SEA LEVEL PREDICTION MODEL FOR COLOMBO COASTAL AREA USING MATLAB SOFTWARE

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Abstract - Sea level rise can be explained as an increase in the volume of water in the oceans of the world. But the rates of rise over local areas are variable. There are several reasons for the rise of the sea level; mainly thermal expansion of the sea and melting of ice caps. Sea level has significant impact on construction industry near coastal areas in the world. It affects Sri Lankan coastal areas also, especially in the Colombo coastal area. So, it is necessary to do an analysis on the tide gauge data collected from 2006-2018 in the Colombo coastal area, and build a model to predict the sea level to minimize the impact from rising sea level for future construction projects. The tide gauge data collected can be displayed as a frequency distribution with time as the x axis and Sea Level as the y axis. Missing values will be filled with linear interpolation. Then the wave type distribution will be decomposed until a residual can be gained from it using Empirical Mode Decomposition (EMD) method. After that the residual will be selected from the Intrinsic Mode Functions (IMFs) that has been created from the EMD process. The selected residual will be then curve fitted using a polynomial interpolation technique of a higher degree. Then the fitted curve extrapolated to a given time domain, following which the prediction results can be given. Analysis of the sample data of 8 months of Tide gauge data resulted in an unreliable prediction result but it was closer to the current prediction levels of the Intergovernmental Panel on Climate Change.

Keywords: Sea level rise, Prediction, Tide Gauge data, Intrinsic Mode Functions, Residual, Curve fitting, Polynomial interpolation

I. INTRODUCTION

A sea level rise can be explained as an increase in the volume of water in the oceans of the world. But the rate of rise over local areas are variable. There are several reasons for the rise of the sea level and they are

i. Thermal expansion of the sea (Mainly)
ii. Melting of Ice caps
iii.Freshwater content flowing to the sea
iv. Salinity
v. Density

Etc…

Rising sea level makes a significant impact for construction sites near coastal areas since the construction in these sites does not stop for few years but instead of that the people continuously construct and upgrade components in these sites for centuries. Main impacts can be categorized as follows…

i. exacerbated inundation and flooding of low-lying coastal areas
ii. increased coastal erosion
iii.effects on coastal ecosystems such as salt marsh, mangroves and coral reefs
iv. salt water intrusion into estuaries and aquifers
v. changes in sediment deposition along river channels

the research focuses on finding a sea level prediction model for the Coastal area around Colombo and analysing the impact caused by the sea level rise for the construction sites.

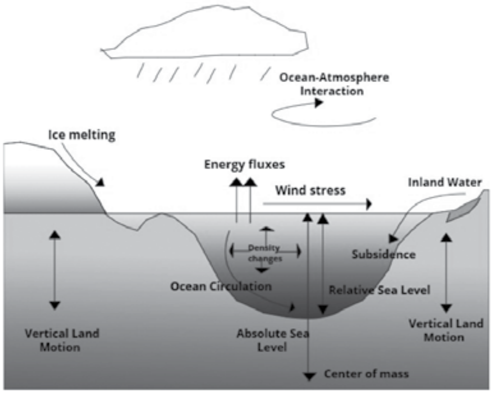

Figure 1. Process that influence Regional Sea level

The research type is analytical research which uses the Tide Gauge data for the analysis and prediction of the sea level. The Colombo tide station tide gauge data collected over decades were stored IOC Sea Level Monitoring Facility website. The data collected can be displayed as a frequency distribution with time as the x axis and Sea Level as the y axis. But there may be missing values. These missing values will be filled with linear interpolation. Then frequency distribution or the wave type distribution will be decomposed until a residual can be gain from it using Empirical Mode Decomposition(EMD) method. After that the residual will be selected from the Intrinsic Mode Functions(IMFs) that has been created from the EMD process. The selected residual will be curve fitted using a polynomial interpolation technique of a higher degree. Then the fitted curve will be extrapolated to a given time domain. Then the prediction results can be given.

The Research hypothesis is the Sea Level near Colombo shore line rises impacting the construction sites within 200 years.

Scope and the delimitations of the study:

i. Data Collection for a Sea Level prediction there must be sea level data collected for more than 19 years. But there were only 12 years of raw data in Colombo tide gauge (pressure gauge). Also from that data only 3 years of refined raw data were collected for processing. This raw sea level data must be refined again for wind wave errors.

ii. For the Data collection only, the pressure gauge sensor data were taken as recommended by the National Aquatic Resources Research and Development Agency (NARA) staff.

iii. Full physical understanding of the Ocean is lacking.

iv. For the processing part need high powered computers which are networked since lots of data are involved in the process.

II. LITERATURE REVIEW

A. Sea Level Change:

Sea level changes anytime over the sea are a composite of a Global Mean Sea Level change and regional procedures. Generally ocean level speaks to the mean height of the ocean sea surface as estimated either as for Earth's centre point of mass (absolute sea level) or, then again, with respect to the crust or ocean bottom (relative sea level). Figure 1 describes the above schematically. Procedures prompting changes in sea level are connected on the global scale to changes in the aggregate mass (freshwater content) as well as volume (warm content) of the seas, but at the same time it is related with geometric distortions of the ocean bottom. On regional scales, sea level can be influenced by changes in the Atmosphere and Oceanic circulation (from this point forward referred to as powerful changes) and by solid Earth processes, i.e., huge scale deformations of ocean basins and varieties in Earth's gravity field in addition to nearby ground movement impacts (henceforth referred to as static changes). (Stammer et al., 2013).

B. Current Rate of Sea Level Rise:

The time mean rate of Global Mean Sea Level rise during the 21st century is very likely to exceed the rate of 2.0 [1.7 to 2.3] mm yr–1 observed during 1971–2010 (Boretti, 2011, 2012b, 2012a, 2012c, 2013a, 2013b. 2013c; Boretti and Watson, 2012; Parker, 2013a, 2013b, 2013c). It is very likely that the mean rate of global averaged sea level rise was 1.7 [1.5 to 1.9] mm/yr between 1901 and 2010 and 3.2 [2.8 to 3.6] mm/yr between 1993 and 2010 (IPCC, 2014).

C. Empirical Mode Decomposition(EMD):

It is a method of breaking down a signal while staying within the given time domain. This method is useful for analysing most often non-linear and no-stationary natural signals such as sea level. EMD filters out functions which form a whole and almost orthogonal basis for the authentic signal. Completeness is primarily based at the method of the EMD; the manner it is decomposed implies completeness. The functions, referred as Intrinsic Mode features (IMFs), are therefore enough to describe the signal, even though they may be now not necessarily orthogonal. The way that the functions into which a signal is decomposed are all in the time-domain and of the same length from the first signal considers differing frequencies in time to be protected. (Lambert et al., 2018).

III. METHODOLOGY AND EXPERIMENTAL DESIGN

A. Algorithm or the Model:

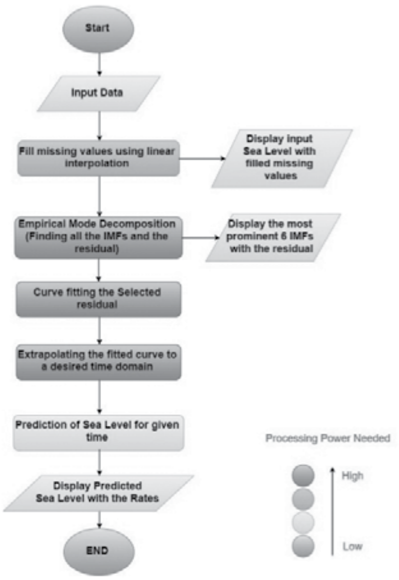

Figure 1. Process that influence Regional Sea level

B. Input Data:

12 years of data were selected from the IOC Sea Level Monitoring facility website from 2006-2017. But from those 12 years, 3 years of data were selected since they were collected continuously without corruption. Collected data were saved as Data Sheets in a .xlsx format book and named as "sea-level.xlsx". while collecting missing data entries at the start and end of sheets were removed. This "sea-level.xlsx" file was set as the input data file for the Model or the program created.

C.Filling the Missing values:

There were missing values inside the Data Sheets. Those entries should be filled for continuous arrangement of data. Linear interpolation was adapted for filling the existing gaps. There the missing values and the 0 valued entries were converted to NaN (Not a Number) values. After that those values were called and filled with linear interpolation. Significant amount of processing power is needed for this process.

D. Displaying the Input Sea Level with filled missing values:

Then a graph will be shown to examine the continuousness of the sea level data with time as the x axis and the sea level as the y axis.

E.Empirical Mode Decomposition (Finding all the IMFs and residual):

1) The EMD will decompose a frequency distribution or a signal into its segment IMFs.

2) An IMF is a function that:
   i. has just a one extreme between zero intersections, and
   ii.has a mean value of zero.

3) The filtering Process

The filtering process is the thing that EMD uses to fragment the signal into IMFs.

For a signal X(t), let m1 be the mean of its upper and lower envelopes as decided from a cubic-spline interpolation of local maxima and minima. The locality is controlled by an arbitrary parameter; the processing time and the viability of the EMD depends extraordinarily on such a parameter.

i. The first segment h1 is processed:

$$h_1 = X(t) - m_1$$

ii. In the second filtering process, h1 is dealt with the data, and m11 is the mean of h1's upper and lower envelopes:

$$h_{11} = h_1 - m_{11}$$

iii. This filtering system is repeated k times, until the point when h1k is an IMF, that is:

$$h_{1(k-1)} - m_{1k} = h_{1k}$$

iv. Then it is assigned as c1=h1k, the main IMF part from the data, which contains the most limited time frame segment of the signal. We isolate it from whatever is left of the information: X(t)- $c_1 = r_1$The strategy is repeated on rj: r_1-c_2 = r_2, ... ,rn-$_1$ - cn = rn

v. The result is an arrangement of functions; the quantity of functions in the set relies upon the original signal.

4) Following image shows the IMFs and the residual that resulted from the EMD processing of Sea Level Data.

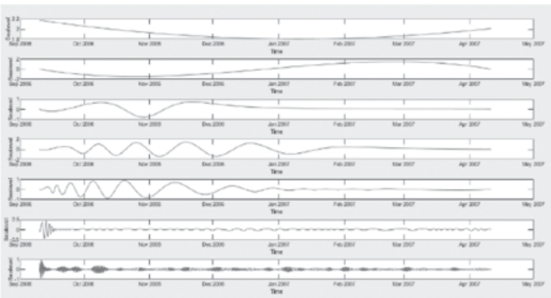

Figure 4 : Example for IMFs and the residual

Each IMF shows different segments or components of the signal, giving an excellent breakdown or decomposition of the original signal. The residual can be identified as the trend of the signal. Very High amount of processing power is needed for this process.

F. Curve fitting the selected residual:

The residual or the last IMF is selected from the group of IMFs created by the EMD process of the model. Then fitting the residual curve with 95% confidence level. The curve fitting is done according to a higher desired polynomial degree (3 or 4 depends on the existing residual curve). Significant amount of processing power is needed for this process.

G. Extrapolating the fitted curve to a desired time-domain:

The fitted curve is used for the extrapolation of the residual or the trend of the past Sea level to a desired time domain with 95% confidence interval. Significant amount of processing power is needed for this process.

H. Prediction of Sea level for a given time:

By analysing the extrapolated data of the residual, we can get the di sea level rising rate can be calculated.

I.Displaying the predicted Sea level with the rate:

The predicted or extrapolated sea level and the sea level rising rate will be displayed.

IV. DATA COLLECTION

Tide gauge data from the Colombo Tide station was collected from following source :IndianOceanSeaLevelMonitoringfacility<http://www.ioc-sealevelmonitoring.org/station.php?code=colo>.From 2006/09/10 to 2010/02/27; about 3 years of data were selected for the processing part. The following diagram shows the schematic of the pressure gauge established at the Colombo station.

Pressure tide gauges measure the water pressure over the sensor. Regardless of whether pneumatic, strain gauges or quartz crystals, they don't require a stilling well. They should be immersed sufficiently so they stay submerged during equinox low tides. Set on the seabed, they measure the ambient pressure, which reflects the height of the water column and the atmospheric pressure at the surface. It is valuable to know atmospheric pressure and the water density to decide water depths.

Let's consider the pressure sensor located and set on the seabed.

i. H : depth of the measurement location (average immersion of the sensor)
ii. h (t) : the change in sea level, a function of time t and the zero mean h(t) = 0
iii. p (t) : the pressure measured by the sensor
iv. pa (t) : the atmospheric pressure at sea level,
vi. ρ : the average density of the sea water (a function of temperature, salinity, the effect of the pressure being neglected for immersions less than a few hundred meters) on the height H h (t),
vii. G: the acceleration of gravity

The pressure given by the sensor is equal to the sum of the atmospheric pressure and the hydrostatic pressure,

$$p(t) = p_a(t) + \bar{\rho}\mathrm{g}[\mathrm{H} + \mathrm{h}(t)]$$

The height of water above the bottom sensor is:

$$\mathrm{H} + \mathrm{h}(t) = \frac{[p_a(t) - p(t)]}{\bar{\rho}\mathrm{g}}$$

p(t) - pa (t) is measured directly by some systems, this differential pressure equal to the hydrostatic pressure of the water column. But this means that atmospheric pressure measurement must be available at the differential sensor through an air intake, which is not feasible when the unit is submerged far from the shore. Moreover, in some applications, especially in the field of physical oceanography, the pressure p(t) is the useful information. Thus, to determine changes in sea level h(t) at sea based on pressure on the seabed p(t) three variables must be known:

i. g
ii. pa (t)
iii. (ρ)

About the acceleration of gravity g, it varies with latitude L according to the formula (in m/s^2)

$g = 9.7803185 (1 + 0.005302357 \sin^2 L - 0.0000059 \sin^2 2L)$ m/s^2

V. DATA ANALYSIS

1) For the data analysis from the 3 years of continuous dataset 8 months of sample sea level data were selected to do the analysis.

2) The selected data were subjected to fill missing values process. There the linear interpolation is used to interpolate the missing values.

3) Then the fully continuous data set is subjected to Empirical Mode Decomposition method so that it can simplify the complex signal until it gives the valuable residual or the trend.

4) This Trend is subjected to curve fitting by using polynomial interpolation technique.

5) Then the prediction is done from 2007-04-11 to 2008-04-11.

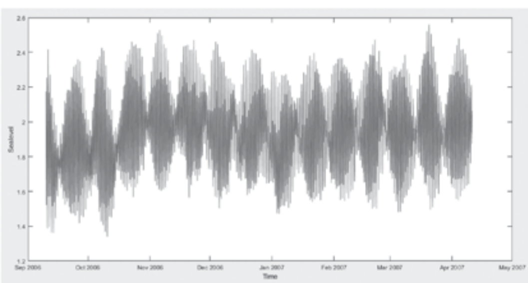

Figure 8. 8 months of Sea Level data with filled missing values

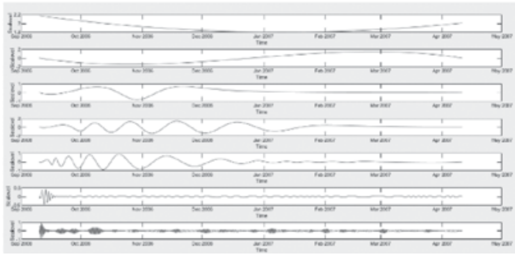

Figure 5 : Example for IMFs and the residual

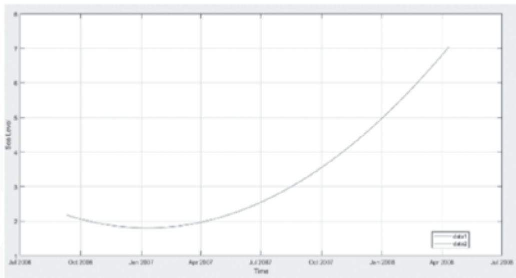

Figure 6: Predicted Sea Level data(Data 2), Collected data(Data1)

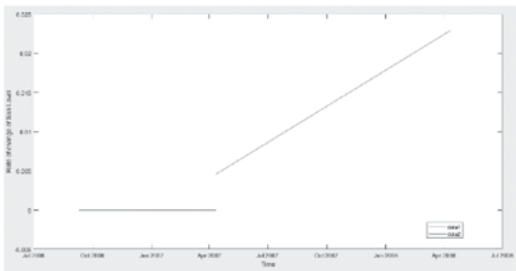

Figure 7: Predicted Sea Level Rate (Data 2), Collected Sea level Rate(Data1)

By taking the differentiation of the resulting residual values the rate of change of Sea Level vs Time was calculated.

VI. RESULTS

If the environmental conditions (such as Sea surface temperature, Salinity, Global warming) were continued as of 2007-04-10 to 2008-04-11 the following result can be gain.

Table 1: Result Comparison

No.	Property	Result	
1.	Date	2007-04-10 2359h (current data)	2008-4-11 0000h (predicted data)
2.	Sea level	2.010 m	7.0337 m
3.	Rate of Change of Sea level	3.48864e-06m year-1	0.02287 m year-1
4.	Rate of change of change of Sea level	1.4610e-11m year-2	2.505e-05m year-2

Here the accuracy of the results increases with the Increase of the Volume of data collected.

VII. DISCUSSION

1) Limitations:

i Need Higher computer power or parallel computing techniques to provide a reliable result.
ii. Require higher data volume to provide a reliable result.

2)Applications:

Can be used for predicting much larger Sea level data sets to predict sea levels for over 100 with the prevalence of current environment conditions.

VIII. CONCLUSION

Even the prediction results are unreliable with low data volume, it is closer to the current predicted rate of sea level rise by Intergovernmental Panel on Climate Change. It is [2.8 to 3.6] mm/yr between 1993 and 2010 (IPCC, 2014). Prediction result of this research gives 2.287 cm/year rate of change of sea level. This rate of change sea level also changing with the time showing that the sea level rise has been accelerated.

In the near future there will be results such as

i. exacerbated inundation and flooding of low-lying coastal areas
ii. increased coastal erosion
iii.effects on coastal ecosystems such as salt marsh, mangroves and coral reefs
iv. salt water intrusion into estuaries and aquifers
v. changes in sediment deposition along river channels

What can the present government do to protect the Colombo coastal area from above future scenarios.

i.Armor shoreline with seawalls and dykes
ii.Elevate Construction site Finished Floor level near to shoreline
iii.Elevate Buildings and Structures near to the shoreline
iv.Allow selective incursions to protect key areas
v.Add sand and plant mangroves in a gradual retreat
vi.Manage relocation

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