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DETERMINATION OF MEAN SEA LEVEL FROM 1980 TO 2018 USING TIDAL OBSERVATION DATA, BONNY PRIMARY PORT, NIGERIA

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ABSTRACT

Mean Sea Level (MSL) is the average height of the sea for all stages of tide over 19 years; and it is obtained through tidal analysis. This research work aims at determination and assessment of the MSL for the Bonny port. Tidal data of 1980, 1994 and 2018 years of observation were employed using the Least Squares Adjustment method with MATLAB programming codes for data processing. The results of the monthly analysis were compared and subjected to statistical analysis (Mean, standard deviation, t-test and Analysis of variance (ANOVA). The difference between the computed 1980 yearly mean and that of 1994 is 3.0 mm; while that of 1994 and 2018 is 5.1 mm. The yearly variation for 1980 to 1994 is (3.0/14) mm = 0.20 mm; and for 1994 to 2018 is (5.1/24) mm = 0.21 mm. The variation for 1980 to 2018 is (0.20-0.21) mm. The results show gradual rise in MSL for the period of 1980 to 2018 as further explained by the month and the year variables. Therefore, it can be concluded that there is a gradual rise in sea level of about 0.01 mm for the period of study in Bonny which does not take into consideration the subsidence phenomenon. Although, the rate is low, however, the results suggest that the relative sea level could be much higher because there is a lot of fluid extraction.

Keywords: Time series, analysis, Mean Sea Level (MSL), primary port, Least Squares Adjustment, Bonny,

INTRODUCTION

Sea level rise is one of the most important factors for the results of global warming and climate change (IPCC, 2014; Cazenave & Moreira, 2022). Mean Sea Level (MSL) is the average height of the sea for all stages of tide over 19 years (Ojinnaka, 2007; Gregory et al., 2019). Itis the basic datum for precise geodetic levels and for determination of a datum for its charts (Gregory et al., 2019; Cazenave & Moreira, 2022). On land, elevations are referred, directly to MSL; and in harbours depths are referred for safety purposes to some low water datum, dependent upon the precise determination of MSL (Cazenave & Moreira, 2022). MSL is obtained through tidal analysis (Lee et al., 2023); and its computation is dependent on the time-span of data used in the analysis. Tidal observation for determination of MSL is grouped into two, namely short period observations between seven (7) and fifteen (15) days (Sabhan et al., 2021; Setiyawan et al., 2022; Lee et al., 2023); and long period observations ranging from a minimum of one month to 19 years which covers the period of the moon's node of 18.61 years (Morakinyo, 2003; Ojinnaka, 2007; Sabhan et al., 2021). The availability of tidal constants and MSL above the chart datum for the place under review helps to predict the tides of the locality (Ojinnaka, 2007).

Different approaches have been used in the determination of MSL, for example tidal level observations using ultrasonic sensors at intervals of 0.6 seconds for 10 consecutive days for Korea ocean (short period observation) (Lee et al., 2023): estimation of global MSL (GMSL) rise and its uncertainties by 2100 and 2300 using structured expert judgement and broad elicitations methods (Horton et al., 2020); acceleration in the GMSL from 2005-2015 using combinations of observations from TOPEX/Poseidon and Jason satellites, Gravity Recovery and Climate Experiment (GRACE) satellites, gravimetry, and in situ measurements of the ocean (Yi et a., 2017); and the use of tidal gauge stations for studying secular trends in tidal parameters along the coast of Japan (Rasheed & Chua, 2014) etc.

Several researchers have used various methods for tidal analysis, which include Least Squares Harmonic Analysis method for non-stationary and non-linear time series data (Morakinyo, 2003; Ezer & Corlett, 2012a; Ezer & Corlett, 2012b; Ezer, 2013; Ezer, 2016; Cheng et al., 2016; Ezer, 2016; Cheng et al., 2017; Pan et al., 2018); the MATLAB toolbox T_TIDE (Pawlowicz, 2002); enhanced harmonic analysis (EHA) for non-stationary tides (Pan et al., 2018); Enhance harmonic analysis used with MATLAB toolbox) (Lee et al., 2023); response method (Morakinyo, 2003; Cauwenberghe, 1992); continental shelf model method (Chu et al., 2022).

In addition, ocean thermal expansion, land ice loss (glacier melting and ice sheet mass loss) and terrestrial water storage changes are the three main identified causes of GMSL rise (Gregory et al., 2019; Horton et al, 2020; Cazenave & Moreira, 2022; Lee et al., 2023;). Quantification of these three contributions has evolved through time and they can be directly assessed with different observing systems (Cazenave & Moreira, 2022). Prior to the altimetry era, their estimation was based on modelling only or on the combination of models and observations e.g. (Slangen et al., 2017; Frederikse et al. (2020).

Previous studies had already reported increasing in GMSL rise (Watson et al., 2015; Dieng et al., 2017; Nerem et al., 2017; Nerem et al., 2018; Dangendorf et al., 2019; Moreira et al., 2021) with the estimated acceleration ranges from 0.084 ± 0.025 mmyr-^{2} (Nerem et al., 2017; Nerem et al., 2018) for 1993-2017 (after correcting for the Pinatubo volcanic eruption) to 0.093 ± 0.01mmyr-^{2} (Veng & Andersen, 2020) for 1991-2019 and 0.11 ± 0.01 mmyr^{-2} (Moreira et al., 2021) for 1993-2019. According to Ablain et al. (2019), the uncertainty of GMSL acceleration estimates may not be better than 0.07mmyr^{-2} (90 % confidence level) for the1993-2017-time span, a value about twice the dispersion range of the above reported

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values. The continuous and accelerating rise of sea level is a major driver of shoreline retreat and erosion that acts in combination with other processes of natural (e.g. storm surges and cyclones) and anthropogenic (sand extraction, urbanization and land use) origin (Nicholls, 2021).

The crucial gap before this research is that limited study has been carried out on the determination of MSL for the Bonny port, and very little publication has been produced on it. The basis for this study is the determination of MSL; and evaluation of yearly mean and the combine 3 years results in order to assess the annual changes. The research questions used for this study are: (1) Is there any difference in the monthly value of MSL for the Bonny port? (2) What are the differences in the MSL results of each year mean? (3) Can one-year MSL results give the same results as the combine 3 years results? Based on the above research questions, the primary aim of this study is to evaluate the monthly computed Bonny port MSL for the 3 years; and to know if there is sea rise at the Bonny port. The objectives for this study are: (1) Computation of astronomic arguments (E, u and f) used for the harmonic tidal analysis for the Bonny port; (2) Monthly tidal analysis for determination of MSL; (3) Determination of yearly MSL mean and the combine 3 years MSL mean; (4) Statistical analysis of MSL results using t-test, analysis of variance (ANOVA), regression analysis (linear and multiple).

MATERIALS AND METHODS

Study Site

Bonny town, a coastal town in Rivers State is one of the stations where tidal observations and analysis have been carried out in Nigeria. Bonny is an important town to Nigeria because (i) It is home of Nigeria's largest liquefied gas project; (ii) It is located at the mouth of Bonny River estuary which is the major gateway to Nigeria's second largest port in Port Harcourt; (iii) It is one of the early ports of settlement for the colonial masters who were engaged in oil exploration.

The Bonny tidal station is the only internationally published standard port in Nigeria till date. The geographical coordinate for the tide gauge station at Bonny is at Latitude 4° 27' N and Longitude 7° 10' E (Figure 1). A tide gauge was established at Bonny in 1956 for the purpose of safe navigation for oil exploration. Water level data obtained from this station for a period of one year was employed for tidal analysis. The tidal constants derived from this analysis have since then been published in the yearly volume of the Admiralty Tidal Tables (ATT) and used for tidal prediction over the years.

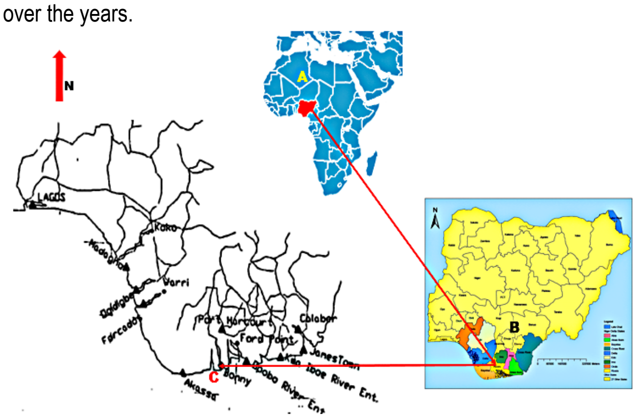

Figure 1: A) Map of Nigeria in Africa; B) Map of Rivers State in Nigeria; C) Map of the location of Bonny Port in Rivers State (Google Earth, 2024).

Study Data

Three (3) years (1980, 1994 and 2018) data of tidal observations of every month were used for the study. The data were recorded at every one (1) minute interval. Table 1 show a sample of one hour of corrected water level (CWL) readings recorded for Bonny port on 01/01/1980.Table 2 shows the lowest and highest water level readings for each month of the year 1980, 1994 and 2018.

Table 1: Sample of One Hour of CWL Readings for Bonny Port on 01/01/1980

S/N	CWL reading	Observed time (A.M)	S/N	CWL reading	Observed time (A.M)
1	1.84	7.01	31	1.82	7.31
2	1.83	7.02	32	1.81	7.32
3	1.84	7.03	33	1.80	7.33
4	1.82	7.04	34	1.81	7.34
5	1.83	7.05	35	1.81	7.35
6	1.82	7.06	36	1.82	7.36
7	1.81	7.07	37	1.80	7.37
8	1.82	7.08	38	1.81	7.38
9	1.80	7.09	39	1.79	7.39
10	1.79	7.10	40	1.79	7.40
11	1.81	7.11	41	1.79	7.41
12	1.81	7.12	42	1.83	7.42
13	1.83	7.13	43	1.84	7.43
14	1.82	7.14	44	1.84	7.44
15	1.79	7.15	45	1.83	7.45
16	1.78	7.16	46	1.82	7.46
17	1.80	7.17	47	1.79	7.47
18	1.81	7.18	48	1.78	7.48
19	1.80	7.19	49	1.77	7.49

20	1.80	7.20	50	1.78	7.50
21	1.82	7.21	51	1.78	7.51
22	1.79	7.22	52	1.79	7.52
23	1.78	7.23	53	1.82	7.53
24	1.78	7.24	54	1.81	7.54
25	1.77	7.25	55	1.82	7.55
26	1.78	7.26	56	1.80	7.56
27	1.77	7.27	57	1.80	7.57
28	1.79	7.28	58	1.81	7.58
29	1.80	7.29	59	1.82	7.59
30	1.80	7.30	60	1.82	8.00

Table 2: Lowest and Highest Water Level Readings (m)

Month	1980		1994		2018	
	Lowest	Highest	Lowest	Highest	Lowest	Highest
January	0.70	2.83	0.31	2.64	0.45	2.54
February	0.68	2.93	0.37	2.76	0.37	2.66
March	0.78	2.98	0.21	2.75	0.40	2.61
April	0.75	2.98	0.12	2.73	0.39	2.67
May	0.70	2.88	0.58	2.61	0.58	2.53
June	0.70	2.73	0.53	2.51	0.37	2.51
July	0.70	2.85	0.70	2.54	0.61	2.45
August	0.78	2.89	0.68	2.62	0.63	2.61
September	0.90	3.05	1.06	3.17	0.96	3.17
October	0.73	3.05	0.98	3.20	0.93	3.12
November	0.65	2.98	0.92	3.28	0.92	3.14
December	0.55	2.80	0.78	3.13	0.78	2.97

Methods

MATLAB Programming Codes

For MSL determination, tidal analysis must be carried out first because it is one of the final results obtained from it. The Least Squares Method (LSM) of harmonic tidal analysis was adopted (Zetler, 1982; Rusdin et al., 2024) for tidal analysis of monthly data of each year because of its accuracy advantages and computational efficiency (Abubakar et al., 2019; Li et al., 2019). The algorithms for data processing were programmed into MATLAB codes and then used for the computation of equilibrium arguments parameters required for the analysis of monthly tides. The yearly mean values of MSL were computed from monthly results. The basic equation for tide can be expressed by this general formula (Thomson & Emery, 2014; Annunziato & Probst, 2016; More, 2020; Abubakar et al., 2021).

$$h_t = h_0 + \sum_{i=1}^{m} f_i H_i Cos(E_i + u_i + n_i t - g_i) \quad (1)$$

Where,
h_0=Height of MSL above the chart datum;
f =Nodal factor;
H=Amplitude constant;
E=Phase of theoretical tide raising force at Greenwich. It increases at a rate n°/hr;
U=Nodal correction to phase lag;
N =Speed of constituents in °/hr;
t=Time of observations;
g=Phase lag constant at the place of observation;
h_t=Height of tide above chart datum;
m =Number of constituents.

From equation 1, the astronomical arguments (E) and the Nodal corrections (u and f) for each harmonic constituent are computed as functions of the five orbital elements s, h, P, N and P^1 as discussed in Merriman (1985).
Where,
s =Mean longitude of the moon, increasing by 0.0549017° per mean solar hour;
h = Mean longitude of the sun, increasing by 0. 041068° per mean solar hour;
P =Mean longitude of lunar perigee, increasing by 0.0 004642° per mean solar hour;
N =Mean longitude of the moon's ascending node, increasing by 0. 002206°;
P^1 =Mean longitude of the solar perigee, increasing by 0.000002° per mean solar hour.

These orbital elements are calculated from the following expressions:

$$s = 277.02° + 129.3848° (Y - 1900) + 13.1764° (D + i) \quad (2)$$

$$h = 280.19° - 0.2387° (Y - 1900) + 0.9857° (D + i) \quad (3)$$

$$P = 334.39° + 40.6625° (Y - 1900) + 0.1114° (D + i) \quad (4)$$

$$N = 259.16° - 19.3282° (Y - 1900) - 0.0530° (D + i) \quad (5)$$

$$P1 = 282.8° \text{ assumed for the century 1900 to 2,000} \quad (6)$$

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Where,
Y =Year of observations;
D =Number of days elapsed since January first in the year;
i= The integral part of 0.25 (Y − 1901) which is the number of leap years between 1900 and the year Y, excluding Y as the leap day in this year is counted in D (Meriman, 1985).

The MATLAB programming codes was used for monthly analysis of observed water level data for 1980, 1994 and 2018. The interval of 38 years is more than 19 years which is the required number of years of daily observations of tide for the computation of MS. Figure 2 show the stages of methodology for data processing.

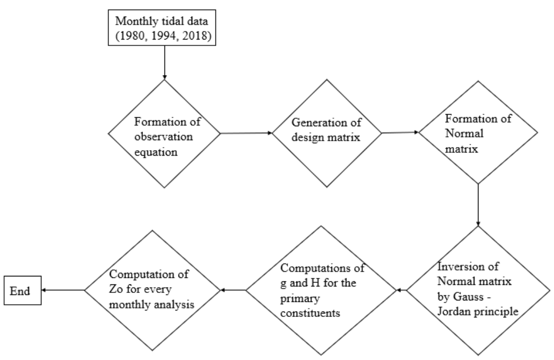

Figure 2: Methodological diagram for processing MSL(Z_o).

Statistical Analysis
The results obtained were subjected to statistical analysis using mean ($\bar{X}$), standard deviation (σ), t-test, analysis of variance (ANOVA) (Morakinyo, 2003), and regression (pairwise linear and multiple) analysis (Morakinyo, 2015; Morakinyo, 2023; Morakinyo et al., 2023). The reliability of the results was assessed by comparing the results of the monthly analysis using computed yearly mean of MSL (Z_o), computed three-year mean of (Z_o), computation of residuals of yearly (Z_o) mean, computation of residuals of 3 years (Z_o) mean, t-test, ANOVA analysis and regression analysis. For ANOVA and regression analysis, a parameter δMSL was defined for Bonny MSL in order to ascertain the quantitative verification of changes in MSL. δMSL is the difference between the 1980, 1994 and 2018 monthly MSL results. The parameter (δMSL) is used to form relationship with the each of the study year and also with the available factors (month and year) that can impact δMSL.

C

RESULTS AND DSCUSSION
Computation of Orbital Elements
The monthly value of each of the five orbital element (s, h, P, N and P[1]) for the years 1980, 1994 and 2018 were computed from equations 2-6. The results obtained are presented in Tables 3-5. The column 1 show the date of the month used for the computation, columns 2-6 show the computed value of the orbital elements.

Table 3: Computed Values of Orbital Elements for 1980

Date	S	h	P	N	P^1
16/01/1980	275.80	294.61	351.17	151.10	282.80
16/02/1980	324.27	325.16	354.80	149.46	282.80
16/03/1980	346.39	353.75	357.86	147.92	282.80
16/04/1980	034.85	024.31	001.32	146.28	282.80
16/05/1980	070.15	053.88	004.66	144.69	282.80
16/06/1980	118.61	084.43	008.11	143.05	282.80
16/07/1980	153.91	114.01	011.45	141.46	282.80
16/08/1980	202.37	144.56	014.91	139.81	282.80
16/09/1980	250.84	175.12	018.36	138.17	282.80
16/10/1980	286.14	204.69	021.70	136.58	282.80
16/11/1980	334.60	235.24	025.15	134.94	282.80
16/12/1980	009.90	264.82	028.50	133.35	282.80

Table 4: Computed Values of Orbital Elements for 1994

Date	S	h	P	N	P^1
16/01/1994	339.89	295.21	200.90	240.30	282.80
16/02/1994	028.36	325.77	204.35	238.65	282.80
16/03/1994	037.30	353.37	207.47	237.17	282.80
16/04/1994	085.77	023.92	210.92	235.53	282.80
16/05/1994	121.06	053.49	214.27	233.94	282.80
16/06/1994	169.53	084.05	217.72	232.29	282.80
16/07/1994	204.82	113.62	221.06	230.70	282.80
16/08/1994	253.29	144.18	224.51	229.06	282.80
16/09/1994	301.76	174.73	227.97	227.42	282.80
16/10/1994	337.05	204.30	231.31	225.83	282.80
16/11/1994	025.52	234.86	234.76	224.18	282.80
16/12/1994	060.81	264.43	238.11	222.59	282.80

Table 5: Computed Values of Orbital Elements for 2018

Date	S	h	P	N	P^1
16/01/2018	150.61	295.23	003.66	162.93	282.80
16/02/2018	199.08	325.80	007.11	161.29	282.80
16/03/2018	208.02	353.40	010.48	159.80	282.80
16/04/2018	256.49	023.95	013.69	158.16	282.80
16/05/2018	291.78	053.52	017.03	156.57	282.80
16/06/2018	340.25	084.08	020.48	154.93	282.80
16/07/2018	015.54	113.65	023.82	153.34	282.80
16/08/2018	064.01	144.21	027.28	151.69	282.80
16/09/2018	112.48	174.76	030.73	150.05	282.80
16/10/2018	147.77	204.34	034.72	148.46	282.80
16/11/2018	196.24	234.89	037.53	146.82	282.80
16/12/2018	231.53	264.46	040.87	145.23	282.80

Statistical Analysis
Tables 6-10 presented the computed MSL for 1980, 1994 and 2018 in m, computed MSL for the 1994 overlapping analysis, computed residual of Z_o from yearly mean, computed residuals of $Z_o$yearlymean from 3-year meanand t-test results. Figure 3 presented the results obtained for yearly MSL (Zo) mean for 1980, 1994, 2018, 1994 overlapping year, 3 years which is supported by Morakinyo (2003) and Ojinnaka (2007) and the value published in 1980 Admiralty Tidal Table (ATT).

Table 6: Computed MSL(m) for 1980, 1994 & 2018

Month	1980	1994	2018
January	1.582	1.500	1.459
February	1.599	1.573	1.503
March	1.551	1.528	1.461
April	1.524	1.519	1.453
May	1.470	1.531	1.465

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June	1.442	1.534	1.417
July	1.475	1.579	1.490
August	1.552	1.591	1.529
September	1.565	1.592	1.548
October	1.637	1.498	1.479
November	1.592	1.550	1.501
December	1.484	1.432	1.486
Total	18.472	18.429	17.794
Mean	1.539	1.536	1.483
3 Years mean		(4.558)/3 =1.519 m	

Table 7: Computed MSL (m) for 1994 Overlapping Analysis

Date	MSL (Z_o) m
January 16-February 15	1.538
February 16-March 15	1.549
March 16-April 15	1.523
April 16-May 15	1.514
May 16-June 15	1.551
June 16-July 15	1.534
July 16-August 15	1.576
August 16-September 15	1.533
September 16-October 15	1.575
October 16-November 15	1.529
November 16-December 15	1.491
Total	16.912
Mean	1.537

Table 8: Computed Residual of Z_o from Yearly Mean ($\bar{X}$)

Month	Year 1980	1994	2018
January	0.043	-0.036	-0.024
February	0.060	0.037	0.020
March	0.012	-0.008	-0.022
April	-0.015	-0.017	-0.030
May	-0.068	-0.005	-0.018
June	-0.097	-0.002	-0.066
July	-0.064	0.044	0.007
August	0.013	0.055	0.047
September	0.026	0.056	0.065
October	0.098	-0.038	-0.003
November	0.053	0.014	0.018
December	-0.055	-0.104	0.004

Table 9: Computed Residuals of Z_o Yearly Mean ($\bar{X}$) from 3-year Mean

S/N	Year	Residual
1	1980	0.020
2	1994	0.017
3	2018	-0.036

Table 10: t-test Results

Months	1980	1994	2018
January	2.272	-2.840	-2.530
February	0.271	1.930	2.160
March	0.379	-2.530	-2.480
April	-2.370	-2.670	-2.160
May	-2.680	-1.580	-2.850
June	-2.780	-3.160	-2.980
July	-2.890	2.780	1.210
August	2.110	2.898	1.970
September	2.740	2.950	1.940
October	2.820	2.000	-2.160
November	2.790	2.210	2.850
December	-2.890	1.741	2.160

Analysis of Variance (ANOVA) of Monthly Change in MSL (δMSL) for 1980, 1994 and 2018

In order to ascertain the quantitative verification of changes in MSL, a parameter δMSL was defined for Bonny MSL. δMSL is the difference between the monthly MSL which is used for 1980, 1994 and 2018 results. In order to investigate the reliability of δMSL as a true measure of changes in MSL at Bonny port, an analysis of variance (ANOVA) was carried out in order to test whether monthly δMSL and yearly δMSL results are significantly difference with a choice of significance level $\alpha = 0.01$. ANOVA analysis of monthly δMSL data was carried out; and P-values for all data i.e. from January to December 1980, 1994 and 2018 were processed; and the range of δMSL for 1980, 1994 and 2018 are obtained as presented in Table 11.

Table 11: Monthly p-values Range Computed from ANOVA

δMSL difference	p-values range	δMSL(m) range
δMSL_{1980}	0.0196-0.678	1.442-1.599
δMSL_{1994}	0.0177-0.965	1.432-1.592
δMSL_{2018}	0.0193-0.674	1.417-1.548

Furthermore, the available parameters (month and year) that are expected to influence δMSL at the Bonny port were investigated with regression analysis. Linear and non-linear relationships of regression analysis were tested against the three δMSLs (δMSL_{1980}, δMSL_{1994} and δMSL_{2018}). Only linear analysis gives better results, hence, linear relationships (pairwise and multiple) linear regressions of statistical analysis were considered for further analysis in order to assess the impacts of these factors on δMSL at the Bonny port.

Pairwise Linear Regression Analysis of δMSL_{1980}, δMSL_{1994} and δMSL_{2018}

The three-relationship considered for this analysis are as stated below:

$\delta MSL_{1980,\ 1994}$ = Relationship between δMSL_{1980} and δMSL_{1994}

$\delta MSL_{1980,\ 2018}$ =Relationship between δMSL_{1980} and δMSL_{2018}

Two scenarios considered for this analysis are (1) When $\boldsymbol{\delta}$MSLwith p-values greater than $\boldsymbol{\alpha} = 0.01$ are included; and (2) When $\boldsymbol{\delta}$MSLwith p-values greater than $\boldsymbol{\alpha} = 0.01$ are not included. The results obtained when $\boldsymbol{\delta}$MSLwith p-values greater than $\boldsymbol{\alpha} = 0.01$ were included for the analysis are presented in Table 12. Table 13 show the results for when $\boldsymbol{\delta}$MSLwith p-values greater than α = 0.01 were not used for the analysis.

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Table 12: Computed Values of r^2 and p-value with $\boldsymbol{\alpha}$ =0.01 for $\boldsymbol{\delta}MSL_{1980}$, $\boldsymbol{\delta}MSL_{1994}$ and $\boldsymbol{\delta}MSL_{2018}$

δMSL	r^2	p-value
$\delta MSL_{1980,\ 1994}$	-0.0001	0.965
$\delta MSL_{1980,2018}$	0.017	0.594

Table 13: Computed Values of r^2 and p-value with α = 0.01 for $\boldsymbol{\delta}MSL_{1980}$, $\boldsymbol{\delta}MSL_{1994}$ and $\boldsymbol{\delta}MSL_{2018}$

δMSL	r^2	p-value
$\delta MSL_{1980,\ 1994}$	0.104	0.020
$\delta MSL_{1980,2018}$	0.682	0.945

Results presented in Tables 12 and 13 shows that there is no significant difference in the results of δMSL obtained for 1980, 1994 and 2018 for the Bonny port though there is a slow gradual rise in MSL for the period of study covered as shown in the range of δMSL in Table 11.

Pairwise Linear Regression using the Factors (Month and Year)

The relationships between the δMSL's and the two available factors (month and year) were subjected to pairwise linear regression analysis with the significance level of α = 0.01. The r-values, p-values and type of correlation obtained when δMSL with p-values greater than α = 0.01 were included in the analysis are presented in the Table 14. Table 15 show r-values, p-values and the correlation type when δMSL with p-values greater than α = 0.01 were not included for the analysis. All relationships give insignificant effect as shown in the p-values obtained in Tables 14 and 15 (Morakinyo, 2015; Morakinyo, 2023; Morakinyo et al., 2023).

Table 14: r and p Values for Month and Year used to Assess $\boldsymbol{\delta}$MSL for $\boldsymbol{\alpha}$ = 0.01

Relationship	r-value	p-value	Correlation type
Month v δMSL_{1980}	0.061	0.2785	+
Month v δMSL_{1994}	0.212	0.0361	+
Month v δMSL_{2018}	0.312	0.0514	+
Year v δMSL_{1980}	0.003	0.5357	+
Year v δMSL_{1994}	-0.004	0.8156	−
Year v δMSL_{2018}	-0.0085	0.5084	−

In Table 14, the relationship between Month and each of δMSL_{1980}, δMSL_{1994} and δMSL_{2018} give + correlation and insignificant results. Only Year and δMSL_{1980} relationship give + correlation while Year versus δMSL_{1994}, and Year versus δMSL_{2018} show − correlation. Also, all relationships give insignificant results. For Table 15, the Month's three relationship show +correlations while all the Year's three relationship show − correlation. Similarly, all relationships give statistically insignificant results.

Table 15: r and p values for Month and Year used to assess $\boldsymbol{\delta}$MSL for $\boldsymbol{\alpha}$ = 0.01

Relationship	r-value	p-value	Correlation type
Month v δMSL_{1980}	0.2136	0.0672	+
Month v δMSL_{1994}	0.2234	0.0757	+
Month v δMSL_{2018}	0.2259	0.0577	+
Year v δMSL_{1980}	-0.0273	0.5376	−
Year v δMSL_{1994}	-0.1142	0.8158	−
Year v δMSL_{2018}	-0.0376	0.5284	−

Results in Tables 12-15 shows that all results obtained are statistically insignificant. This is supported by Morakinyo (2015), Morakinyo (2023) and Morakinyo et al. (2023). However, the results show little variations but the difference in their values does not have the effect on the overall MSL at Bonny port. This shows that a year data can give reliable results as when three years data are combined.

Multiple Linear Regression Analysis

This analysis helps to analyze the relationships among multiple variables. The analysis uses the estimation of a relationship y = f(x_1, x_2,..., x_k). The obtained results answer the question of how much y changes with changes in each x(x_1, x_2,...,x_k), and to predict the value of y based on the x values.

For this research, x_1 = month, x_2 = year;

$y_1 = \delta MSL_{1980}$, $y_2 = \delta MSL_{1994}$, $y_3 = \delta MSL_{2018}$

x_1, x_2 = predictor variables;

Generally, the linear model for multiple regressions is y = bx (7)

y_1, y_2, y_3= response variables and each variable is standardized as shown in equations 8-9.

Where b = relative quantitative contribution of each x predictor variable

month = [month – (meanmonth)] ÷ σ_{month} (8)

year = [year– (meanyear)] ÷ σ_{year} (9)

For this research, equation 7 has become the following:

For y_1,

$\delta MSL_{1980} = b_o + b_1 \times (month)' + b_2 \times (year)'$ (10)

For y_2,

$\delta MSL_{1994} = b_o + b_1 \times (month)' + b_2 \times (year)'$ (11)

For y_3

$\delta MSL_{2018} = b_o + b_1 \times (month)' + b_2 \times (year)'$ (12)

Where,

b_o= constant.

Table 16: Multiple Linear Regression Analysis Results for Equations 10, 11 and 12

Equation	r^2	p-value	b0	b1	b2
10	0.050	0.016	~ 0.000	0.090	0.146
11	0.050	0.011	~ 0.000	0.054	0.207
12	0.050	0.022	~ 0.000	0.069	**0.254**

The results presented in Table 16 show gradual rise of 0.254 mm in MSL for the period of 1980 to 2018 for Bonny port as explained by the month and year variables and δMSL_{1980}, δMSL_{1994} and δMSL_{2018}. Other unavailable parameter that may account for the unexplained δMSL include volume of liquid extracted at the Bonny port, and subsidence data for the port.

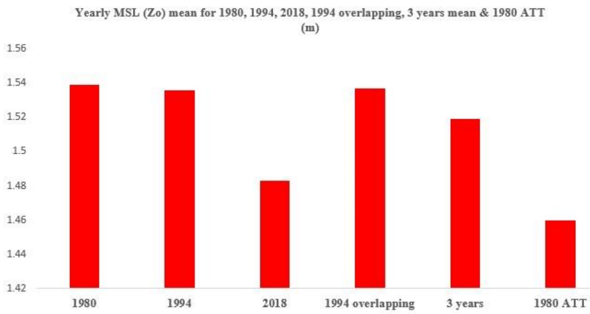

Figure 3: Yearly MSL (Zo) mean for 1980, 1994, 2018, 1994 overlapping year, 3 years and 1980 ATT

Figure 3 shows that the 1980 ATT MSL published for Bonny is 1.460 m which is lower compared to the yearly mean (1.539) m obtained for the 1980 in this study. In addition, the yearly mean for 1994 (1.536) m and 2018 (1.483) m are higher than the 1980 ATT published value. Hence, these results show that the MSL at Bonny is increasing gradually. This is supported by Ojinnaka (2007). The difference between yearly mean of 1980 and 1994 is 3.0 mm; and that of 1994 and 2018 is 5.3 mm. The annual variation between 1980 and 1994 is 0.21 mm; and for 1994 and 2018 is 0.22 mm. The variation from 1980 to 2018 is (0.210-0.220) mm.

In addition, results from ANOVA analysis, pairwise linear and multiple regression analysis discussed above show statistically insignificant. The maximum changes (0.254 mm) in the MSL obtained for the period 1980 to 2018 for the Bonny port is presented in bold in Table 16.

Conclusion

The results obtained from the analysis shows that the difference in the monthly value of MSL and the yearly mean for the Bonny port for the years studied (1980-2018) is insignificant; and that one-year MSL results can give the same results as the combine 3 years results. The difference between yearly mean and 3 years mean of MSL shows that yearly mean is as good as 3 years mean. From the study, it is evident that there is gradual rise in sea level from (0.210-0.254) mm for the period of study in Bonny which does not take into consideration the subsidence phenomenon. This is supported by the previous studies that reported increasing in the GMSL (Watson et al., 2015; Dieng et al., 2017; Nerem et al., 2017; Nerem et al., 2018; Dangendorf et al., 2019; Moreira et al., 2021) as a result of the impacts of climate change. Although, the rate is slow, however, the results obtained show that the relative sea level could be much higher because there is a lot of fluid withdrawal at Bonny. Therefore, it can be concluded that there is gradual increasing in the sea level at the Bonny, Nigeria.

Availability of continuous tidal data and lack of data on subsidence monitoring are two major challenges to this research. Hence, a further study need to be carried out using these two datasets in order to improve on the results obtained for this study. The following recommendations are made:

- Nigerian Government should ensure that daily tidal observation is taking place at Bonny;
- Nigerian Government should establish more tide gauge stations at Bonny port in order to have several readings from different gauges at the same port;
- Nigerian Government need to enforce all oil companies operating at the port and area to gather data on subsidence and submit such data to the Government;
- Nigerian Government should be strict on policy regarding sea level monitoring and management;
- Funds should be made available to both Federal and State Survey Departments and all concerned parastatals for the purpose of data gathering on seal level;
- Public relationship and awareness is an important strategy for combating sea level rise. This will help the communities to know what the problem is all about and how to solve it;
- The need to incorporate indigenous technologies in addressing the impacts of sea level rise cannot be ignored; and
- Training of more scientists is necessary in assessing and monitoring the sea level rise.

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