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The Impact of Climate Change and Sea Level Rise in the Nigerian Coastal Environment

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***Abstract*: The study was carried out to assess the impact of climate change and sea level rise around the Nigerian coastal environment. Tidal data (2013,2015,2017-2021) from semidiurnal tides for six stations (Apapa, Benin, Akassa, Bonny, Brass, Calabar) and Mean Sea Level data (1989-1992) for Bonny were analyzed for trends using Mann-Kendall test (non-parametric) and Sen's slope for the purpose of forecasting future variations. The Mann-Kendall Zs values for the stations indicated a statistically significant trend in Bonny, Calabar, Akassa and Brass stations during High Waters(evening) with Akassa station having the strongest trend. The p-value for the stations during High Waters(evening) also indicates the presence of a trend in the same four stations. Apapa and Brass stations displayed higher Sens's slopes of 0.00013 and 0.00014 respectively while Bonny and Calabar stations displayed lower Sen's slopes of -0.00057 and -0.00056 respectively. The analysis of the monthly Mean Sea Level for Bonny estuary gave a Z value of 0.217 and positive Sen Slope value of 0.0045m resulting to a non- significant trend although, indicating a tendency for the sea level to rise over time at the rate of 45mm per annum. The results suggest a statistically significant trend in sea level. These observations can affect both the livelihood and natural environment of coastal areas causing widespread elevation in oceanic levels, and perhaps lead to coastal strain and infiltration of saltwater. Hence, it is imperative to adopt mitigation and adaptation measures like reduction of greenhouse gas emissions, construction of seawalls and restoration of wetlands.**

***Keywords*: adaptation strategies, climate change, coastal regions, data analysis, Mann-Kendall test, Nigeria, sea level rise, Sen's slope, tide, trend analysis.**

1. Introduction

Climate change, being a shift in temperature and weather patterns and temperature over a period of time negatively impacts sustainable development around the globe. This change has been occurring for many decades with the impact being felt by various communities but is now happening at a rapid rate (Akubor, 2014). This has been a concern for coastal regions since it was discovered more than twenty years ago (Anthoff *et al.,* 2010).

The main factors causing these changes are natural processes (biogeographical) and human activities (anthropogenic). Industrialization, burning fossil fuel and gas flaring are all human activities which emit large amount of greenhouse gases that deplete the ozone. Deforestation, land use change, water pollution and agricultural practices are also human activities which reduce the amount of carbon absorbed by the atmosphere. Changes in global climate patterns have led to environmental problems like melting of sea ice and extreme weather conditions such as storms, floods and heavy winds. Nigeria, being situated on the coasts of West Africa, has its coastal and marine areas around the Atlantic Ocean. Their elevations, location and nearness to the ocean makes them more vulnerable to climate change and sea level rise (Danladi *et al.,* 2017). Climate change has numerous impacts and cannot be overemphasized. These impacts include alteration of ocean flow patterns like the Gulf Stream (Marotzke, 2000**),** biodiversity (Gitay *et al.,* 2001), worsening of extreme weather events (Odjugo 1999), changes in surface temperature and subsurface ocean temperature, ocean acidification (and coral bleaching), pest infestations, deterioration of reef fisheries, increased communicable disease and structural damage (Lazrus, 2009).

Coastal regions are important as they house a huge population and have diverse ecosystems. Combining sea-level rise with climate change may cause salt water intrusion in major estuaries resulting in habitat destruction, loss of agricultural potential, risks of salinity invasion, reduction in irrigated areas and depletion of water resources. According to research, Nigeria already faces a wide range of environmental problems that are directly linked to the climate change coupled with a low-level coping ability (Jagtap, 2007). The potential impact of sea-level rising in Africa was evaluated by Brown et.al., (2009) and revealed that even though Africa is not one of the most exposed regions in the world, sea level rise poses a serious risk. Fluctuations in sea levels and the impact it may have on the environment needs to be known since continuous existence and survival is important. This substantial uncertainty creates a problem in terms of the physical impact that is expected, as well as the level and type of response or adaptation.

Sea level rise poses a significant threat to coastal regions worldwide, including Nigeria's coastline along the Gulf of Guinea. From survey of literature, Africa's population is growing so fast with its contribution towards the main causes of climate change minimal yet is hardest hit by the impacts of climate change (Tarfa *et al.* 2019). The magnitude and rate of

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sea level rise is expected to be greater in the next century than it was in the last (Rahmstorf, 2007). Wongsa *et al* (2010) noted in a paper that climate change has affected the salinity of many rivers in the world. Even though it is difficult to determine the exact effects of climate changes on estuaries or the processes that occur in the alluvial basin, the paper asserted that the impact is significant. The coastal area is a significant economic resource and should be protected.

Noting that tides are caused by the gravitational pull between the sun and the moon on the Earth as it rotates, Carson *et al.* (2018) used data from tide gauges to analyze sea-level variations.

Trend analysis is an effective tool to help understand hydrological variables. It can be used to display patterns using climate parameters. Mann-Kendall is a non-parametric test that detects if a trend exists in a given time series, without specifying the linearity or non-linearity of the trend (Yue *et al.,* 2002). This test is widely used to detect monotonic trend in series of data from environmental, hydrological or climate variables. It is important to assess the impact that the rising sea level will have on the coastal environment as this information can be used by coastal planners, managers and coastal authorities in the region in order for them to make improvements and adaptations in the sustainable development of this area (Popoola, 2012). Using different indices, many studies have been conducted to assess the effects of climate changes in Nigeria.

This study assesses the impact of sea level rise by applying the Mann-Kendall test for trend analysis to tidal data which would give an overview of rising tides and the impact they have on coastal areas using the selected stations**.** It would also provide a better understanding on how to cope with new scenarios and help to plan mitigation and adaptation strategies.

2. Materials and Methods

A. Description of Study Area

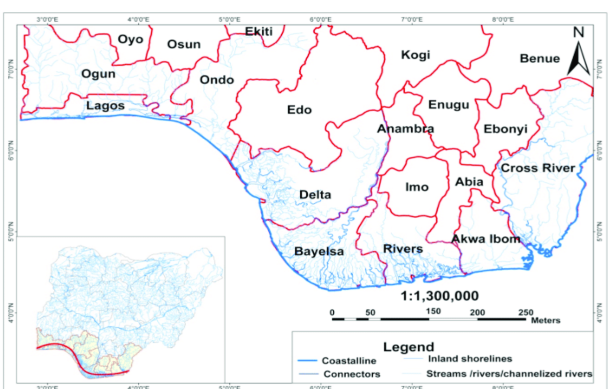

Fig. 1. Map of Nigeria showing coastal areas

Nigeria is situated on the coasts of West Africa having a coastline extending 853km in length and covers a total area of approximately 923,770 km^2. The study areas were Apapa (06° 27´ and 03° 23´), Benin (05° 43´ and 05° 02´), Akassa-nun (04° 19´ and 06° 04´), Bonny (04° 27´N and 07° 10´), Calabar (04° 20´ and 08° 22´) and Brass River (04° 19´ and 06° 15´) with their stations located in Lagos, Delta, Bayelsa, Rivers and Cross River states respectively. These are major communities along the coastal region in Nigeria with fishing and water transportation as their main source of livelihood. Apapa is also a home to Nigeria's largest Port and West Africa's maritime and aviation hub.

B. Tide Levels

Climate change is resulting into sea level rise. The study used daily tide data from six stations for the period (2013, 2015, 2017-2021), which were collected from the database of the Nigerian Navy Hydrographic school, Lagos, Nigeria. This data was used to study the trends on annual basis. The data was sorted and analyzed using trend analysis, a statistical method to identify trends over time. In this study, the analysis was carried out using XLSTAT, a statistical software (adds-in) in Microsoft Excel. The main idea of trend analysis is to detect whether values of data are increasing, decreasing or trendless over time (Kisi and Ay 2014). The results of the analysis are presented in tables 1-3.

C. Mann-Kendall test

The Mann-Kendall test has been used frequently to quantify the significance of trends in hydrometeorological time series (Yue et al. 2002). It is calculated as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sign}(x_j - x_i) \quad (1)$$

where x_i and x_j are the values of the data series at time i and j respectively (j>i),

n is the numbers of data points.

The variance is computed as:

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5)}{18} \quad (2)$$

Where n is the numbers of data points, P is the number of tied groups.

The standard normal test statistic, Z_s is computed as:

$$Z_s = \begin{cases} \frac{s-1}{\sqrt{\text{Var}(s)}}, & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{s+1}{\sqrt{\text{Var}(s)}}, & if\ S < 0 \end{cases} \quad (3)$$

Positive values of Z_s indicate increasing trends while negative values of Z_s indicate decreasing trends. The test was done at a 95% confidence interval ($p \leq 0.05$). Missing values were allowed and the data was not conformed to any particular distribution. The test interpretation is thus: H_0 - no trend in the series, H_a - a trend in the series. The p-value measures the probability of rejecting the null hypothesis. If the computed p-value is lower than significance level 0.05, the null hypothesis, H_0 is rejected and alternative hypothesis, H_a is accepted. The continuity correction was applied. Appropriate corrections were applied where ties were detected in the data. At 5% alpha significance level, the Z_s value is classified as a significant positive trend for $Z_s > 1.96$, a significant negative trend for $Z_s < -1.96$ and no significant trend for $-1.96 \leq Z_s \leq 1.96$.

D. Sen's Slope

This is a method used to estimate the slope of a linear trend in a time series. The Sen's slope is computed as:

$$Q_{med} = \begin{cases} \frac{Q_{(N+1)}}{2}, & if\ n\ is\ odd \\ \frac{Q_{\frac{N}{2}} + \frac{Q_{(N+2)}}{2}}{2}, & if\ n\ is\ even \end{cases} \quad (4)$$

where the Q_{med} sign reflects data trend and the value shows the steepness of the trend. Sen's slope is widely used in hydrometeorological time series (Gocic and Trajkovic 2013).

E. Mean Sea Level

The Mean Sea Level data (1989-1992) was extracted from the Tidal analysis programme (1990) of the Liquified Natural Gas project.in Bonny. The data was checked to ensure that there were no missing values that might affect the analysis. Trend analysis for the monthly Mean Sea Levels using the Mann-Kendall (non-parametric) test was done by sorting the data and computing the test statistics S (using equation 1). The computation was based on the number of positive and negative differences between all pairs of data points in the time series. The variance and the Z_s value were computed using equations 2 and 3 respectively. The significance level of 5% was used to determine the threshold for rejecting the null hypothesis. Sen's slope was then calculated to quantify the magnitude of the trend, if any, using equation 4.

A positive slope indicates an increasing trend while a negative slope indicates a decreasing trend. This analysis would help to know the level at which the sea level is rising using one of the stations (Bonny River) as reference being the accessible data at the time.

3. Results and Discussion

A. Analysis of Tide Levels

The results of the trend analysis using Mann-Kendall test and Sen's slope are presented in in Table 1 for Low Waters and Tables 2 and 3 for High Waters (morning and evening). During High Waters(evening) at a significant level of 5%, the result from the Mann-Kendall Z_s value indicated a significant decreasing trend at Bonny, Calabar, Akassa, Brass stations since the Z_s values are negative and greater than 1.96. The null hypothesis was rejected, and the alternative hypothesis accepted. Apapa and Benin stations do not indicate a statistically significant trend as Z_s value is less than 1.96.

The p-value indicates the probability of obtaining test results, assuming that the null hypothesis is true. At a significant level of 5%, Bonny, Calabar, Akassa, Brass stations showed a p-value less than 0.05 as shown in Table 3. The null hypothesis is rejected, thus, indicating a statistically significant trend in these stations Also, Apapa and Benin stations do not indicate any trend. During High Waters (morning) and Low Waters, the Z values were not significant at the 5% level and the p-values were greater than 0.05 in all six stations indicating no trend. This shows that the null hypothesis of no trend cannot be rejected.

Since the magnitude of the Z value indicates the strength of the trend, Table 3 shows that Akassa with Z value of -2.002, has the strongest decreasing trend and Bonny with Z value of -2.206, has the weakest decreasing trend. The observed trend is statistically significant and not due to random chance. Relating the p-value to the significance level of 5%, conveys the

Table 1
Results from tidal analysis for the stations during Low Waters

STATION	MEAN (m)	VARIANCE	TEST STATISTICS(S)	p-value	MANN KENDALL(Z)	SEN SLOPE	RESULT
BONNY	0.575	66923	120	0.643	0.460	0.00009	Not significant
CALABAR	0.177	66912	165	0.526	0.634	0.00011	Not significant
AKASSA	0.089	66922	187	0.472	0.719	0.00012	Not significant
BRASS	0.179	66965	200	0.442	0.769	0.00014	Not significant
BENIN	0.333	66947	149	0.567	0.572	0.000099	Not significant
APAPA	0.389	66922	187	0.472	0.719	0.00013	Not significant

Table 2
Results from tidal analysis for the stations during High Waters (morning)

STATION	MEAN (m)	VARIANCE	TEST STATISTICS(S)	p-value	MANN-KENDALL(Z_s)	SEN SLOPE(SS)	RESULT
BONNY	2.097	66972	-185	0.477	-0.711	-0.00025	Not significant
CALABAR	1.821	66953	-267	0.304	-1.028	-0.00035	Not significant
AKASSA	1.278	67002	-118	0.651	-0.452	-0.00017	Not significant
BRASS	1.642	66951	-208	0.424	-0.800	-0.00028	Not significant
BENIN	1.371	46826	-133	0.610	-0.610	-0.00017	Not significant
APAPA	1.432	66919	-202	0.437	-0.777	-0.00025	Not significant

Table 3
Results from tidal analysis for the stations during High Waters (evening)

STATION	MEAN (m)	VARIANCE	TEST STATISTICS(S)	p-value	MANN-KENDALL(Z_s)	SEN SLOPE(SS)	RESULT
BONNY	1.967	66998	-572	0.027	-2.206	-0.00057	significant
CALABAR	1.709	67012	-563	0.030	-2.171	-0.00056	significant
AKASSA	1.202	66939	-542	0.037	-2.091	-0.00051	significant
BRASS	1.541	66947	-519	0.045	-2.002	-0.00048	significant
BENIN	1.289	66970	-487	0.060	-1.878	-0.0005	Not significant
APAPA	1.347	66970	-487	0.060	-1.878	-0.0004	Not significant

certainty of the results

The Sen's slope values for all the stations during Low Waters indicate very slight positive trends. The positive values mean that the data shows an increasing trend even though they are very small. The negative Sen's slope values observed during High Waters (morning and evening) indicate negative trends. The absolute values of these slopes are very small, indicating that the changes over time are minimal. The analysis show that Apapa and Brass were stations with higher slopes of 0.00013 and 0.00014 respectively as presented in Table 1 while Bonny and Calabar were stations with lower slopes of -0.00057 and -0.00056 respectively as presented in Table 3.

Figures 3, 4, 5, 6, 7, 8 show the plot for the mean tide height for each river during High Waters (morning) for 2013, 2015, 2017-2021. Figures 9, 10, 11, 12, 13, 14 show the plot for the mean tide height for each river during Low Waters for 2013, 2015, 2017-2021. Figures 15, 16, 17, 18, 19, 20 show the plot for the mean tide height for each river during High Waters (evening) for 2013,2015,2017-2021. It was observed that graphs show the tides increasing and decreasing in a similar way thus, forming a semi-diurnal pattern having nearly the same height. This type of tide is commonly experienced along the coasts having two tides every 24 hours which is supported by Amoo (2018) findings that tides along the Nigerian coast are semidiurnal.

The average annual tide level within the study area range from 0.089m to 0.575m for Low Waters with the highest value in Bonny station and the lowest in Akassa station. A downward trend is seen in Calabar, Bonny stations during High Waters (m) and in all the station during High Waters (evening) as presented in Figures 3,7,15,16,17,18,19,20 while a slightly downward trend is seen in Apapa, Akassa, Benin and Brass stations as shown in Figures 4,5,6,8 respectively. Additionally, slightly upward trend can be seen in all six stations during Low Waters as presented in Figures 9, 10, 11, 12, 13, 14. By examining the graph over a long period, these trends can be conspicuous, this would indicate a rise in sea level. The results suggest that climate change and sea level is affecting the coastal areas.

The annual mean tide level for Apapa, Brass, Akassa, Bonny and Benin stations during Low waters were 0.333m, 0.179m, 0.088m and 0.389m respectively. The impact of climate change may not be immediately apparent in non- significant trends but its long-term effects can still influence tidal patterns and trends over time. A longer data series may be considered for more reliable trend analyses and seasonal variations in tidal levels should be accounted for.

Rising tide levels indicate several environmental and societal changes. The impacts include sea level rise, coastal erosion which threaten infrastructure, property and the ecosystem. During storms, there is the risk of flooding. When saltwater intrudes into freshwater aquifers, rivers and estuaries, Sea level rise would increase the salinity of rivers and estuaries. Since the level of the water table is determined by sea level, a rise in sea level would cause the freshwater or saltwater boundary to rise and can affect the availability of freshwater for drinking, agriculture and industry.

Some mitigation plans and adaptative measures need to be put in place. Policy makers and coastal management might include considerations for infrastructure development, conservation efforts and future monitoring. Communities may need to invest in coastal defenses such as seawalls, dunes restoration to protect against rising tides. Urban planning and policies may need to incorporate considerations for rising sea levels and mitigation plan.

B. *Analysis of Mean Sea Level*

The analysis of the Mean Sea Level for Bonny River was carried out using the Mann-Kendall test. A four-year Mean Sea Level data was used to calculate the test statistics S, the variance Var(s), the Mann-Kendall Z_s value and Sen's slope. The computed values of S, Var(s) and Z_s were 15, 4160.62, 0.217 respectively. For Mann Kendall test, the computed Z_s when compared with the critical value of 1.96 (from the standard normal distribution), at a 95% confidence level, detected a weak, non- significant upward trend for Bonny station. Thus, the null hypothesis cannot be rejected. The computed Sen slope was 0.0045m which suggests a small, positive trend in the data. This means that, on average, Mean Sea Level at Bonny station increases by 0.0045m per annum.

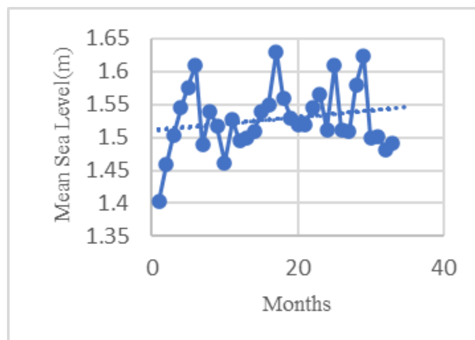

Fig. 2. Mean Monthly Sea Levels for Bonny station (1989-1992)

Figure 2 presents the Mean Monthly Sea Levels for Bonny station between 1989 and 1992. The observed mean sea level per annum ranged between 1.482m and 1.630m. The average annual sea level within the study area is 1.528m. Also, a consistent upward trend was observed from the graph in Figure 2 which would indicate a rise in sea level.

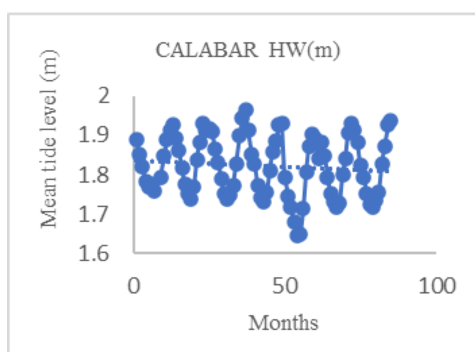

Fig. 3. Mean tide levels for Calabar river during High Waters (m) for 2013, 2015, 2017-2021

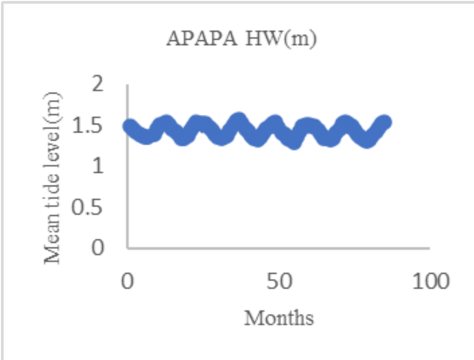

Fig. 4. Mean tide levels for Apapa river during High Waters(m) for 2013, 2015, 2017-2021

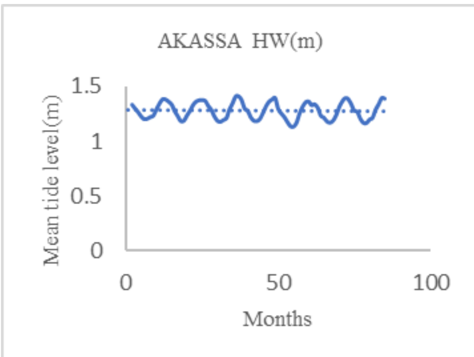

Fig. 5. Mean tide levels for Akassa river during High Waters (m) for 2013, 2015, 2017-2021

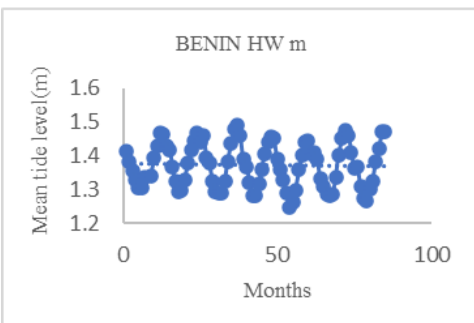

Fig. 6. Mean tide levels for Benin river during High Waters(m) for 2013, 2015, 2017-2021

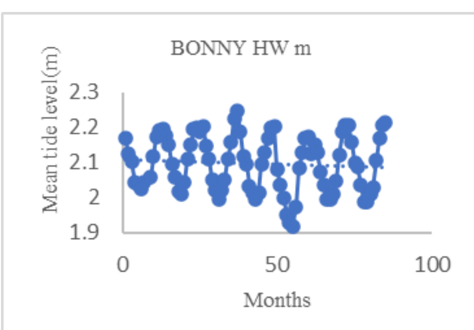

Fig. 7. Mean tide levels for Bonny River during High Waters (m) for 2013, 2015, 2017-2021

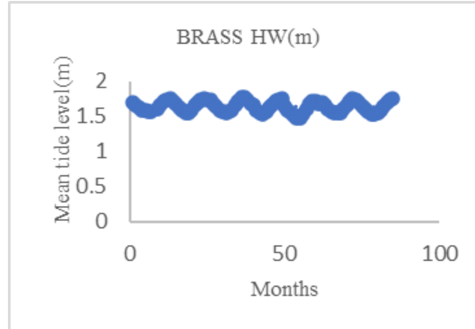

Fig. 8. Mean tide levels for Brass River during High Waters (m) for 2013, 2015, 2017-2021

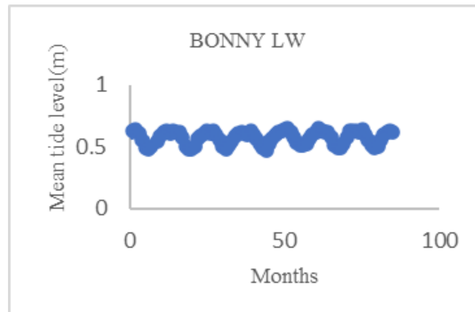

Fig. 9. Mean tide levels for Bonny River during Low Waters for 2013, 2015, 2017-2021

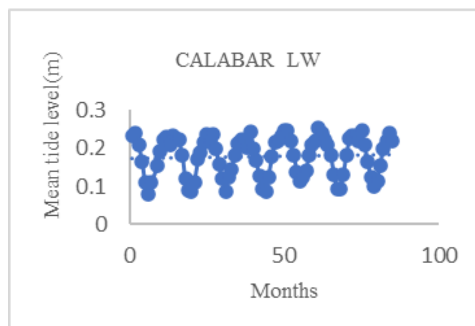

Fig. 10. Mean tide levels for Calabar river during Low Waters for 2013, 2015, 2017-2021

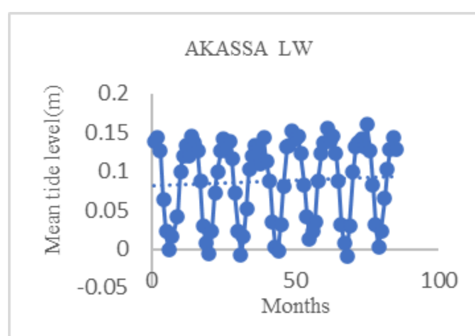

Fig. 11. Mean tide levels for Akassa river during Low Waters for 2013, 2015, 2017-2021

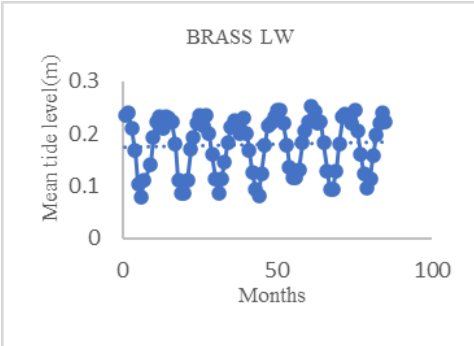

Fig. 12. Mean tide levels for Brass River during Low Waters for 2013, 2015, 2017-2021

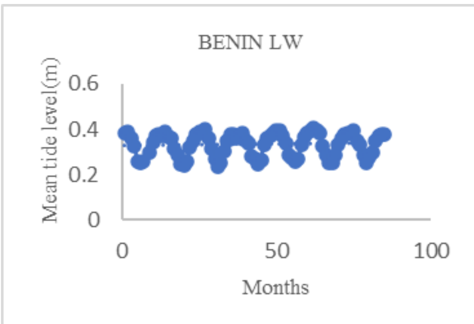

Fig. 13. Mean tide levels for Benin river during Low Waters for 2013, 2015, 2017-2021

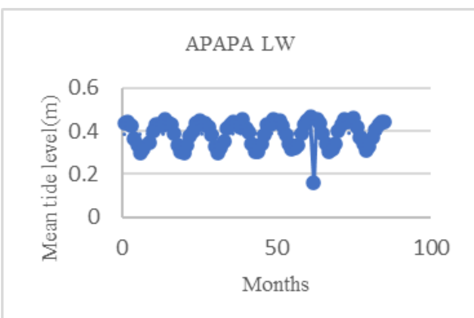

Fig. 14. Mean tide levels for Apapa river during Low Waters for 2013, 2015, 2017-2021

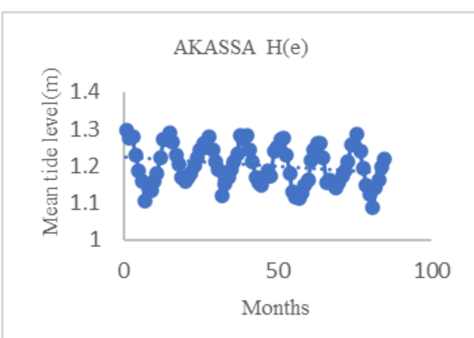

Fig. 15. Mean tide levels for Akassa river during High Waters (e) for 2013, 2015, 2017-2021

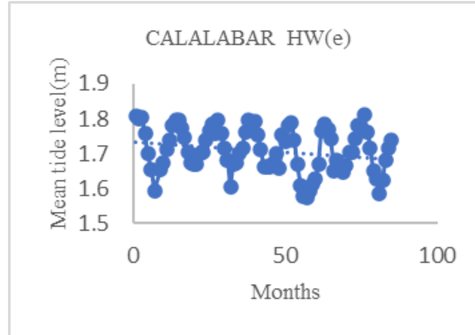

Fig. 16. Mean tide levels for Calabar river during High Waters (e) for 2013, 2015, 2017-2021

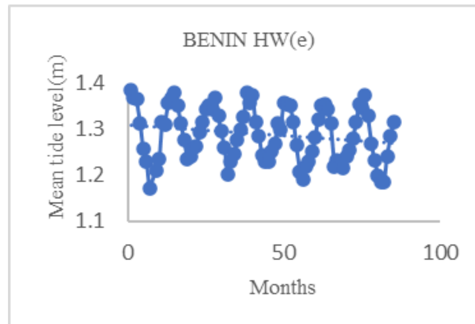

Fig. 17. Mean tide levels for Benin river during High Waters (e) for 2013, 2015, 2017-2021

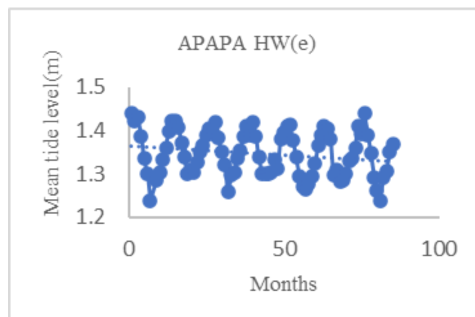

Fig. 18. Mean tide levels for Apapa river during High Waters (e) for 2013, 2015, 2017-2021

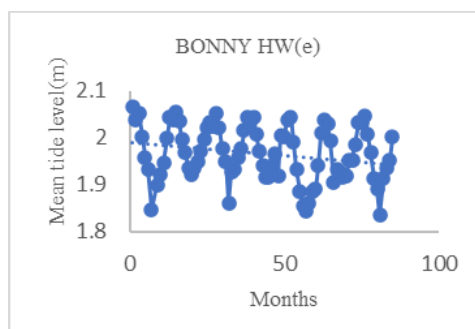

Fig. 19. Mean tide levels for Bonny River during High Waters (e) for 2013, 2015, 2017-2021

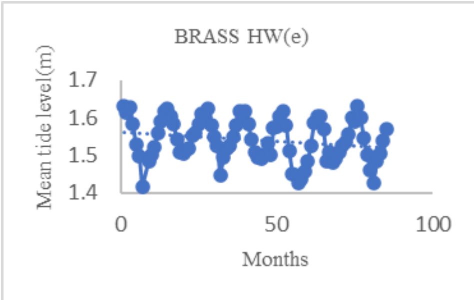

Fig. 20. Mean tide levels for Brass River during High Waters (e) for 2013, 2015, 2017-2021

4. Conclusion

In this study, collation of seven years of tidal data for six stations and four years of Mean Sea level data for Bonny station was done and trend analysis was performed using the Mann-Kendall tests and Sen's slope estimator. At a significance level alpha of 5% and comparing with the critical value of 1.96 (from the standard normal distribution), the results accept or reject the null hypothesis, H0. The following observations were made from the results of the analysis:

i. The Mann-Kendall Zs value for the various stations when compared with the critical value 0f 1.96 indicated that there was a statistically significant trend in Bonny, Calabar, Akassa and Brass stations during High Waters(evening).
ii. The p-value which indicates the probability of obtaining test results assuming the null hypothesis is true showed a statistically significant trend at 5% significant level for Bonny, Calabar, Akassa and Brass stations. Since the p-value for these stations during High Waters(evening) was < 0.05, there is strong evidence that the tidal levels are changing over time.
iii. The Sen's slope of the Mean Sea Level from chart datum for Bonny estuary was of 0.0045m, indicating that the sea level is rising significantly at the rate of 45mm per annum. Apapa and Brass were stations having the higher Sens's slopes of 0.00013 and 0.00014 respectively while Bonny and Calabar were stations with lower Sen's slopes of -0.00057 and -0.00056 respectively.
iv. The results of the analysis indicate that there is a significant trend in Bonny, Calabar, Akassa and Brass stations. Hence, an impact in sea level with the tendency to rise over time.
v. As a result of climate change and sea level rise, the variation in tides and mean sea level for the observed period show a significant trend which provide robust evidence of the consistent upward and downward trends in sea level along the Nigerian coastline.

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