



## ASSESSMENT OF CLIMATE CHANGE IMPACT ON TIDAL LEVEL RISE FOR LAGOS COASTAL AREA USING STATISTICAL METHODS

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### ABSTRACT

*This paper presents an evaluation of the impacts of climate change on tidal level rise in the coastal area of Lagos State. The meteorological data such as air temperature, relative humidity, wind speed, rainfall and tidal level rise were obtained from Nigeria Meteorological Agency (NIMET), Oshodi spanning a period of 1992-2013. The meteorological parameters were subjected to statistical analysis to obtain the maximum, minimum, mean values, standard deviation, variance, coefficient of variation, coefficient of skewness values. Autoregressive moving-average (ARMA) was also adopted to fit the parameters by considering the Tidal level rise as the dependent variable while other parameters were the independent variables. The analysis revealed the value of correlation coefficient as 0.64, which is an indication of a good fit. The relationship between the predicted tidal level rise and other meteorological factors shows a downward trend with temperature and wind, while an upward trend were exhibited between the predicted tidal level rise with rainfall and relative humidity. The relationship of predicted tidal level rise with time shows an upward trend, which implies that there is tendency for increase in tidal level rise in future. The Pearson type III distribution revealed return period of 23 and 25 year for the maximum value of tidal level rise and rainfall depth of 1250mm and 368 mm respectively. The statistical distribution also revealed that tidal level rise and rainfall value of 1400mm and 430mm respectively is rear.*

**KEYWORDS:** Climate Change, tidal level rise, Lagos coast, statistical methods, ARMA

### 1.0 INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC 2007) Fourth Assessment Report gave the most acceptable definition of climate change as a change in the state of the climate that can be identified using statistical tests by changes in the mean and/or the variability of its properties, and that persists for an extended period of time typically in decades or longer. This includes shifts in frequency and magnitude of sporadic weather events as well as slow continuous rise in global mean surface temperature. Climate has great impact on water resources, biophysical and socioeconomic systems as they are highly interconnected in complex ways. A change in any one of these induces a change in another. Anthropogenic climate change adds a major pressure to every nation's water resources sustainability especially in Africa. Adefolalu (2007) quoted United Nations Framework Convention on Climate Change (UNFCCC) to have defined climate change as an attribute directly or indirectly affecting human activities and which alters the composition of global atmosphere, in addition to natural climate variability

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observed over comparable time periods. The climate change could be caused by natural or/and anthropogenic factors.

Researchers have shown that for the past few decades, anthropogenic factors like urbanization, deforestation, population growth, industrialization and the release of greenhouse gases such as carbon dioxide contribute to the depletion of the ozone layer and result in global warming and climate change (Buba, 2004; Porbeni, 2004; Odjugo, 2007). Study has shown that impact of climate change was noticed in the coastal areas of Lagos State in a decade tidal level rise increase by 0.3 m and rainfall increase by 5mm (Nwilo 1995). These tidal level rise and precipitation caused serious coastal erosion, flooding of the houses, inundation, destruction of the roads and the beaches, salinity intrusion into the coastal lagoons and sources of

water for domestic use in Victoria Island and other parts of the Lagos coast. In some cases up to 20 m of the beach was lost in a single Tidal event. Victoria Island is of much concern because it is fully developed, has several private, public and commercial houses and is about the most expensive part of Nigeria. Recent experiences in Victoria Island and other coastline show that the tidal level rise is becoming more frequent. The more frequent occurrences of tidal level rise could be attributed to the global sea level rise, subsidence, topography and the concentration of several heavy infrastructures in an island that is already subject to natural compaction (Nwilo, 1995). Tidal level rise could equally be dependent on meteorological variables being influenced by climate change (Ikpee, 2015). The above identified problems have been attributed to climate change among other things. It is imperative therefore to study the impact of climate change on the coastal area of Lagos in order to confirm the aforementioned climate change impact and to predict the future trend.

## 2.0 THEORETICAL BACKGROUND

A multiple linear regression analysis was carried out to form a model for the prediction of the values of a dependent variable,  $Y$ , given a set of  $p$  explanatory variables  $(x_1, x_2, \dots, x_p)$ . In this paper, the necessary theory for multiple linear regressions is applied and the regression analysis is carried out on data collected from the Meteorological Station for the development of a model that can be used to predict the behaviour and dependence of the tidal level rise. The models can be in many forms ranging from simple linear equations to complex equation and more tedious algebra like quadratic, exponential, trigonometry etc. examples. Among other techniques, Autoregressive-Moving-Average (ARMA) models are mathematical models of the persistence, or autocorrelation, in a time series. ARMA models are widely used in hydrology, econometrics, and other fields. Here, simple equations were developed and the best that shows the representation of the behaviour of the system was used. Complicated or tedious algebra are avoided. The multiple linear regression analysis is the simple linear regression. It is carried out to estimate the relationship between a dependent variable,  $Y$ , and a single explanatory variable,  $x$ , given a set of data that includes observations for both of these variables for a particular observation. There are several possible reasons for fitting ARMA models to data. Application of ARMA models in short-term rainfall prediction for real-time flood forecasting was investigated

by Sunyyoung et al. (1998). They used three models including ARMA, ANNs and nearest-neighbour approaches. Whitford (2001) compared an ARMA ( $p, q$ ) model with an ANN to forecast time series. He presented a summary of other researchers' work and concluded that ANNs are not better than traditional ARMA models in performance if there is no non-linearity in the data. There have been several attempts to estimate the parameters of ARMA models by different researchers (Yeon, 1988). Most of these methods are based on the Kalman filter which needs a great amount of computation. Monte-Carlo experiments have shown that for ARMA models with relatively short lengths of data, e.g. 50 or 100 observations, exact maximum likelihood estimation is far superior to conditional maximum likelihood estimation or least-squares estimation (Witford, 2001). Recently, artificial neural network techniques have been used to estimate ARMA parameters. Chen and Banner (2000) showed that an ANN is not able to estimate the order of ARMA models accurately when the number of data points is less than 100. Advances in computers have assisted in solving the estimation and it is possible to compute large matrices and obtain the answers in a short time

As stated earlier, dependence is very common in time series observations. To model with ARMA, the time series dependence is normally started with univariate ARMA models and then preceded to multivariate ARMA depending though on the available variables from which the forecast is to be made. To motivate the model, basically we can track two lines of thinking. First, for a series  $X_t$ , we can model that the level of its current observations depends on the level of its lagged observations. One would expect that where there is increase in the observation at a particular time there would also be at another time period in a trend. This way of thinking can be represented by an AR model. AR model is also called autoregressive model. It is one of the subsets of ARMA models. An AR model expresses a time series as a linear function of its past values. The order of the AR model tells how many lagged past values are included. The results are then improved upon by the MA model, the so-called moving average model which is another subset of the ARMA. The ARMA ( $p, q$ ) is one of the most used techniques in time series analysis where  $p$  is the order of the AR and  $q$  is the order of the MA. The ARMA model is represented in Equations 1- 8 as:

$$\text{AR: } \phi(L)X_t = \epsilon_t \quad (1)$$

$$\text{MA: } \Theta(L)\epsilon_t = X_t \quad (2)$$

$$\text{ARMA: } \Phi(L)X_t = \Theta(L)\epsilon_t \quad (3)$$

Finally, given an invertible ARMA (p, q) process,

$$\Phi(L)X_t = \Theta(L)\epsilon_t \quad (4)$$

$$X_t = \Phi(L)^{-1}\Theta(L)\epsilon_t \quad (5)$$

$$X_t = \Psi(L)\epsilon_t \quad (6)$$

So, since,

$$\Phi(L)^{-1}\Theta(L)\epsilon_t = \Psi(L)\epsilon_t \quad (7)$$

$$\Theta(L) = \Phi(L)\Psi(L) \quad (8)$$

The normal or Gaussian distribution is frequently used distribution for describing hydrologic variables. It provides a reasonable approximation in the central, but is inadequate at one or both tail of the distribution (Warren et al., (1972); Mustapha and Yusuf, (1999)). The normal probability distribution is for random variable with parameter mean ( $\mu$ ) and standard deviation ( $\sigma$ ). It has a general formula of the form given in equation (9).

$$Q_{Tr} = Q_{av} + k\sigma \quad (9)$$

Where,  $Q_{Tr}$  is the predicted variable for a return period of  $T_r$  (year);  $Q_{av}$  is the average value of the parameters;  $\sigma$  is the standard deviation,  $k$  is a parameter depending on probability or return period and can be selected for a particular probability or returned period from the standard normal distribution table available in many text books or statistics.

Since normal distribution only provides a reasonable approximation in the central, inadequate at one or both tail of the distribution (Warren *et al.* (1972); Mustapha and Yusuf (1999)). There is need to consider another distribution that considered the skewness tendency of the hydro-meteorological variables. The Pearson type III is a probability distribution model which shows that hydro-meteorological variables are rarely normally distributed. A histogram of such series is usually skewed in that the mean value does not coincide with the mode. The Pearson type III model is similar to the normal distribution model in estimating future events, with the additional complication of using a skew coefficient ( $G$ ) given as

$$G = \frac{n^2(\sum \log Q)^3 - 3n(\sum \log Q)(\sum (\log Q)^2) + 2(\sum \log Q)^3}{n(n-1)(n-2)(\sigma_{\log Q})^3} \quad (10)$$

The event of the future is obtained as

$$\text{Log}Q_{Tr} = \log Q_{av} + k'\sigma_{\log Q} \quad (11)$$

Where  $k'$  can be selected for a particular probability or returned period and skew coefficient  $G$  from standard tables.

### 3.0 MATERIALS AND METHODS

#### 3.1 Study Area

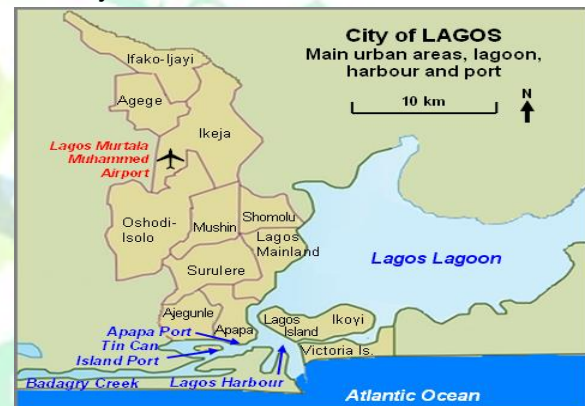


Figure 1: Lagos City Map

Source: Gandy (2005)

Lagos is Africa's second most populous city after Cairo in Egypt. Lagos State, which was created in 1967, served as the capital of Nigeria up till December 12th, 1991. It has grown spatially from a traditional core settlement of about 3.85 km<sup>2</sup> in 1881 to a huge metropolis of over 1,183 km<sup>2</sup>. Metropolitan Lagos constitutes about 33% of Lagos State, with 455 km<sup>2</sup> of the metropolis being water bodies, wetlands and mangrove swamps. It is a group of islands surrounded by creeks and lagoons and bordered by the Atlantic Ocean. It lies between latitude 4° 10' and 6° 20' N, and longitude 2°45' and 8° 35'E, adjacent to the Gulf of Guinea. A common feature of this geomorphic zone is their low-lying nature. Most areas along these zones are less than 3m in elevation. With a GDP triple that of any other West African countries; Lagos is the commercial and industrial hub of Nigeria, home to many industries and has much larger commercial infrastructure. An overview of the

state of Nigerian cities particularly Lagos is shown in Figure 1 (Gandy, 2005). Victoria Island is located approximately between latitudes 06°25'00" and 06°26'20" and longitudes 03°24'00" and 03°25'00" (Balogun, 1995). It is located immediately east of the sea entrance into Lagos harbour. On the south it is bounded by the Atlantic Ocean, on the north by the Five Cowrie Creek, and on the east by the Kuramo Waters and the Igboere Creek. This is, however, only an administrative boundary as the beach continues as a narrow strip between the sea and Lagos Lagoon further inland and merges at about 5 km distance with the Ilado-Maroko beach (Ibe, 1988).

### 3.2 Data collection

The data required for this study are the meteorological data which includes rainfall, tidal level rise, air temperature, relative humidity and wind speed which were obtained from the Nigeria Meteorological Agency (NIMET) Oshodi, Lagos. The sampling station for this study is the Victoria Island marine station. The data available are presented in Table 1.

### 3.3 Data Analysis

#### 3.3.1 Statistical Summary

The hydro-meteorological parameters were subjected to statistical analysis such as maximum, minimum, mean values, standard deviation, and variance, coefficient of variation and coefficient of skewness. The statistical summary for the analysis such as maximum, minimum, mean values, standard deviation, and variance, coefficient of variation and coefficient of skewness coefficient results are presented in Table 2.

Table 1: Meteorological Parameters with Years at Victoria Island Marine station

| S/No | Meteorological Parameters | Years of Record |
|------|---------------------------|-----------------|
| 1    | Air temperature           | 1992 - 2013     |
| 2    | Rainfall                  | 1992 - 2013     |
| 3    | Relative Humidity         | 1992 - 2013     |
| 4    | Wind Speed                | 1992 - 2013     |
| 5    | Tidal level               | 1992 - 2013     |

Source: NIMET Oshodi, Lagos

Table 2: Statistical summary of hydro-meteorological variables (1992 - 2013)

| Summary of statistics         | Parameters           |                  |               |                       |                  |
|-------------------------------|----------------------|------------------|---------------|-----------------------|------------------|
|                               | Tidal level rise (m) | Temperature (°C) | Rainfall (mm) | Relative humidity (%) | Wind speed (m/s) |
| Mean                          | 0.80                 | 26.57            | 165.51        | 79.33                 | 4.55             |
| Median                        | 0.74                 | 26.78            | 140.70        | 79.88                 | 4.49             |
| Standard Deviation            | 0.24                 | 0.93             | 101.37        | 3.25                  | 1.07             |
| Coefficient of Variation (CV) | 0.29                 | 0.04             | 0.69          | 0.04                  | 0.24             |
| Skew                          | 0.65                 | -0.90            | 0.83          | -0.24                 | 0.00             |
| Minimum                       | 0.51                 | 24.56            | 43.36         | 72.95                 | 2.82             |
| Maximum                       | 1.25                 | 27.61            | 368.64        | 83.86                 | 6.29             |

#### 3.3.2 Auto Regressive Moving Average (ARMA) model

The computer programming language (MATLAB) was adopted to develop the Auto Regressive Moving Average (ARMA) model. The 252 monthly data sets of air temperature, relative humidity, wind speed, tidal level rise and rainfall were analyzed and a scatter plot was generated. In the analysis, air temperature, relative

humidity, wind speed, tidal rise and rainfall data were used as input, while the tidal level rise data were used as output data. The network's output (predicted tidal value) was compared with the observed tidal level rise and other meteorological variables. The Auto Regressive (AR) model was used and the generated model is presented in equation (12).

$$TR = -0.0513T - 0.0378W + 0.0163RH + 0.0004R + 0.9891 \quad (12)$$

Where: T = Air temperature (°C)

Ws = Wind speed (m/s)

RH = Relative humidity (%)

R = Rainfall (mm)

TR = Tidal level rise (m)

The correlation coefficient (r), the Mean Square Error (MSE), Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) are the performance criterion for the regression stage and obtained as 0.64, 0.12, 0.34 and 0.26 respectively. The predicted Tidal level rise values were plotted against the observed tidal level rise, period, temperature, rainfall, relative humidity and wind speed and their relationships are presented in Figures 2– 7 along with the value of the coefficient of determinations.

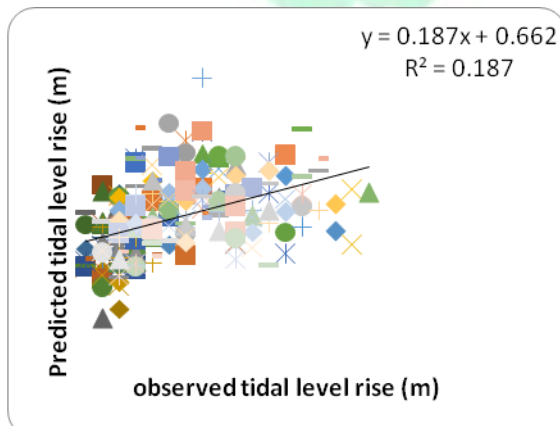


Figure 2: Predicted Tidal rise versus observed Tidal level rise

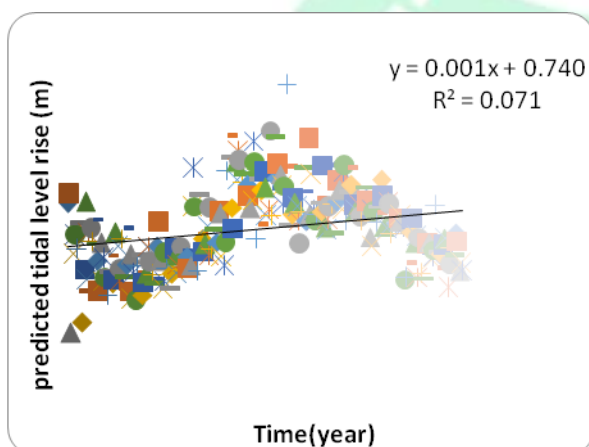


Figure 3: Predicted Tidal level rise versus Time

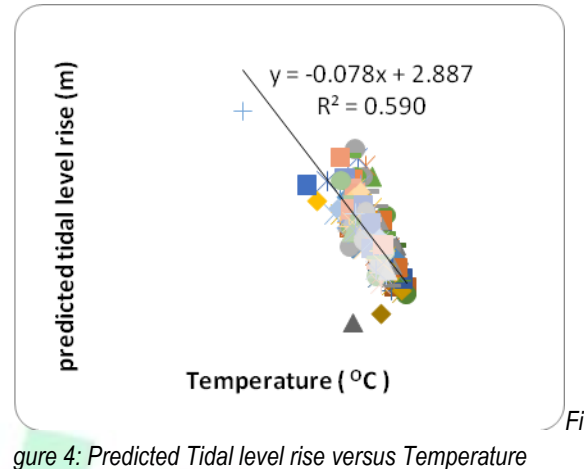


Figure 4: Predicted Tidal level rise versus Temperature

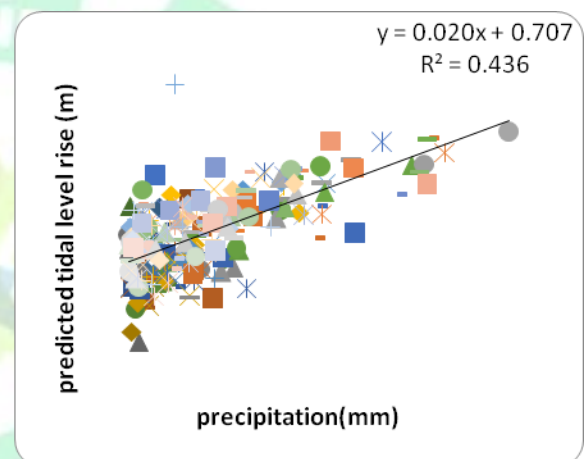


Figure 5: Predicted Tidal level rise versus Rainfall

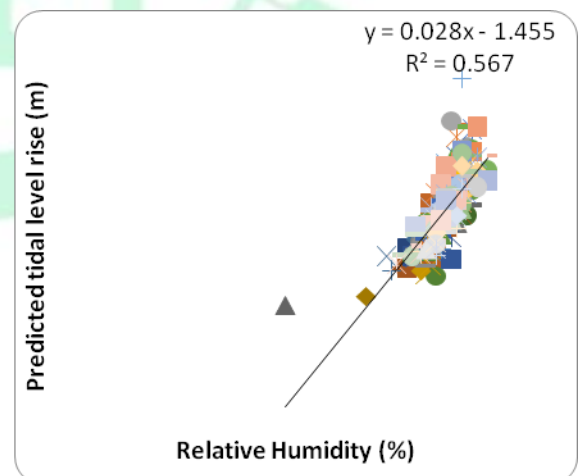


Figure 6: Predicted Tidal level rise versus Relative Humidity

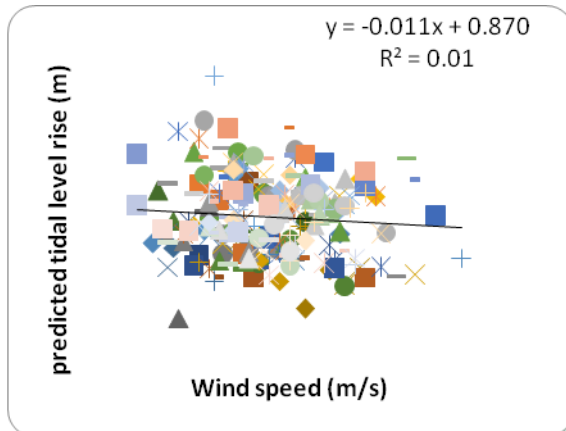


Figure 7: Predicted Tidal level rise versus Wind speed

This analysis involves estimation of regression parameters for the AR which is normally used to determine the parameters of the Moving Average (MA) that in turn improve the AR for the ARMA model. The AR generated

was turned to excel to generate the MA displayed as the various graphs; the parameters for each input are adjusted by the moving average. The performance indicator of predicted tidal level rise with the observed Tidal level rise, Temperature, Rainfall, Relative humidity and wind speed are presented in Table 3.

Table 3 Relationship between the predicted tidal level rise and other variables

| Hydro-meteorological variables         | Predicted Tidal level rise | Temperature | Rainfall | Relative humidity | Wind Speed |
|----------------------------------------|----------------------------|-------------|----------|-------------------|------------|
| Coefficient of determination ( $R^2$ ) | 0.19                       | 0.59        | 0.44     | 0.57              | 0.01       |
| Correlation coefficient (r)            | 0.43                       | 0.77        | 0.66     | 0.75              | 0.1        |

### 3.3.3 Fitting of probability distributions for prediction

The statistical summary of the variables presented in Table 2 was adopted to establish normal equation for Tidal level rise and precipitation as presented in equations (13) and (14).

Tidal level rise,  $TR$  (m):

$$TR_T = 0.8 + 0.24k \quad (13)$$

Rainfall,  $R$  (mm):

$$P_T = 165.51 + 101.37k \quad (14)$$

The equations were used to estimate the return periods for the maximum values of the two parameters. The results obtained are presented in Table 4.

Similarly, the established Pearson type III equations for Tidal level rise and precipitation are presented in equations (15) and (16).

Tidal level rise,  $TR$  (m):

$$TR_T = 0.8 + 0.24k' \quad (15)$$

Rainfall,  $R$  (mm):

$$P_T = 165.51 + 101.37k' \quad (16)$$

The equations were also used to estimate the return periods for the maximum values of Tidal level rise and precipitation and presented in Table 4.

Table 4: The return period for maximum Tidal level rise and Precipitation

| Hydrological variables   | Maximum Values | Skewness coefficient | Return periods $T_r$ (Year)Normal distribution | Return periods $T_r$ (Year) Pearson type III |
|--------------------------|----------------|----------------------|------------------------------------------------|----------------------------------------------|
| Tidal level rise, TR (m) | 1.25           | 0.65                 | 25                                             | 23                                           |
| Rainfall, R (mm)         | 368.64         | 0.83                 | 46                                             | 25                                           |

However, the Normal and Pearson type III statistical distribution models presented in equations (12), (13), (15) and (16) were used to determine the probabilities of various values of Tidal level rise and rainfall. The probabilities estimated for each hydrological variable based on normal and Pearson type III distribution models are presented in Table 5.

#### 4.0 DISCUSSION

The hydrometeorological variables used for the analysis and the year of records are presented in Table 1, while the statistical parameters such as mean, median, standard deviation, coefficient of variation, skewness coefficient,

minimum and maximum values are presented in Table 2. The maximum values for tidal level rise, temperature, rainfall, relative humidity and wind speed are obtained as 1.25m, 27.61°C, 368.64 mm, 83.86 % and 6.29 m/s respectively, the mean values are 0.80 m, 26.57°C, 165.51 mm, 79.33 % and 4.55 m/s respectively, while the standard deviation are 0.24m, 0.93°C, 101.37 mm, 3.25 % and 1.07 m/s ,respectively and the skewness coefficient values are 0.65 m, -0.90°C, 0.83 mm, -0.24% and 0.00 m/s, respectively.

Table 5: Probabilities for various Tidal level rise and rainfall values

| Tidal levelrise (m) | Normal distribution | Pearson type (III) distribution | Rainfall (mm) | Normal distribution | Pearson type (III) distribution |
|---------------------|---------------------|---------------------------------|---------------|---------------------|---------------------------------|
|                     | Probability (%)     |                                 |               | Probability (%)     |                                 |
| 1.40                | -                   | -                               | 430           | -                   | -                               |
| 1.39                | -                   | 0.06                            | 425           | -                   | 0.04                            |
| 1.38                | -                   | 0.99                            | 420           | -                   | 1.13                            |
| 1.35                | -                   | 3.80                            | 410           | -                   | 3.30                            |
| 1.32                | -                   | 6.62                            | 400           | -                   | 5.47                            |
| 1.31                | 0.55                | 7.55                            | 368           | 3.46                | 12.29                           |
| 1.30                | 1.55                | 8.49                            | 350           | 7.84                | 16.32                           |
| 1.25                | 6.53                | 13.17                           | 300           | 19.63               | 27.17                           |
| 1.00                | 31.41               | 36.59                           | 250           | 31.41               | 38.02                           |
| 0.75                | 56.30               | 60.00                           | 200           | 43.19               | 48.87                           |
| 0.50                | 81                  | 83.42                           | 150           | 54.98               | 59.73                           |

The ARMA model revealed a good fit between the tidal level rise with other variables, the performance indicator values of MAE, RMSE, MSE and Correlation coefficient (r) values were obtained as 0.2606, 0.1154, 0.3398 and 0.64 respectively. This is an indication of good fitness of the observed and predicted tidal level rise.

The graphical relationship established between the predicted tidal level rise with time and other hydro

meteorological parameters shows that the predicted tidal rise exhibited positive relationship with rainfall and relative humidity, while it exhibited negative relationship with temperature and wind speed. The relationships are depicted in Figures 2 - 6. The implication of the relationship of tidal level rise with rainfall and relative humidity is upward trend which implies that the higher the rainfall and relative humidity there is tendency for tidal level rise to

increase. Conversely, the relationship of tidal level rise with temperature and wind speed is downward trend which implies that the higher the temperature and wind speed there is tendency for reduction in tidal level rise.

Normal and Pearson type III statistical distributions methods were adopted to fit the tidal level rise and rainfall in order to predict the return period of the maximum values of the two parameters. The estimated return periods for maximum tidal level rise and rainfall were presented in Table 4. The return period obtained for maximum value of tidal level rise (1250 mm) based on Normal and Pearson type III distributions are 25 year and 23 year respectively. While the return period obtained for maximum value of rainfall (368 mm) based on Normal and Pearson type III distributions are 46 year and 25 year respectively. The high value of return period of 46 year obtained for rainfall based on Normal distribution may be due to inability of normal distribution to handle the high value of skewness coefficient exhibited by the precipitation data.

The Normal and Pearson type III distribution models presented in equations (13), (14) and (15), (16) were used to predict probabilities for various values of tidal level rise and rainfall presented in Table 5. It could be observed that Pearson type III distribution was found to be able to estimate lower values of probabilities than normal distribution; this could be due to level of skewness exhibited by the two variables. The probabilities obtained for various tidal level rise and precipitation values indicated that tidal level rise value of 1400mm is rare, while rainfall depth value of 430mm is rare.

Apart from the established scientific fact that tidal level rise is caused by the gravitational pull of the moon, it can be affirmed from this study that tidal level rise could be influenced by meteorological variables.

## 5.0 CONCLUSION

The implication of this study is that, there is tendency for increasing in tidal level rise relative humidity and rainfall, while there is tendency for decreasing in temperature and wind speed. The autoregressive moving average (ARMA) model for tidal rise have Correlation Coefficient ( $r$ ) of 0.64, showing good fitness, thus ARMA model is a very versatile tool in water resources management with good reference to Lagos coastal area. From this work it can be inferred that the Lagos coast is prone to flood due to tendency of tidal level rise to increase due to excessive rainfall. The return period obtained for maximum value of tidal level rise of 1250mm

and rainfall of 368mm is 23 and 25 year respectively based on Pearson type III statistical distributions which take the level of skewness exhibited by the two variables into consideration. It was also revealed that tidal level rise and rainfall depth values of 1400mm and 430mm respectively are rare. It is recommended that flood control measures should be put in place to mitigate the impact on life and properties.

## 6.0 ACKNOWLEDGMENTS

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