ARDHI UNIVERSITY

ESTABLISHMENT OF LOCAL TIDAL CONSTITUENTS USING HARMONIC TIDAL PREDICTION MODEL

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ESTABLISHMENT OF LOCAL TIDAL CONSTITUENTS USING HARMONIC TIDAL PREDICTION MODEL

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A Dissertation Submitted to the Department of Geospatial Sciences and Technology in Partially Fulfilment of the Requirements for the Award of Bachelor of Science in Geomatics (BSc. GM) of Ardhi University

CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by Ardhi University a dissertation titled "**ESTABLISHMENT OF LOCAL TIDAL CONSTITUENTS USING HARMONIC TIDAL PREDICTION MODEL**" in partial fulfilment of the requirements for the award of degree of Bachelor of Science in Geomatics of the Ardhi University**.**

………………………………	……………..................................
MR. BAKARI MCHILA	**MR. TIMOTHEO JOSEPH**
(Main Supervisor)	(Second Supervisor)
Date……………………….	Date…………………….

DECLARATION AND COPYRIGHT

I MBEMBELA, JULIETH J, hereby declare that, the contents of this dissertation are the results of my own findings through my study and investigations, and to the best of my knowledge they have not been presented anywhere else as a dissertation for diploma, degree or any similar academic award in any institution of higher learning.

……………………………

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22794/T.2019

(Candidate)

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DEDICATION

Thanks to God for his hands of victory that upholding me. I would like to dedicate this research to my late mother Grace Mkinga, my father Joseph Mbembela and other closely siblings and friends for being out of home all time for my studies, for their endless love, great care, advice and encouragement they give me throughout my bachelor degree study.

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ABSTRACT

This dissertation focuses on the establishment of local tidal constituents using harmonic tidal prediction model, with a specific emphasis on Zanzibar and Mtwara tide gauge stations.

The research employed a methodology that involved collecting and analyzing in-situ tidal data from Zanzibar and Mtwara tide gauge stations. The U-tide software was utilized for data processing, generating tidal parameters and predictions for both stations. Using data from the WTide software (windows harmonic tides predictor) the research examined the predicted tides with direct tidal observations in two locations (Zanzibar and Mtwara tide stations). The tidal parameters of Dar es Salaam tide gauge station was obtained by interpolating tidal parameters of Zanzibar and Mtwara tide gauge stations.

From the findings of this study, tidal parameters of Zanzibar and Mtwara tide gauge station were obtained. The tidal constituents were then used to predict tides so as to check for the accuracy of prediction using U-tide. Assessment of the prediction was done by comparing the predicted tidal data from the in-situ tidal data using RMSE method and the results obtained were between 0.025m to 0.110m for Zanzibar tide gauge station and 0.070m to 0.140m for Mtwara tide gauge station. The predicted data from WTide software were also assessed to determine their accuracy by RMSE method and the results were 1.608m to 1.688m for Zanzibar tide gauge station and 1.27m to 1.98m for Mtwara tide gauge station. However, 29 tidal parameters of Dar-es-salaam tide gauge station were obtained based from the results of tidal parameters of Zanzibar and Mtwara tide gauge station. Tidal prediction was done using harmonic prediction model to predict tides assessment of the prediction was done by RMSE method and the results were 1.4992m.

Due to the inconsistences of the local predicted tides and global predicted tidal data it is necessary to establish local tidal prediction model using local tidal parameters. The predicted tides from the local tidal prediction model should be assessed by comparing with in-situ tidal data.

Keyword: Tidal constituents, U-tide software, harmonic prediction method, Tidal observation (in-situ tidal data).

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ACRONYMS AND ABBREVIATIONS

IHO	International Hydrographic Organization.
MSL	Mean Sea Level
LW	Low Water
HW	High-Water
LAT	Local Astronomical Tide
VDATUM	Vertical Datum Transformation
TPA	Tanzania Port Authority
IOC	Intergovernmental Oceanographic Commission
PSMSL	Permanent Service for Mean Sea Level
UHSLC	University of Hawaii Sea Level Centre
WOCE	World Ocean Circulation Experiment

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Tides are periodic rise and fall of sea level caused by addition or removal of water (Triatmodjo, 1999). Tidal readings can be determined directly from the tide gauges, GPS buoys and satellite altimetry (Hanxing, 1984). Tidal measurements are necessary for tidal analysis to determine tidal parameters. These tidal parameters are used for tidal prediction.

Tidal prediction is the oldest form of oceanic prediction and still is the most accurate method for preparation of tide tables for mariners (Foreman, 2004). Before tides are predicted they have to be analysed. Prediction of tides maybe from long term time series or short time series data. The analysis of tides can either be harmonic or non-harmonic method. From the tidal analysis of the observed data tidal constituents are determined hence knowing the tidal parameters (amplitude and phase). The longer the period of analysis the more the accurate the prediction will be (Parker, 2007).

Predicted tides in Tanzania are derived from the global tidal prediction model. Tides at a given location are obtained from the standard geodetic datum known as NAVD88 (NOAA). Where the tidal height of a particular tide gauge station is derived from the relationship of the tidal datum of that station and the geodetic datum of NAVD1988. Unfortunately, not all stations are able to establish this relationship because many stations are particularly older or temporary stations and they lack survey benchmarks. So, in order to solve for this problem Vertical Datum Transformation (VDatum) tool is used. VDatum uses a modelling technique to create relationship between tidal and geodetic datum at a desired location, based on the near-by locations with a measured relationship between tidal and geodetic datum. However, it’s difficult for one to establish the relationship of the standard geodetic datum and the tidal datum of a given tide gauge station.

The sea level report network of Tanzania consists of five tide gauge stations where the operational tide gauge stations are Zanzibar and Mtwara tide gauge station and the non-operational tide gauge stations are Dar es Salaam, Tanga and Pemba tide gauge stations. Lack of technical capacity in the maintenance of tide gauges has hinder marine activities such as navigation (Mahongo, 2009). To overcome this problem Tanzania uses tidal prediction data for coordinating marine activities.

In Tanzania, the organization that is responsible to provide tidal prediction data is the Tanzania Ports Authority (TPA). One of the responsibilities of TPA is to provide tidal data across the coastal with online tidal prediction services (TPA, 2012). Yet, this tide prediction lacks of information related to the tide data. The information that this tide data lack are vertical references, tidal constituents that are used to predict tides are not clearly stated. Also, there some tide gauge station information that cannot be found online such as Tanga tide gauge station.

1.2 Previous Studies

In 2017, a study was done on the development of a tidal prediction model for the Gulf of Thailand in which the authors collected observational data on tides and used the data to develop a numerical model for predicting tides in that area. (Pholprasit, 2017)

In 2020, a study was done on the accuracy assessment of the geospatial information agency's tidal prediction and found that the tidal prediction data that are provided lack some tidal information such as the vertical references. So, the study aimed at examining the feasibility of the tidal prediction model. (Khomsin & Pratomo, 2020)

Also, from previous research study accuracy assessment of the predicted data to insitu data was conducted and the results obtained did not validate predicted data to be used in bathymetric mapping since the difference of RMSE was very large. Then, from that case this research will provide accuracy assessment of the global predicted data and local predicted data and see how do they deviate and be able to conclude if predicted tides from local prediction model can be used for bathymetric mapping and other purposes.

Generally, tidal prediction is mandatory since it helps in the preparation of the tide tables. Tanzania has not clearly stated how tidal prediction is carried out. Therefore, this study will tend to analyse and assess the global tidal prediction model and then establish local tidal prediction model.

1.3 Statement of the problem

Tanzania is out of many countries that uses tide gauge for depth measurements. Lacking of technical capacity in the maintenance of tide gauges makes only Zanzibar and Mtwara to be the operational tide gauge stations (Mahongo, 2009). This makes difficulties in marine activities. To overcome this problem Tanzania uses global tidal prediction models for tidal determination. Different studies have proven that global tidal prediction model is not suitable for a local area because it does not account for the local conditions of that tide gauge station such as winds, atmospheric pressure, and change in salinity and water temperature (Parker, 2007). To account for their local condition of a station this study intends to determine tidal parameters which will reflect station condition.

1.4 Objectives of the study

1.4.1 Main Objective

The main objective of this research is to establish local tidal constituents using harmonic tidal prediction model for Zanzibar and Mtwara tide gauge station.

1.4.2 Specific Objectives

- Collect and analyze sea level data from Zanzibar and Mtwara tide gauge station.
- To determine the tidal parameters for Zanzibar and Mtwara tide gauge station.
- To perform tidal prediction for Zanzibar and Mtwara tide gauge stations.
- To compare the in-situ data with the predicted data from the tidal analysis software.
- To compare the in-situ data with the predicted data from the global tidal prediction model.

1.5 Significance of the Study

This research plays a big role in the following areas such as navigation, fishing, coastal engineering, planning and management. Also, this research will stimulate other Geomatics students to conduct more researches about hydrographic survey.

1.6 Beneficiaries

Beneficiaries of this research are Tanzania port authority (TPA), geologists, mariners, fishers, engineers and other researchers base on the data from this research.

1.7 Study Area

This research is conducted based on the Zanzibar Tide gauge station and Mtwara tide gauge station in Tanzania.

- **Zanzibar Tide gauge station**

  Location: The gauge is located on the main jetty of Zanzibar Harbor.

  Latitude: 06° 09.3’S

  Longitude: 39° 11.4’E

- **Mtwara tide gauge station**

  Location: The gauge is located at Mtwara Harbor.

  Latitude: 10°16'7. 9"S

  Longitude: 40°12'1.3"E

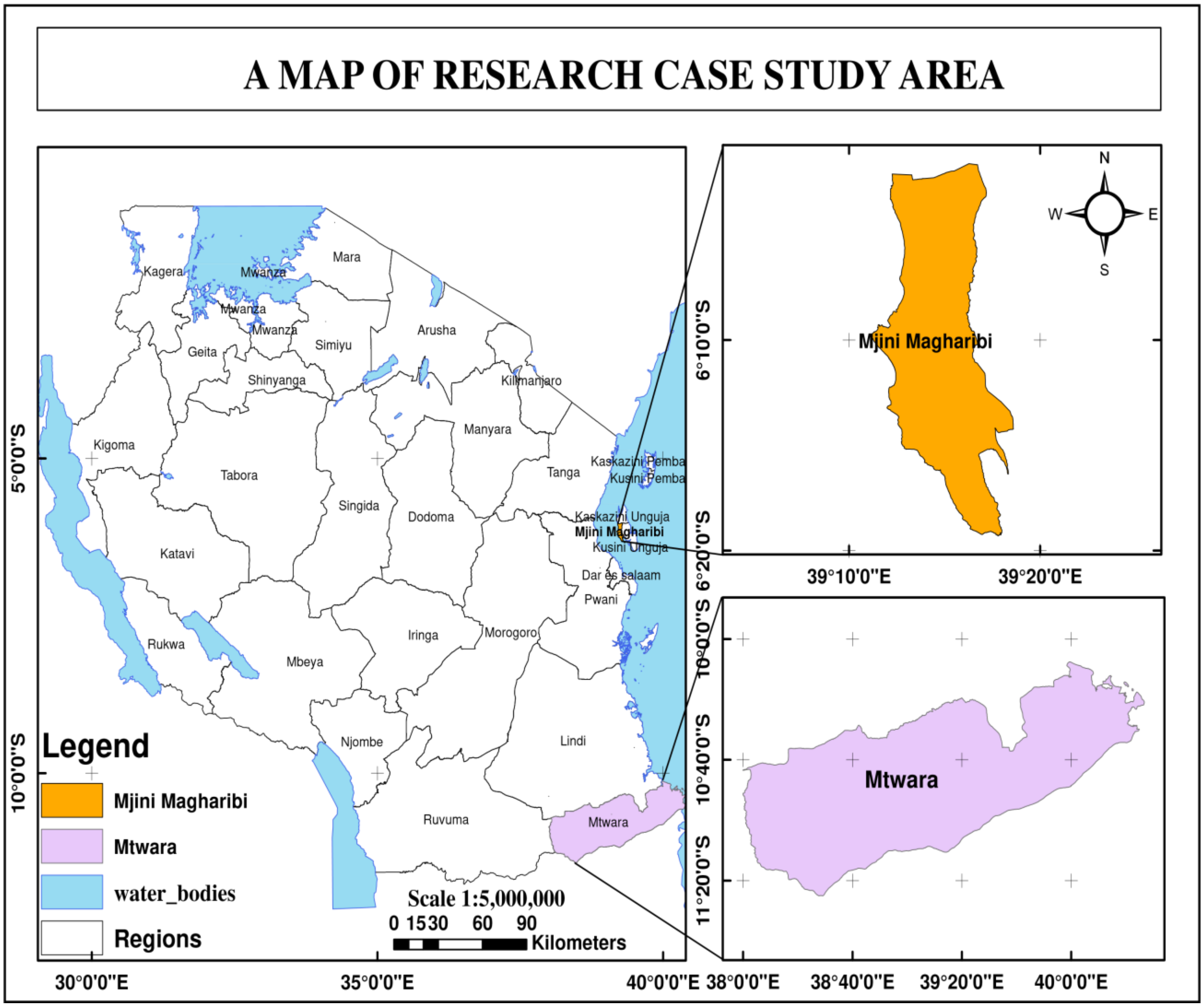

Figure 1.1 Study area map

1.8 Thesis Outline.

This thesis is organized in five chapters. Chapter one introduced the main concept of this study including previous related studies, objectives, study area, significances and beneficiaries. Chapter two discuss on important concept regarding to this study and analysis techniques from different literatures. Chapter three contain detailed methodology used to obtain data and how processing was done to obtain the results to be analyzed. Chapter four, presents the results and discussion and finally chapter five provides the conclusion and recommendations regarding to the findings of this research.

CHAPTER TWO

LITERACTURE REVIEW

2.1 Overview

This chapter presents various in-sights about predicted and observed tide and types of tide gauges.

Tide is a periodic rise and fall of the sea level caused by addition or removal of water (Parker, 2007). Or is the rise and fall of sea levels caused by the combined effects of the gravitational force exerted by the moon and the sun, and the rotation of the earth (IHO, 2005). Tides varies on time scales ranging from hours to years due to number of factors, which determine the lunar-tidal interval. To make accurate records, tide gauges at fixed stations measure water level over time. Gauges ignore variations caused by waves with periods shorter than minutes.

Tidal phenomena are not limited to the oceans but can occur in other systems whenever gravitational field that varies in time and space is present. For example, the shape of the solid part of the earth is affected slightly by earth tide, though this is not easily seen as the water tidal movements. (Parker, 2007)

Measurements of tides can be done either by using visual tidal scale or automatically by using tide gauges, GPS buoys and satellite altimetry. Tidal measurements are required for tidal analysis to determine tidal constituents. These constituents are used in the tidal prediction for tide tables.

2.2. Concept of predicted tides.

Predicted tides are typically displayed in tide tables or charts, which provide information on the expected high and low tides for a specific location and time (Foreman & Henry, 1979). These predictions can be useful for a wide range of activities, such as boating, fishing, surfing, and beachcombing. By knowing the predicted tides, people can plan their activities accordingly and ensure that they can safely navigate the waters during high and low tides (NASA, 2012). However, it's important to note that predicted tides are only estimates, and they may not always be accurate due to unexpected weather conditions, local oceanographic effects, or other factors, due to this the assessment of predicted tides with the in-situ observed tides direct from the station is important and necessary (Zafaryab, 2005). However, before tides can be predicted they must first be observed and analyzed. The longer the period of observations the better the analysis will be, hence the more accurate the prediction. For a good prediction, at least one-year observation has to be analyzed. For the best results a record of 18.6 years should be analyzed.

2.2.1 Methods of Tides Prediction (How tides are predicted).

The most preferred and satisfactory methods for tidal analysis and prediction of tides are:

- The Harmonic method and
- The Response/Time Series method**.**

The Harmonic method

Tidal harmonic analysis was first developed by William Thomson (later Lord Kelvin) in England in 1867, but was developed independently in 1874 in the U.S. by William Ferrel. In England, Thomson's work was modified and improved by George Darwin (1883) and Arthur Doodson (1921, 1928) and others, and in the U.S. Ferrel's work was modified and improved by Rollin Harris (1897- 1907), Paul Schureman (1924) and others in the U.S. Coast and Geodetic Survey (Schureman, 2001). By analyzing historical data, the method determines how the water level responds to all of the tidal constituents that are proven to be significant (Murray, 1964). It then makes the assumption that each constituent will have the same effect when combined in the future as predicted by astronomical theory.

The height of the tide, h, at any time, t, is typically represented by a formula summing up the contributions of the individual tidal constituents, such as the formula below from Schureman (1958):

$$\zeta(t) = A_0 + \sum_{i=1}^{n} A_i \mathrm{Cos}(\omega_i t - \varepsilon_i) \qquad \text{....... eq 2.1}$$

Where;

$\zeta(t)$ is the height of the tide at any time t

A_o is the Mean Sea Level

n is the number of tidal constituents to be determined

A_i is the amplitude of the i^{th} constituent

ω_i is the speed of the i^{th} constituent

t is the time reckoned from the start of the series

ε_i is the phase lag of the i^{th} constituent.

2.3 Concept of in-situ tides

Tidal observations refer to the measurement and records of movement of ocean tides over time. Tidal observations can be made in various ways, including using tide gauges and satellite altimetry. The commonly used method for tidal observation is tide gauges. These measurements can be used to calculate the amplitude, frequency, and phase of the tides at that location.

2.4 Tide gauge

Tide gauges are instruments that are used to measure and record the changes in sea level (Caldwell, 2015). Tide gauges work by measuring the height of the water surface relative to a fixed point on land, which is usually a benchmark that is well above sea level (NOAA, 2023).

2.5 Types of Tide Gauges

There are two types of tide gauges;

a. Manual recording or Visual Tide Scale
b. Automatic recording

2.6 Automatic Recording Tide Gauges

The principle of operation of an automatic recording tide gauge may be one of the following:

i. Flotation
ii. hydrostatic pressure
iii. acoustic
iv. electronic/radar/GPS

2.6.1 Float Gauges

These consists of a vertical tube or stilling well, open to the sea through a small orifice at the bottom and in which a float sits on the water surface. A wire joins the float to a recording mechanism, and it is kept taut by a counter balance weight or sometimes a spring. By a system of gears, a pen is moved across a recorder paper as the height of tide changes. The paper is secured round a drum which is rotated by clockwork/ or electric motors and the height of tide is recorded against time. Some instruments are now available which record on magnetic tapes/discs at regular intervals, and some can transmit the data on real time via radio or satellites to a receiving station on another part of the world. One of the float type gauges in Tanzania is the Dar es Salaam tide gauge and The Zanzibar Port Tide Gauge has a satellite link that transmit the data to the University of Hawaii Sea Level Center.

Importance of Float Tide Gauges:

- They still form a large part of the global network
- No need of paper charts now. They can be made digital with the use of shaft encoders
- Even if they are now being replaced with acoustic, pressure and radar systems, they were the source of the most historical record.

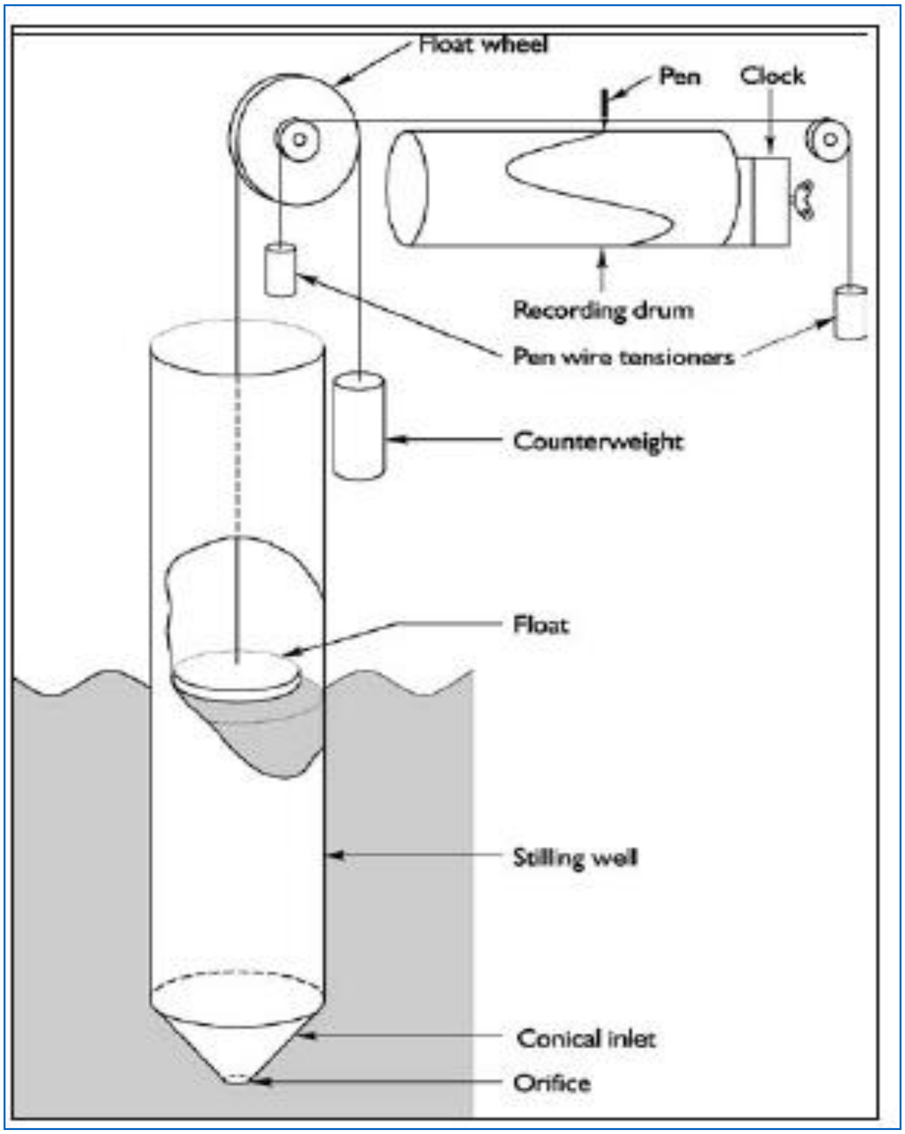

Figure 2.1 Float tide gauge (Woodworth, 2006)

2.6.2 Hydrostatic Pressure Tide Gauges

These consists of a pressure sensitive capsule held in position underwater and connected with a flexible tubing to a recorder on the surface. The variation of the water level above the capsule, due to tides, is sensed by the capsule and transmitted to the recorder. The old models comprised of a rubber diaphragm, a pressure tube and a Bourdon tube which drives a pen. The recording paper is driven by a clockwork mechanism on top of the recorder. Modern pressure gauges are more compact, portable, runs on batteries and records digitally in internal memories or linked to computers. Most of these types however are for shallow water use only. There are deep water versions of pressure tide gauges which are installed on the sea bed and can record internally for some time or transmit the data to surface recorders

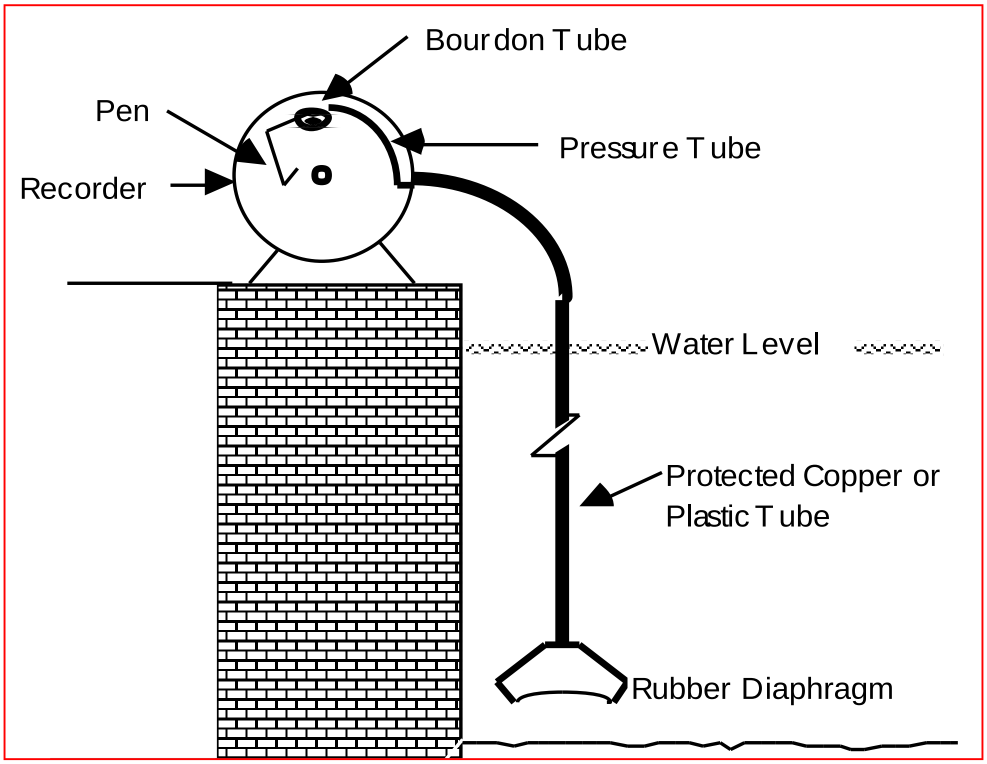

Figure 2.2 Hydrostatic pressure tide gauge

2.6.3 Acoustic tide gauge.

These consists of a device which transmits sound waves and detects the reflection on the air/water or water/air boundary. Knowing the speed of sound in air/water, and the time interval from transmission of the pulse to the reception of the echo, the variation of the water level due to tides can be determined.

Acoustic tide gauges are of two types:

a. **Stilling well type:** In this type the transmitting and receiving devices (transducer) is fixed on top of the stilling well, and the sound waves travels in the air medium and reflects on the water surface. The measured height should be divided by the height of the transducer from the seabed in order to determine the depth of the water level from the seabed.

b. **Sea bed type:** In this type the transducer is moored on the sea bed, and the sound waves travels in the water medium to reflect on the water/air boundary

2.6.4 Radar Tide Gauge

Similar to acoustic gauges, radar tide gauges use electromagnetic signals instead of acoustic ones. It is necessary to know the emitter's height above the datum. (Woodworth & Philip , 2016).

2.7 Tide Gauge Stations in Tanzania.

The observing network of sea level in Tanzania is currently consists of two operational and three non-operational (historical) tide gauge stations. Those stations are placed in harbor areas.

1. Operational stations:

Currently, operational tide gauge stations in Tanzania are Zanzibar and Mtwara.

i. Zanzibar station

Zanzibar station (GLOSS Station No. 297) is located on the seaward end of main jetty in Zanzibar Harbor off the coast of Zanzibar town at Latitude 06° 09.3'S and Longitude 039° 11.4'E. This station which is linked to UHSLC and IOC/GLOSS has been operating well since 1984 with few gaps in some days. A satellite sea level transmitting station (tide logger, float type) was installed in February 1993 and upgraded in July 2006 as seen in figure 2 below to accommodate three channels of sea level data collected and transmitted every 15 minutes. Apart from tidal measurements, it is one of the western Indian Ocean tide gauge stations that used for monitoring long term changes of sea level and sea level science studies in the region.

Figure 2.3 Zanzibar tide gauge station

ii. Mtwara station

Mtwara station (GLOSS Station No. 9) was firstly installed in the main harbor sites between latitude 10°17’S and longitude 040°11’E. Munro IH 109 floats type operated from 1959 to 1962 and Munro IH 40 from 1956 to 1957. In September 2009 Mtwara became operational station after reallocation of station to new position at latitude 10°16'7.9"S and longitude 40°12'1.3"E and installed Radar/Pressure (2)/VaisalaWXT510 Met.

2. Non-Operational stations:

i. Dar es Salaam station

Dar es Salaam tide gauge Station is located at the Ferry Terminal of the Dar es Salaam Harbor (06° 49.2’S; 039° 17.3’E). This station was established since 1986 operated until 1990 when the instrument was damaged by a boat. An analogy SEBA float gauge was then installed in 1997 and it worked until 2001. The tide charts for this new instrument have however not been digitized to date. The digitizing interval for the analogue charts was hourly, daily values were obtained by filtering of the hourly data. A simple average of all daily values was used to obtain the monthly data.

Figure 2.4 Dar tide gauge station (Mahongo, 2008)

ii. Tanga station

The Tanga tide gauge station is located in Tanga Harbor area at 05° 04S and 039°06E operated from 1962 to 1966. The Pemba Island station is located on Mkoani harbor at 05° .21S 039°. 38E.In that station the tide gauge was incorrectly installed in July 1991 and up to this moment it has never be in operation. The tide gauge at Latham Island was installed at 06°50S 039° .50E as an offshore station, it was operational prior up to 1961. There is no supplementary information and data.

Figure 2.5 Tanga tide gauge

iii. Pemba station

The Pemba Island station is located on Mkoani harbor at 05°21S 039°38E. In that station the tide gauge was incorrectly installed in July 1991 and up to this moment it has never be in operation.

2.8 The Tanzania Tide Gauge Network of Stations.

The map in figure 2.6 shows the network of tide gauge stations in Tanzania operational and non-operational

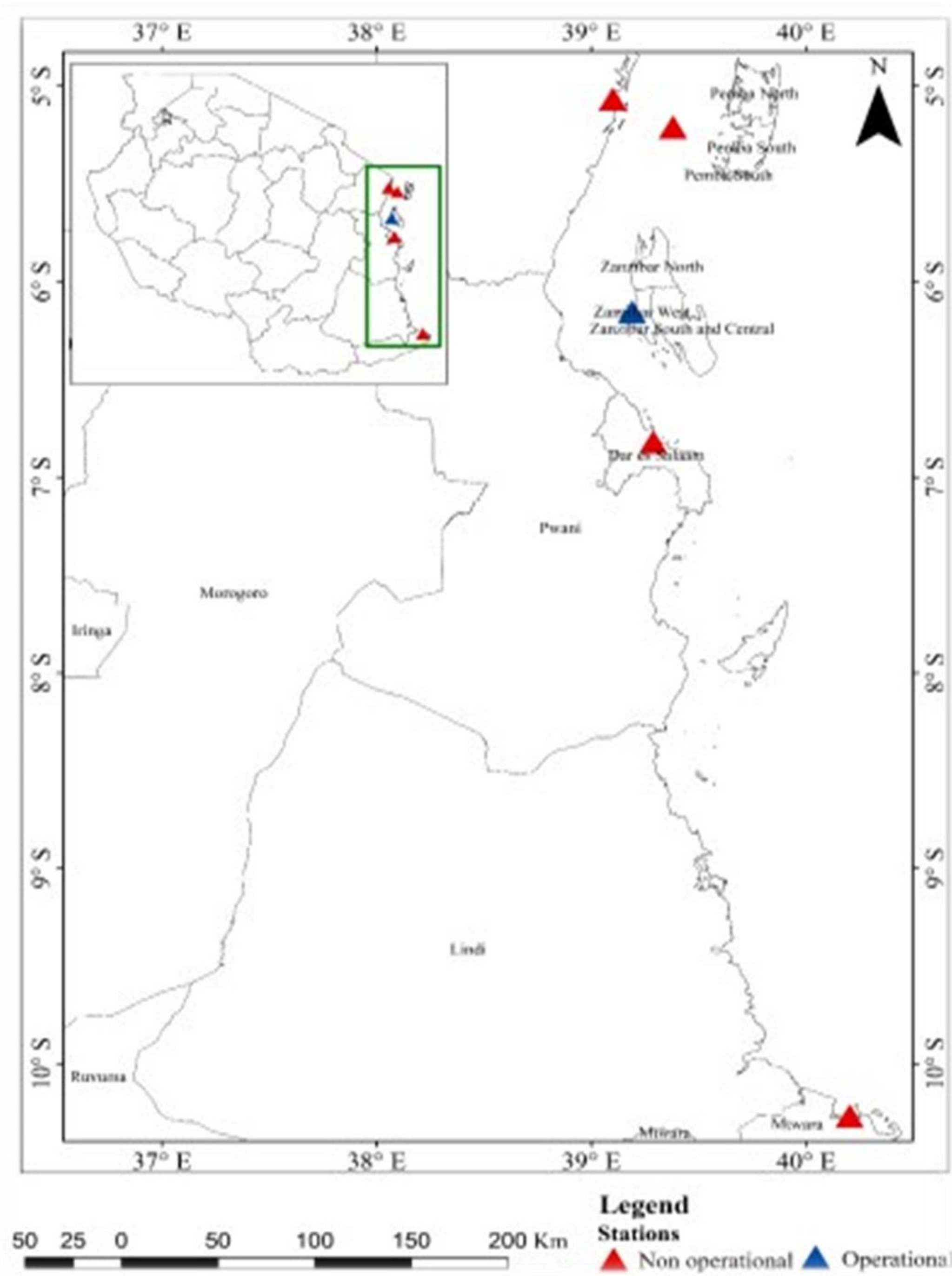

Figure 2.6 Tanzania sea-level network

CHAPTER THREE

METHODOLOGY

3.1 Overview

This chapter presents the data used, the overall methods and materials used to attain the research objectives. It mainly explains the data required in conducting the research, how are they acquired and processing the data.

3.2 Software used.

a) **WTide Software**: This is a free program that uses harmonics data to predict tide heights at many locations throughout the World, and displays a graph of the results according to the time zone of the target location.

b) **Utide Software**: this is a free program that comprises harmonic constants and performs tidal analysis and prediction.

c) **Microsoft office package**: performing comparison analysis process to obtain the RMSE, drawing graphs as well as for report writing and presentation.

3.2 Data requirement

The required data of this research are

- In-situ(actual) tidal data and
- Predicted tidal data.

3.2.1 Description of in-situ tidal data

The in-situ tidal data are the actual observed tidal data from a specific tide gauge station. The in-situ tidal data are available at different international data centers such as WOCE (World Ocean Circulation Experiment), PSMSL (Permanent Service for Mean Sea Level), IOC (Intergovernmental Oceanographic Commission) Sea Level Station Monitoring Facility and UHSLC (University of Hawaii Sea Level Centre). In this study the In-situ tidal data were obtained from the IOC Sea Level Station Monitoring Facility, these data comprise of date and time of observation as well as the water elevation. The time is recorded in UTC (Universal Time Coordinate) thus, the time was converted to the local time, which is UTC + 3/24 hours.

3.2.2 Description of predicted tidal data

The predicted tidal data are given as high depth and low depths that a certain station receives within a day. In most cases there are two high tides and two low tides in a day. The predicted tides then need to be interpolated so as to obtain the missing data between one high tide and the next low tide or between one low tide and the next high tide. The time is recorded in terms of the local time, the EAT, hence no time conversion is needed.

3.3 Data acquisition

Two set of data were downloaded which are in-situ tidal data and predicted tidal data.

- **In-situ tidal data** were downloaded freely directly from University of Hawaii Sea level center website https://www.ioc-sealevelmonitoring.org . These tide gauge data provide information relative to the sea level information relative to the tidal datum.
- **Predicted tidal data** are available from a software known as WTide.

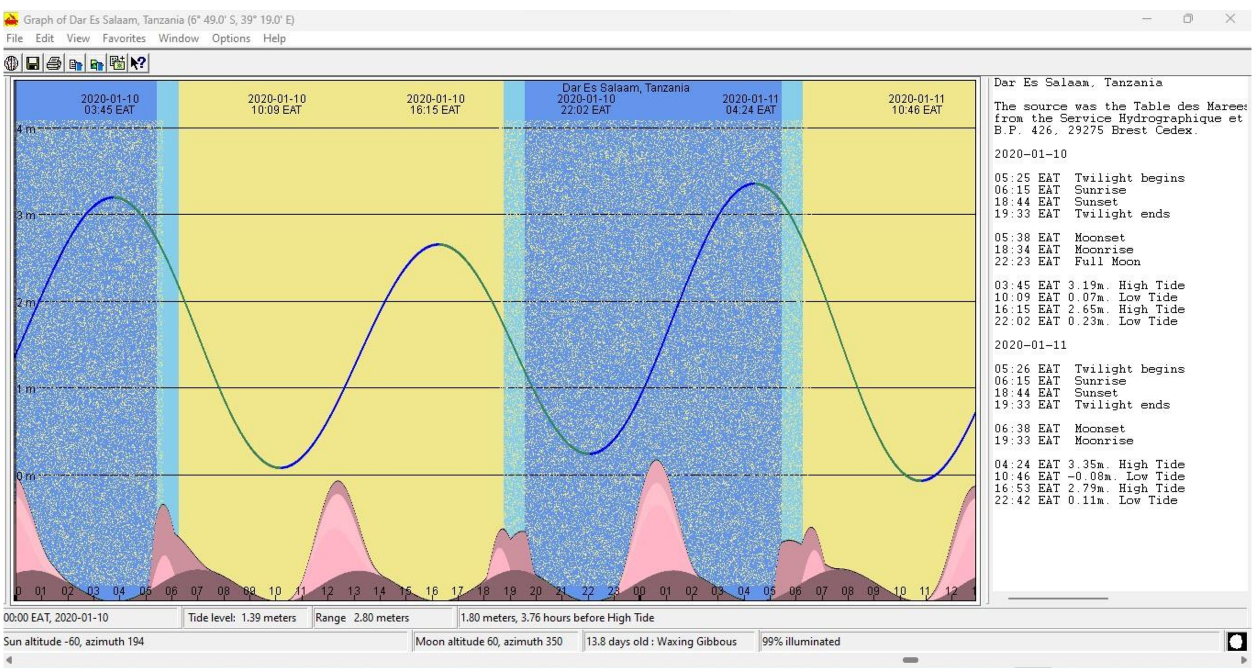

Figure 3.1 Predicted tides from WTide

3.4 Data pre-processing

This is the way of transforming the raw data into an understandable format it is done so as to make it suitable and usable for data processing. Data pre-processing is useful as it makes datasets complete and more efficient to perform data analysis. In this research the preprocessing of data involved interpolation of predicted tidal data as well as the time conversion.

3.4.1 Data interpolation

Data pre-processing involved data interpolation since the predicted data are found in only high and low tidal level. The interpolation of data was carried out after downloading data from the WTide software.

3.4.2 Time conversion

The in-situ data downloaded had the time format of UTC and the predicted data were in time format of east African time (EAT). Thus, time conversion was carried out on the in-situ data to

obtain for the local East African Time as UTC+3/24 hours.it is necessary to convert time of the in-situ data in order to match time with the predicted time data.

3.5 Data processing

After obtaining the in-situ data they were imported into Utide which works on MATLAB for further processing so that we can obtain the tidal parameters and later predict tides for that area and also draw graph showing the trends of predicted data and in-situ data. The figure 3.1 below shows how data were processed.

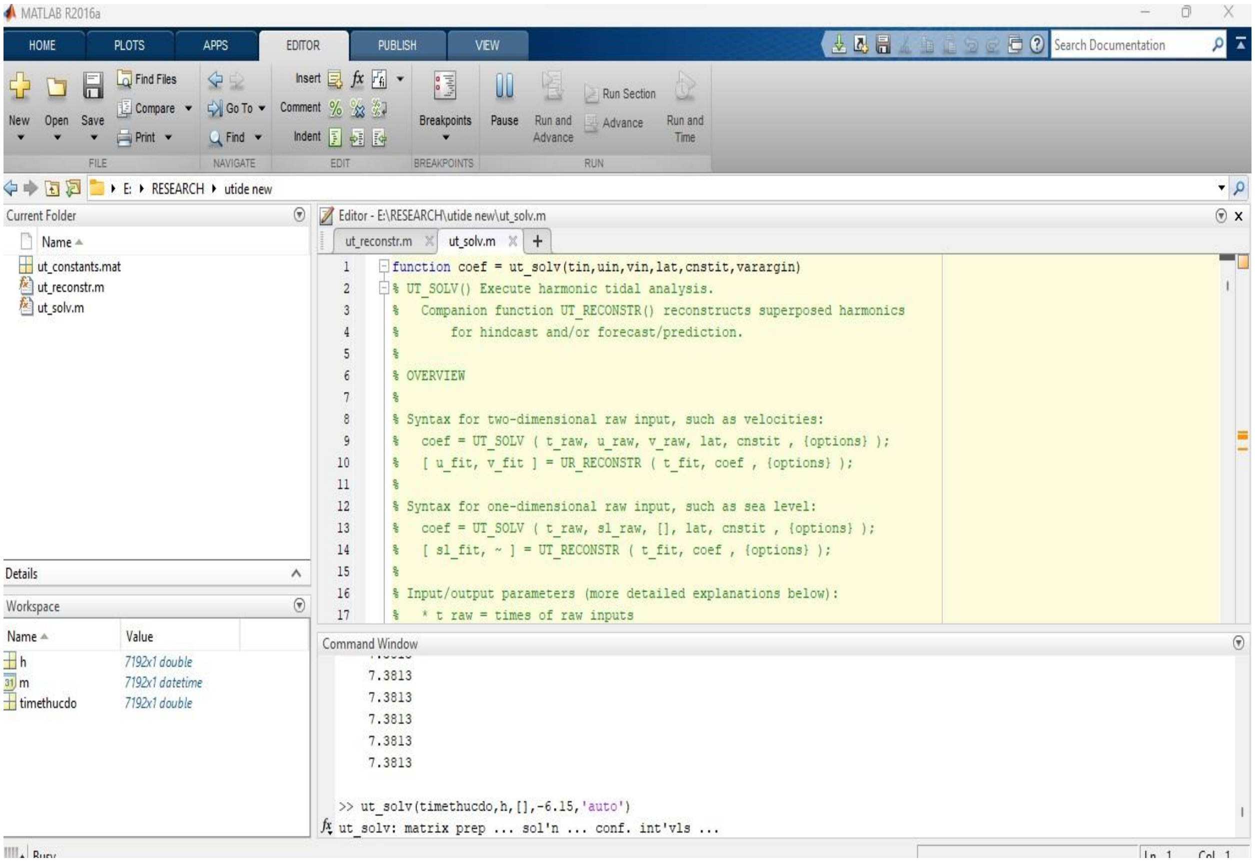

Figure 3.2 Data processing using Utide.

3.6 Data analysis

Data analysis involves the process of extracting useful information from the data. The method used for data analysis is statistical analysis. The difference between the tide prediction and in-situ data is computed to get the accuracy. Here the accuracy is represented by root mean square error. Root mean square was computed for in-situ and predicted data from the Utide and also for in-situ data and predicted data from the WTide software.

3.6.1 Statistical analysis

The difference between the tide prediction and in-situ data is computed to get the accuracy. Here the accuracy is represented by root mean square error. RMSE is a frequently used measure of the difference between values predicted by a model and the values observed from the environment that is being modelled. These individual differences are also called residuals. The formula below shows how root mean square error is computed.

$$RMSE = \sqrt{\sum \frac{(Pi - Oi)^2}{n}} \text{ ....eq 3.1}$$

Where;

Σ is a fancy symbol that means “sum”

RMSE is the Root Mean Square Error.

$\boldsymbol{Pi}$ is predicted tidal data,

$\boldsymbol{Oi}$ is observed tidal data

n is the number of tidal data under consideration i is the time.

3.7 Local tidal parameters

Spatial interpolation method used in the interpolation of tidal parameters was Inverse distance method(IDW). Tidal parameters of Zanzibar and Mtwara tide gauge station were interpolated to Dar es salaam tide gauge station. The tidal prediction was done based on the harmonic constants which were obtained. The equation that was used in preparing the MATLAB code was harmonic prediction equation where the parameters that were needed were amplitude, phase lag and speed of the tidal constituents. In the appendix there is a code for interpolating tidal constituents to the desired tide gauge station.

CHAPTER FOUR

RESULTS AND ANALYSIS

4.1 Overview

This chapter represents the results and analysis from different stages basing on the objectives of this research. The results are presented in terms of graphs showing in-situ versus predicted depth obtained from Utide and in-situ versus predicted depth from WTide program. Analysis of the data is computed in terms of root mean square and vertical references.

4.2 Results

Based on the methodology described in chapter three the results were obtained. The results presented here under includes the graphs of In-situ tides versus predicted tides, statistical analysis of the residual RMSE and their graphs.

4.2.1 Tidal analysis

From tidal analysis we were able to obtain tidal parameters for Zanzibar and Mtwara tide gauge station. The table below shows the tidal parameters of Zanzibar and Mtwara tide gauge station:

Table 4.1 Tidal parameters of Mtwara tide gauge station

S/N	Constituents	Amplitude(m)	Phases	S/N	Constituents	Amplitude	Phases
1	M2	0.998	27.624	20	SN4	0.019	90.98
2	S2	0.476	78.385	21	SK3	0.015	68.54
3	N2	0.195	16.808	22	EPS2	0.013	128.43
4	K1	0.146	9.282	23	ETA2	0.012	106.84
5	O1	0.110	9.681	24	2MK5	0.012	259.94
6	MS4	0.087	110.184	25	NO1	0.012	75.74
7	L2	0.084	41.240	26	OO1	0.011	39.72
8	M4	0.083	59.856	27	MO3	0.009	297.84
9	MSF	0.082	42.351	28	M3	0.007	279.26
10	2MS6	0.051	312.139	29	M8	0.007	75.36

11	MM	0.046	341.687	30	J1	0.005	345.66
12	MU2	0.043	153.096	31	ALP1	0.004	121.94
13	S4	0.040	154.379	32	3MK7	0.004	157.99
14	MN4	0.036	39.608	33	2SK5	0.004	348.53
15	M6	0.032	257.111	34	2Q1	0.002	316.56
16	2SM6	0.029	8.162	35	UPS1	0.002	349.85
17	MK3	0.025	28.407				
18	Q1	0.024	354.974				
19	2MN6	0.019	239.497				

Table 4.2: Tidal parameters of Zanzibar tide gauge station

S/N	Constituents	Amplitude(m)	phases	S/N	Constituents	Amplitude	Phases
1	M2	1.190	25.70	40	SO1	0.0033	352.00
2	S2	0.599	62.80	41	MSK6	0.0032	130.00
3	N2	0.214	4.03	42	2Q1	0.0028	327.00
4	K1	0.173	356.00	43	MK3	0.0023	306.00
5	K2	0.164	59.10	44	CHI1	0.0023	2.30
6	O1	0.111	0.61	45	SN4	0.0022	202.00
7	P1	0.063	1.56	46	MO3	0.0022	127.00
8	NU2	0.042	8.95	47	UPS1	0.0019	52.60
9	L2	0.041	47.40	48	SO3	0.0017	275.00
10	2N2	0.027	329.00	49	THE1	0.0015	303.00
11	MF	0.024	340.00	50	PHI1	0.0015	2.86
12	M6	0.023	49.60	51	MKS2	0.0014	326.00
13	Q1	0.021	347.00	52	ALP1	0.0012	353.00
14	MU2	0.017	13.90	53	SK4	0.0011	278.00
15	M4	0.015	181.00	54	MSN2	0.0010	251.00
16	2MS6	0.015	100.00	55	BET1	0.0007	233.00
17	2MN6	0.014	8.50	56	2MK5	0.0006	219.00

18	LDA2	0.014	54.30	57	3MK7	0.0006	271.00
19	NO1	0.012	65.90	58	M8	0.0004	4.08
20	OO1	0.012	28.80	59	S4	0.0004	74.20
21	MM	0.010	4.57				
22	MS4	0.009	275.00				
23	SSA	0.009	69.80				
24	ETA2	0.009	74.80				
25	J1	0.007	6.10				
26	2MK6	0.006	102.00				
27	SK3	0.006	350.00				
28	MN4	0.006	112.00				
29	2SK5	0.005	279.00				
30	EPS2	0.005	8.54				
31	RHO1	0.005	5.89				
32	SIG1	0.005	345.00				
33	M3	0.005	134.00				
34	2SM6	0.004	111.00				
35	OQ2	0.004	291.00				
36	MSM	0.004	353.00				
37	MSF	0.004	240.00				
38	MK4	0.003	270.00				
39	TAU1	0.003	31.50				

4.2.2 Tidal prediction

Zanzibar tide gauge station

a) Graph of in-situ versus predicted depth from Utide

Figure 4.1 to Figure 4.3 show plotted in-situ and predicted tides for Zanzibar station. The plotting involves tidal depth against time.

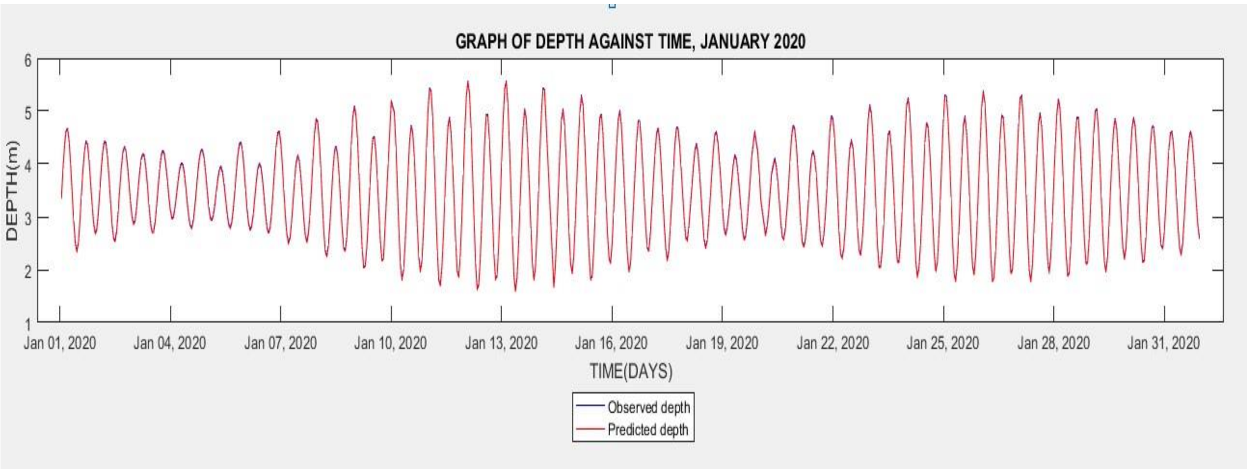

Figure 4.1 Graph of depth against time, January 2020

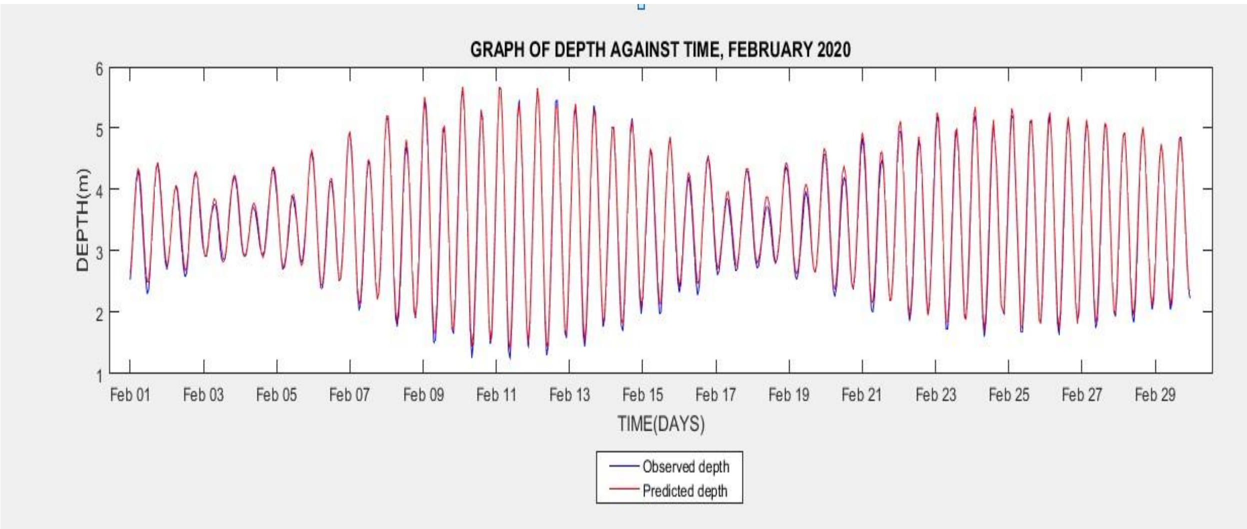

Figure 4.2 Graph of depth against time, February 2020

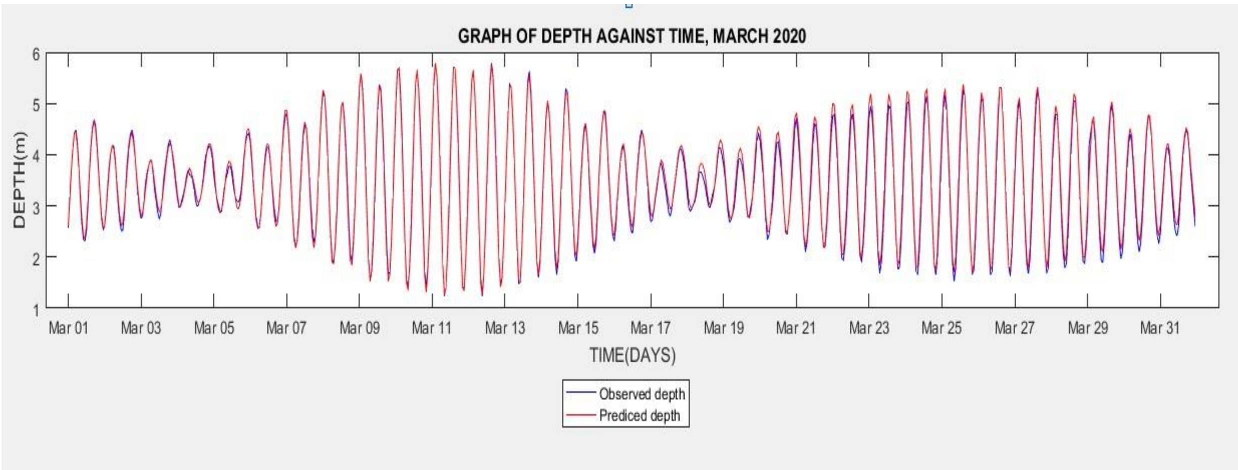

Figure 4.3 Graph of depth against time, March 2020

b) The graphs of residual between predicted tides from Utide and in-situ tides.

Figure 4.4 to figure 4.6 show the residual plots against time for Zanzibar station.

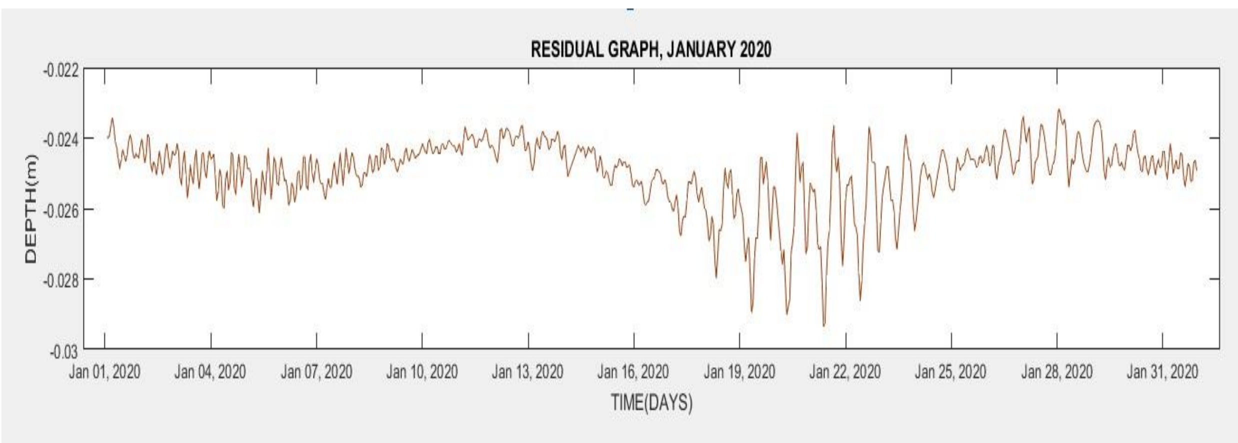

Figure 4.4 The residual graph of observed and predicted depth, January 2020

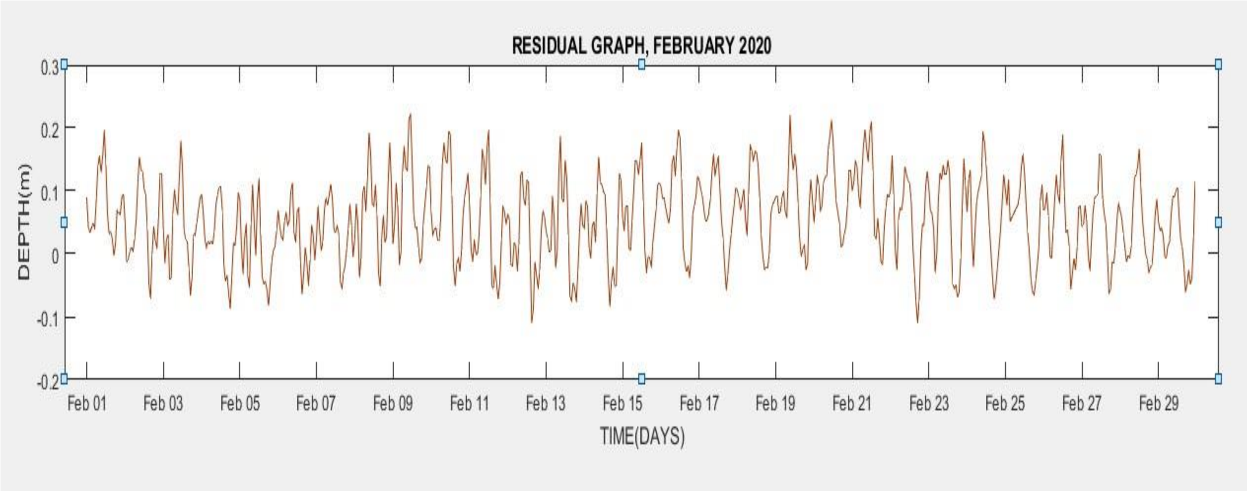

Figure 4.5 The residual graph of observed and predicted depth, February 2020

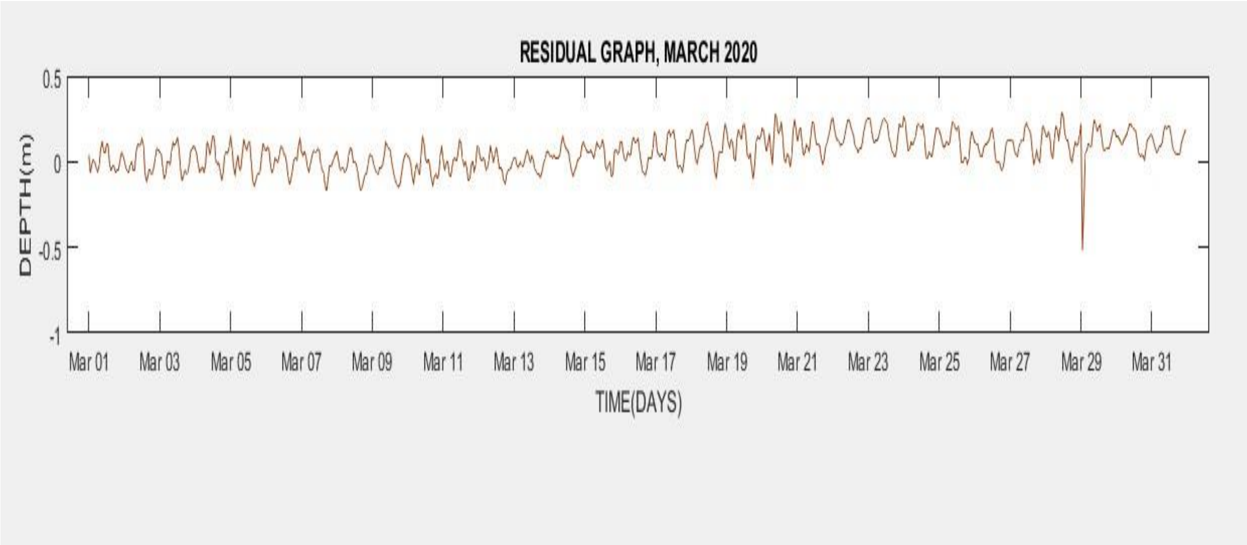

Figure 4.6 The residual graph of observed and predicted depth, March 2020

Mtwara tide gauge station

c) Graph of in-situ versus predicted depth from Utide.

Figure 4.7 to figure 4.9 show plotted in-situ and predicted tides for Zanzibar station. The plotting involves tidal depth against time.

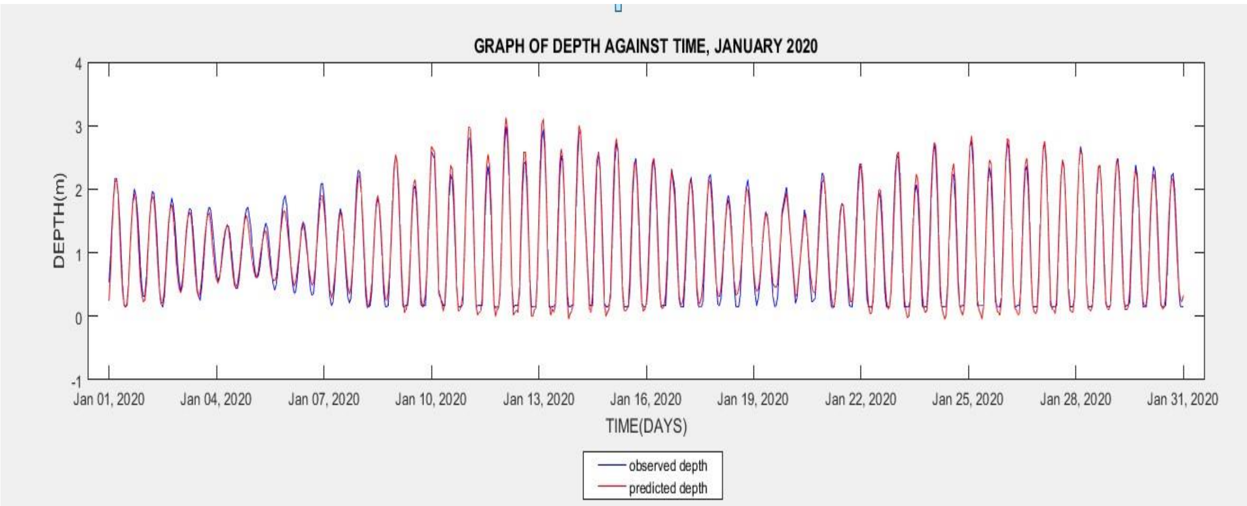

Figure 4.7 Graph of depth against time, January 2020

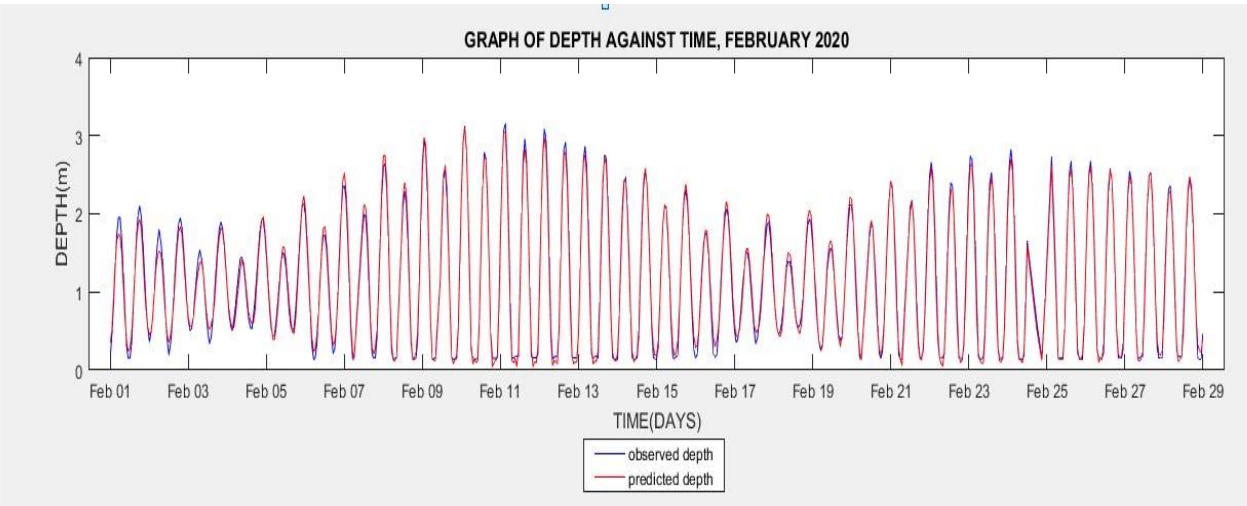

Figure 4.8 Graph of depth against time, February 2020

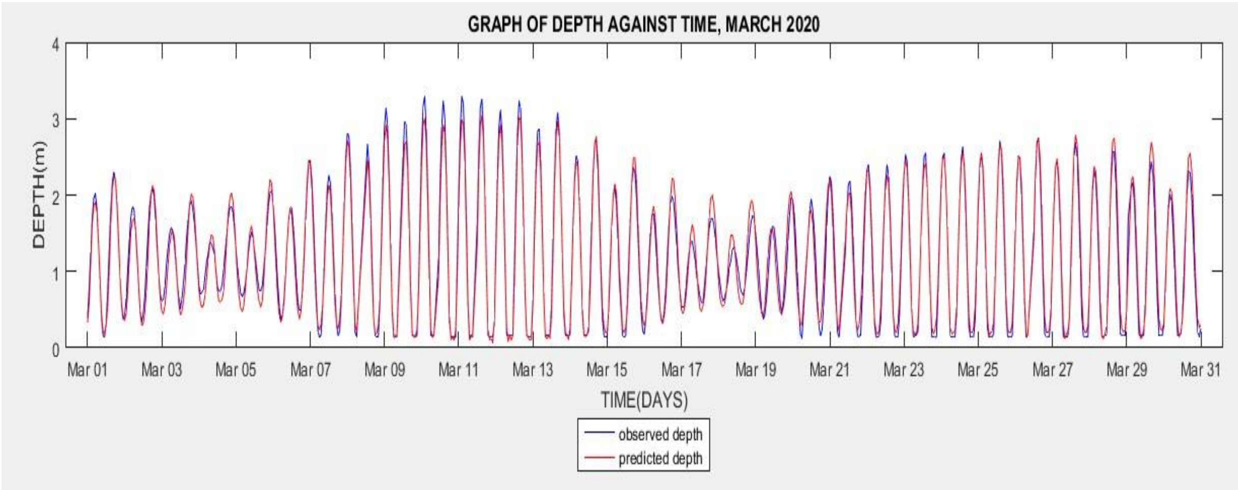

Figure 4.9 Graph of depth against time, March 2020

d) The graphs of residual between predicted tides from Utide and in-situ tides.

Figure 4.10 to figure 4.12 show the residual plots against time for Mtwara tide gauge station.

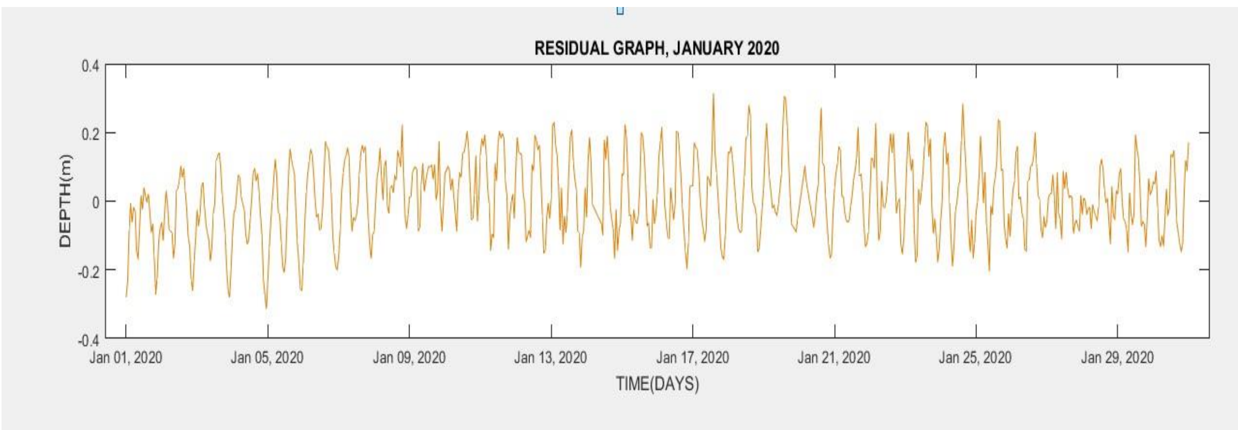

Figure 4.10 The residual graph of observed and predicted depth, January 2020

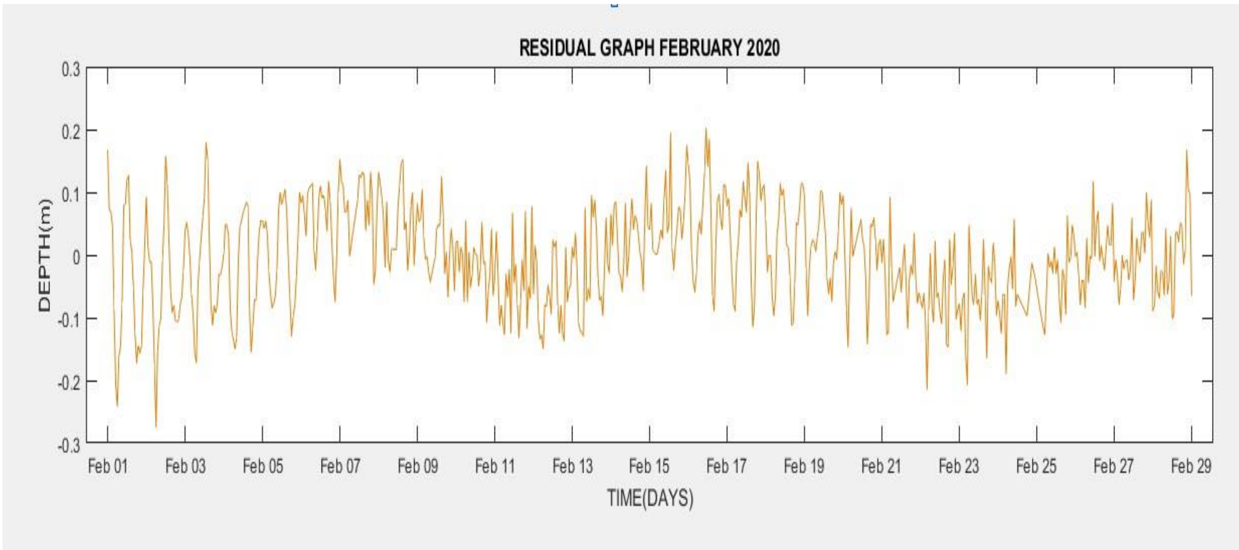

Figure 4.11 The residual graph of observed depth and predicted depth, February 2020

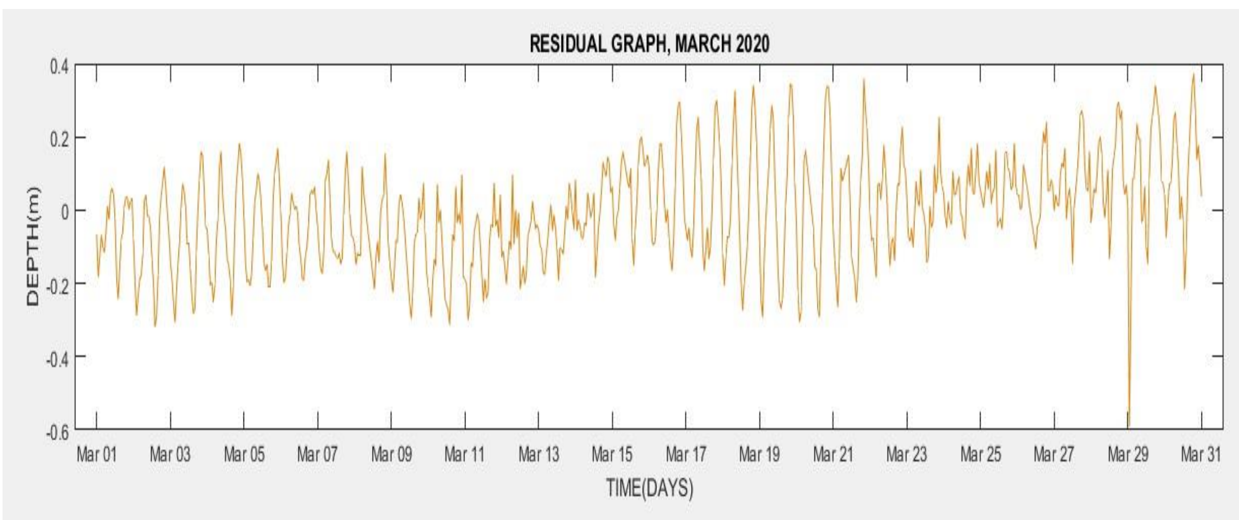

Figure 4.12 The residual graph of observed depth and predicted depth, March 2020

Zanzibar tide gauge station

- Graph of in-situ versus predicted depth from WTide.

Figure 4.13 to figure 4.15 show plotted in-situ and predicted tides for Zanzibar station. The plotting involves tidal depth against time.

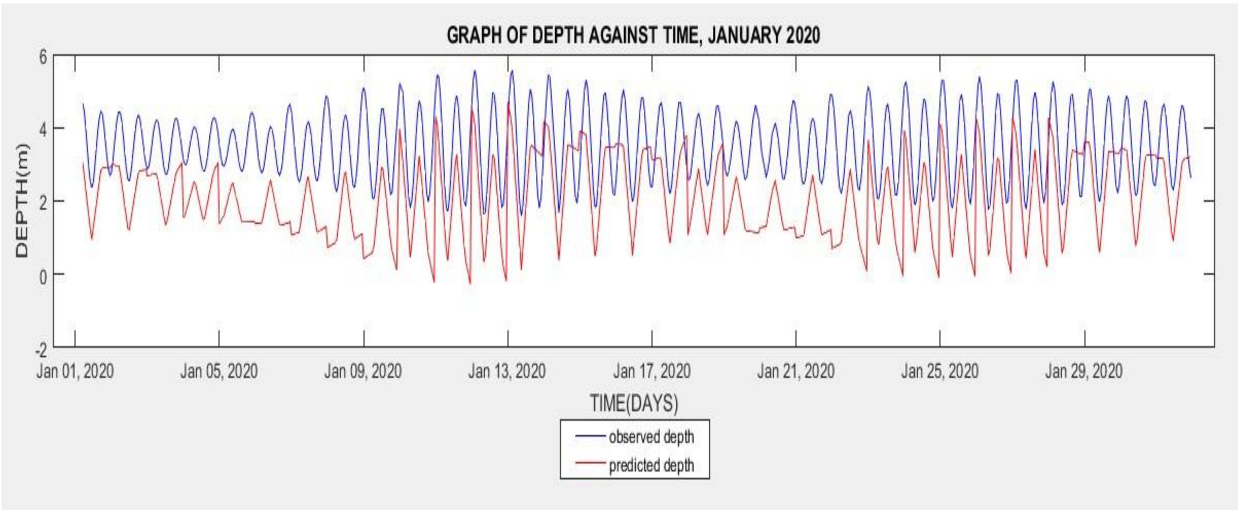

Figure 4.13 The Graph of depth against time, January 2020

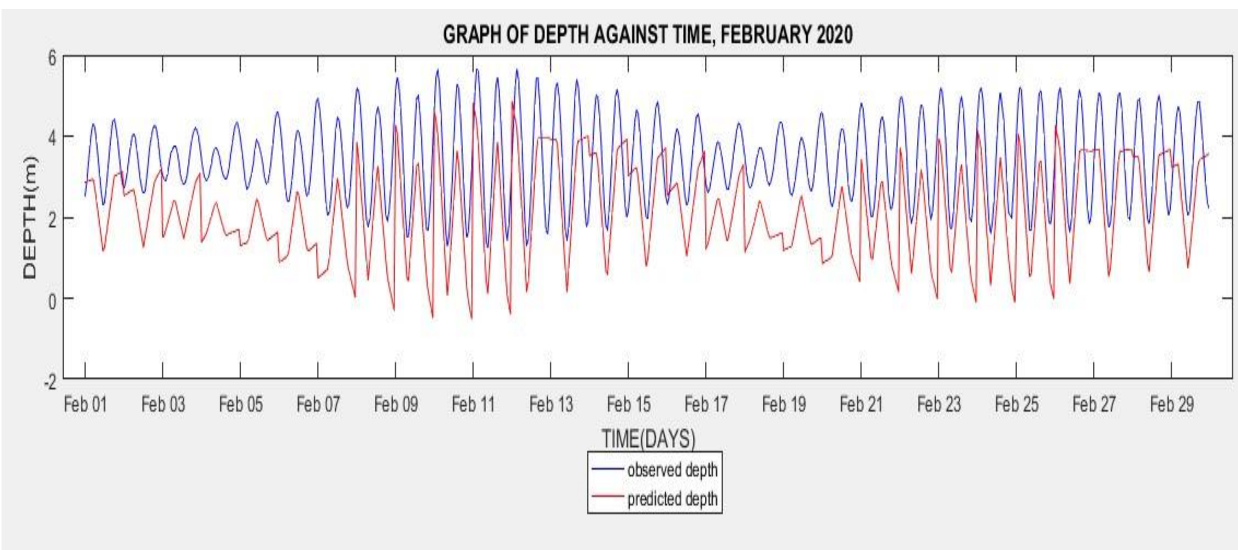

Figure 4.14 The Graph of depth against time, February 2020

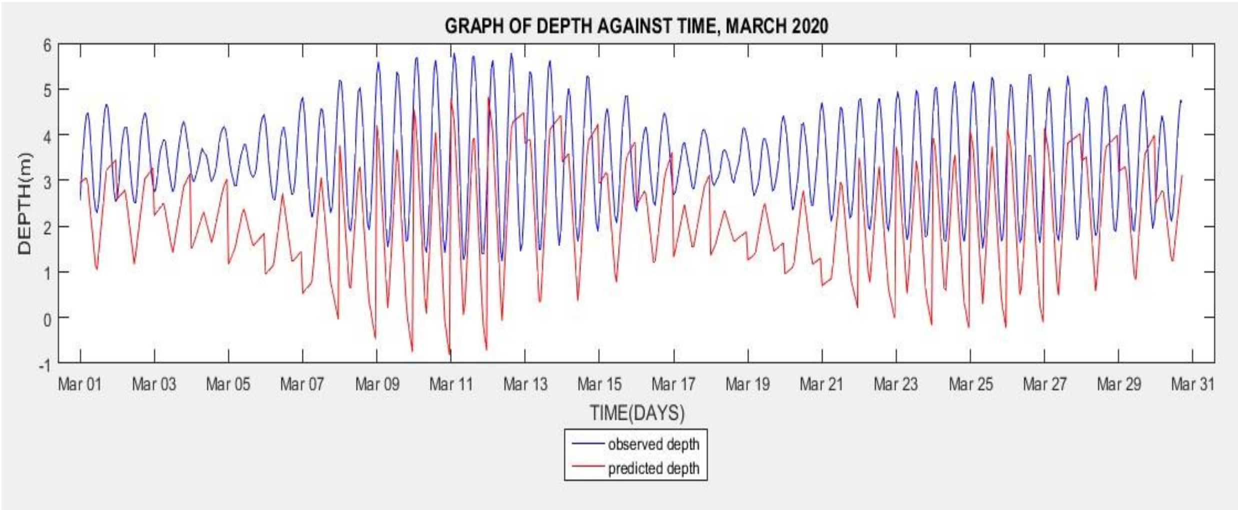

Figure 4.15 The Graph of depth against time, March 2020

- The graphs of residual between predicted tides from WTide and in-situ tides.

Figure 4.16 to figure 4.18 show the residual plots against time for Zanzibar tide gauge station.

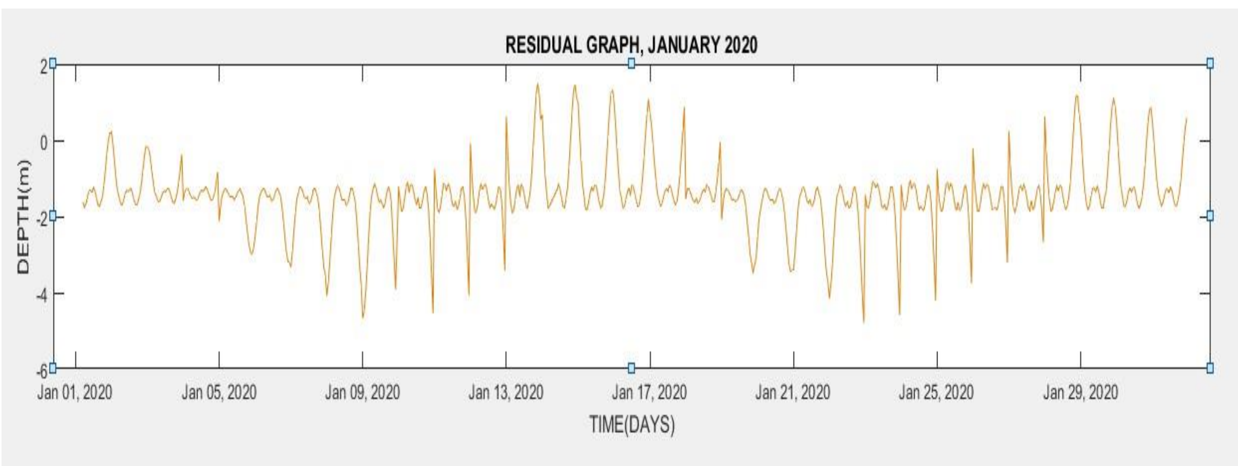

Figure 4.16 Residual graph, January 2020

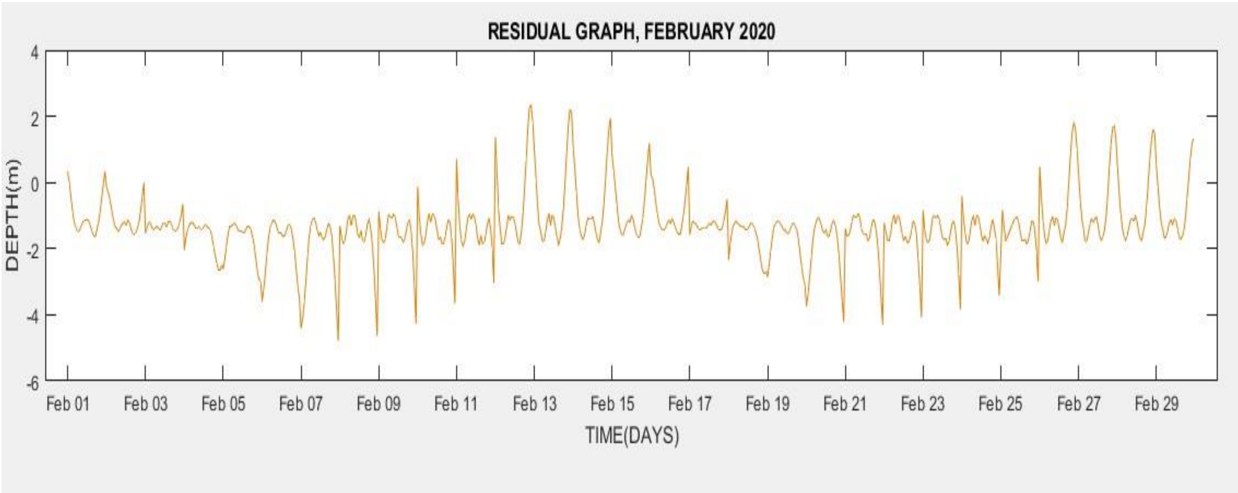

Figure 4.17 Residual graph, February 2020.

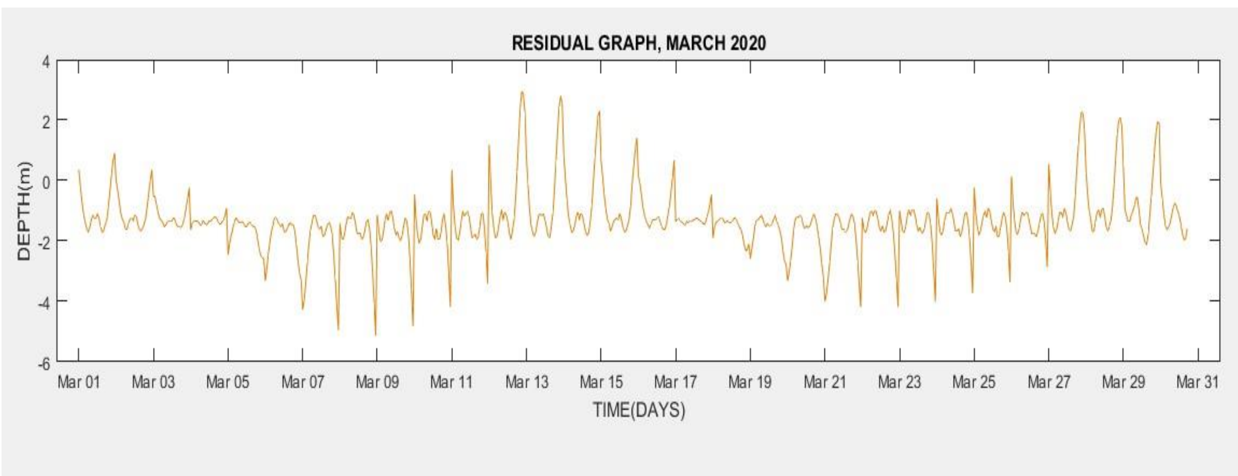

Figure 4.18 Residual graph, March 2020

Mtwara tide gauge station

- Graph of in-situ versus predicted depth from WTide.

Figure 4.19 to figure 4.21 show plotted in-situ and predicted tides for Zanzibar station. The plotting involves tidal depth against time.

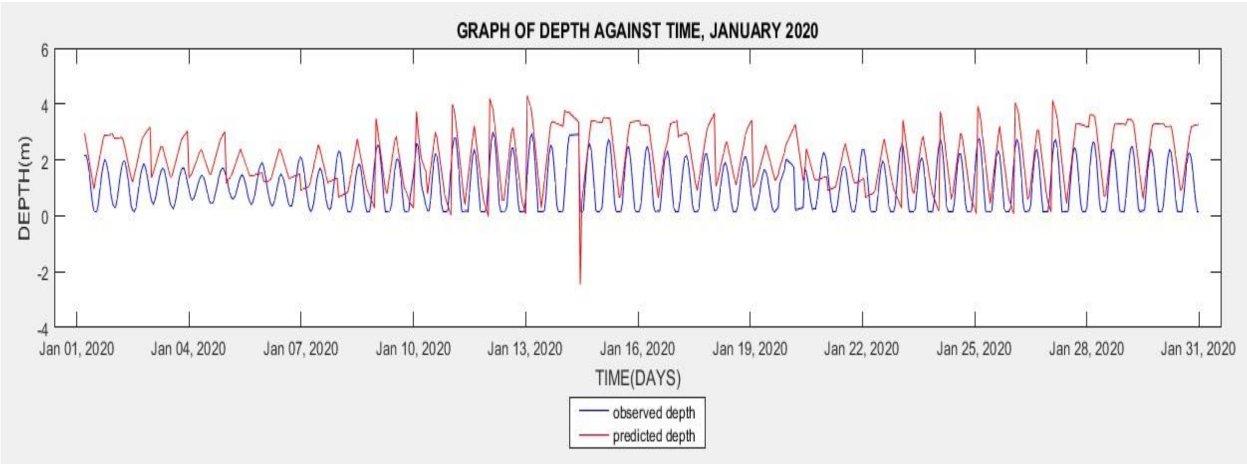

Figure 4.19 Graph of depth against time, January 2020

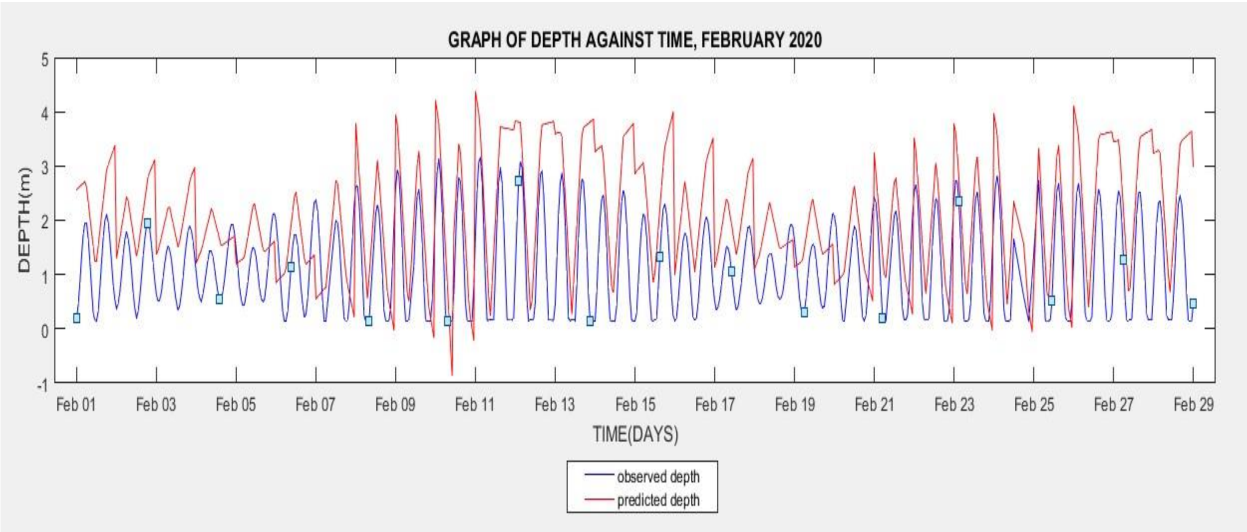

Figure 4.20 Graph of depth against time, February 2020

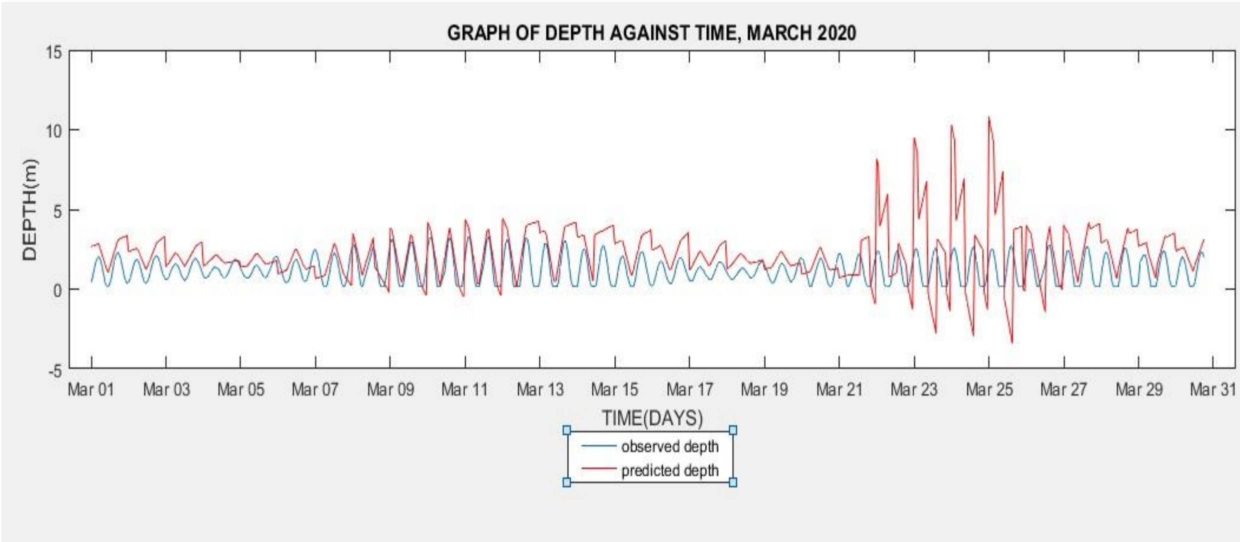

Figure 4.21 Graph of depth against time, February 2020

e) The graphs of residual between predicted tides from WTide and in-situ tides.

Figure 4.22 to figure 4.24 show the residual plots against time for Mtwara tide gauge station.

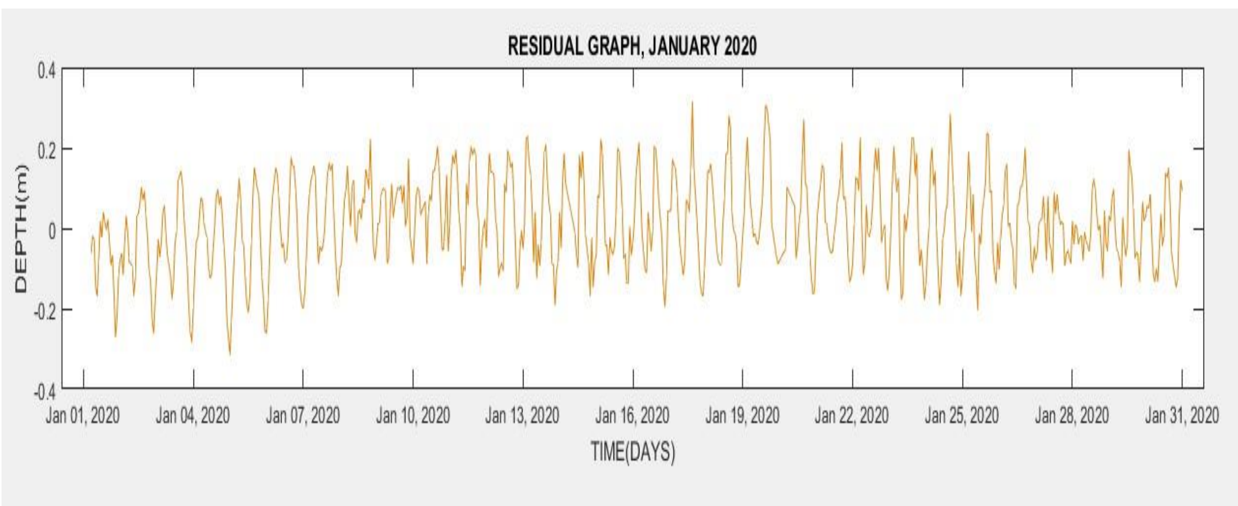

Figure 4.22 The Residual graph of Mtwara, January 2020

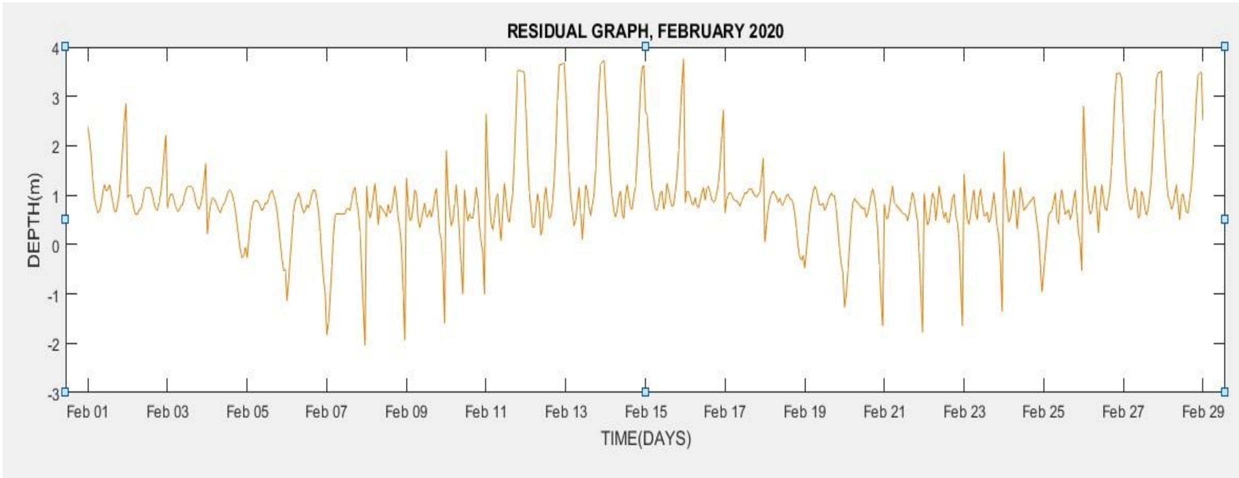

Figure 4.23 The Residual graph of Mtwara, February 2020

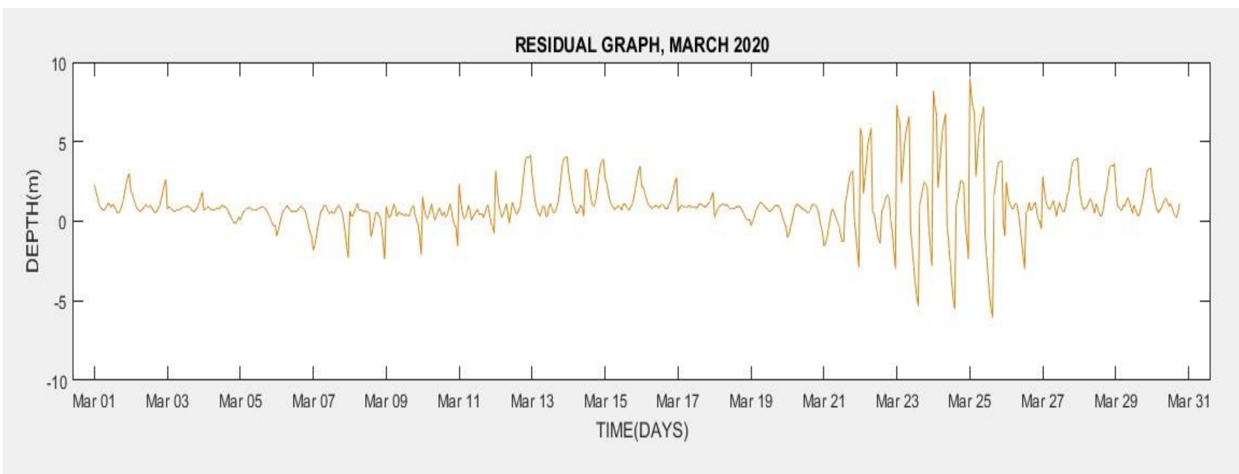

Figure 4.24 The Residual graph of Mtwara, February 2020

4.3 Results of local tidal prediction model

4.3.1 Tidal parameters of Dar es salaam tide gauge station

The table below shows the tidal parameters of Dar es salaam which were obtained by interpolating tidal parameters of Zanzibar and Mtwara.

Table 4.3 Tidal parameters of Dar es salaam tide gauge station

S/N	Constituents	Amplitude(m)	Phases	S/N	Constituents	Amplitude	Phases
1	M2	1.188	25.721	22	SN4	0.0024	200.786
2	S2	0.598	62.970	23	MO3	0.0023	128.868
3	N2	0.214	4.170	24	ALP1	0.0012	350.473
4	K1	0.173	352.208	25	2MK5	0.0008	219.448
5	O1	0.111	0.706	26	3MK7	0.0007	269.764
6	L2	0.042	47.333	27	M8	0.0005	4.860
7	M6	0.023	51.870	28	S4	0.0009	75.077
8	Q1	0.021	347.087	29	MK3	0.0025	302.964
9	MU2	0.017	15.422				
10	M4	0.016	179.675				
11	2MS6	0.015	102.320				
12	NO1	0.012	66.008				
13	OO1	0.011	28.919				
14	MS4	0.010	273.197				
15	ETA2	0.009	75.150				
16	J1	0.007	9.814				
17	MN4	0.006	111.208				
18	2SK5	0.005	279.760				
19	M3	0.005	135.589				
20	2SM6	0.005	109.875				
21	2Q1	0.003	326.886				

4.3.2 Tidal prediction

Tidal prediction was done for Dar es salaam tide gauge station using the tidal parameters obtained from table 4.3. Figure 2.5 below shows the pattern of the tidal data obtained from harmonic prediction model and WTide.

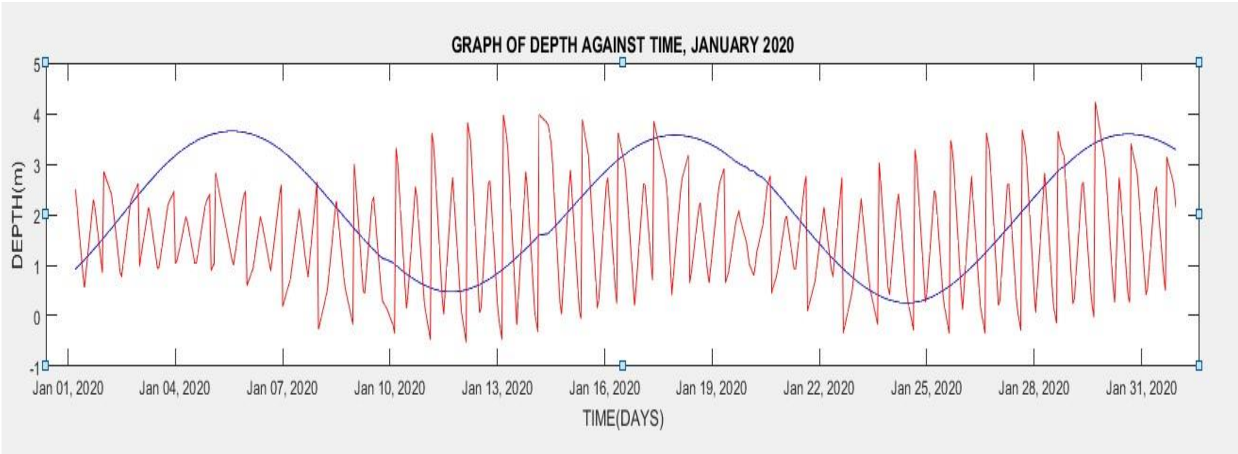

Figure 4.25 Graph of depth against time, January 2020 Dar es Salaam tide gauge

4.4 The results of statistical analysis of the residual.

The results of statistical analysis of the tidal prediction.

Zanzibar tide gauge station.

Table 4.4: Statistical analysis of tidal prediction using RMSE for Utide for Zanzibar.

YEAR	MONTH	RMSE(m)	Mean(m)	Standard deviation(m)
2020	JANUARY	0.025	3.490	0.875
	FEBRUARY	0.086	3.490	0.979
	MARCH	0.110	3.513	1.039

From the table 4.4 above it can be seen that the prediction of January was more accurate because it has the smallest RMSE of 0.0250m compared to February and March.

Table 4.5: Statistical analysis of tidal prediction using RMSE for WTide for Zanzibar.

YEAR	MONTH	RMSE(m)	Mean(m)	Standard deviation(m)
2020	JANUARY	1.688	2.074	1.034
	FEBRUARY	1.608	2.132	1.103
	MARCH	1.642	2.145	1.144

From the table 4.5 above it can be seen that the accuracy of the prediction was almost the same for all months.

Mtwara tide gauge station.

Table 4.6: Statistical analysis of tidal prediction using RMSE for Utide for Mtwara.

YEAR	MONTH	RMSE(m)	Mean(m)	Standard deviation(m)
2020	JANUARY	0.1122	1.111	0.812
	FEBRUARY	0.0778	1.152	0.818
	MARCH	0.1422	1.211	0.817

From the table 4.6 above it can be seen that the prediction of February was more accurate because it has the smallest RMSE of 0.077822m compared to January and March.

Table 4.7: Statistical analysis of tidal prediction using RMSE for WTide for Mtwara.

YEAR	MONTH	RMSE(m)	Mean(m)	Standard deviation(m)
2020	JANUARY	1.287	2.041	0.973
	FEBRUARY	1.270	2.078	1.035
	MARCH	1.980	2.250	1.705

From the table 4.7 above it can be seen that the accuracy of the prediction was almost the same for January and February. But March tends to have greater RMSE than other months this showing its prediction is not accurate.

Results of the local tidal constituents for Dar es Salaam tide gauge station

From the statistical analysis the RMSE obtained was 1.49922m this was done by assessing how the global tidal prediction model deviates from the local tidal prediction model.

4.5 Discussion of the results

4.5.1 Zanzibar Tide gauge station

Tidal analysis was done where 59 tidal parameters were obtained. To check for the performance of the software used to analyse the tidal data tidal prediction was conducted where we predicted tides for three months and compared them to the in-situ tidal height as shown in Figure 4.1 to Figure 4.3. From those graphs it can be seen that they have the similar trend that the prediction was so close enough to the actual values. The residual for each tidal depth from time to time are provided from figures from Figure 4.4 to Figure 4.6, the residual graphs seem to have same patterns.

As for the prediction from WTide predicted data of three months were used to compare them to the in-situ tidal height as shown in the figures from Figure 4.13 to Figure 4.15. From the graphs it can see be seen that the they don't have the similar pattern and trend that the tend to much deviate from each other as shown in the residual graphs from Figure 4.16 to Figure 4.18.

On assessing the accuracy of the tidal prediction root mean square error, standard deviation and mean were computed for both Utide and WTide software. Table 4.3 shows the statistical analysis of the Utide and it can be seen that 0.110387m as the maximum RMSE and 0.0250m as the minimum RMSE. Table 4.4 shows the statistical analysis of WTide and it can be seen that 1.688m as the maximum RMSE and 1.608m as the minimum RMSE.

4.5.2 Mtwara Tide gauge station

Tidal analysis was done where 35 tidal parameters were obtained. To check for the performance of the software used to analyse the tidal data tidal prediction was conducted where we predicted tides for three months and compared them to the in-situ tidal height as shown in Figure 4.7 to

Figure 4.9. From those graphs it can be seen that they have the similar trend that the prediction was so close enough to the actual values. The residual for each tidal depth from time to time are provided from figures from Figure 4.10 to Figure 4.12, the residual graphs seem to have same patterns.

As for the prediction from WTide predicted data of three months were used to compare them to the in-situ tidal height as shown in the figures from Figure 4.19 to Figure 4.21. From the graphs it can see be seen that the they don’t have the similar pattern and trend that the tend to much deviate from each other as shown in the residual graphs from Figure 4.22 to Figure 4.24.

On assessing the accuracy of the tidal prediction Root mean square error, Standard deviation and mean were computed for both Utide and WTide software. Table 4.5 shows the statistical analysis of the Utide and it can be seen that 0.142172m as the maximum RMSE and 0.077822m as the minimum RMSE. Table 4.6 shows the statistical analysis of WTide and it can be seen that 1.98046m as the maximum RMSE and 1.27m as the minimum RMSE.

4.5.3 Local tidal constituents

From the tidal constituents of Zanzibar and Mtwara tide gauge station obtained, a MATLAB code was created to predict tides for Dar es salaam. Tidal parameters of Dar es salaam were obtained by interpolating the tidal constituents of Zanzibar and Mtwara. The harmonic prediction model was able to predict tides for Dar es salaam for January 2020 and then assessed by comparing it with the predicted data from WTide as shown in Figure 2.5. The result of the RMSE difference of the in-situ tidal data and predicted data was 1.499218m.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The main objective of this study was to establish the local tidal constituents using harmonic prediction model which was achieved successfully. In order to achieve this, first tidal parameters of Zanzibar and Mtwara tide gauge station were determined using the tidal analysis and prediction software known as U-tide. Tidal prediction was done for both Zanzibar and Mtwara tide gauge stations. The results were then assessed using statistical analysis by assessing how predicted tides deviated from the actual tides. The results obtained were as follows for Zanzibar tide gauge station the RMSE was between 0.025m to 0.11m as shown in Table 4.4 and for Mtwara tide gauge station the RMSE was between 0.07m to 0.14m from Utide software. Assessment of the WTide software was done to check for the accuracy of predictions of the global tidal prediction model and the results were as follows; for Zanzibar tide gauge station the RMSE was between 1.608m to 1.688m as shown in Table 4.5 and for Mtwara tide gauge stations the RMSE was between 1.27m to 1.98m as shown in Table 4.7. From the assessment of the WTide, it can be seen that it does not accurate predict tides.

Using Zanzibar and Mtwara tidal constituents, the tidal constituents of Dar es salaam tide gauge station were obtained through interpolation. Using harmonic prediction model, tides for Dar es salaam station were predicted and compared global tides from WTide software. It was found that the RMSE difference between the predicted tidal data from harmonic model and predicted tidal data from WTide was 1.499218m. However, due to lack of in-situ tidal measurements for Dar es Salaam station, the predicted tides from local harmonic constituents were not assessed. Therefore, it is necessary to assess the global predicted tides and predicted tides from interpolated local tidal constituents with in-situ tides.

Since the local predicted tides and global predicted tides show inconsistences (see Table 4.4, 4.5 and 4.7), it is necessary to establish a local tidal prediction model which will take account for the local tidal parameters of a specific tide gauge station. To give the model more significance, future researchers are encouraged to validate the model by comparing the predicted tides with actual in-situ observations. This validation process would enhance the reliability and accuracy of the tidal prediction model.

5.2 Recommendations

From the results and findings obtained in this research, the following is recommended:

- The next researcher should use in-situ tides at Dar es Salaam and other tide gauge stations to assess the locally predicted tides using local interpolated tidal constituents.
- Since this research used Utide in the tidal analysis, further analysis should be done on the performance of other tidal analysis and prediction software example XTide and World tides.

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APPENDICES

MATLAB code for interpolating tidal parameters.

APPENDIX A

MATLAB CODES

The code below shows how to interpolate tidal parameters using harmonic tidal prediction.

```
% Load file data
data=readtable('DAR.csv');
% Extract the data from the table
Amplitude=data.Amplitude;
phases=data.phases;
Speed=data.Speed;
% Display the loaded data
disp(data);
% convert phase to radians
phases1 = deg2rad(phases);
start_date = datetime(2020,2,1,0,0,0); %Start date and time
end_date = datetime(2020,2,29,23,0,0,0); %end date and time
t = start_date:hours(1):end_date; %create the time vector with hourly
intervals
t=datenum(t); % convert the datetime values to MATLAB serial date numbers
% define the harmonic equation
y=zeros(size(t));%initialize the tide height array
% iterate over each tidal constituent and add its  contribution to the tide
height
for i=1:length(t)
    for j=1:length(Amplitude)
        y(i)=y(i)+Amplitude(j)*cos(Speed(j)*t(i)+phases(j));
    end
end
```