Progress Report on

Analysis and interpretation of sea level data in Kenya

KMFRI RESEARCH PROGRESS REPORT

DECEMBER, 2024

Cover Image: *Mombasa Tide Gauge Station*

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ACKNOWLEDGEMENT

The authors would like to thank KMFRI, UNESCO through IOC-AFRICA and WIOMSA for supporting this exercise. We also wish to thank members of the tidal analysis team in the region for their cooperation and sharing of knowledge and experiences on the use of the three tidal analysis and prediction softwares. Special thanks to Patrick Caldwell and Nokolai Turetski of University of Hawaii Sea Level Centre (UHSLC) for the assistance provided. Many thanks to KMFRI management for supporting the sea level monitoring programme in Kenya since inception and colleagues assisting in this programme.

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1.0 Introduction

Performance target being addressed

Analyze and interpret sea level data and prepare a technical report to assist in marine resources management and decision making by June 2025 (50%)

1.1 Country Status on Sea level observations and related activities/network

The Intergovernmental Oceanographic Commission (IOC) of UNESCO developed a Global Sea Level Observing System (GLOSS) program in 1985 to address the growing concern about the rise in mean sea level around the globe. The objective of GLOSS was to provide high quality standardized data from which valuable sea level products can be produced for international oceanographic such as World Ocean Circulation Experiment (WOCE), Tropical Oceans Global Atmosphere (TOGA) and regional research programmes as well as for practical application on a national level. Kenya is one of the countries participating in GLOSS and has already received support and assistance in terms of training of our specialists and provision of equipment through IOC.

1.2 Kenya's Participation in Sea Level Monitoring Program

Kenya lies along the equator on the east coast of Africa in the Western Indian Ocean (WIO) region. It has a land surface area of 590,000 km^2 and a coastline of about 600 km. The coastline extends from Shimoni on the south near the border with Tanzania to Kiunga on the north near the border with Somalia (Figure 1).

In Kenya, the first gauge was installed in 1933 in Kilindini harbour, Mombasa by the former East Africa Railways and Harbours Corporation (EARHC) and was in operation until 1956. Another gauge (Munro gauge) was installed in the 1960's at the Kipevu pilot jetty at the present Kenya Ports Authority Headquarters and operated intermittently upto1976. However, little data is available from this gauge. In 1975/6, a team from the Permanent Service for Mean Sea Level (PSMSL) collected one-year continuous data.

In the late 1980's, the University of Hawaii in collaboration with the TOGA Sea Level Centre established a network of sea-level stations, which continue to provide useful information. Realising the importance of sea level data for navigation and harbour planning, beach protection and development and overall marine research, Kenya Marine & Fisheries Research Institute (KMFRI) requested for a tide gauge through IOC-UNESCO from the University of Hawaii (UH) in June, 1986 to start its tide gauge network. Following that request, the University of Hawaii donated a tide gauge, which was installed at Liwatoni jetty in Kilindini harbour, Mombasa. A second tide gauge was installed by UH in Lamu in 1996. KMFRI is responsible for maintaining both the Mombasa and Lamu tide gauge stations. Two KMFRI Technicians are attached to each station.

1.3 Status of GLOSS Stations in Kenya

1.3.1 Mombasa Tide Gauge (Latitude: 04^o 04´S; Longitude: 039^o 039'E)

A Leopold Stevens gauge was installed in Mombasa in 1986 with technical assistance from University of Hawaii Sea Level Centre (UHSLC). This was later changed to a Fisher and Porter float gauge in 1991. The station continues to operate well and data is available. Some of the benchmarks were removed during construction work at the harbour where the gauge is located. The Mombasa gauge is float type installed on a stilling well. The station is equipped with modern data logger, measuring sea level every minute and storing on diskette at 15 minutes interval.

In August 2006, a major upgrading of the Mombasa tide gauge was carried out with the assistance of field technicians from UHSLC. This involved a thorough overhaul of the existing equipment, installation of additional sensors (pressure and radar sensor). The station was also equipped with satellite data transmition facilities to enable near real-time data access. Mombasa tide gauge is a Principal station on the GLOSS network and also a dedicated component of the proposed Indian Ocean Tsunami Warning System (IOTWS).

1.3.2 Lamu Tide Gauge (Latitude: 02^o 17´ S; Longitude: 040^o 54' E)

The Lamu gauge is a float type installed on a stilling well. It was installed in 1996 by the University of Hawaii Sea Level Centre (UHSLC). The station is equipped with modern data loggers, measuring sea level every minute and storing on diskette at 15 minutes interval. In addition, the Lamu tide gauge is equipped with a satellite data transfer device to enable real time access to data. Earlier, there was a Valeport BTH 700 gauge was installed at the end of 1988 but was not operational since 1992. This was due to a problem with electrical connection on the jetty where it was installed. During the time the gauge was out of operation, data was collected manually at half hour interval during day time (0900 to 1600 HRS).

In August 2006, the Lamu tide gauge station also underwent a major overhaul of equipment. The station was also fitted with additional sensors (pressure and radar sensor). Lamu is also a principal station on the GLOSS network and a dedicated component of IOTWS. Data from this station (and others like it in the region) can be used to confirm or cancel a tsunami warning throughout the region.

Both stations Mombasa and Lamu stations continue to operate well and data is available. Kenya is also coordinating the regional component of GLOSS. The profiles of both historical and operational stations in Kenya are presented in Tables 1 and 2.

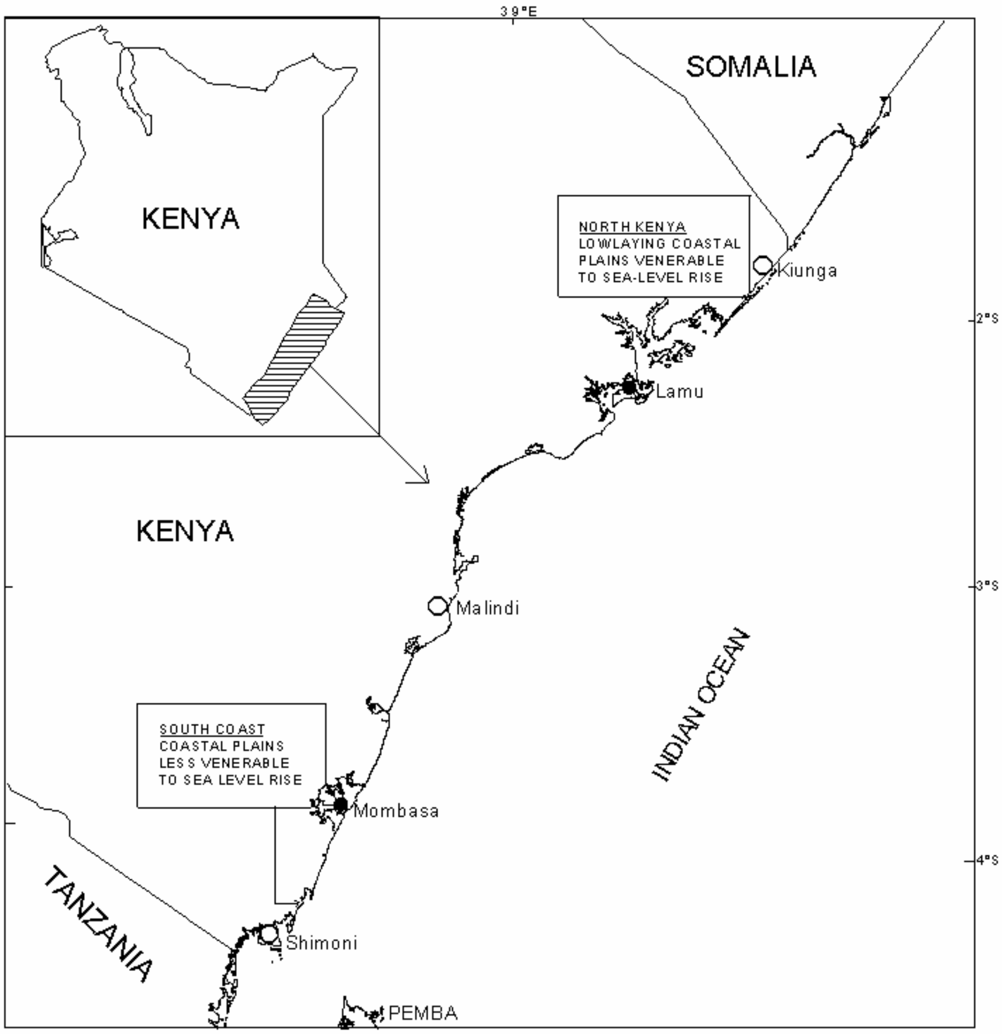

Fig 1: Map of Kenya Coastline showing location of installed tide gauge stations (●) and planned stations (o).

Fig 2: Photo of upgraded Mombasa tide gauge station

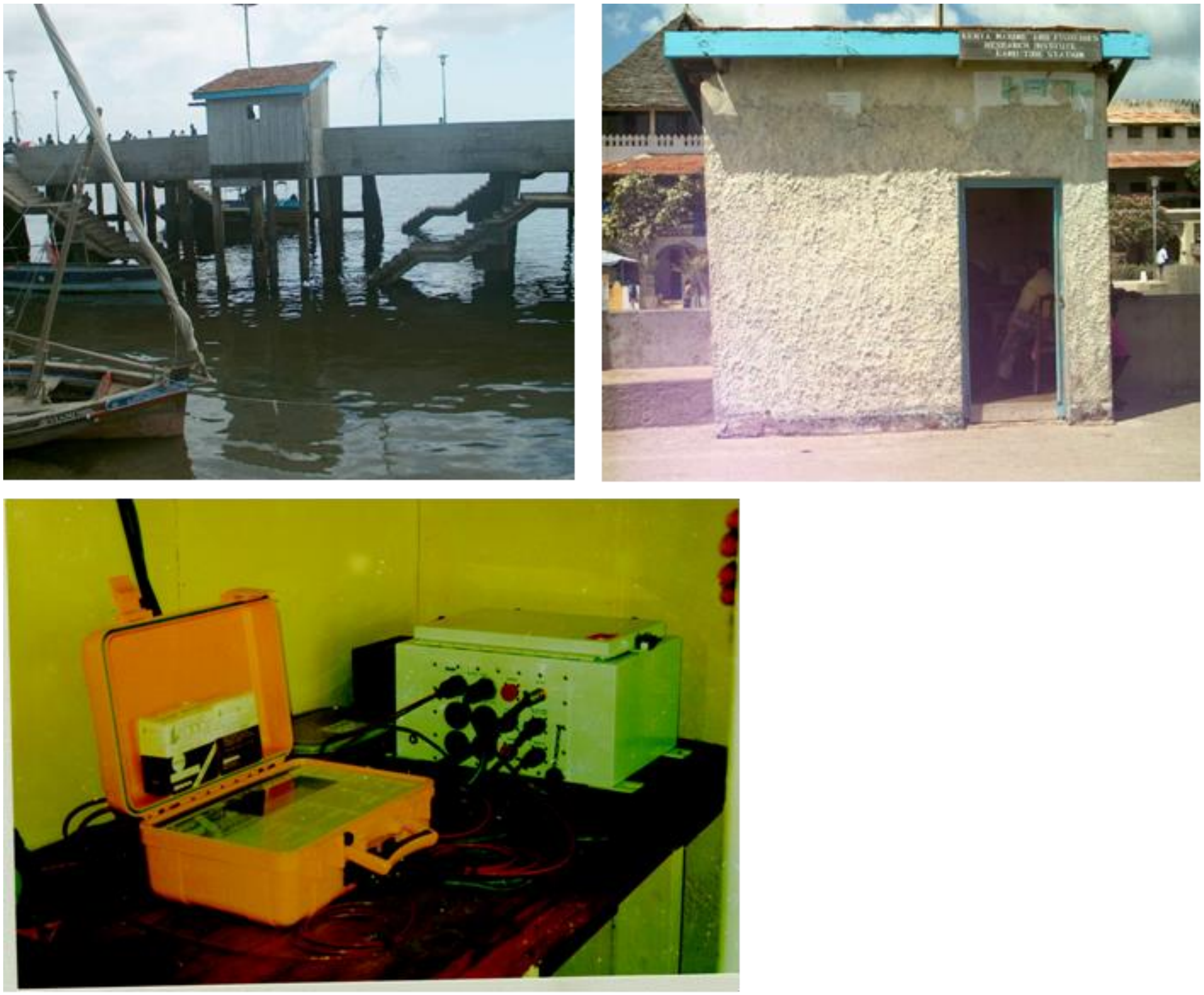

Fig 3: Photo of Lamu tide gauge station

1.3.3 Additional Stations by KMD

The Kenya Meteorological Department (KMD) is in the process of installing and testing three additional stations along the Kenyan coastline. These are at: Shimoni (4º 39´ S, 39º 23´E), Malindi (3º 15´S, 40º 08´E) and Lamu (02º 17´ S, 040º 54’ E) . Photos of the 3 new stations is shown in Figs 4, 5 and 6. Once the stations are fully operational, there shall be five stations covering the Kenyan coast. The gauges are also equipped with additional sensors and transmiting data in real-time (Table 1). However, data access from those stations is restricted. Additional information can be obtained by contacting the director of KMD (director@meteo.go.ke).

Fig 4a: Stilling well of the tide gauge at the Old Jetty of Kilifi Mnarani club.

Fig 4b: Tide gauge at Kilifi Mnarani Club.

Fig5a: Wasini Island Tidal and Automatic Weather Station installed at the Old Navy Jetty

Fig 5b: The stilling well of the tide gauge at Wasini Island.

Fig 6a: Lamu Island Automatic Weather Station, at the New Fisheries Jetty.

Fig 6b: Stilling Well of tide gauge at New Fisheries Jetty in Lamu Island.

1.4 Capacity (Technical and Scientific)

There is still limited capacity for repair and maitenance of the our tide gauges. Lack of spare parts and tools has been a major hindrance to carrying out minor repair jobs and levelling. We rely on services of technicians from UH Sea Level Centre for installation and maintenance of the two tide gauges. Regular maintenance of both gauges is supervised by KMFRI's Principal Laboratory Technologist (Jacqueline Olando) and the National Sea Level contact (Dr. Charles Magori).

Two KMFRI Technicians are attached to both stations. None of the Technicians on site has received training at PSMSL, UHLC, etc. However, a few of them have received in-service training and some additional hints during the visits to Kenya by field technicians from UHSLC. This has contributed fairly well in improving the accuracy and quality of the data.

Several Scientists at KMFRI have received post graduate training in Physical Oceanography. There is sufficient capacity on analysis and interpretation of sea level data. In addition, four Kenyan scientists have received training sponsored by IOC on Sea Level Data Analysis and Interpretation. They are Mika Odido at PSMSL, UK in 1992, Charles Magori at Dehra Dun, India in 1995, Clive Angwenyi in Cape Town, South Africa in 1998 and Antony Kibue in Oostende, Belgium in 2006.

2.0 Objectives

The objectives of this exercise are to:

- Collect and analyse sea level data from Mombasa and Lamu sea level stations in Kenya and generate tidal predictions for the two stations for the period 1 January to 31 December 2024.
- Disseminate the comprehensive tide tables produced by KMFRI by distributing them to stakeholders.
- Build-up sea level database for detection of extreme oceanic events such as tsunamis, storm surges and tropical cyclones as part of Indian Ocean Tsunami warning System.

3.0 Data from Mombasa and Lamu Stations

The sea level data (hourly, daily and monthly means) for the Kenyan stations are available at KMFRI in JASL format. Because of our close collaboration with UHSLC, both Mombasa and Lamu stations are now transmitting data on near real-time time basis to UHSLC database. Quality Control of data is performed at UHSLC. Monthly means are also available at the Permanent Service to Mean Sea Level (PSMSL). It should be noted that the available data has some unprecedented data gaps resulting from occassional breakdown of equipment.

For Mombasa station, available data is from 1975/6 and 1986-2024.

The data available from Lamu station is in digital form and analogue charts. The digital data is from 1989, and 1996–2024 and the analogue chart is from 1990 to 1992. All the digital data from both stations are available in International data centres namely PSMSL and UHSLC. The archived data can be downloaded for free from the following web sites.

- http://www.soest.hawaii.edu/UHSLC
- http://www.pol.ac.uk/psmsl/gloss.info.html

Real-time data from both stations can be accessed via the World Meteorological Organization (WMO) Global Telecommunication System (GTS) on the UHSLC and ODINAFRICA websites using the liks below:

- http://ilikai.soest.hawaii.edu/RSL

- http://www.vliz.be/vmdcdata/iode

3.1 Data Selection for Tidal Analysis

Data used in this study was downloaded from the "Research Quality" database on the UHSLC website that archives data in hourly, daily and monthly means. For Mombasa station, hourly time series data for year 2015 was selected as the base period to be used for the analysis with 2024 as the validating period. For Lamu station year 2016 was selected as the analysis period and 2024 as the validating period. This was based on the consideration that there are few data gaps (or no gaps) in the available hourly data sets for the selected years.

4.0 Methodology

The selected data was subjected to manipulation in Textpad environment in order to fit the required format that is compatible with the tidal analysis softwares mentioned below. The base period data was then subjected to harmonic analysis procedure and finally the prediction of high and low and hourly values for the specified period. Plots of hourly data and quality checks were carried out before producing tide tables for year 2024.

Harmonic analysis is a mathematical method of extracting sinusoidal components of specific frequencies from for example time series of water levels (hourly intervals). It is based on the methods of least squares. Instead of fitting a straight line to the data by varying its slope and intercept, a set of cosine (or sine) curves with given frequencies w are fitted by varying amplitudes and phases, minimizing the sum of deviation from the original curve. In classical harmonic analysis, the tidal signal is modelled as a sum of a finite set of sinusoids at specific frequencies related to astronomical parameters.

Two tidal analysis softwares that were utilized in this exercise are (a) SLPR2, (b) T_TIDE.

SLPR2 software is a FORTRAN based programme that operates under the DOS environment. It performs harmonic analysis of hourly time series observations of sea levels to extract tidal constituents, predict hourly and also the High and Low listings of sea levels. The software includes the Foreman's tidal analysis and prediction routines. Further details regarding the software can be obtained by referring to Caldwell, 1998.

T_TIDE is a set of programs that has been written in MATLAB to:

i) perform classical harmonic analysis for time series data for periods of about one year of data (or shorter)
ii) use nodal corrections to account for some unresolved tidal constituents, and
iii) compute confidence intervals for the analysed components

T_Tide comprises a translation of the Foreman Tide analysis mark the theory. Further details of the theory can be found in "Classical Tidal Harmonic Analysis Including Error Estimates in MATLAB using T_TIDE", (Pawlowicz *et. al*., 2002).

TASK-2000 software is a FORTRAN based and uses the Microsoft Excel environment. The software performs harmonic analysis and tidal predictions in form of high and low listings as well as hourly values. The software package is derived from the TIRA tidal analysis programs. For further details, please refer to Bell *et. al*., 2000.

Table 1: Profile of Operational Stations in Kenya

Station Name	Location Lat	Lon	Responsible Organisation	Collaborating Institution(s)	Type of guage/ Manufacturer	Data Span	Mode of Transmision	Data Sources	Others Sensors	Remarks
Mombasa	04º4' S	39º 39'E	KMFRI	UHSLC	Fisher & Porter Float gauge on stilling well	1986-2024	Near Real-time	-UHSLC -ODIN-AFRICA -KMFRI	-Radar -Pressure	-Significant gaps -digital data
Lamu	02º17'S	040º 54'E	KMFRI	UHSLC	-Float gauge on stilling well -UH Ref. level switch	1996-2024	Near Real-time	-UHSLC -ODIN-AFRICA -KMFRI	-Radar -Pressure	-Few gaps - digital data
Shimoni	4° 39´ S	39° 22´ E	Kenya Met Dept. (KMD)	-	Acoustic gauge with automatic weather station (AWT) – Sutron Corporation, USA.	July 2007 - 2010	Real-Time	KMD	-pressure -wind -temp. -atmsp. pressure -humidity	-Restricted data access
Kilifi	3° 38´ S	39° 51´E	KMD	-	Acoustic gauge with AWT – Sutron Corporation, USA.	July 2007 - 2010	Real-Time	KMD	-pressure -wind -temp. -atmsp. pressure -humidity	-Restricted data access
Lamu	2° 17´S	40° 54´E	KMD	-	Acoustic gauge with AWT – Sutron Corporation, USA.	July 2007 - 2010	Real-Time	KMD	-pressure -wind -temp. -atmsp. pressure -humidity	-Restricted data access

Table 2: Profile of Historical Stations in Kenya

Station Name	Location Lat	Lon	Responsible Organisation	Collaborating Institution(s)	Type of guage/ Manufacturer	Data Span	Data Sensors	Remarks
Lamu	02°17 'S	040° 54' E	KMFRI	KPA	Valeport BTH 700 gauge	1988-1992	-	data in analogue charts
Kilindini harbour - Mombasa	-	-	EARHC	KPA	-	1933-1956	-	-scant info on gauge and data
Kipevu Pilot Jetty - Mombasa	-	-	KPA	-	Munro gauge	1960 - 1976	-	-scant info on gauge and data
Kilindini harbour - Mombasa	-	-	PSMSL	KPA	-	1975-1976	-	- data available at PSMSL

5.0 Analysis and Interpretation

Table 3a:- Main tidal constituents from harmonic analysis results

Station Name: Mombasa

Constituent	Constituent name	Amplitude (cm)	Phase (deg)
M2	Principal Lunar semi diurnal	104.57	66.72
S2	Principal Solar semi diurnal	51.29	66.59
O1	Lunar declinational diurnal	11.45	242.62
K1	Luni-solar declinational diurnal	19.28	156.03
K2	Luni-solar declinational semi diurnal	13.93	203.83
N2	Larger Lunar elliptic semidiurnal	19.23	27.50

Table 3b:- Main tidal constituents from harmonic analysis results

Station Name: Lamu

Constituent	Constituent name	Amplitude (cm)	Phase (deg)
M_2	Principal Lunar semi diurnal	97.90	227.36
S_2	Principal Solar semi diurnal	48.60	72.80
O_1	Lunar declinational diurnal	12.51	34.64
K_1	Luni-solar declinational diurnal	20.79	160.92
K_2	Luni-solar declinational semi diurnal	14.09	215.06
N_2	Larger Lunar elliptic semidiurnal	18.01	233.28

Table 4: Tidal statistics, amplitudes and phases based on harmonic analysis.

Parameter	Formula	Mombasa station	Lamu station
Form number	$(K_1+O_1)/(M_2+S_2)$	0.20	0.23
Spring Range	$2.0(M_2+S_2)$	3.12 m	2.93 m
Neap Range	$2.0(M_2-S_2)$	1.07 m	0.99 m
Mean Range	$2.2(M_2)$	2.08 m	1.96 m

From harmonic analysis performed by SLPR2 software, the tidal characteristics for both Mombasa and Lamu stations are very similar as shown in Tables 3 and 4 above.

Table 5: KMFRI staff on sea level monitoring programme.

Staff	Mombasa	Lamu
Scientific	Dr. Charles Magori Athman Salim	Dr. Amon Kimeli Damaris Mutia
Technical	Jacqueline Olando Vanessa Orenge	Dismus Kosieny John Ochengo

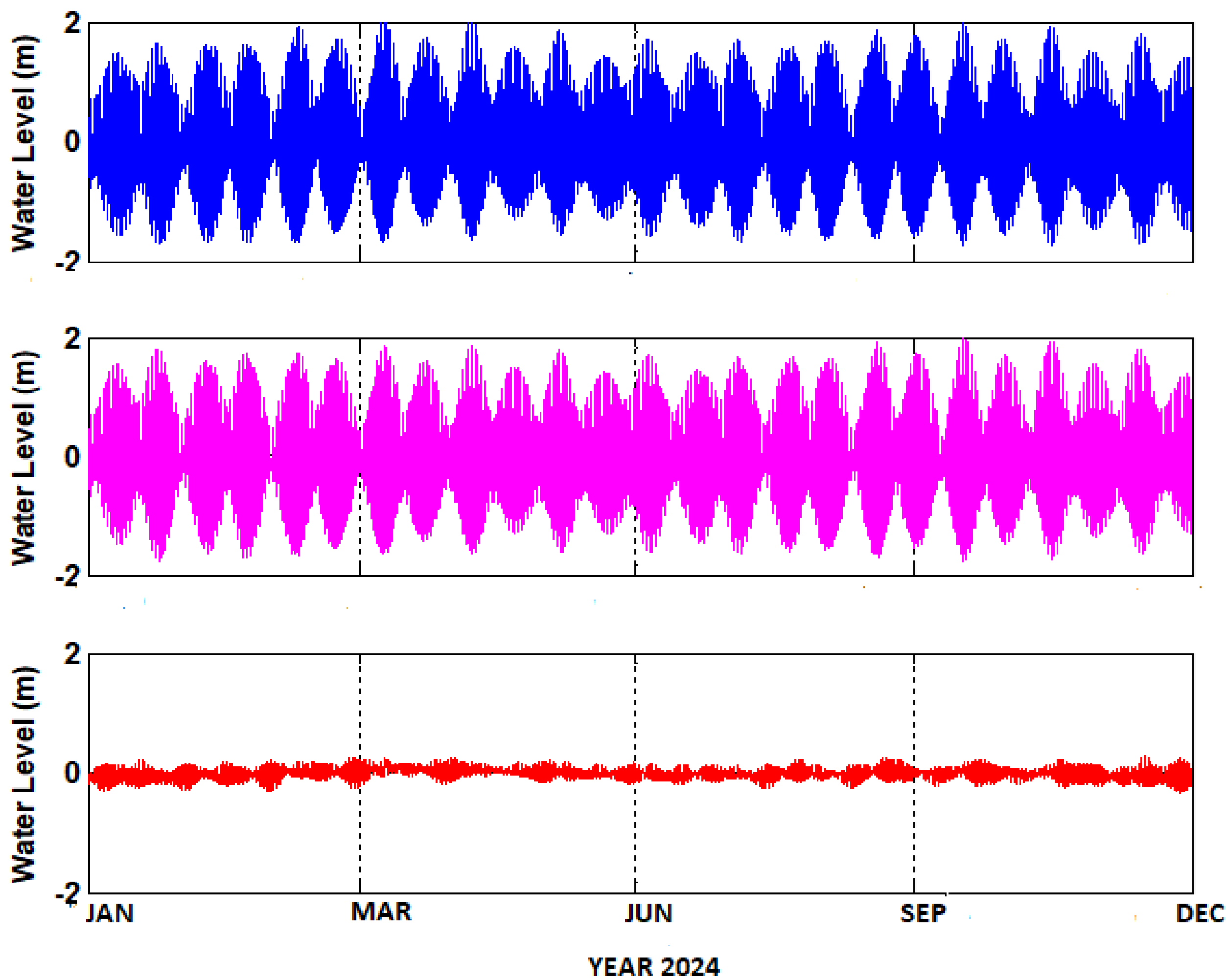

Fig 7: Graphs of Observed (blue), computed (magenta) and residual (red) sea levels for Mombasa by T_TIDE.

Validation results for Mombasa and Lamu for the period of 1 January 2021 to 31 December 2021 are shown in Figures 7 and 8 respectively. These are based on comparison between tide predictions (produced by constituents generated by harmonic analysis using 2015 sea level data for Mombasa and 2016 for Lamu tide gauges) and actual observations. For both stations, the residuals are less than 20 cm indicating that the observed sea levels compare fairly well with the predicted values.

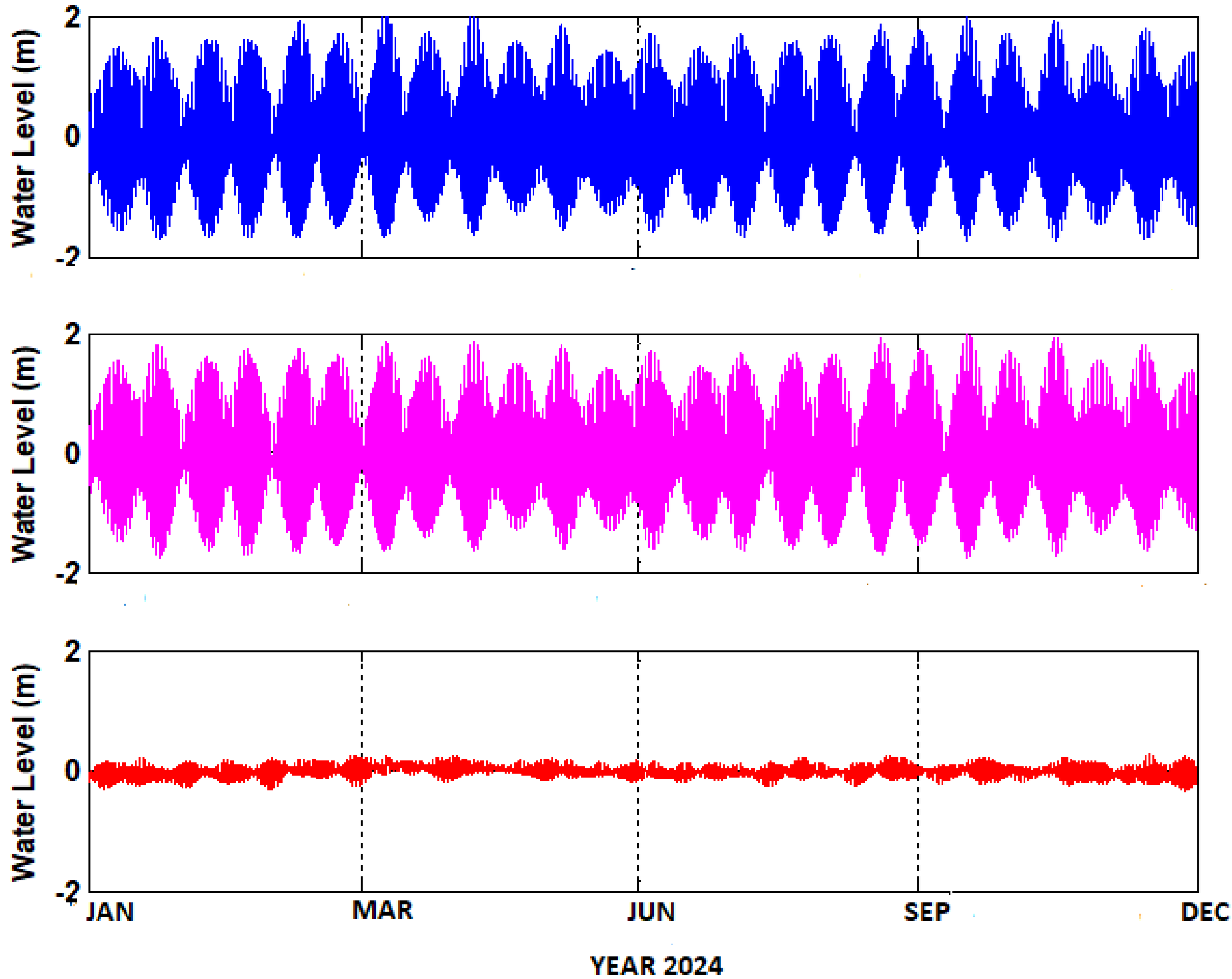

Fig 8: Graphs of Observed (blue), computed (magenta) and residual (red) sea levels for Lamu by T_TIDE.

In general, the selected datasets were subjected to the data management procedures, extraction of tidal constituents through harmonic analysis and finally the generation of tide predictions in form of high and low listings and hourly values for the specified period. Since the results may be affected by validation based on the output and known variations, the residuals were computed from a year whose data is outside the period used in the harmonic analysis phase.

From harmonic analysis results presented in Tables 3(a) & (b), Principal Lunar (M_2) and Principal Solar (S_2) tidal constituents account for more than 50% of water level variations in both stations. This is a clear indication that semi-diurnal tides are the primary drivers of tidal forcing. The tide tables generated for both Mombasa and Lamu reveals that Kenyan coastline experiences two high tides and two low tides in a period of 24 hours (i.e. daily), typical semi-diurnal tidal patterns.

A form number, F, has been defined as the ratio of the sum of amplitudes of diurnal tidal species over semi diurnal species. According to Defant (1958), a simplified definition for F, $F = (k_1+O_1)/(M_2+S_2)$, can be used to characterize tidal types. If F is less than 0.25, the tide is referred to as semi-diurnal, and if F is greater than 3.0, the tide is diurnal. Value of F between 0.25 and 3.0 are considered as mixed tides. From results of harmonic analysis, the form numbers for Mombasa and Lamu stations are 0.20 and 0.23 respectively, indicating that the tides are typically semi-diurnal. The spring tidal range for Mombasa and Lamu are 3.12 m and 2.93 m respectively while the corresponding neap range is 1.07 m and 0.99 m respectively (Table 4).

The residuals are small (~20 cm) for both stations as can be seen in Figures 7 and 8. They could be due to local forcing by wind stress and air pressure fluctuations. This indicates that meteorological forcing plays a minor role in the water level variations at both stations. It also further indicates that water level variations are exclusively driven by tidal forcing.

SLPR2 and T_TIDE softwares that were used have given fairly similar results of the harmonic constituents for each station (See Annex I). The tides can be characterized as being strongly semidiurnal, with the major constituents having similar amplitudes, phase lags and consequently similar tidal ranges for the two stations.

From observed data, water level variations at Mombasa and Lamu tide stations are sinusoidal with two unequal peaks daily. In addition, high water occurs in Mombasa roughly 5 minutes earlier than in Lamu. This phenomenon is also reproduced in high low listings and hourly values on the tide tables for both stations (Annex II).

Both tidal analysis softwares were able to resolve tidal constituents with higher periods. A total of 68 harmonics were generated with corresponding amplitudes and phase lags (Annex I). This is attributed to the one-year continuous hourly data set (with few gaps) that was used as input data in harmonic analysis.

6.0 Concluding Remarks and Recommendations

Water level variations in Mombasa station are typically semi-diurnal with spring tide range of 3.12 m and neap tide range of 1.07 m. The corresponding values for Lamu are 2.93 m and 0.99 m respectively. As indicated by the residuals, meteorological forcing due to wind stress or fluctuations in air pressure plays a minor role in the water level variations. At both stations, astronomical tides account for more than 90% of the water level variations.

SLPR2 and T_TIDE run on the same routine but operate on different environments. The two softwares generate exactly the same number of tidal constituents. Tide tables from both packages compare fairly well.

Both Mombasa and Lamu are principal stations on GLOSS network and are also dedicated components of the IOTWS. In order to enable Kenya to generate high quality sea level data and products for local scientists, regional as well as international oceanographic programmes and data centres and also IOTWS, there is an urgent need to develop technical capacity for installation and maitenance of tide gauges and also for analysis and quality control of sea level data.

There is sufficient scientific capacity for analyis and interpretation of sea level data in Kenya. Although a few of our tide gauge technicians have received in-service training and some additional hints during the visits to Kenya by field technicians from UHSLC, there is still limited technical capacity for repair and maitenance of the our tide gauges. IOC-AFRICA and WIOMSA could contribute to capacity building by providing Marine Research Grants (MARG II) for tide gauge technical staff.

The IOTWS fellowship programme on Sea Level Sciences and Applications programme should consider providing grants for our local technicians to visit specialised sea level data centres e.g UHSLC, PSMSL for training courses. The topics to be covered during the training should include review of sea level equipments, types, installation, levelling and maintenance as well as processing and quality control of sea level data.

References

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Annex I: Harmonic Constituents for Mombasa and Lamu Stations

Harmonic Analysis Results *(by T_TIDE Software)*

Mombasa Station

No.	Name	Frequency	Amplitude (cm)	Phase (degrees)
1	Xo	0.0000000	287.00	0.00
2	SA	0.0001141	2.51	162.78
3	SSA	0.0002282	1.12	27.05
4	MSM	0.0013098	0.66	23.00
5	MM	0.0015122	0.14	321.83
6	MSF	0.0028219	0.45	351.48
7	MF	0.0030501	1.35	27.42
8	ALP1	0.0343966	0.07	309.05
9	2Q1	0.0357064	0.3	332.54
10	SIG1	0.0359087	0.44	344.54
11	Q1	0.0372185	2.21	1.63
12	RHO1	0.0374209	0.5	358.06
13	O1	0.0387307	11.49	0.89
14	TAU1	0.0389588	0.13	335.65
15	BET1	0.0400404	0.18	351.41
16	NO1	0.0402686	1.6	273.83
17	CHI1	0.0404710	0.17	46.15
18	PI1	0.0414385	0.14	87.40
19	P1	0.0415526	5.43	354.12
20	S1	0.0416667	2.42	311.99
21	K1	0.0417807	18.97	354.56
22	PSI1	0.0418948	0.17	327.35
23	PHI1	0.0420089	0.34	324.02
24	THE1	0.0430905	0.32	346.94
25	J1	0.0432929	1.07	345.98
26	SO1	0.0446027	0.13	56.28
27	OO1	0.0448308	1.11	7.49
28	UPS1	0.0463430	0.23	41.05
29	OQ2	0.0759749	0.17	210.21
30	EPS2	0.0761773	0.2	44.68
31	2N2	0.0774871	1.67	318.22
32	MU2	0.0776895	1.53	23.99
33	N2	0.0789992	18.78	4.49
34	NU2	0.0792016	3.99	2.95
35	H1	0.0803973	1.1	2.07
36	M2	0.0805114	103.85	25.27
37	H2	0.0806255	0.64	84.10

38	MKS2	0.0807396	0.52	356.10
39	LDA2	0.0818212	1.16	46.57
No.	**Name**	**Frequency**	**Amplitude (cm)**	**Phase (degrees)**
40	L2	0.0820236	3.07	36.12
41	T2	0.0832193	3.02	55.74
42	S2	0.0833333	51.49	64.31
43	R2	0.0834474	0.58	75.55
44	K2	0.0835615	14.38	62.33
45	MSN2	0.0848455	0.29	289.02
46	ETA2	0.0850736	0.55	64.64
47	MO3	0.1192421	0.32	147.61
48	M3	0.1207671	0.33	131.49
49	SO3	0.1220640	0.11	154.16
50	MK3	0.1222921	0.19	32.82
51	SK3	0.1251141	0.17	334.81
52	MN4	0.1595106	0.66	100.54
53	M4	0.1610228	1.13	136.53
54	SN4	0.1623326	0.03	195.61
55	MS4	0.1638447	0.59	172.55
56	MK4	0.1640729	0.17	179.76
57	S4	0.1666667	0.26	195.64
58	SK4	0.1668948	0.12	190.03
59	2MK5	0.2028035	0.01	32.77
60	2SK5	0.2084474	0.08	294.32
61	2MN6	0.2400221	0.03	203.77
62	M6	0.2415342	0.04	125.51
63	2MS6	0.2443561	0.24	139.13
64	2MK6	0.2445843	0.06	166.25
65	2SM6	0.2471781	0.14	201.60
66	MSK6	0.2474062	0.08	186.26
67	3MK7	0.2833149	0.04	244.35
68	M8	0.3220456	0.05	315.56

Harmonic Analysis Results *(by T_TIDE Software)*

Lamu Station

No.	Name	Frequency	Amplitude (cm)	Phase (degrees)
1	Xo	0.0000000	227.00	0.00
2	SA	0.0001141	3.03	145.93
3	SSA	0.0002282	4.21	44.51
4	MSM	0.0013098	1.08	153.40
5	MM	0.0015122	1.39	13.12
6	MSF	0.0028219	0.8	5.22
7	MF	0.0030501	1.75	40.15
8	ALP1	0.0343966	0.26	5.47
9	2Q1	0.0357064	0.4	341.17
10	SIG1	0.0359087	0.59	3.99
11	Q1	0.0372185	2.61	345.69
12	RHO1	0.0374209	0.42	354.37
13	O1	0.0387307	11.81	4.31
14	TAU1	0.0389588	0.49	64.62
15	BET1	0.0400404	0.16	323.74
16	NO1	0.0402686	0.74	61.43
17	CHI1	0.0404710	0.24	2.99
18	PI1	0.0414385	0.34	352.23
19	P1	0.0415526	5.56	0.02
20	S1	0.0416667	2.91	316.47
21	K1	0.0417807	19.95	358.53
22	PSI1	0.0418948	0.16	25.98
23	PHI1	0.0420089	0.32	345.62
24	THE1	0.0430905	0.32	343.51
25	J1	0.0432929	1.18	42.35
26	SO1	0.0446027	0.55	96.11
27	OO1	0.0448308	1.03	36.28
28	UPS1	0.0463430	0.2	66.16
29	OQ2	0.0759749	0.17	80.50
30	EPS2	0.0761773	1.06	60.00
31	2N2	0.0774871	1.63	5.16
32	MU2	0.0776895	2.68	62.60
33	N2	0.0789992	18.12	11.38
34	NU2	0.0792016	3.79	14.55
35	H1	0.0803973	0.86	51.91
36	M2	0.0805114	98.71	31.34
37	H2	0.0806255	0.48	97.82
38	MKS2	0.0807396	0.32	149.39
39	LDA2	0.0818212	1.42	19.78

No.	Name	Frequency	Amplitude (cm)	Phase (degrees)
40	L2	0.0820236	4.71	40.33
41	T2	0.0832193	3.46	75.28
42	S2	0.0833333	48.57	72.92
43	R2	0.0834474	0.48	77.35
44	K2	0.0835615	12.95	69.38
45	MSN2	0.0848455	0.32	185.25
46	ETA2	0.0850736	0.6	82.01
47	MO3	0.1192421	0.85	173.15
48	M3	0.1207671	0.26	97.76
49	SO3	0.1220640	0.64	221.09
50	MK3	0.1222921	0.68	153.24
51	SK3	0.1251141	0.51	216.69
52	MN4	0.1595106	0.93	157.42
53	M4	0.1610228	2.41	179.06
54	SN4	0.1623326	0.42	233.15
55	MS4	0.1638447	1.96	226.25
56	MK4	0.1640729	0.51	236.78
57	S4	0.1666667	0.63	282.12
58	SK4	0.1668948	0.31	282.04
59	2MK5	0.2028035	0.23	350.12
60	2SK5	0.2084474	0.11	9.96
61	2MN6	0.2400221	0.34	45.15
62	M6	0.2415342	0.61	65.47
63	2MS6	0.2443561	1.12	123.59
64	2MK6	0.2445843	0.25	112.36
65	2SM6	0.2471781	0.4	159.09
66	MSK6	0.2474062	0.21	156.15
67	3MK7	0.2833149	0.07	119.97
68	M8	0.3220456	0.22	226.86

Annex II: High – Low Tide Predictions for Mombasa and Lamu Stations

Annex III: Hourly Tide Predictions for Mombasa and Lamu Stations

Annex IV: Dissemination email of tide tables and sea level data to stakeholders

Detailed plan of activities for sea level monitoring, analysis and interpretation programme in Kenya.

Activity	**Project Period 2024-25 FY**			
	Q1	**Q2**	**Q3**	**Q4**
Quality control of sea level data				
Harmonic Analysis of sea level data				
Generation of tide predictions				
Calibration and validation of tide predictions				
Progress Report on sea level monitoring				
Distribution of tide tables and sea level data to stakeholders				
Update of sea level database				
Report preparation and submission				