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DEVELOPMENT OF TIDAL ANALYSIS AND PREDICTION SOFTWARE USING THE METHOD OF WAVELET-BASED HARMONIC FOR EFFECTIVE MANAGEMENT OF EARTH RESOURCES, AND NATIONAL SECURITY

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Abstract

Tides are Natural Phenomena that occur due to the alternating rise and fall in sea level which is produced by the gravitational attraction of the moon and the sun. For effective decision making in the improvement of the digital economy and the enhancement of National Security, it is essential to study tides along the Nigerian coastal areas. The possibilities of having a hundred percent accurate row data continue to remain a major problem in the study of tidal patterns along the Nigerian coastal area. To achieve a novelty in innovative technology for tidal analysis, WaziTides software was developed by the Department of Surveying and Geoinformatics, Waziri Umaru Federal Polytechnic Birnin Kebbi, Kebbi State, Nigeria, to perform tidal analysis and prediction. The software WaziTides allows for small data gaps, spikes and datum shifts. The mathematical method adopted for the development of the programming of the software was the method of Wavelet-Based Harmonic while Matlab environment was used in writing the program. Two years of water level data were downloaded from the University of Hawaii Sea Level Centre (UHSLC) website and it was divided into three sections. The first Six Months and a complete one-year data were used for training purposes, while the remaining second-year data was used for comparison after prediction to test the performance of the software. The result shows a great prediction accuracy ranging from 0.012 to 0.025 in terms of Mean Square Error (MSE) and 0.82 to 0.97 in terms of the correlation coefficient. With this great achievement and good performance of the software, WaziTides can be deemed as a useful tool for a wide variety of Coastal Engineering Development, Construction and Management for the improvement of the Nigerian Digital Economy and enhancement of the Nigerian National Security.

Key Words: - Tides; Tidal Analysis; Wavelet; Harmonic Analysis and Tidal Prediction.

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Introduction

The knowledge of future coastal sea levels is very vital due to its significance in the effective planning of coastal structure, the establishment of controls in the coastal zones, accurate prediction and monitoring of surges, absolute control of maritime traffic, reduction of bathymetric data, determination of mean sea level, determination of Maritime Baseline and many more, especially in the management of Earth resources, improvement of the digital economy and National Security (Zhang et al., 2018). The difference in near-shore sea level is due to the rise and fall of the water surface which covers the rotating Earth planet (Ew & Ugust, 2003). Tides occur as a result of the gravitational attraction of the Moon and Sun (Zilrn et al., 2017). The history of tidal analysis and prediction can be traced back to several centuries when Issc Newtone in 1987 proposes the equilibrium tidal theory (Abubakar et al., 2019). Moreover, the equilibrium theory of tides was used by Darwing in 1892 to predict sea levels, (Abubakar et al., 2019). The theory of tide was later improved by many researchers such as Doodson (1921), Cartwright and Taylor (1971). Classical Harmonic Analysis remains the most popular method of calculating tidal analysis and prediction. It is based on the fact that tides are periodic phenomena that can be expressed by the superposition of several sinusoidal functions, each sinusoidal function has three parameters to be determined, that is amplitude frequency and phase (Cai et al., 2018). Numerous computer programs have been developed based on the harmonic analysis approach which are widely used for many years to perform tidal analysis and tidal heights prediction. The harmonic analysis approach has proved successful and advanced over time (Foreman et al., 2009; Pawlowicz et al., 2002). Other techniques exist as well, such as tidal spectroscopy and prediction used by Munk and Cartwright (1966). Xu et al., (2019) Extract tidal frequencies using multivariate harmonic analysis of sea level height time series to predict tides. However, these methods and many more were not been widely adopted like the classical harmonic analysis. Many studies on Nigerian tides have been published which include those presented by (O. Badejo et al., n.d, 2017.; O. T. Badejo & Akintoye, 2017; Okwuashi & Olayinka, 2017). Systematic investigation of the tidal pattern along the Nigerian coastal area and estuaries has remained one of the major problems in National Hydrographic operations (Ojinnaka, 2013). Moreover, the possibility of having a hundred per cent accurate row data continue to remain a major problem in the study of tidal pattern along the Nigerian coastal area. To achieve a novelty in innovative technology for tidal analysis and prediction, WaziTides software was developed by the Department of Surveying and Geoinformatics, Waziri Umaru Federal Polytechnic Birnin Kebbi, Kebbi State, Nigeria, to perform tidal analysis and prediction.

This paper is structured as follows: Section 1 provides a brief overview of tides and a survey of the related literature on tidal analysis and prediction. In the second section, classical harmonic analysis and wavelet-based harmonic analysis are briefly expressed mathematically. The software *WaziTides* and its operating structure are briefly introduced in section three. Section four dealt with data sources and the result obtained from the Matlab program of the software. A comparison was made with known data before it was packaged to become a standalone software. Section five discusses the conclusion, recommendation and future work.

The Harmonic Analysis

The harmonic analysis method using the least squares adjustment technique is best suited for tidal analysis and prediction due to its ability to calculate the recurrent observation data for a long period and also the calculation process is shorter, faster and simpler. The harmonic analysis of tides is moulded down into a few periodic components using the harmonic analysis method, each of which is produced by a theoretical analysis of the celestial body for a certain tide station with a

tidal height of h(t) at time t, this can be represented as;

$$h(t) = H_0 + \sum_{k=1}^{\infty} a_k \cos(\omega_k t_k) + b_k \sin(\omega_k t_k) \quad (1)$$

where $h(t_k)$ is the measured water levels, t_k is the time (k ranges from 1 to N number of water levels measurements), h_o is the mean water level (unknown), n is the number of the expected constituents,
a_k is the cosine parameters (unknown), b_k is the sine parameter (unknown), ω_k is the frequency of the expected constituent.

The Wavelet

Any oscillatory waveforms of a short period with an amplitude that decomposes rapidly to zero at both ends showing signs of similarities to sine waves in the Fourier transform are termed a wavelet. The wavelet domain's primary signal is the mother wavelet $(\psi(t))$, which differs from the Fourier transform. However, the primary function of the Fourier transform is to fix either sine or cosine function. Like any other model, the Fourier transform has a few drawbacks. For instance, Fourier gives information on the frequency domain representation of a sequential procedure of a signal or function found in the time domain. While Fourier analysis shows frequency information that can be generated for the signal's full extent, it provides no information on local variation in time and needs the signal to be stationary. Wavelet transform has gained tremendous popularity and instance acceptance by resolving some of the Fourier drawbacks in various fields. However, there is an existence of similarity between continuous wavelet transformation (CWT) and Fourier transform but, continuous wavelet transform is based on a single function ψ and this function is scaled and also shift, thus generating a two parameters family of function that is scaling and shifting unlike Fourier transform. Therefore, a continuous wavelet transform is a device that provides a complete representation of a signal by letting the translation and scale parameters of the wavelet differ continuously. For any function to be a continuous wavelet transform the mother wavelet function $\psi(t) \in L^2(R)$, which is limited in the time domain that is ψ (t) has a value in a certain range and zero elsewhere. The scaling and shifting functions are the families of wavelets mathematically represented as,

$$X(a,b) = a^{-1/2} \int_{-\infty}^{+\infty} x(t)\overline{\psi}(t - b/a)dt$$

where ψ(t) is the mother wavelet, *x*(t) refers to the signal input, *a* refers to the scaling factor and *b*
refers to the shifting factor, while *X*(*a*, *b*) constitutes the similarity among the mother wavelet scaling at *a* and shifting at *b* together with signal input

The Wavelet-Base Harmonic Model

The summation of a finite number of cosine waves that have a specified amplitude, frequency, and phase normally describes the changes in elevation of the sea at a point by harmonic analysis is given in the equation for further studies on the derivation of the wavelet-base harmonic reader is referred to (Abubakar et al., 2020, Abubakar et al., 2021). The wavelet-based harmonic is given as follows

$$h_i(t) = z_0 + \sum_{i-i}^{n} (\sum_{j-0}^{p} \psi_j(t)(\alpha_j \cos i\omega t - \beta_j \sin i\omega t_i)$$

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Where $h_i(t)$ is the predicted tide, z_o is the calculated mean from the observed tides, $\sum_{j-0}^{p} \psi_j(t)$ is both the translation (shifting) of the wavelet function $\psi_{j,}(t)$ as well as the dilation (scaling) of the function.

The Study Area

Lagos, which has a population of over 15 million, is one of the bigger cities in Africa (Vijverberg et al., 2012). The country's import and export of goods depend on its harbour. More and bigger ships have been calling at the port for a while. Due to its proximity to Lagos and Tin Can Port, it serves as the country's economic hub. Large portions of the products and goods imported into Nigeria pass through the tin can port (O. T. Badejo & Akintoye, 2017). The Lagos harbour is situated at Latitude 6° 25'N and Longitude 3° 23'E. The data that was used for this study is downloaded from Hawaii Sea Level Centre (HSLC) website. The source of the data was the major setback of this project due to its. Figure 1.0 shows the Google image of the Lagos Harbour.



Figure 1 Google Image of Study Area (Lagos Harbour)

The *WaziTides*

WaziTide:- Due to the present development of computer technology, all the complex calculations can be done easily through programming. Thus, Wavelet-based harmonic analysis was used and the method of Least Square Estimation was also involved to solve the solution of big dimension matrices without difficulty. With the understanding of the theory, formula and computation technique of the Least Square Estimation method, this study has produced a software that can be used to determine the types of constituents, amplitude and phase of the constituents and sea level of the studied area, moreover, the software is targeted to performed tidal analysis and prediction on Nigerian coastal areas.

The software WaziTides is named after the institution Waziri Umaru Federal Polytechnic Birnin Kebbi, the full meaning of the acronym WaziTides is Waziri Tidal Analysis and Prediction Software. The software can be used for training purposes, research purposes, analysis of tides, and

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prediction of sea level. It is being developed using MATLAB version R2022b software. The WaziTides program used a total data of six months or one year from any Nigerian tidal gauge data. The operational framework of the software is as follows:

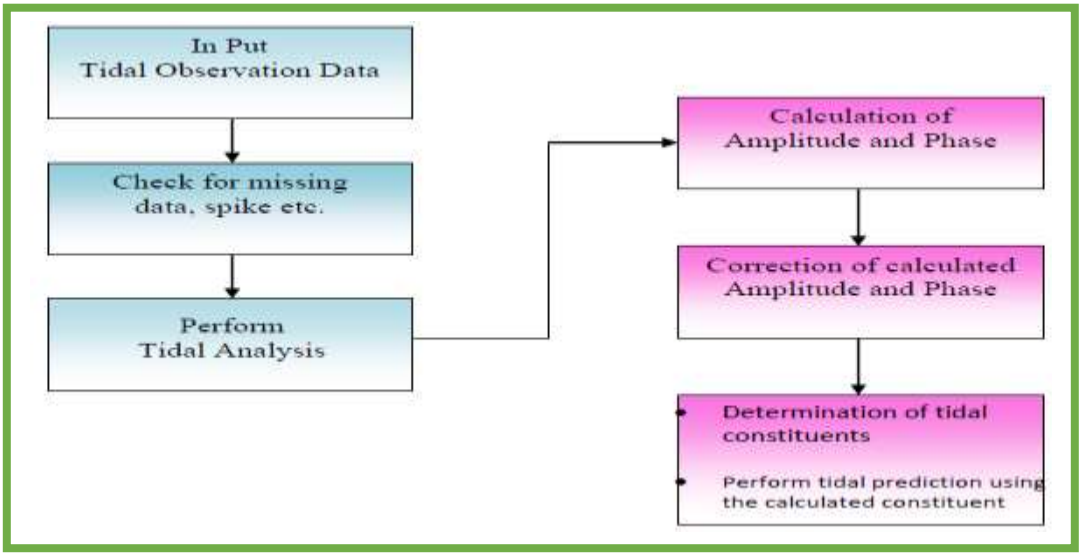
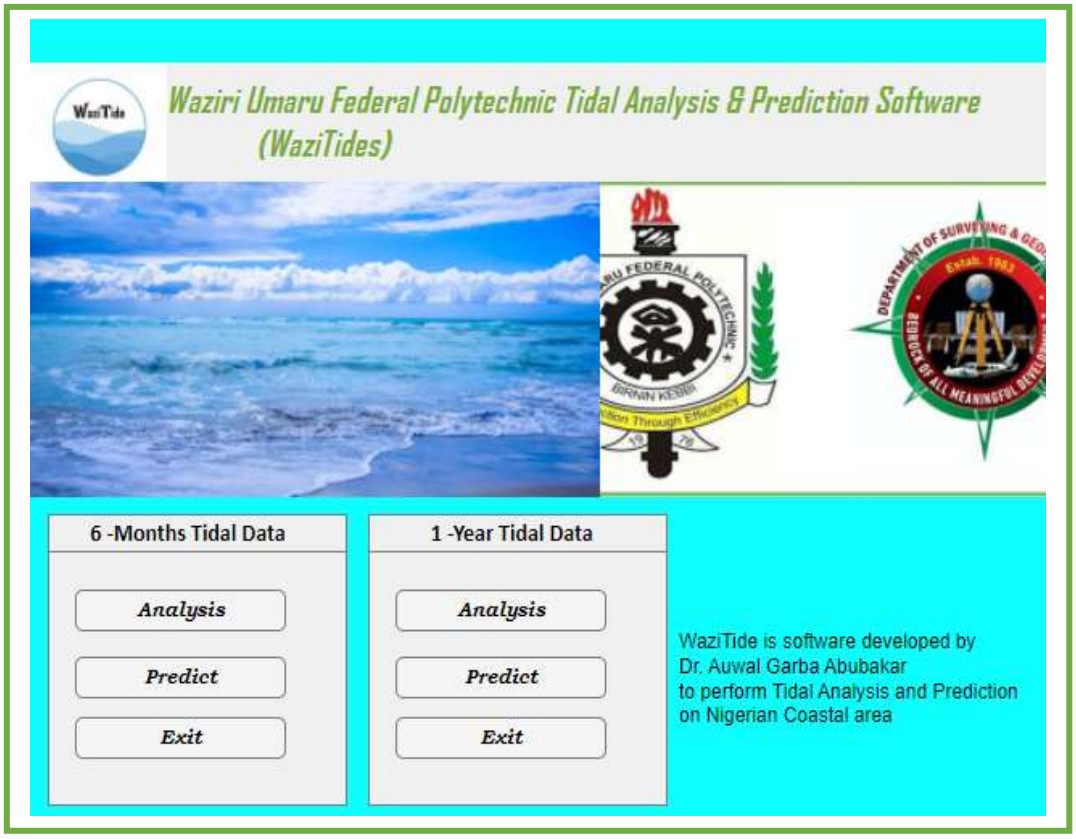


Figure 2.0 The operational framework of WaziTides

Figure 2 The operational framework of WaziTides



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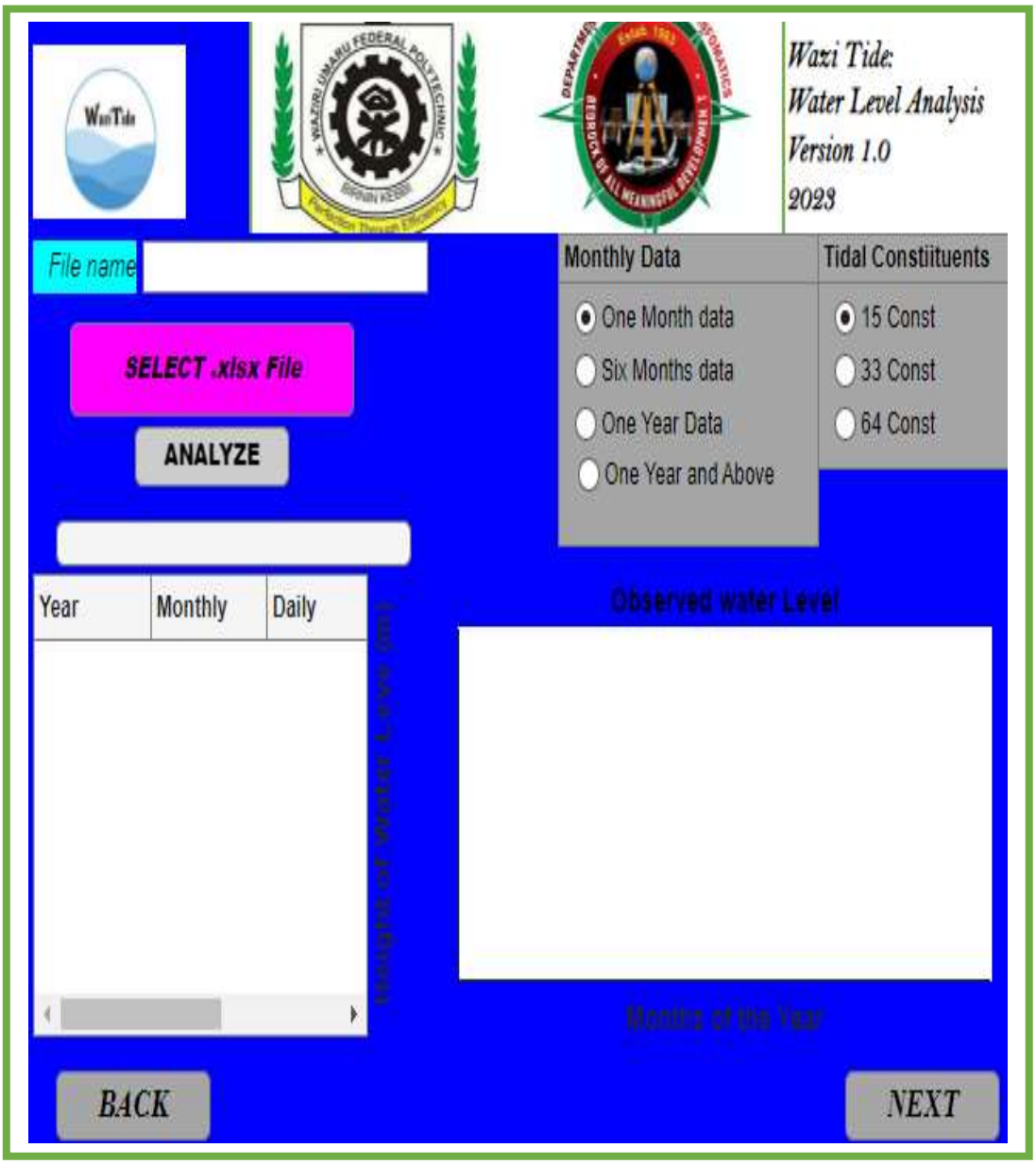


Figure 3 The Main Menu of WaziTides

Data Source and Result.

Two years data set of Lagos harbour tide gauge station was obtained via online source from University Hawaii Sea Level Center, http://uhslc.soest.hawaii.edu/datainfo/ from January 1994 to December 1995, and the data was divided into three. The 1994 data set was used for training purposes (input) while the 1995 data sets were used for comparison. In this paper only the January prediction is shown in the Table1 while the graph of the tidal prediction for one year is shown in Figure 4 In many other tidal-level prediction studies, the performance is assessed in terms of root mean square error RMSE, the correlation coefficient R and the scatter index SI. In this study, the same is applied

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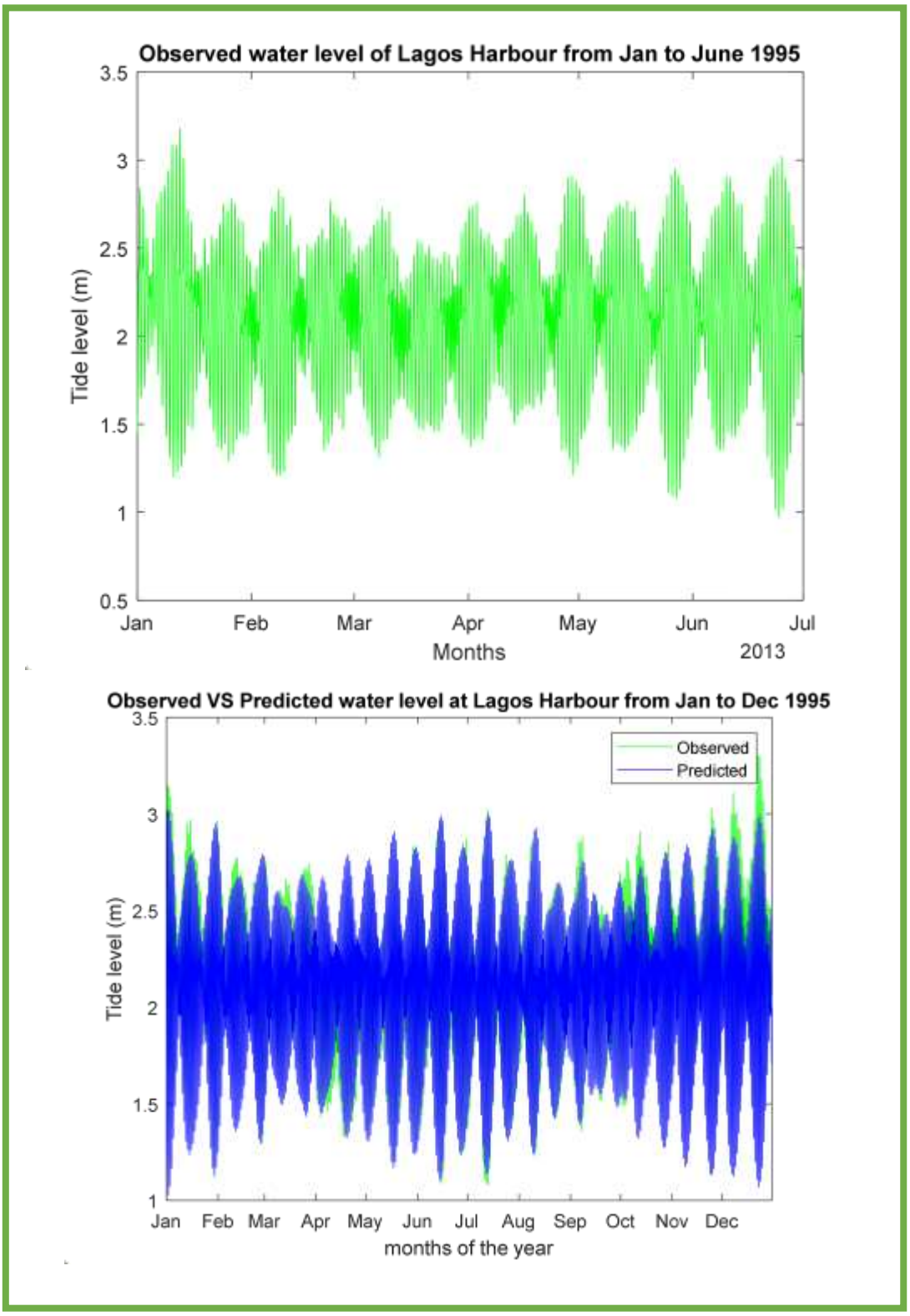


Figure 4 Predicted tides against Observed tides at Lagos Harbour 1995

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Table1 Sample of a Tide Table produced using WaziTides Software

YEAR 1995 JANUARY

HEIGHTS IN METRES

Hour / Date	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	1.239	1.430	1.648	1.872	2.068	2.211	2.293	2.333	2.375	2.454	2.572	2.716	2.864	2.977	3.014	2.953	2.784	2.512	2.162	1.782	1.435	1.184	1.051	1.030
2	1.111	1.273	1.482	1.709	1.930	2.111	2.233	2.295	2.324	2.367	2.457	2.588	2.741	2.892	2.998	3.020	2.938	2.745	2.452	2.090	1.712	1.385	1.168	1.073
3	1.084	1.192	1.370	1.582	1.800	1.999	2.152	2.244	2.281	2.297	2.342	2.438	2.571	2.724	2.869	2.960	2.963	2.863	2.659	2.365	2.015	1.666	1.384	1.218
4	1.165	1.211	1.339	1.521	1.719	1.911	2.077	2.192	2.249	2.260	2.264	2.305	2.397	2.522	2.662	2.788	2.856	2.840	2.731	2.531	2.256	1.945	1.651	1.434
5	1.328	1.321	1.396	1.535	1.706	1.877	2.035	2.159	2.233	2.253	2.240	2.229	2.260	2.335	2.438	2.551	2.646	2.688	2.658	2.552	2.375	2.143	1.894	1.674
6	1.533	1.488	1.523	1.618	1.755	1.904	2.042	2.159	2.240	2.273	2.262	2.324	2.195	2.284	2.250	2.316	2.390	2.450	2.469	2.436	2.350	2.214	2.046	1.876
7	1.739	1.673	1.683	1.747	1.849	1.973	2.096	2.199	2.276	2.316	2.314	2.273	2.209	2.155	2.132	2.136	2.155	2.188	2.219	2.226	2.205	2.154	2.077	1.985
8	1.897	1.840	1.838	1.887	1.965	2.063	2.172	2.268	2.338	2.379	2.385	2.352	2.282	2.189	2.101	2.036	1.989	1.963	1.963	1.978	1.990	1.996	1.995	1.985
9	1.970	1.957	1.964	2.007	2.075	2.155	2.247	2.340	2.412	2.455	2.468	2.445	2.382	2.280	2.152	2.024	1.911	1.818	1.758	1.743	1.759	1.791	1.837	1.892
10	1.947	1.997	2.041	2.090	2.155	2.228	2.306	2.392	2.474	2.528	2.551	2.540	2.490	2.397	2.260	2.091	1.919	1.764	1.639	1.566	1.554	1.587	1.653	1.745
11	1.851	1.958	2.054	2.129	2.196	2.266	2.339	2.417	2.502	2.578	2.621	2.628	2.595	2.517	2.391	2.214	2.003	1.793	1.611	1.475	1.410	1.418	1.482	1.585
12	1.717	1.863	2.004	2.119	2.202	2.269	2.338	2.412	2.494	2.584	2.658	2.693	2.685	2.629	2.522	2.359	2.140	1.893	1.661	1.472	1.346	1.306	1.347	1.445
13	1.582	1.745	1.913	2.063	2.174	2.247	2.309	2.377	2.455	2.547	2.644	2.718	2.745	2.721	2.641	2.502	2.298	2.043	1.775	1.540	1.363	1.266	1.263	1.341
14	1.470	1.632	1.811	1.982	2.119	2.210	2.268	2.323	2.394	2.481	2.585	2.690	2.761	2.777	2.734	2.627	2.451	2.212	1.932	1.660	1.441	1.295	1.239	1.280
15	1.392	1.546	1.722	1.900	2.053	2.163	2.228	2.270	2.323	2.401	2.499	2.614	2.722	2.785	2.786	2.720	2.580	2.370	2.104	1.817	1.568	1.373	1.272	1.265
16	1.347	1.489	1.659	1.836	1.996	2.118	2.194	2.232	2.262	2.318	2.405	2.515	2.635	2.738	2.788	2.767	2.671	2.499	2.262	1.984	1.706	1.482	1.344	1.296
17	1.338	1.459	1.622	1.796	1.958	2.086	2.170	2.211	2.226	2.251	2.314	2.411	2.526	2.645	2.735	2.763	2.713	2.586	2.386	2.134	1.861	1.612	1.439	1.358
18	1.365	1.454	1.605	1.777	1.940	2.073	2.163	2.207	2.215	2.214	2.241	2.314	2.416	2.529	2.637	2.705	2.702	2.621	2.467	2.251	2.001	1.752	1.551	1.440
19	1.420	1.479	1.605	1.772	1.937	2.075	2.171	2.218	2.224	2.207	2.198	2.231	2.310	2.410	2.513	2.600	2.636	2.600	2.494	2.325	2.111	1.882	1.678	1.540
20	1.494	1.532	1.632	1.781	1.945	2.087	2.189	2.243	2.248	2.221	2.187	2.176	2.214	2.292	2.381	2.464	2.520	2.523	2.462	2.344	2.178	1.987	1.803	1.658
21	1.588	1.685	1.687	1.812	1.962	2.107	2.217	2.278	2.288	2.255	2.202	2.156	2.142	2.178	2.246	2.314	2.367	2.392	2.372	2.301	2.190	2.051	1.905	1.781
22	1.703	1.697	1.762	1.869	1.998	2.134	2.250	2.322	2.341	2.311	2.247	2.171	2.113	2.091	2.114	2.158	2.195	2.219	2.223	2.195	2.136	2.055	1.964	1.881
23	1.822	1.807	1.851	1.944	2.057	2.175	2.289	2.373	2.407	2.389	2.325	2.233	2.137	2.057	2.015	2.012	2.021	2.025	2.029	2.029	2.014	1.988	1.959	1.931
24	1.914	1.916	1.951	2.025	2.126	2.229	2.332	2.424	2.480	2.483	2.435	2.342	2.223	2.098	1.988	1.912	1.869	1.840	1.821	1.821	1.834	1.852	1.877	1.910
25	1.948	1.991	2.040	2.104	2.188	2.283	2.375	2.466	2.543	2.579	2.561	2.489	2.360	2.219	2.067	1.905	1.783	1.696	1.636	1.608	1.619	1.662	1.726	1.810

Conclusion and Recommendation

Conclusion

The computed tidal height which is the predicted tide using WaziTides which is built based on the wavelet-based harmonic method is in good agreement with the actual observed data. However, the WaziTide cannot be fully accepted because the data that was used to test the software is very old. The limitation of the software (WaziTides) is not an exceptional to the need of long hourly tidal data for reliable accuracy of tidal prediction when predicting a long period of sea level. The accuracy evaluation and the performance of the software is assessed in terms of root mean square error RMSE, the correlation coefficient R and the scatter index SI. The result shows a great prediction accuracy ranging from 0.012 to 0.025 in terms of Mean Square Error (MSE) and 0.82 to 0.97 in terms of the correlation coefficient

Recommendation

This paper presents the following recommendation.

(1) There is a need for good synergy between government agencies, industries, oil and gas companies with institutions of higher learning offering surveying and geoinformatics to strengthen research work on tidal analysis and prediction.

(2) The software WaziTides can be used for training purposes in our institutions that are offering surveying and geoinformatics.

(3) . The software can be used to support the understanding of tidal analysis and prediction in the following areas. Coastal areas, oil and gas industries, marine industries, Nigerian Navy, fisheries etc

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