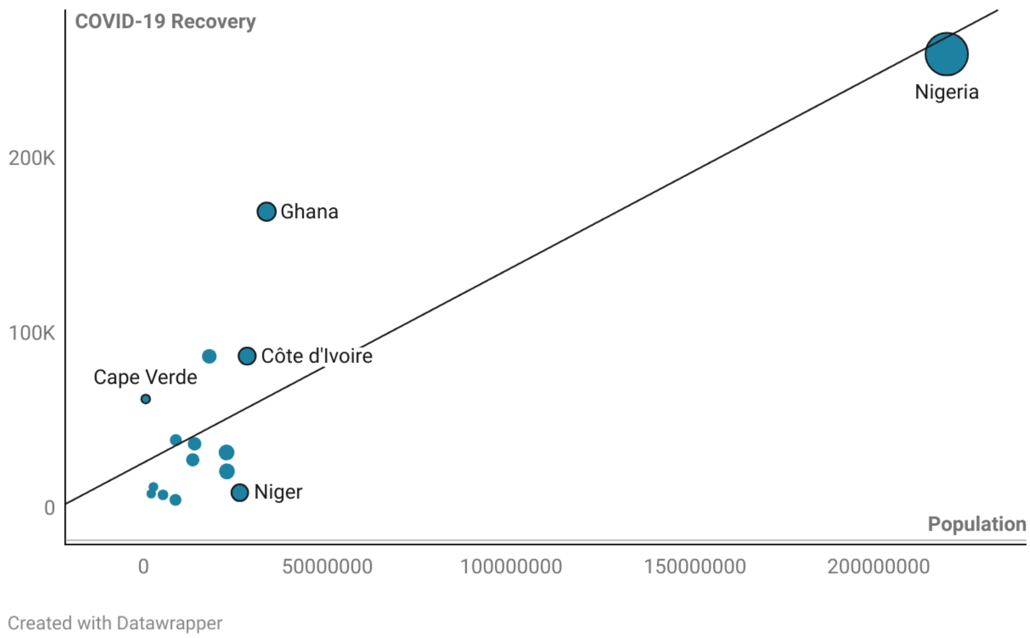

Fig 13: Relationship between COVID-19 Recovery and Population Size

The direct scaling of recoveries with population size indicates that recovery numbers were largely proportional to the initial infection burden.

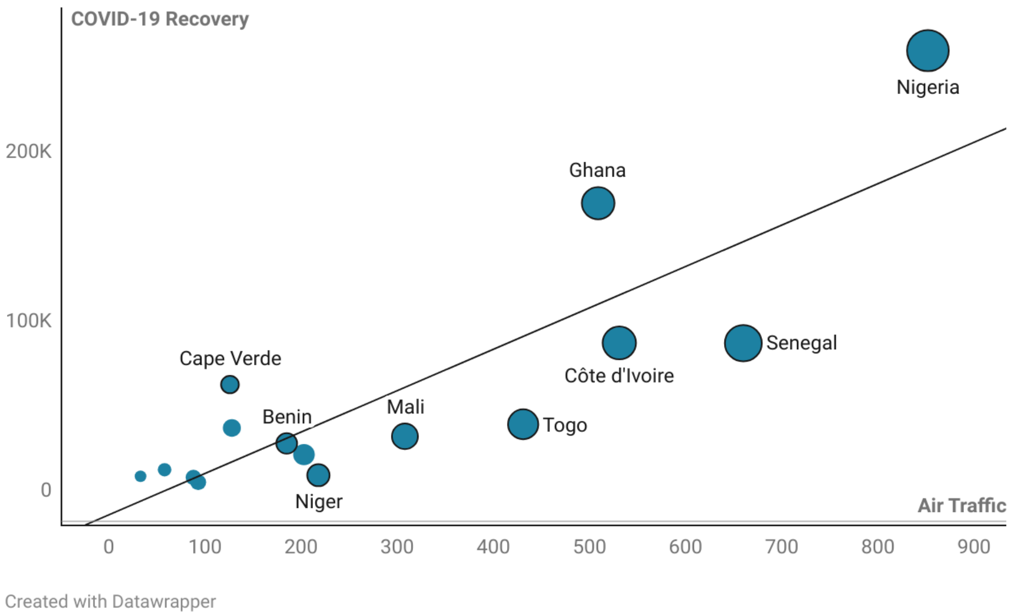

Fig 14: Relationship between COVID-19 Recovery and Air Traffic

The link between air traffic and recoveries reiterates that initial exposure driven by connectivity subsequently influenced recovery totals.

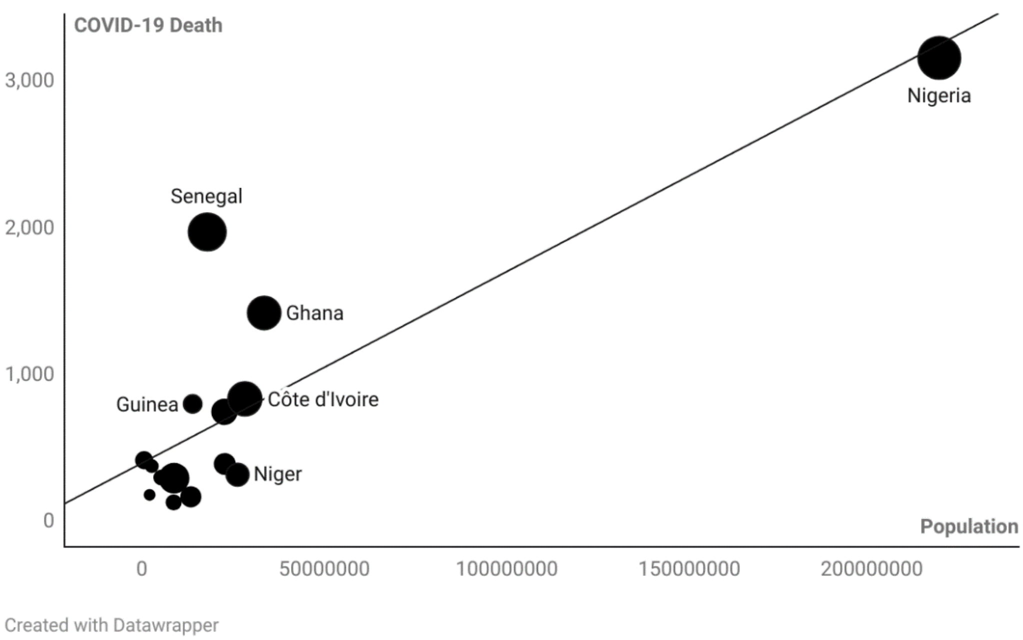

Fig 15: Relationship between COVID-19 Death and Population Size

Population size alone explains a majority of the variance in death counts, demonstrating the demographic basis of absolute mortality.

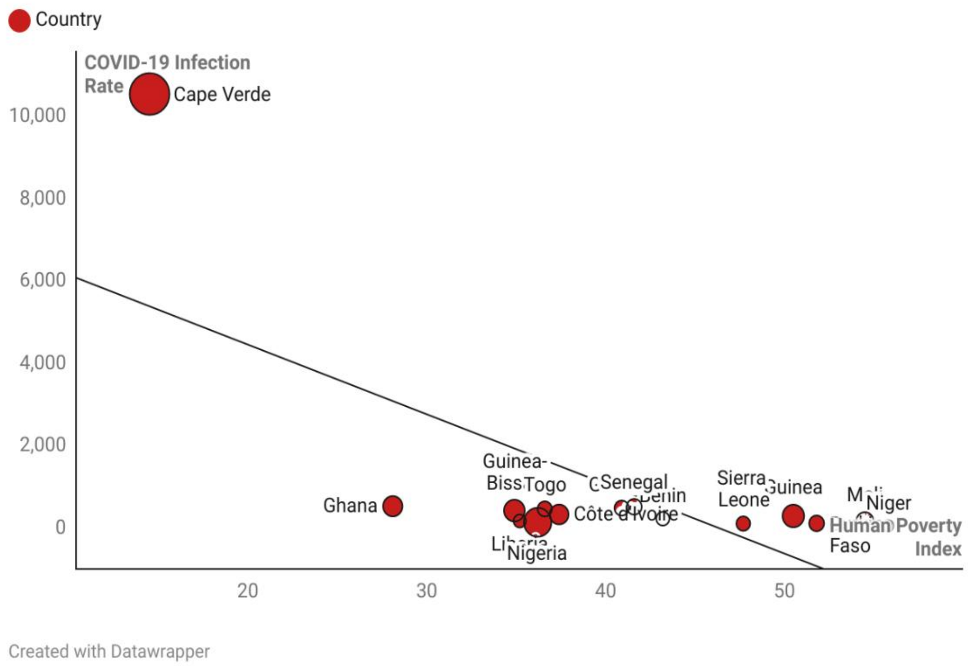

Fig 16: Relationship between COVID-19 Infection Rate and Human Poverty Index

The negative correlation between the Human Poverty Index and infection rate suggests that socioeconomic deprivation is associated with significant under-detection and under-reporting of cases.

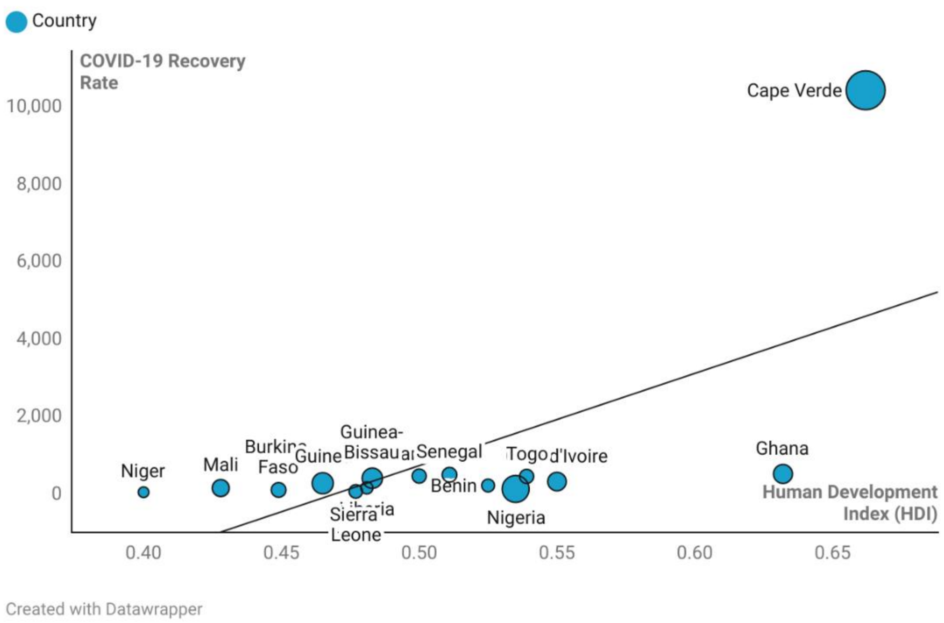

Fig 17: Relationship between COVID-19 Recovery Rate and Human Development Index

The positive association of recovery rate with the HDI indicates that broader developmental advantages likely supported better healthcare outcomes and documentation.

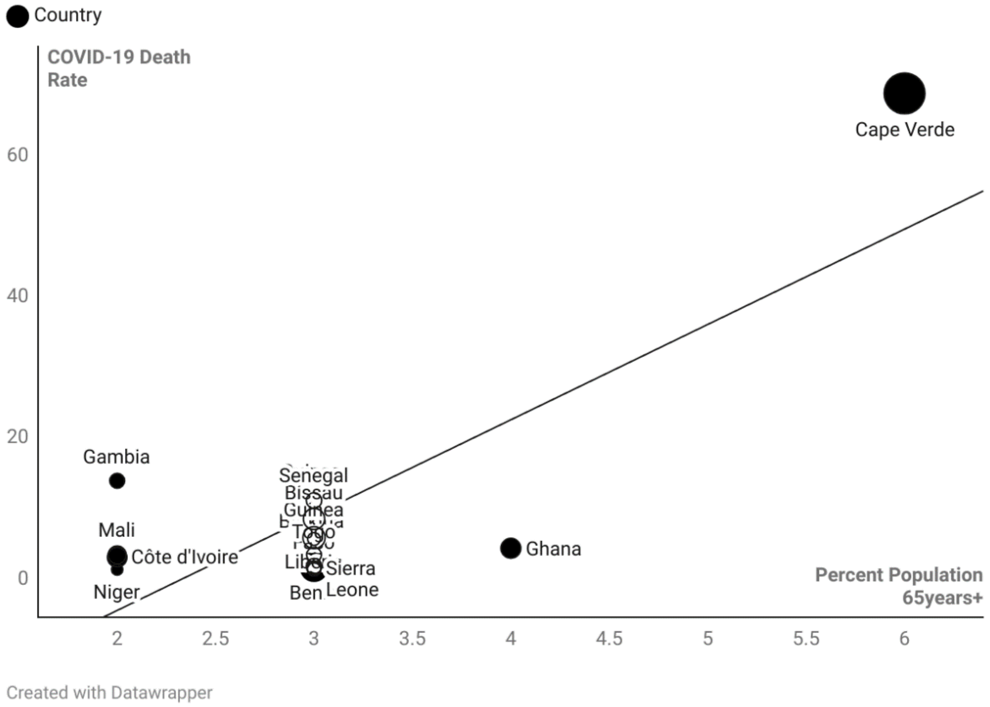

Fig 18: Relationship between COVID-19 Death Rate and Percent Population 65 years+

The strong positive relationship between the elderly population proportion and death rate provides clear evidence of the heightened mortality risk associated with older age.

4.0 Discussion

The paper examined the recent spatial patterns of COVID-19 in West Africa against the backdrop of COVID-19 vaccinations. The cartographical representations of the COVID-19 counts and rates in West Africa, as predicted, displayed unique spatial patterns of the pandemic. Moreover, they revealed that Nigeria and Cape Verde had the highest COVID-19 incidence, recovery, and deaths of COVID-19 in West Africa. It is a well-known fact that Nigeria is the most populous country in Africa, with over 200 million people [58]. A precondition for the widespread spatial diffusion of infectious disease is the presence of a large susceptible population. As previously mentioned, countries with large populations tend to record correspondingly high morbidity and mortality levels for this simple reason. Moreover, the virus's transmission is a function of the geographical proximity of the infected to susceptibles. This clearly explains why Nigeria was the epicenter of the COVID-19 pandemic in West Africa. This somewhat validates the World Health Organisation's apprehension about Nigeria being a COVID-19 transmission hotspot. Besides the population factor, the country generates and receives the largest air traffic volume in the region [13]. These observations are confirmed by [13-14, 18, 22, 59].

Cape Verde, on the other hand, presents a unique case. Though it was the fifth most affected country in the subregion (63,078), the island country ironically had the highest COVID-19 incidence, recovery, and death rates. These can be attributed to a number of factors. First is its relatively small population of over 600,000 people. Second, the archipelago nation occupies a vantage position as a strategic air and water gateway [60], making it a popular tourist destination and "a vibrant hub of cultural exchange and interaction" [61] (p.1). Third, though it is West Africa's smallest country in terms of land mass and population, its national economy is heavily dependent on tourism. In fact, the index case was a foreign tourist. The next 47 COVID-19 reported cases were hotel employees who played host to the imported case [60]. Subsequently, in 2022, there was a spike in the number of cases due to the easing of tight restrictions earlier implemented by the government and the emergence of fast-evolving virus strains [61].

The positive relationship COVID-19 infection has with access to WASH is counterintuitive. One would have expected a negative association between these two, suggesting that increased access to WASH facilities would lower the number of infections. Countries with access to soap and safe water, and that strictly enforce hand hygiene measures, would record lower prevalence of COVID-19. Ironically, this is not so. A plausible explanation for the odd observation could be that the availability or mere access to WASH facilities does not fully guarantee their use. Households may have access but not practice hand hygiene and proper sanitation. This counterintuitive relationship was earlier reported in [62]. It is rather an awkward observation, especially when the World Health Organisation strongly prescribed hand hygiene and improved access to WASH facilities as a major non-pharmaceutical intervention against COVID-19 [1].

Like access to WASH, the positive effect of the Human Development Index, Gross National Income per capita on COVID-19 infection is equally counterintuitive. It is contrary to the expectation that comparatively strong economies would have the adaptive capacity to withstand or respond effectively to the health emergency. It was surprising to see that more infections were recorded in more economically developed countries and fewer cases in low-income countries. The assumption was that low-income households with limited or no access to basic needs and social amenities would be more vulnerable to infectious diseases such as COVID-19. This result brings to mindre-echoes a similar observation by [62]. In their analysis of the African COVID-19 paradox, they saw that poorer countries seemed to have had lower COVID-19 mortality rates, but poverty was not responsible for what Oppong (2020) described as the "African COVID-19 Anomaly". In the end, they concluded there were more complex forces at play and could not simply be restricted to poverty. However, one potential explanation for the positive association is that these economically developed countries have the testing capacity to diagnose COVID-19 and the treatment facilities for emergency and intensive care, which might explain why the richer countries have relatively high counts of COVID-19.

As earlier expressed, the population has a positive relationship with COVID-19 infections, recoveries, and deaths. COVID-19 prevalence would be exceedingly high in countries with a very large population size than in those with smaller sizes. This agrees with [14], where it was reported that population, air traffic, and gross domestic product were significant factors of the pandemic

The role of air traffic underscores the point that human mobility is fundamental to the exposure to and subsequent transmission of infectious disease [63]. One would vividly recall that many of the index cases in African countries were imported via air travel. For instance, the first case in Nigeria was an Italian national who was on a business trip in Nigeria. The role of air transport in the transmission of COVID-19 is confirmed by [13-14, 16, and 59].

The positive relationship between COVID-19 deaths and the elderly population is not far-fetched. COVID-19 mortality is higher among the elderly than the younger age groups. The elderly generally experience a decline in physical health as they advance in age. As a result, they are more vulnerable to COVID-19 infections, hospitalizations, and deaths. This clinical evidence has informed and shaped the way in which caregiving for the elderly is being provided [64]. This finding is supported by [7, 9 & 65].

Lastly, the study noted a weak relationship between COVID-19 and vaccination, which suggests a little but insignificant impact on the progression of the pandemic. A possible reason for this observation could be the simple fact that the pandemic had well advanced not only in the region but also around the world long before a vaccine was finally found in December, 2020. Developed by Pfizer-BioNTech [66], the first batch of the AstraZeneca / Oxford vaccine on the continent arrived Accra, Ghana on the 24th February, 2021 with 600,000 doses [67]. Given the circumstances of time, the distribution of the vaccines therefore had no far-reaching effect on the pandemic in West Africa. Despite global efforts, COVID-19 vaccine coverage in Africa lagged markedly behind other continents, with West Africa facing well-documented challenges in rollout logistics, vaccine hesitancy, and equity of access [49]. Of course, this does not in any way imply that the COVID-19 vaccines as a pharmaceutical intervention, did not confer chemical immunity.

5. Limitations

This study is ecological and cross-sectional in nature. While regression identifies associations, it cannot establish causality, and more dynamic, individual-level longitudinal data would be needed for deeper causal inference. We therefore recommend that future studies explore this route.

6. Conclusion

The paper analysed the post-vaccine spatial patterns of COVID_19 infections, recoveries, and deaths in West Africa, as well as identified the major drivers of the pandemic. In addition, it was an opportunity to determine the possible effect of COVID-19 vaccination on the geography of the pandemic in the subcontinent. The distinct geographies based on counts and rates revealed remarkable disparities in infections, recoveries, and deaths, highlighting Nigeria and Cape Verde as the COVID-19 epicentres in the subregion. Nigeria, influenced by its reputedly large population and heavy international air traffic volume, and Cape Verde, with its small population and tourism-dependent economy, resulted in their positions as outliers in West Africa. The striking regional variations in COVID-19 were driven, in broad terms, by population size, access to WASH, air transportation, and some socioeconomic conditions. Lastly, the COVID-19 vaccine distribution did not significantly alter the geography of COVID-19 in West Africa. It therefore played little or no significance at the time.

This study's findings have implications for understanding the complexities of pandemics and guiding public health policy, enhancing pandemic preparedness, and increasing global health security. It is recommended that, as access to safe water, proper sanitation, and hygiene infrastructure is being strengthened, national awareness campaigns need to clearly emphasise their everyday use not only as a response to public health emergencies but also as a routine health promotion exercise. Secondly, though the pandemic is over, national governments still need to scale up vaccination coverage among their citizens so as to prevent a COVID-19 re-emergence in the future. Lastly, airport authorities need to be further strengthened with the infrastructure to adequately screen air passengers and minimise the risk of disease transmission.

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