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MODELING PATTERNS OF CHOLERA PREVALENCE IN AFRICA: TIME SERIES APPROACH

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Abstract

An adage says, “Health is wealth." Vibrio-cholera continues to pose a global threat to public health and serves as a key indicator of a lack of social development. Today, cholera primarily affects developing countries worldwide, especially in Africa, where it is endemic. Natural disasters like earthquakes, tsunamis, volcanic eruptions, landslides, and floods can contribute to the spread of the outbreak by disrupting the normal way of life. This creates many health problems; foods and water supplies can become contaminated by vectors, causing cholera disease. Developing countries such as Nigeria suffer disproportionately due to differences in their disaster preparedness systems. The aim of this research is to examine the trends in the prevalence of cholera cases in Africa, with the goal of identifying the patterns of these cases between 2018 and 2023. The research employed secondary data, utilizing data from the World Health Organization on the prevalence of cholera cases in five different regions of the world. *The regions are: Africa, Asia, Europe, America, and Oceania. We collected data for six years, ran the analysis using the R package, and employed descriptive and inferential statistical methods such as time-series analysis, ANOVA, augmented Dikey-Fuller test, univariate time-series model, and least squares methods, among others. The analysis revealed that Africa had the highest number of cholera cases between 2018 and 2019, while Asia had the highest prevalence between 2020 and 2023. According to the World Health Organization, the data showed non-stationarity with the chart of the normal distribution over the five regions between 2018 and 2023, which skewed to the right with a value of 3.059. We tested the hypothesis and established a significant difference in the mean cholera prevalence across the five regions at the 5% level of significance. Additionally, this led us to conduct a second differencing Augmented Dickey Fuller unit root test before the data became stationary for forecasting, resulting in a trend estimation of Tt = 61273.03 + 13710.73t using the least squares methods. This suggests that if the government and health providers do not adopt swift, drastic measures, we should expect an increase in cholera prevalence of 13710.03 in the upcoming years across all regions*.

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1.0 INTRODUCTION

Vibrio cholera continues to pose a global threat to public health and serves as a key indicator of social development problems. The infection, once widespread globally, now primarily affects developing countries in the tropics and subtropics. It is endemic in Africa, parts of Asia, the Middle East, and South and Central America. In endemic areas, outbreaks usually occur when war or civil unrest disrupts public sanitation services. Natural disasters like earthquakes, tsunamis, volcanic eruptions, landslides, and floods also contribute to outbreaks by disrupting the normal balance of nature. This createsThis leads to numerous health issues, as the destruction of essential water and sewage systems can lead to the contamination of food and water supplies by parasites and bacteria. The inadequacy of resources, infrastructure, and disaster preparation systems disproportionately affects developing countries. ected areas, outbreaks may occur during any season and affect all ages equally. The organism typically lives in aquatic environments along the coast. People acquire the infection by consuming contaminated water, seafood, or other foods. Once infected, they excrete the bacteria in the stool. Thus, the infection can spread rapidly, particularly in areas where human waste is untreated.

In Nigeria, the infection is endemic, and outbreaks are not unusual. Experts speculated that cholera claimed the lives of over 260 people in four northern states in the last quarter of 2023, with Maidugari, Biu, Gwoza, Dikwa, and Jere council areas of Bauchi state accounting for over 96 of these deaths. Most of the northern states of Nigeria rely on hand-dug wells and contaminated ponds as sources of drinking water. The 2010 outbreak of cholera and gastroenteritis, as well as the attendant deaths in some regions of Nigeria, highlighted the vulnerability of poor communities, particularly children, to the infection. Rain caused the outbreak by washing sewage into open wells and ponds, where people obtain water for drinking and household needs. The regions ravaged by the scourge include Jigawa, Bauchi, Gombe, Yobe, Borno, Adamawa, Taraba, FCT, Cross River, Kaduna, Osun, and Rivers, which depict major outbreak locations. Despite the recorded epidemic in these areas, epidemiological evidence suggested that hypervirulent strains of the organism were responsible for the outbreak, putting the entire country at risk. Between 1970 and 1990, Nigeria reported its first series of cholera outbreaks. Despite my extensive experience with cholera, my understanding of the disease's epidemiology and persistence in outbreak situations is still lacking.

Therefore, this research aims to provide a comprehensive statistical analysis of cholera cases in Africa, as reported by the World Health Organisation. The objective is to identify the trends in cholera prevalence from 2015 to 2020, determine whether there has been a significant mean difference in cholera patient cases over time, and develop a forecast based on these findings.

2.0 LITERATURE REVIEW

Since 1817, the world has faced seven cholera pandemics. During the current seventh pandemic, Africa bore the brunt of the global disease burden. Within barely half a century, cholera has changed from an imported to an endemic disease in most African countries. In 1836, outbreaks on the Indian Ocean coast led to the first reports of cholera in Africa, killing up to 20,000 people in Zanzibar and nearly depopulating the towns of Lamu, Malindi, and Kilwa. The next reports came from Egypt in 1848 with 30,000 deaths [Eichenberg (2011)], from West Africa in 1868 (Macnamara 1876), and from the Senegambia region in 1893–1894. The British Colonial government in East Africa declared cholera a notifiable disease.

Given that populations who had never experienced Vibrio cholera before had low immunity and health systems ill-equipped to effectively treat the disease, the seventh pandemic's impact was particularly devastating (Gangarosa 1971). Between 1970 and 2011, African countries reported 3,221,050 suspected cholera cases to the World Health Organisation, representing 46% of all cases reported globally (WHO, Global Health Observatory 2012). The number of African countries with indigenous cholera cases reported to the WHO rose from 24 in 1971 to 30 in 1998, reaching a record of 36 in 2008. In 2011, the number fell to 27. Excluding the Haitian epidemic, Africa accounted for 86% of reported cases and 99% of deaths worldwide in 2011 (WHO, Global Health Observatory).

Africa may have far more cholera cases than the WHO reports. Underreporting and inadequate systems are among the reasons. One source on country-specific incidence rates for Africa says there are 1,341,080 cases and 160,930 deaths each year, which is 52.6% of the estimated 2,548,227 cases and 79.6% of the estimated 209,216 deaths worldwide (Sack, 2013). Another source says there are 1,411,453 cases and 53,632 deaths each year, which is 50% of the estimated 2,836,669 cases and 58.6% of the estimated 91,490 deaths worldwide.

The World Health Organisation recommends the use of vaccines in combination with health services that provide rapid detection and treatment of cholera cases with appropriate agents while making provisions for accessibility to safe water, good sanitation, promotion of personal hygiene, improvement in health education, and community mobilisation [Vicari *et al.*, 2013; WHO, 2012]. While this is ongoing, some reports have taken the time to analyze the impact of myths and perceptions on the acceptability of cholera vaccines. The willingness to participate is high in populations that have received awareness about cholera have a high willingness to participate.

3.0 METHODOLOGY

3.1 Study Area

The study covered the five regions of the world using the obtained information from the World Health Organization on cholera cases; the regions are: Africa, Asia, Europe, Americas and Oceania.

3.2 Data and Study Population

Secondary data were obtained to assess the cholera cases in five regions of the world. Hence, the entire population of the research was based on the Africa, Asia, Europe, Americas and Oceania regions between 2018 to 2023.

3.3 Hypothesis of the Research

H_0: There is no significant mean difference in cases of Cholera Patients from the year 2015 – 2020.

H_1: There is significant mean difference in cases of Cholera Patients from the year 2015 – 2020.

3.4 Analysis of Variance (ANOVA)

ANOVA or analysis of variance is used to evaluate the difference in average scores measured on a continuous scale among one or more characteristics defined by categories. In this research, five regions (Africa, Asia, Europe, Americas, Oceania) are considered over the years 2018 to 2023 in order to analyze the differences in the region means among the regions.

Randomized Complete Block Design (RCBD)

Randomized complete block designs differ from the completely randomized designs in that the experimental units are grouped into blocks according to known or suspected variation which is isolated by the blocks. Therefore, within each block, the conditions are as homogeneous as possible, but between blocks, large differences may exist.

Model for Randomized Complete Block Design (RCBD)

$$Y_{ij} = \mu + \tau_i + \beta_j + \varepsilon_{ij} \qquad (1)$$

Yij- Observation taken under the ith treatment (regions) and jth block (years)
μ- the overall mean

i - is the regions factor

j - is the blocking (years) factor

τ_i - the effect for being in treatment *i*

β_j - is the effect for being in block *j*

ε_{ij}= Random error terms NID (0, σ^2).

3.5 Concept of Time Series

A time series is a collection of observation made sequentially at equal interval of time, this is denoted by X_t; where X_t is the cholera rate at time (t) measured in years. The fundamental important of time series is that the observation on time and the successive observations are dependent on one another. Time Series Analysis (TSA) involves the degree and pattern of dependent observation X_t. This assumption can be conventionally express as a linear model.

$$X_t = \psi_1 X_{t-1} + \psi_2 X_{t-2} + \mathrm{L} + \psi_q X_{t-q} + \omega_t \qquad (2)$$

Where $\psi_1, \psi_2, ..., \psi_q$ are unknown fixed regression coefficient, and (ω_t) is a random error or noise process consisting of independent and identically distributed normal variables with mean zero and variance σ_ω^2.

Time Plot

This is the graph of time series observation against time. Time plot helps in understanding the past behaviors of a variable and also helps to determine the rate of growth extent and direction of periodic fluctuation. Time series analysis has four major components; The Trend(T_t), The Seasonal Variation(S_t), The Cyclical Variation(C_t) and The Irregular Variation(I_t).

Unit Root Tests (Testing for Series Stationarity)

For a univariate time series, the unit root test is frequently employed for testing stationarity. The first test poses the null hypothesis that the given time series has a unit root, which means that the time series is non-stationary, and tests if the null hypothesis is to be statistically rejected in favour of the alternative hypothesis that given time series is stationary. To detect whether a given series is non-stationary, let us assume that the relationship between current (in time t) and last value (in time t-1) in the time series is as follows (Enders, 1995):

$$X_t = \phi X_{t-1} + \varepsilon_t \quad (3)$$

Where X_t is an observation value at time t, ε_t is white noise process. This model is a first order autoregressive process. The time series X_t converges, as $t \to \infty$, to a stationary time series if $|\phi| < 1$. If $|\phi| = 1$ or > 1, the series X_t is not stationary and the variance of X_t is time independent. In to their words, the series has a unit root. The unit root test subsequently tests the following one-sided hypothesis

H_0: $\phi = 1$ (has a unit root) vs H_1: $\phi < 1$ (has root outside the unit circle).

A well-known test that is valid in large samples is the Augmented Dickey-Fuller test. The optimal finite sample tests for a unit root in autoregressive models were developed by John Denis Sargan and Alok Bhargava. Other tests are the Phillips-Perron (PP) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests. These tests use the existence of a unit root as the null hypothesis.

Augmented Dickey-Fuller Test

An Augmented Dickey-Fuller test (ADF) is a test for a unit root in a time series sample. It is an augmented version of the Dickey-Fuller test for larger and more complicated set of time series models. The Augmented Dickey-Fuller (ADF) statistic, used in the test, is a negative number. The more negative it is, the stronger the rejection of the hypothesis that there is a unit roots at some level of confidence.

Testing procedure:

The testing procedure for the ADF test is the same as for the [Dickey –fuller test]

$$\Delta y_t = \alpha + \beta t + \gamma y_{t-1} + \ldots + \delta p\text{-}1 \Delta y_{t-p+1} + \varepsilon_t \quad (4)$$

Where α is a constant, β is the coefficient on a time trend and p is the lag order of the autoregressive process.

By including lags of order p the ADF formulation allows for the higher-order autoregressive process. This means that the lag length p has to be determined when applying the test. One possible approach is to test down from higher orders and examine information criteria such as the (Akaike information criterion), (Bayesian information criterion), or the (Hannan-Quinn information criterion). The unit root test is then carried out under the null hypothesis $\gamma = 0$ against the alternative of $\gamma < 0$. Once a value for the test statistic

$$DF_T = \frac{\gamma}{SE(\gamma)} \quad (5)$$

Is computed it can be compared to the relevant critical value for the Dickey- Fuller test. If the test statistic is less (this test is non-symmetrical so we do not consider an absolute value) than (a larger value negative) the critical value, then the null hypothesis of $\gamma = 0$ is rejected and no unit root is present.

Autoregressive Process AR(p)

A stationary time series $\{X_t\}$ is said to be an autoregressive process of order p if it satisfies;

$$X_t = \phi_1 X_{t-1} + \phi_2 X_{t-2} + \text{L} + \phi_p X_{t-p} + \varepsilon_t \quad (6)$$

Where $\phi_1, \phi_2, \text{K}, \phi_p$ are autoregressive parameters and $\{\varepsilon_t\}$ is a white noise process with mean zero and constant variance σ^2. The above equation can be re-written as

$$(1 - \phi_1 B - \phi_2 B^2 - \text{L} - \phi_p B^p) X_t = \varepsilon_t \quad (7)$$

And this implies $\Phi(B) X_t = \varepsilon_t$

Where $\Phi(B)$ is a polynomial in B. For stationarity the roots of $\Phi(B)$ must lie outside the unit circle i.e. $|B| > 1$.

Moving Average Process MA(q) Process

A stochastic process $\{X_t\}$ is said to be a moving average process of order (q) if it satisfy the difference equation;

$$X_t = \varepsilon_t + \theta_1 \varepsilon_{t-1} + \theta_2 \varepsilon_{t-2} + \ldots + \theta_q \varepsilon_{t-q} \quad (8)$$

Which can also be written as; $X_t = (1 + \theta_1 B + \theta_2 B^2 + \ldots + \theta_q B^q) \varepsilon_t$

For MA(q) the invertibility condition holds.

Autoregressive Moving Average (ARMA) process

We can express AR(1) as an MA(∞) and MA(1) can be expressed as an AR(∞). Hence to have a minimum number of parameters, it is then logical to describe a system by as few parameters, it is then logical to describe a system by as few parameters as possible by expressing a time series model as a combination of AR and MA processes, called an autoregressive moving average process (ARMA) model.

Thus a stationary process $\{X_t\}$, satisfy an ARMA (p,q) process if

$$X_t - \phi_1 X_{t-1} - \ldots - \phi_p X_{t-p} = \varepsilon_t - \theta_1 \varepsilon_{t-1} - \ldots - \theta_q \varepsilon_{t-q} \quad (9)$$

Where, $\{\varepsilon_t\}$ is a white noise process with $\text{var}(\varepsilon_t) = \sigma^2$. Equation (3.24) can be expressed as;

$$\Phi(B) X_t = \Theta(B) \varepsilon_t \quad (10)$$

Where, $\Phi(B) = (1 - \phi_1 B - \phi_2 B^2 - \text{K} - \phi_p B^p)$.

For stationary, we require the root of the characteristic equation $\Phi(B)=0$ to lie outside the unit circle and the condition for invertibility is that the root of the characteristic equation $\Theta(B)=0$ lie outside the unit circle.

Akaike Information Criterion

The akaike information criterion (AIC) is defined to be:

$$AIC(k) = \log(\sigma^2(k)) + \frac{2}{T}k \quad (11)$$

$$AIC = \ln\left(\frac{\sum e_i^2}{n}\right) + \frac{2k}{n} \quad (12)$$

$$AIC = \ln\left(\frac{e^1 e}{n}\right) + \frac{2k}{n} \quad (13)$$

Where k is the total number of parameters estimated.

4.0 RESULTS AND DISCUSSIONS

4.1 Model Definition

This aspect defines the Cholera cases in terms of exploratory data analysis (Both Time plot and Descriptive statistics).

Time Plot of Cholera cases

This section gives the definition of the cholera cases in five regions (Africa, Asia, Europe, Americas, Oceania) in terms of exploratory data analysis of the data in terms of Graph. The data is observed over six years (2018 to 2023).

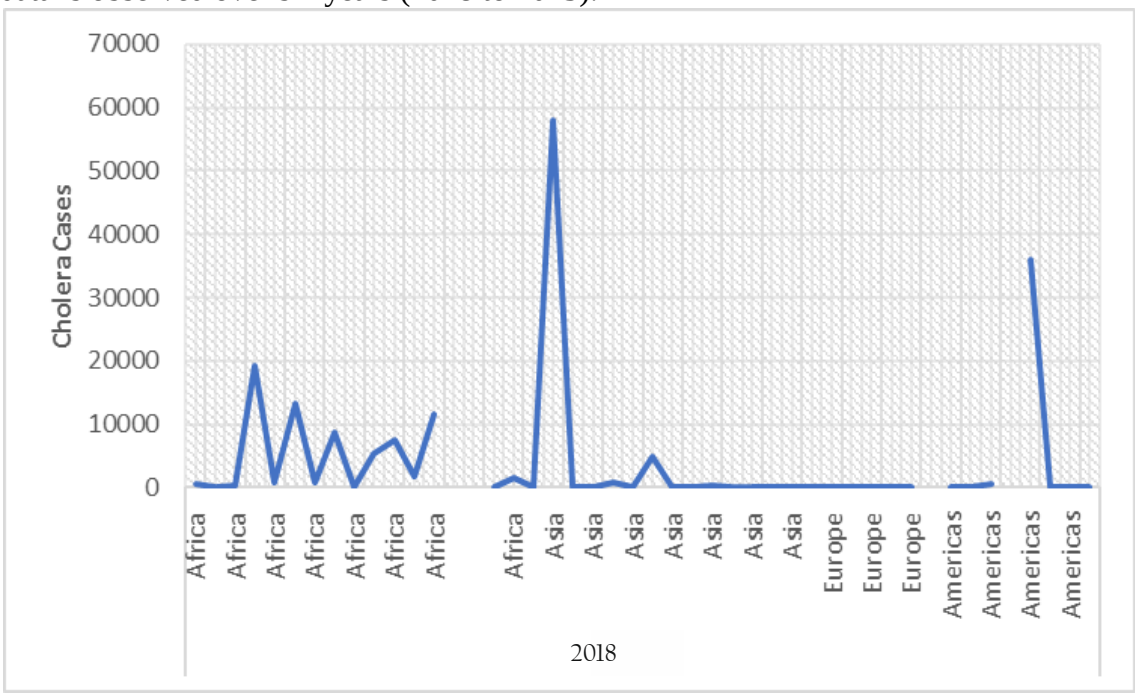

Figure 1: Time Plot of Cholera cases in 2018

The Figure 1 above depicted the cholera cases in the year 2018, it was observed that African region possessed the highest frequency among others.

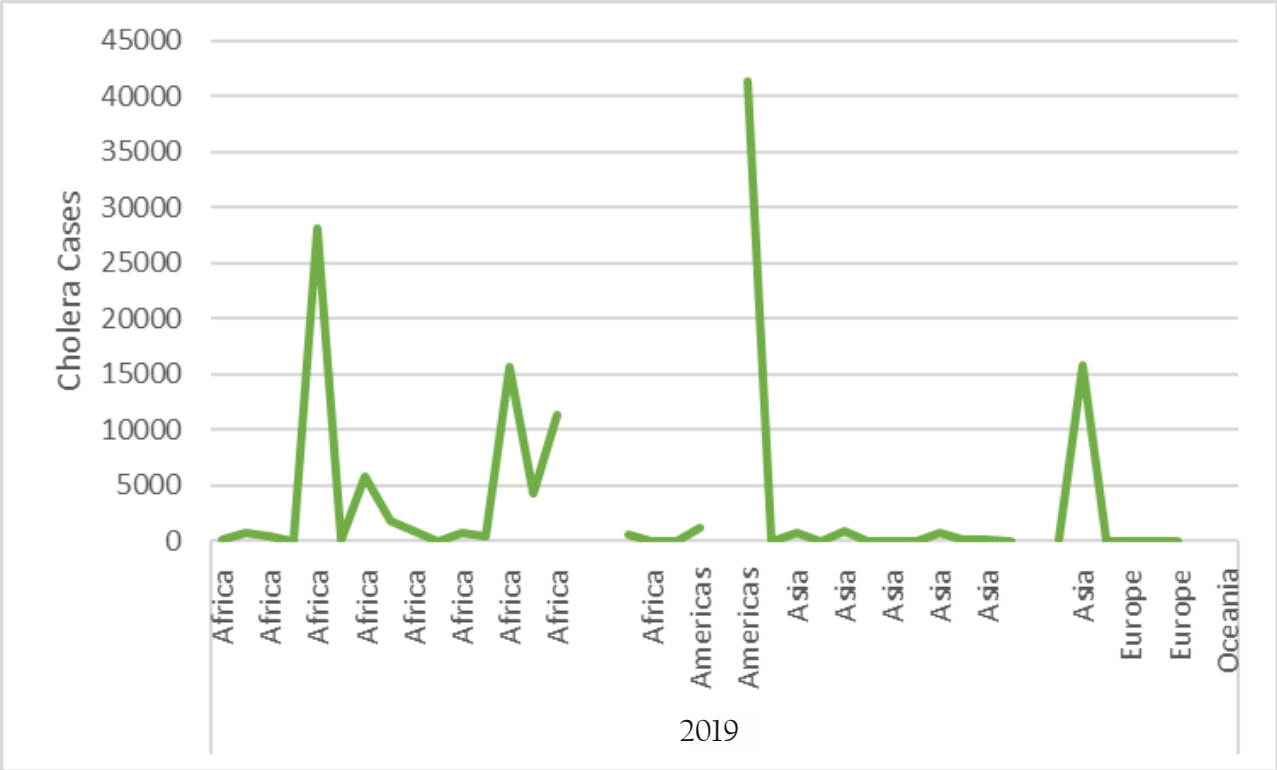

Figure 2: Time Plot of Cholera cases in 2019

The Figure 2 above indicated the cholera cases in the year 2019, it is shown that African region possessed the highest frequency among others.

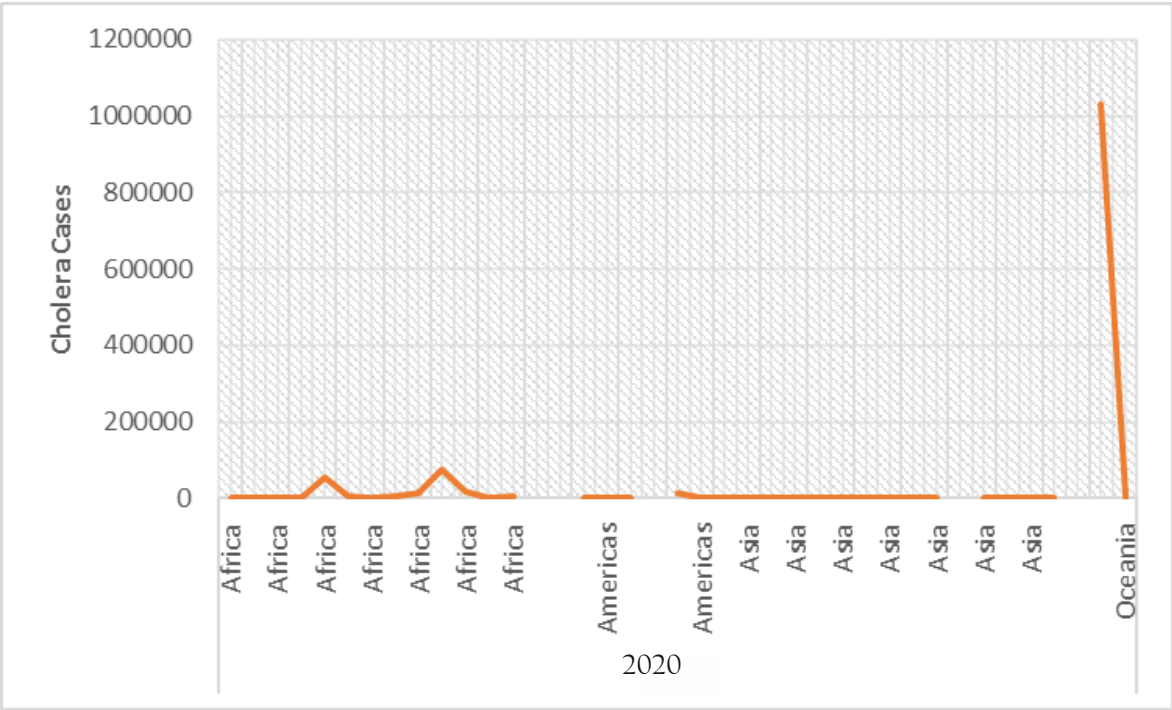

Figure 3: Time Plot of Cholera cases in 2020

The Figure 3 above showed the cholera cases in the year 2020, it is affirmed that Asian region possessed the highest frequency among others.

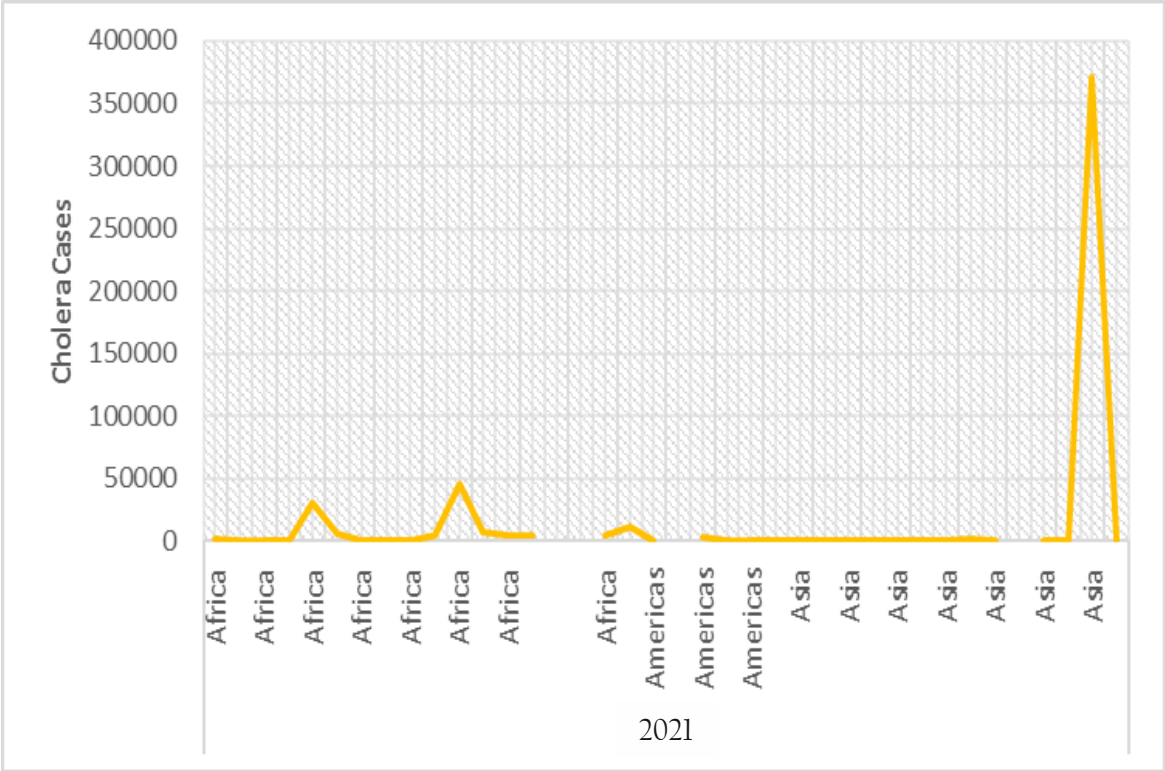

Figure 4: Time Plot of Cholera cases in 2021

The Figure 4 above established the cholera cases in the year 2021, it is shown that Asian region possessed the highest frequency among others.

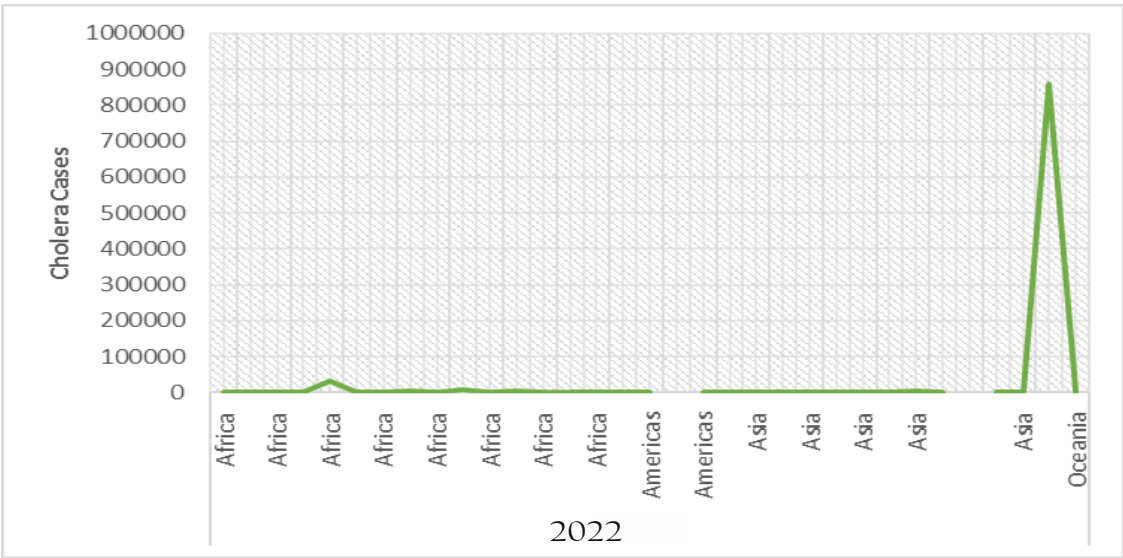

Figure 5: Time Plot of Cholera cases in 2022

The Figure 5 above confirmed the cholera cases in the year 2022, it is observed that Asian region possessed the highest frequency among others.

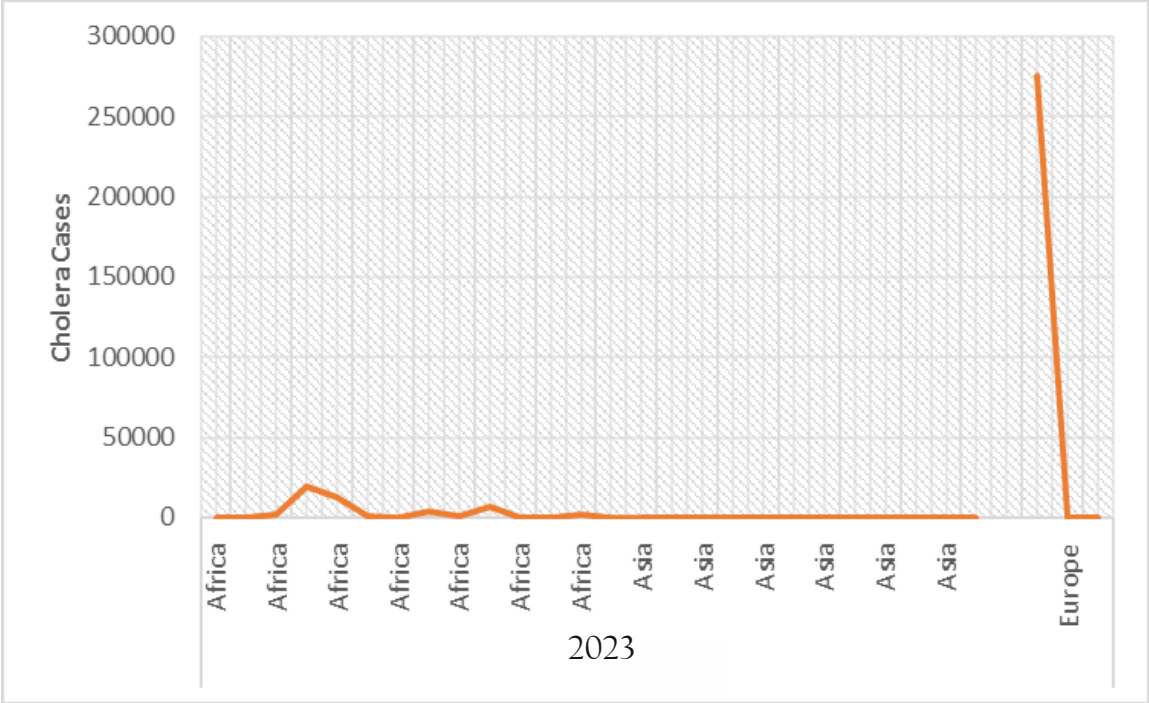

Figure 6: Time Plot of Cholera cases in 2023

It is established from the Figure 6 above that the cholera cases in the year 2023, it is observed that Asian region possessed the highest frequency among others.

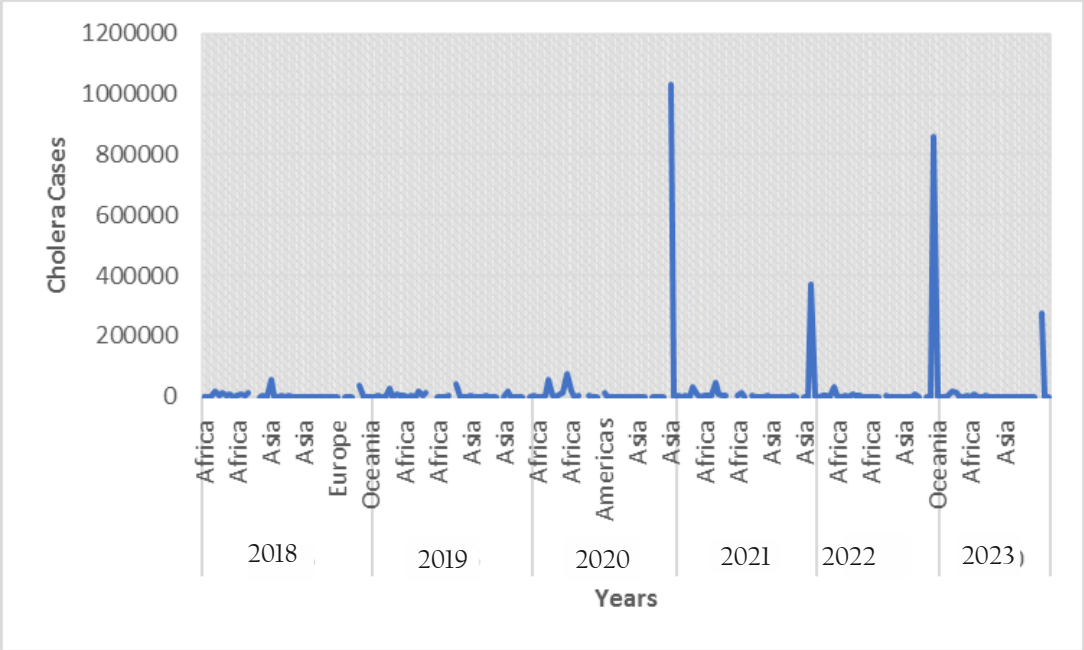

Figure 7: Time Plot of Regions' Cholera Cases

Figure 7 above indicated the summary of the cholera cases over the five regions (Africa, Asia, Europe, Americas, Oceania) of six years, whereby 2018 and 2019 affirmed the highest frequency of Africa region while 2023 to 2023 affirmed the highest frequency of Asia region.

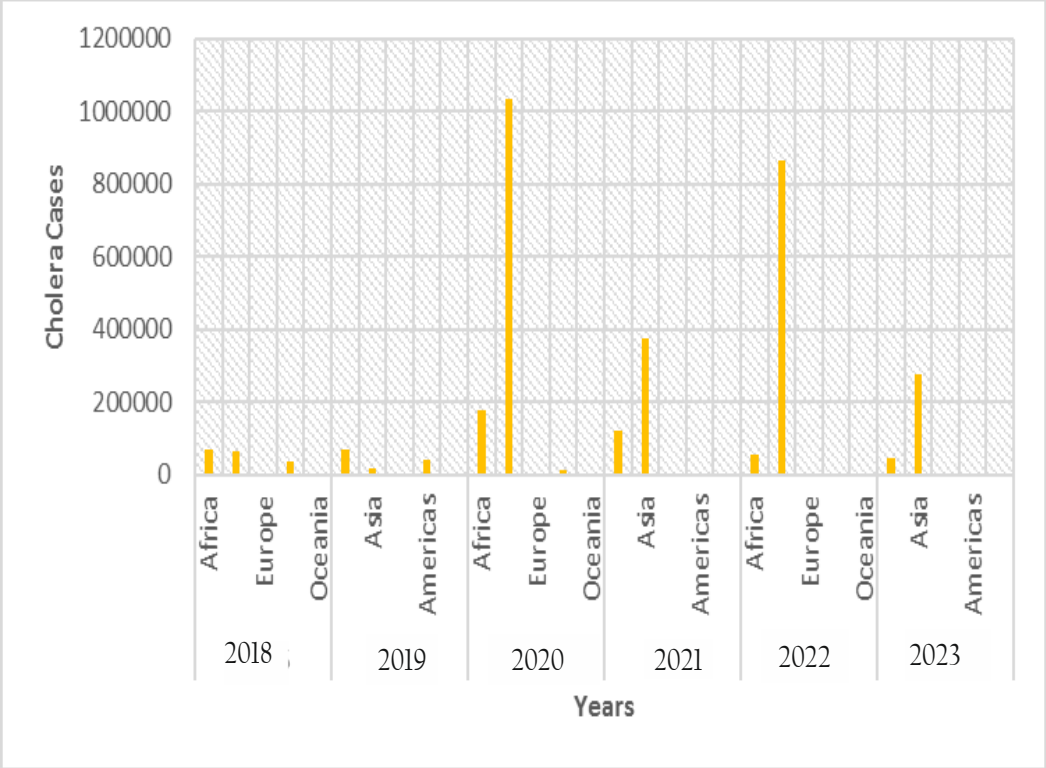

Figure 8: Bar Charts of Regions' Cholera Cases

It is shown from the Figures 8 and 9 above that African region established highest frequency with close to 100,000 cholera cases for the year 2018 and 2019.

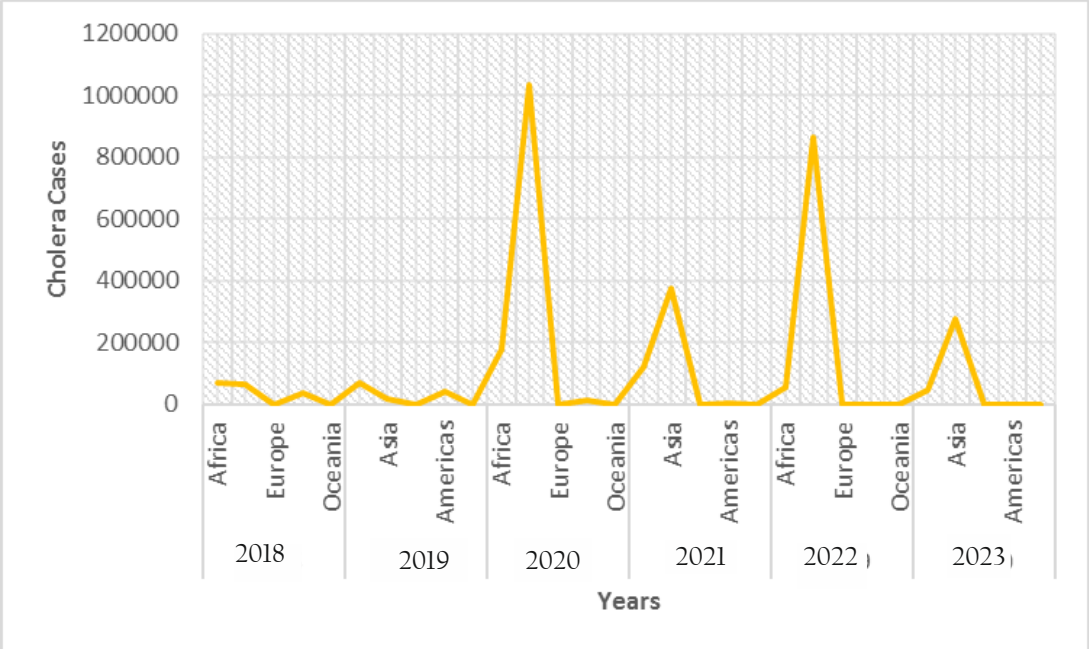

Figure 9: Graph of Regions' Cholera Cases

Additionally, Asian region established highest frequency with over 1,000,000 cholera cases in the year 2020, close to 400,000 cholera cases in the year 2021, more than 800,000 cholera cases in the year 2022 and over 200,000 cholera cases in the year 2023.

Descriptive Statistics of the Variable

The summary of the descriptive statistics of the data of this study are presented in Tables 1 below. The skewness is an indicator of the asymmetry or deviation of the variables from a normal distribution with an expected value of zero and the kurtosis defines the degree of flattening or peakedness of a distribution with an expected value of three.

Table 1: Figure 10 Descriptive Statistics of Cholera cases

Statistics	Cholera cases
Mean	109260.5667
Median	2.000000
Maximum	1033735.00
Minimum	0.000000
Std. Dev.	245614.52673
Variance	60326495740.875
Skewness	3.059
Kurtosis	9.118
Sum	3277817.00
Observations	30

It is observed from the above Table 1 and the below Figures 10 that the Cholera cases are not stationary with the chart of Normal distribution that is skewed to the right with the value of 3.059; that is the Cholera cases data possessed a skewness greater than zero (positively skewed) and the kurtosis of Cholera cases gives leptokurtic result with 9.118.

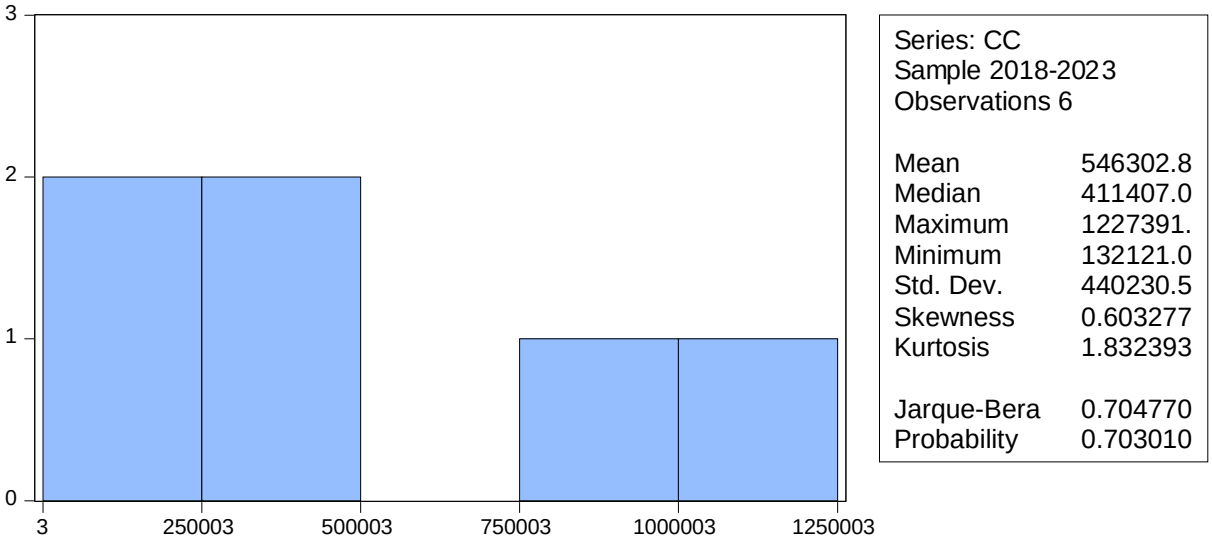

Figure 10: Histogram of the Cholera cases

4.2 Analysis of Significant Mean Difference

This section will assess whether there is a substantial mean difference in the number of cholera cases across the five regions (Africa, Asia, Europe, Americas, Oceania) from 2018 to 2023.

Table 2: Mean Significant Difference of Cholera cases

Dependent Variable: Cholera Cases

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1043961995787.500[a]	9	115995777309.722	3.288	**.013**
Intercept	358136142849.633	1	358136142849.633	10.153	.005
Regions	850159112798.533	4	212539778199.633	6.025	**.002**
Years	193802882988.967	5	38760576597.793	1.099	.392
Error	705506380697.867	20	35275319034.893		
Total	2107604519335.000	30			
Corrected Total	1749468376485.367	29			

a. R Squared = .597 (Adjusted R Squared = .415)

It is affirmed from the table above that the p-value is lesser than the level of significance (α) i.e. 0.002 < 0.05 which shows the significance of the hypothesis set above. Therefore, the null hypothesis is said to be rejected by concluding that there is significant difference in the means of the cholera cases across the five regions. Hence, the test is significant with the reliability coefficient that gives strong positive value of 59.7% which shows the degree of relationship.

4.3 Least Square Estimation of Cholera Cases

This section deals with the least squares method of estimation of trends in Time Series with the equations; $X_t = a + bt + \varepsilon_t$ where t is the period of the observation in years and X_t is the Cholera cases (Observations). Hence, the trend equations are; $T_t = 61273.03 + 13710.73t$.

Trend Estimation of the Cholera cases

Table 3: Derivation of the Coefficients

X_t (Cholera cases): Dependent

Variables	Coefficients	t-values	p-values	r-coefficient	R^2
Intercept	61273.03	0.591569	0.558885	0.096	0.009
X-variable (Years)	13710.73	0.515515	0.610239		

Coincidentally, the $R^2 = 0.009$ (0.009%) implies that 0.9 percent total variation in the Cholera cases is explained by the period of event in the model with low extent of relationship.

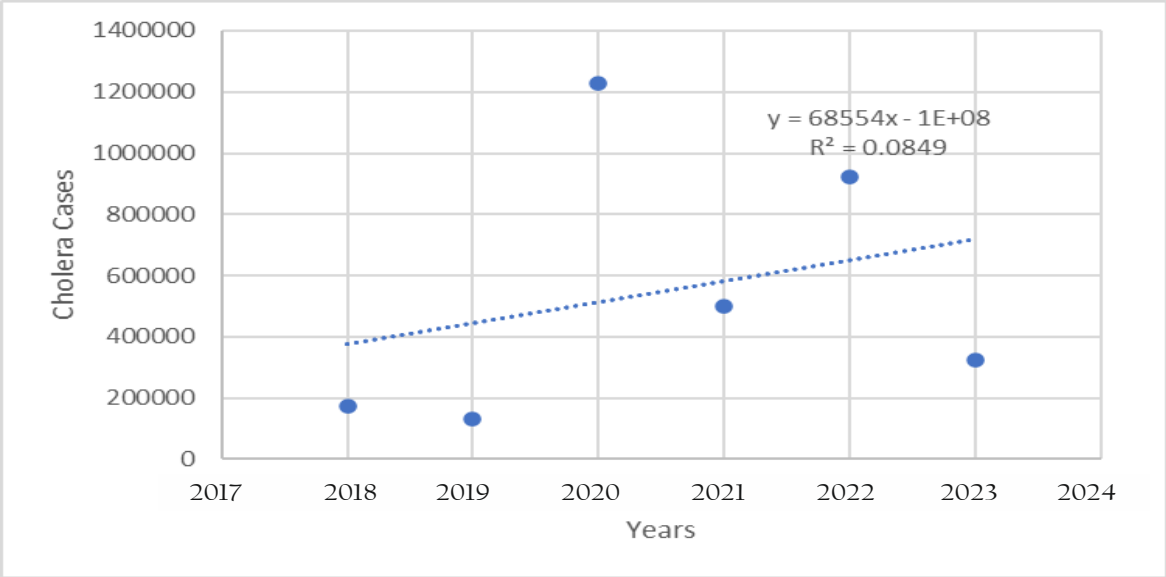

Figure 11: Graph of Trend Estimation without Region

4.4 Unit Root Test of Cholera Cases

This section gives the stationarity of the obtained data using Augmented Dicky Fuller (ADF) at 5% level of significance.

Hypothesis:

H_0: Cholera cases is non-stationary

H_1: Cholera cases is stationary

$\alpha = 5\% = 0.05$

Table 4: Stationary Test of the Cholera cases

		t-Statistic	Prob.*	R^2	AIC
Augmented Dickey-Fuller test statistic		-2.546459	0.1557	0.684	29.33
Test critical values:	1% level	-5.604618			
	5% level	-3.694851			
	10% level	-2.982813			

Since the probability value of the ADF is greater than 5% i.e. prob. = 0.157 > 0.05, this implies that there is insignificant ADF value. Hence, the cholera cases obtained is non-stationary (has no unit root test), so there is need for differencing.

First Differencing

Table 5: First Differencing of the Cholera Cases

		t-Statistic	Prob.*	R^2	AIC
Augmented Dickey-Fuller test statistic		-3.270754	0.0874	0.842	30.167
Test critical values:	1% level	-6.423637			
	5% level	-3.984991			
	10% level	-3.120686			

Since the probability value of the ADF is greater than 5% i.e. prob. = 0.0874 > 0.05, this implies that there is insignificant ADF value. Hence, the cholera cases obtained is still non-stationary (has no unit root test), so there is need for another differencing.

Second Differencing

Table 6: Second Differencing of the Cholera Cases

		t-Statistic	Prob.*	R^2	AIC
Augmented Dickey-Fuller test statistic		-7.858580	0.0108	0.9841	29.598
Test critical values:	1% level	-8.033476			
	5% level	-4.541245			
	10% level	-3.380555			

Since the probability value of the ADF is lesser than 5% i.e. prob. = 0.0108 < 0.05, this implies that there is significant ADF value. Hence, the Cholera cases obtained is stationary (has a unit root test), so there is no need for more differencing.

4.5 Forecast Evaluation

Prediction of future values is the most important objective of time series analysis. It is all about making projection into the future from its past values on the basis of a model that effectively describe the evaluation of a series. Here, we hope to forecast for the next 2 years of 2024 and 2025 across the regions in this research.

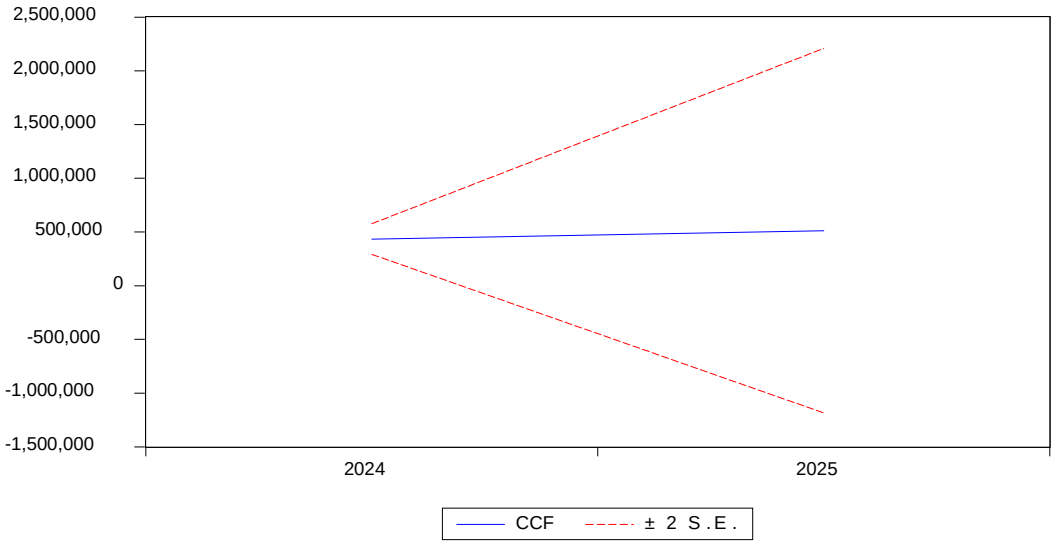

Figure 4.12: Forecast Graph of Cholera Cases

It can be affirmed from the above figure that if proper care is taken across the region by the Government bodies or those who are in charge of health providers, there will be a slight increment in the cases of cholera across the region.

5.0 Conclusion and Recommendations

In this study, it was observed that the Cholera cases over five regions between 2018 to 2023 as available at World Health Organization are not stationary with the chart of Normal distribution skewed to the right with the value of 3.059. This led to the test of hypothesis which established the significant difference in the means of the cholera cases across the five regions at 5% level of significance. Additionally, it was led to the second differencing of the Augmented Dicky Fuller unit root test before it was stationary for forecasting with the trend estimation of T_t = 61273.03 + 13710.73t via the Least Square Methods. The implication is that increment of 13710.73 in the cases of cholera across the region over the period calls for proper health care by the Government bodies and those who are in charge of health provider.

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