SEA LEVEL MEASUREMENT AND ANALYSIS IN THE WESTERN INDIAN OCEAN

NATIONAL REPORT KENYA

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The first part of this report covers the Status of Sea level Observation and related activities in Kenya. Included in this part are physical description, status of the sea level network, and availability of data from stations, human capacity available and utilization of sea level products. The second part of the report focuses on available meteorological data.

1.0 INTRODUCTION

Kenya lies along the Equator on the east coast of Africa between latitudes 50^{o} 40´ N and 4^{o} 4´ S and between longitudes 33^{o} 50´ E and 41^{o} 45´ E. It has a land a coastline of about 600 km long. The coastal plain rises from sea level datum (OD) to over 200m OD There are several rivers that drain into the Indian Ocean. The Kenyan coastline is characterised by mangrove forests, coral reefs and sandy beaches protected from the open ocean by the fringing reefs.

There are several ports along the coastline. Mombasa is the principal seaport of Kenya. The port is linked with the world's major ports with over 20 sailings per week. In addition, Mombasa is the main sea gateway for inland states in East and Central Africa region namely: Uganda, Congo, Rwanda, Burundi and Sudan. The other ports are located in the Old Town, Malindi and Lamu. These other ports offer valuable services for both cargo and fishing vessels. They are situated in shallow lagoons. To facilitate safe navigation for marine vessels using the ports and those on transit, Kenya embarked on a programme of installing tide gauges at the ports as part of the national sea level network.

1.2 Description of the National Network and History of its Development

Time series records of sea level heights are crucial because they provide information on the highly variable nature of the boundary between land and sea. The analysis of long time series of data now available from several stations has revealed a worrying trend of rise in mean sea level. In Kenya, the first gauge was installed in 1933 in Kilindini

harbour, Mombasa by the former East Africa Railways and Harbours Corporation 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 up to 1976. 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.

Realising the importance of sea level data for navigation and harbour planning, beach protection and development and overall marine research, KMFRI requested for a tide gauge through IOC-UNESCO from the University of Hawaii 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. There are critical gaps in data during the periods 1976/1986 that this gauge was not operational. Kenya Ports Authority (KPA) installed another gauge on the Fisheries jetty in Lamu at the end of 1988. The gauge was operated jointly with KMFRI. However, marine growth (barnacles, algae, etc) covered the transducer, affecting the quality of data. Problems with electricity connections at the jetty, led to return to the classical sea level data collection methods; using a graduated string.

In December 1987 Kenya was nominated to coordinate the regional component of GLOSS. Kenya is actively participating in the Cells for Monitoring and Analysis of Sea Level (CMAS)
The activities are:

(i) Overseeing/assisting in data collection and data transmission in collaboration with appropriate national agencies.

(ii) Data storage and analysis to generate products aimed at understanding the data, and products useful for coastal zone management.

Both Mombasa and Lamu are principal stations on the Global Sea Level Observing System (GLOSS). Both stations continue to operate well and data is available.

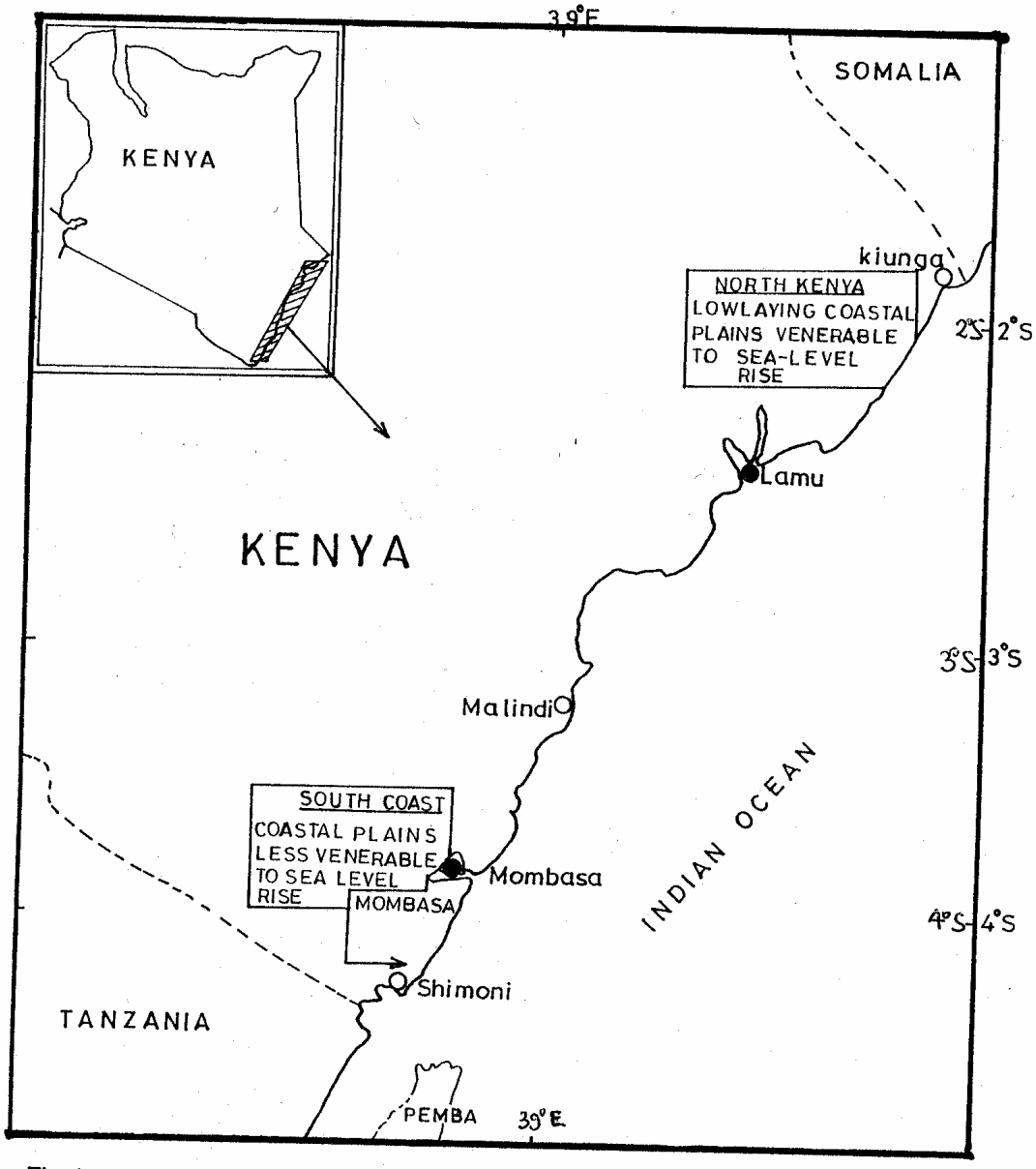


Fig:1. Map of Kenya Coastline showing location of installed tide gauge stations(●) and planned stations(O)

2.0 STATUS OF SEA LEVEL NETWORK

2.1 Installed and operational stations

A Leopold Stevens gauge was installed in Mombasa in 1986. 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. A Valeport BTH 700 gauge was installed in Lamu at the end of 1988 but has not been 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). The TOGA Sea Level Centre agreed to assist in installing another gauge in Lamu in early 1994. Both gauges are float type installed on a stilling well.

The Mombasa and Lamu gauges are located in shallow lagoons. They are installed on jetties and far from rivers to avoid the effect of freshwater on tides. The jetties provide ideal sites with water throughout the tidal cycle. Liwatoni jetty (Mombasa) and Lamu jetty are most suitable because they provide a semi–enclosure for the tide gauge, protects it from strong wave effects and provides a strong and firm supporting structure, the water depth is enough (more than 2m below the lowest predicted astronomical tide) to allow successful operation of the stilling well. Both jetties are also very easily accessible.

Both stations are dedicated to the following global projects
(a) Tropical Oceans Global Atmosphere (TOGA)
(b) Global Sea Level Observing System (GLOSS) and
(c) World Ocean Circulation Expedition (WOCE).

Sea level data from both Mombasa and Lamu is sent to the following Data Centres
(a) University of Hawaii Sea Level Centre (UHSLC)
(b) Permanent Service to Mean Sea Level (PSMSL)

Both stations are equipped with modern data loggers, measuring sea level every minute and storing on diskette at 15 minutes interval. Copies of the data are made on diskettes and the computer hard disk before forwarding them to the TOGA Sea Level Centre in Hawaii where further quality control is performed. The diskette is posted to UHSLC by airmail on a monthly basis. In addition, the Lamu tide gauge is equipped with a satellite data transfer device to enable real time access to data.

The nearest meteorological station to the Mombasa tide gauge station is Moi International Airport. It is approximately 5km from the station. Lamu Airport is the nearest meteorological station to Lamu tide station.

The meteorological data (related to sea level changes winds, rainfall, atmospheric pressure and temperatures) which has been collected by the Kenya Meteorological Department at stations close to the tide gauges is available.

The problems faced in operating the stations are:

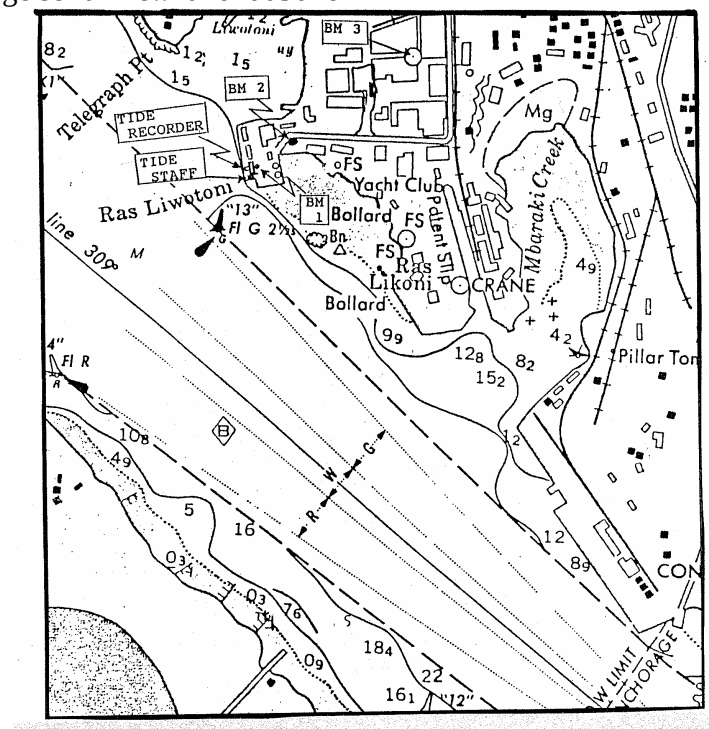
- Rusting of tide gauge parts
- Rusting of the support connecting the tide well to the jetty
- Marine growth on transducer
- Corrosion of stilling well.
- Frequent damage of tide gauge house roof in Lamu by boats which are usually moored around the jetty. Due to this damage, a lot of water leaks from the roof and poses a great danger to the tide gauge computer.
- Non compatibility of tide gauge computer with the PCs used at KMFRI. This results in data not being recorded on diskettes formatted at KMFRI.
- Communication problem – lack of telephone and internet facilities at Lamu station makes it difficult for KMFRI and UHSLC to respond quickly in case of a breakdown of the tide gauge.

KMFRI is responsible for maintaining both the Mombasa and Lamu tide gauge stations.

2.1.1 Mombasa Station (Latitude: 04^o 04´S Longitude: 039^o 039'E)

JASL # : 101A Time Meridian: 045E (GMT + 3hr)
GLOSS # : 008 TOGA # : 1005
NODC # : 30034901 Tide gauge serial No.: 0164003076

In 1989 leveling was performed by Survey of Kenya, P.O. Box 30046, Nairobi. Nikolai Turetsky and Jerard Jardin both of TOGA Sea Level Centre performed leveling of in 1995 and 1998 respectively.



TGZ = ACD – 37.355
TGZ = EARD – 36.165
TGZ = SOK – 110.638
Where ACD – Admiralty Chart Datum
EARD – East Africa Railway Datum
SOK – Survey of Kenya Datum
Heights are in feet above tide staff zero.

2.1.2 Lamu Station (Latitude: 02^o 17´ S; Longitude: 040^o 54' E)

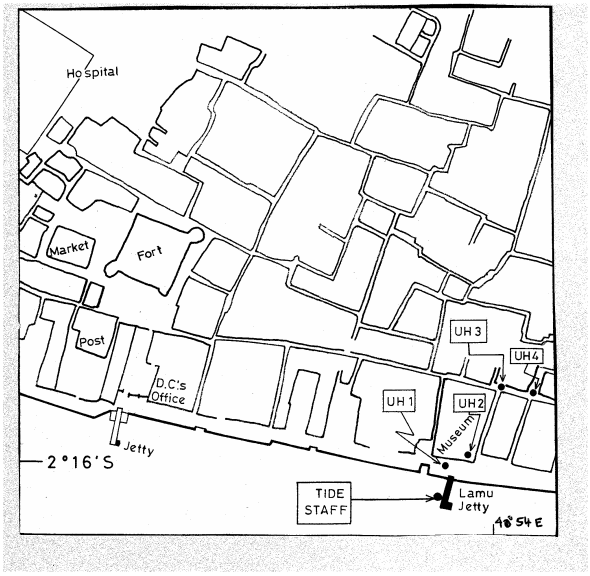
JASL No. : 149A Time Meridian: 045E (GMT + 3hr)
GLOSS No.: TOGA No. : 149 NODC No.:
Serial No. : 16287190

In Lamu there are four Benchmarks (UH1, UH2, UH3, UH4) and they were all installed in 1995.

Benchmark Description:

BM	ESTABLISHED	SURVEYOR	TYPE OF MARK AND COMMENT
@	06/25/95	N. Turetsky	rod stop of 5.0 m staff. Tide staff is from Shelly signs England, model D50. 5 meters long, solid plastic, 5 separate sections mounted to wooden piling which was pile driven into sea floor. It is located just outside of the tide house, onto the new

Site Map for Lamu tide station showing benchmarks



2.2 Planned station

All the installed stations are operational. In addition there are plans to install three more tide gauges. These will be at: Shimoni (4^o 39´ S, 39^o 23´E), Malindi (3^o 15´S, 40^o 08´E) and Kiunga (1^o 45´S, 41^o 29´E).(see Fig 1). Ultimately, there will be five stations to cover the Kenyan coast. The installation for the three tide gauges is being carried out by KMD through the Ministry of Transport Kenya. We intend to evaluate the trends of sea level fluctuations along the entire Kenyan coast. However, it is unfortunate that we are unable to include the southern, middle and extreme Northern parts of the Kenyan coast due to lack of data, as there are no tide gauges in these regions. This is the reason why it is necessary to install tide gauges at the planned stations. Once the proposed stations are installed, we shall obtain high spacial resolution of sea level observations, hence generate better needed time series of sea level data for scientific, management and for local use as well as international use. In addition, Kiunga gauge will be closest to the Equator and the only one within the Somali Current reversal zones and will thus cover an area of great interest to local scientists and the international scientific community as well.

The proposed gauges are part of the National Tsunami early warning system. The aim of the installations is to provide sea level /Meteorlogical data and products to all categories of users in Kenya. This information is particularly important at the moment due to the increasing concern about global warming and related sea level rise. It is also useful for operations within the following institutions: Fisheries department, Kenya Ports Authority, Kenya Navy and Survey of Kenya among others. In addition, the programme will also provide information for international oceanographic projects in which Kenya is participating, like WOCE.

3.0 AVAILABILITY OF DATA FROM STATIONS

The sea level data (hourly, daily and monthly means) for the Kenyan stations are available at the KMFRI CMAS and are in the JASL format.

For Mombasa station, available data is from 1975/6 and 1986-2006.
The data available from Lamu station is in digital form and analogue charts. The digital data is from 1989, and 1996–2006 and the analogue chart is from 1990 to 2006. All the digital data from both stations are available in International data centres namely PSMSL and UHSLC.

The data can also be obtained from the following web sites.
- http://www.soest.hawaii.edu/UHSLC

-http://www.pol.ac.uk/psmsl/gloss.info.html

4.0 CAPACITY AVAILABLE

4.1 Installation and maintenance of gauges

In Kenya, we rely on services of technicians from the TOGA Sea Level Centre in Hawaii for installation and maintenance of the tide gauges.
The TOGA Technicians visit our stations for servicing and maitenance of the gauges once in three years.

Raw data from both stations is processed in KMFRI by DR. Charles Magori on monthly basis. In addition, the raw data is forwarded on a monthly basis to the TOGA Sea Level Centre in Hawaii where further quality control is performed.

The processing of raw sea level data in Kenya is supervised by Dr. Charles Magori.

None of local Technicians on site has received training at PSMSL, TSLC, etc. However, a few of KMFRI Technicians have received on-service training and some additional hints when Nikolai Turetsky and Jerard Jardin visited Kenya in 1995 and 1998 respectively. This has contributed much in improving the accuracy of the data.

Training requirements

Since none of KMD Technicians has received training at specialised sea level centres, there is need therefore to train them at PSMSL, TSLC or within the region. The training should be in form of an attachment of about **six months** during which the following should be covered.

(a) Installation of new stations
(b) Repair of faulty tide gauges
(c) Maitenance checks
(d) Levelling of tide gauge benchmarks

4.2 Analysis and Interpretation of data

In Kenya, six scientists working for KMFRI and one scientists working for KMD have received postgraduate training on Physical Oceanography. Their names, qualifications, and insitutional affiliation is given below:

	Name	Qualifications	Institutional affiliation
1.	Mr. Mika Odido	Msc(Physical Oceanography) PhD candidate ''	Principal Res. Officer
2.	Mr. Michael Nguli	Msc (Physical Oceanography) PhD candidate ''	Principal Res. Officer
3.	Mr. Charles Magori	Msc (Physical Oceanography)	Research Officer
4.	Mr. David Kirugara	Msc (Physical Oceanography)	Research Officer
5.	Mr. Johnson Kitheka	Msc student (Physical Ocean.)	Senior Res. Officer
6.	Mr. Clive Angwenyi	Msc student (Physical Ocean.)	Research Officer
7.	Ms Stella aura	Msc (physical oceanography)	ADOMS (KMD)

Three of them have received additional training sponsored by IOC. **The training was on Sea Level Data Analysis and Interpretation**. They are Mika Odido at PSMSL, UK in 1992, Charles Magori at Dehra Dun, India in 1995 and Clive Angwenyi in Cape Town, South Africa in 1998.

Training Requirements

There is need to train more scientists in the **tide prediction and data analysis within the** Oceanography AND Marine services division of KMD. The training will enhance the idea to initiate sea-level related research activities within KMD. IOC and other organisations should therefore organise more training courses on sea-level research.

Data Analysis

The KMFRI CMAS has performed the following analysis of data in its possesion:

- time series analysis of various data sets
- harmonic and spectral analysis of hourly height data for Mombasa and Lamu
- tide predictions for Mombasa and Lamu.

5.0 SEA LEVEL PRODUCTS

Tide predictions for Mombasa have been performed by the Permanent Service for Mean sea Level (PSMSL), Bidston, U.K. After attending a training course on sea level data analysis, Mr. Charles Magori, a Research Scientist at KMFRI now produces tide predictions for both Mombasa and Lamu using a software provided by the TOGA Sea Level Centre. The predictions compare very well with those produced at Bidston. The predictions are in form of High-Low Listings and Hourly Values. They are distributed free of charge to all organisations dealing with Marine environment in Kenya to facilitate their navigational activities.

Sea level anomalies
Areas along the Kenyan coastline which can be inundated with water for given sea level rise are shown in Fig 1.

Products not produced but would be useful are:
(a) monitoring of storm surges to provide essential statistics on return periods for extreme events.
(b) Design and construction of harbours and other coastal structures
(c) Monitoring circulation and heat transfer.
(d) Input into flood warning procedures

6.0 RECOMMENDATIONS

Kenya is trying to develop a sea level observing network. Two stations have been established and three other stations are planned to complete the national network. However, to achieve this, there is an urgent need to develop capacity not only for installation and maitenance of tide gauges, but also for analysis and quality control of data. This will enable KMD/KMFRI to produce high quality sea level products for local scientists and international programmes and data centres.

A first step in this regard would be attachment for local Marine Meteorologists and Meteorological technicians to a specialised sea level centre (UHSLC, PSMSL, etc) for a at least one month to enable them acquire the necessary techniques for installation and maitenance of the tide gauges, processing, quality control and analysis of sea level data, and products preparation. The topics to be covered during the attachment period should include:

(a) review of sea level equipments: types, installation, levelling and maintenance.
(b) Processing and quality control of data.
(c) Analysis of data and products preparation.

Emphasis should be placed on strengtening the national network through regular maintenance and levelling of benchmarks, maintenance of gauges, supply of spares and observer supervision. In addition the gauges that are being for establishment of sea level stations at Shimoni, Malindi and Kiunga will provide a better spatial resolution.

The Mombasa tide station will be equipped with facilities for Meteorologigical observations and satellite transmission of data. This will provide a real-time data network. KMD being the organisation in charge of the Multi-Hazard early warning center should be responsible for the tide gauges in Kenya and should be encouraged to archive copies of the data. The Kenya National Oceanographic Data Centre (KeNODC) which was established recently should encourage exchange of sea level data and information in the country. One of the priorities of KeNODC should be to build a higher database of sea level and associated environmental data.

PART II: AVAILABLE METEOROLOGICAL DATA

1. Daily rainfall for Lamu meteorological station, Malindi meteorological station and Moi international Airport meteorological station, mombasa,

2. Hourly wind speed (knots) for Lamu meteorological station Malindi meteorological station and Moi international Airport meteorological station, Mombasa.

3. Hourly relative humidity at Lamu meteorological station, Malindi meteorological station and Moi international Airport meteorological station, mombasa,
4. Hourly air temperature (Max and Min) over Lamu, Malindi meteorological station and Moi international Airport meteorological station, mombasa,

ACKNOWLEDGEMENT

I would like to thank Dr. Charles Magori of KMFRI, Mr. Mika Odido Regional Coordinator Of UNESCO IOC Kenya and MR Ali Mafimbo of KMD for their valuable contribution and assistance. I also thank them for their support and encouragement.