AJLP & GS
African Journal on Land Policy and Geospatial Sciences

e-ISSN : 2657-2664, Vol.7, Issue.4, September 2024

https://revues.imist.ma/index.php/AJLP-GS/index

https://doi.org/10.48346/IMIST.PRSM/ajlp-gs.v7i4.49529 *Category of the manuscript : Articles*

***Received in**: 12 June 2024* **Revised in:** 26 September 2024 ***Accepted in**: 30 September 2024*

ASSESSMENT OF THE RATE OF SEDIMENTATION AT THE ENTRANCE CHANNEL OF THE DAR ES SALAAM HARBOUR

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ABSTRACT

The marine environment in Tanzania faces significant pollution originating mainly from land-based sources such as industrial, agricultural, and municipal waste, as well as coastal construction, oil discharges, and dredging activities. Siltation, a significant problem in the Dar es Salaam harbor, has led to a decrease in the depth of the entrance channel, requiring more frequent dredging.

Goal and Objectives:

This study assessed the sediment deposition rate at the entrance channel of Dar es Salaam harbour by analyzing three sets of Bathymetric data obtained in 1998, 2010, and 2016.

Methodology:

The data was gridded to generate colour relief maps and a 3D view of the area was created to analyze the terrain. Cross sections of the berth basins were generated to compare the depths after dredging, time series graphs were drawn for each section at the main quay to indicate the rate. A direct method was used to calculate the sediment accumulation rate

Results:

The study revealed the sediment rate varies in different parts of the channel. Sediment accumulates more heavily at the main quay, likely due to ship maneuvers. In 2010, the sediment rate in the entire channel of Dar-es-Salaam harbour was up to 3.3cm/year (0-4m total or less consistent with earlier assessment that is contributed as a result of scouring on large part of the channel), while in 2016, it ranged from 2.2cm/year to 6.7cm/year. Time series graphs for each section showed sedimentation rates ranging from 1.59cm/year to 12.25cm/year. The sediment deposition pattern at the harbor is cyclical and unpredictable. Scouring occurs in the entrance channel where the magnitude differs from section to section and in the harbour basin for the year 2010 and 2016, and sedimentation is concentrated near the quays.

Keywords *Sediment Rate, Siltation, Bathymetric Data, Dar es Salaam Harbour, Dredging*

1. INTRODUCTION

Pollution is a significant problem for Tanzania's marine environment, with land-based sources such as industrial, agricultural, and municipal waste, as well as coastal construction, oil discharges, and dredging, contributing to the issue. The high sedimentation rate in the ship channel is caused by waste materials, which can be an indicator of the level of deposition in the channel. The Dar Es Salaam harbour, Tanzania's primary port, is a pollution hotspot with sediments containing high levels of heavy metals and organophosphates (Mohammed et al, 2008).

The Dar Es Salaam port is situated in a low-lying region, and certain sections are susceptible to sea level rise owing to substantial sedimentation that decreases the entrance channel's depth. The inner harbor functions as a tidal basin and contains a narrow opening to the sea, with a deep-water region. Despite being well-protected from powerful winds and waves, research indicates that ebb currents during the NE monsoon season transport particulate matter offshore, resulting in sediment accumulation in the channel (Sanga and Dubi, 2004).

The Dar Es Salaam harbor has been affected by unequal siltation and scouring for more than 20 years since dredging of entrance channel was conducted in 1998. This siltation and scouring happen at different location along the entrance channel. Although this problem is being monitored through different measurements, the rate of siltation and scouring is not known which may endanger some ships when entering the channel.

Vessels with greater draft were compelled to rely on tides to access the harbor, while the numerous bends in the entrance channel posed navigation challenges at night, causing delays for most larger ships and incurring higher costs for port entry and exit (Tanzania Harbour's Authority, 1998/99). Besides the entrance channel's limitations, the inner harbor suffered from excessive siltation, leading to inadequate under keel clearance for larger vessels. Pilots of such ships frequently reported grounding during low tides, necessitating an upgrade of the entrance channel. Bathymetric surveys conducted in 1993 revealed sedimentation layers up to 3.7 meters thick in some areas (SLI Consultants, 1994).

In 1998, the Tanzania Harbour Authority (THA) upgraded the harbor basin and entrance channel to enhance the management and regulation of harbor activities. Prior to the upgrade, the controlling depth below the chart datum in the entrance channel was 7.4m, which increased to 10.2m below the chart datum after the upgrade, and the width expanded to 120m, 20m wider than before. The upgrade had an impact on sediment deposition, with sedimentation rates ranging from 13 to 43cm/year after the upgrade, compared to between 7 and 25cm/year before.

Thus, this study intends to determine the current sediment deposition rate and to establish a pattern of sedimentation along the entire channel using three data sets of 1998, 2010 and 2016 which will give clear information on which monitoring methods can be adopted to control deposition of materials on the entrance channel.

2. METHODS AND DATA

The entrance channel survey data of Dar-Es-Salaam harbour of 1998 after first dredging were obtained from TPA. The channel was designed to be dredged into specific depth in segment of areas. 1998 surveyed data set were given in the N, E, Z format together with data of 2010 and 2016. The 2010 and 2016 bathymetric survey data were also obtained from TPA as scanned paper maps (bathymetric maps) showing depth as surveyed by the Tanzania Ports Authority using multibeam echo sounding.

Hydrographic survey in 2016 (April-May) was done under a South African company called Tritan Survey. Bathymetry was achieved through the use of sonar transmitters and receivers specifically the multibeam echo sounders. Two dedicated survey boats were used and the multibeam transducers attached transmitted multiple pings per epoch in an across track fan; this method provided a near-full coverage of the bottom which allowed for much finer details to be captured. The observed soundings were reduced to charted depth by applying the corrections.

2.1 Data Gridding

The data at the time of dredging (1998) and the following bathymetric data sets (2010 and 2016) were gridded using surfer software by nearest neighbor method because of the nature of data. The grid report was obtained showing error associated by each interpolated data. The relief maps were then generated and 3D view obtained to show the relief of the terrain from the time of dredging to 2010 and 2016. Cross sections of the entrance channel of the Dar es Salaam Harbour were generated from the gridded data. These cross sections were generated to compare depths after dredging in 1998, 2010 and 2016. The relief maps and cross sections generated were then used to show and analyze the pattern of sedimentation along the berth basin. Time series maps were then drawn for each section at varying depth to show the rate of sedimentation and how it differs between the sections.

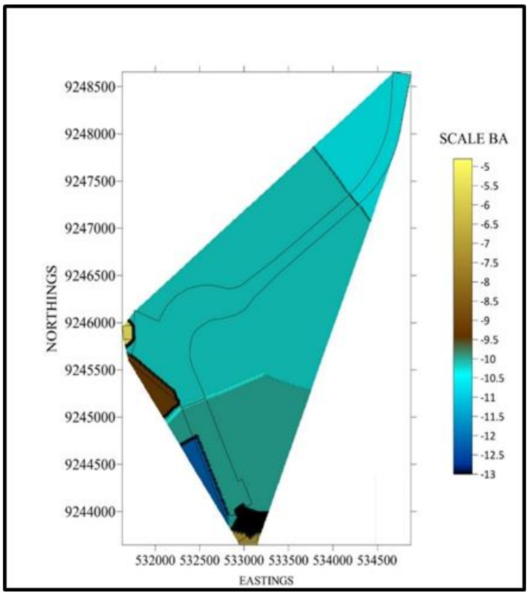
2.2 Digital Terrain Model Generation

In order to generate a digital terrain model of the entire Dar-es-Salaam channel for visual representation of the topographical surface for all the bathymetric data sets, a standard Triangular Irregular Network (TIN) modeling was used. The technique is employed to visualize the nature of terrain using bathymetric data at time of dredging (1998) and to the set of bathymetric data in the year 2010 and 2016. The analysis is made for the sea bed levels overtime for the entire channel to extract approximate sedimentation rate from the data which is best over rasterized digital elevation model in mapping and analysis because the points of a Triangular Irregular Network are distributed variably based on an algorithm that determines which points are most necessary to create an accurate representation of the terrain.

3. RESULTS, ANALYSIS AND DISCUSSION

3.1 The Pattern of Sedimentation Rate along the Berth Basin

From the results obtained, the maps show clearly varying depths of the channel terrain from the time of dredging in 1998 and the years 2010 and 2016 where bathymetric surveys were conducted. The 1998 colour relief map shows different parts of the channel dredged at a specific depth shown also in Figure 4.4 and Figure 4.5 The terrain has changed significantly in 2010 and 2016 as shown by relief maps where some areas have been accumulated by sediments and other areas have undergone scouring or simply erosion. This is shown by the scale bar where depths increase from 0 to 18m with change of colours.



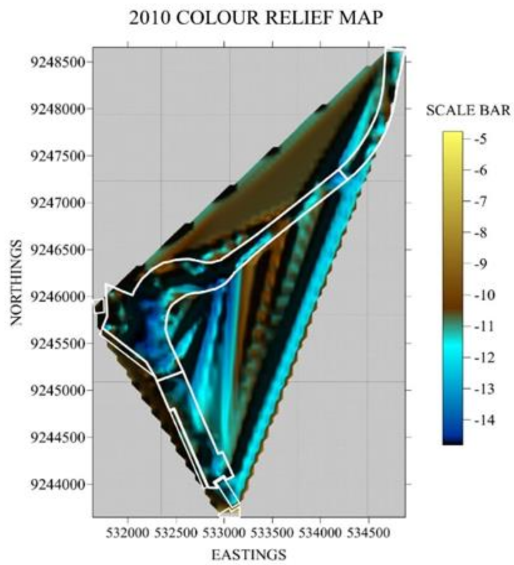


Figure 1(a): Colour relief maps of 1998 and 2010

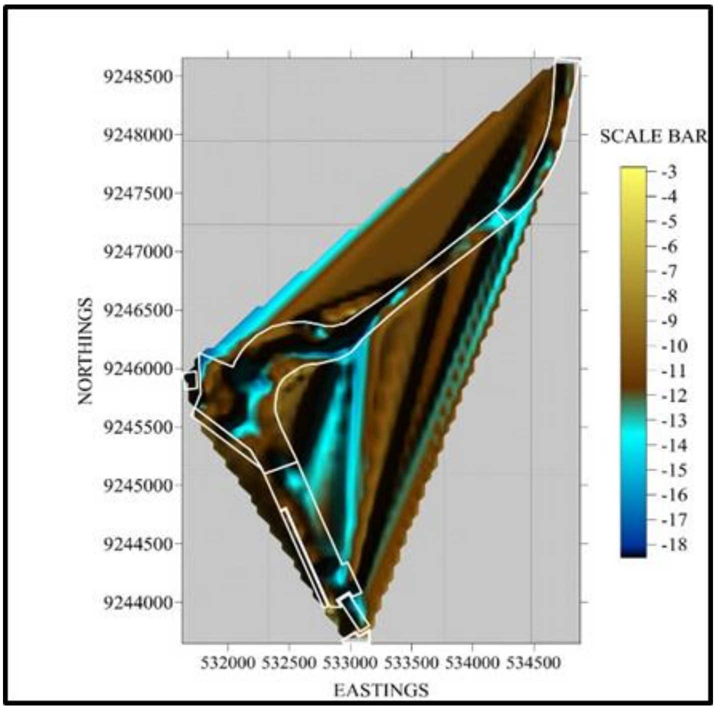


Figure 1(b): Colour Relief maps of 2016

3.2 Designed sections along the channel

From the cross-sections below, it can be seen that after dredging in 1998, the entrance channel has experienced both scouring and deposition of sediments. Bathymetry along the berth basins in section 3 which is Q in figure 4.4 and 4.5, indicates that sediment deposition in some areas has reached up to 4.8m and 10m in thickness for the year 2016 and 2010 respectively. Sediment deposition is also seen in section 5, 6, 7 and 8 which is R, Z, M and N as respectively indicated in figure 2. The trend of sediment deposition shows that there is scouring in the entrance channel where the magnitude differs from section to section and in the harbour basin, sedimentation is seen closer to the quays. The sections S1 to S46 from Figure 2, also shows both deposition and scouring in which scouring has manifested. The pattern from the cross sections drawn is not regular that is it does not occur at regular interval. This type of pattern is called a cyclical pattern in which it is difficult to predict if deposition or erosion will occur at that particular place and at a particular time.

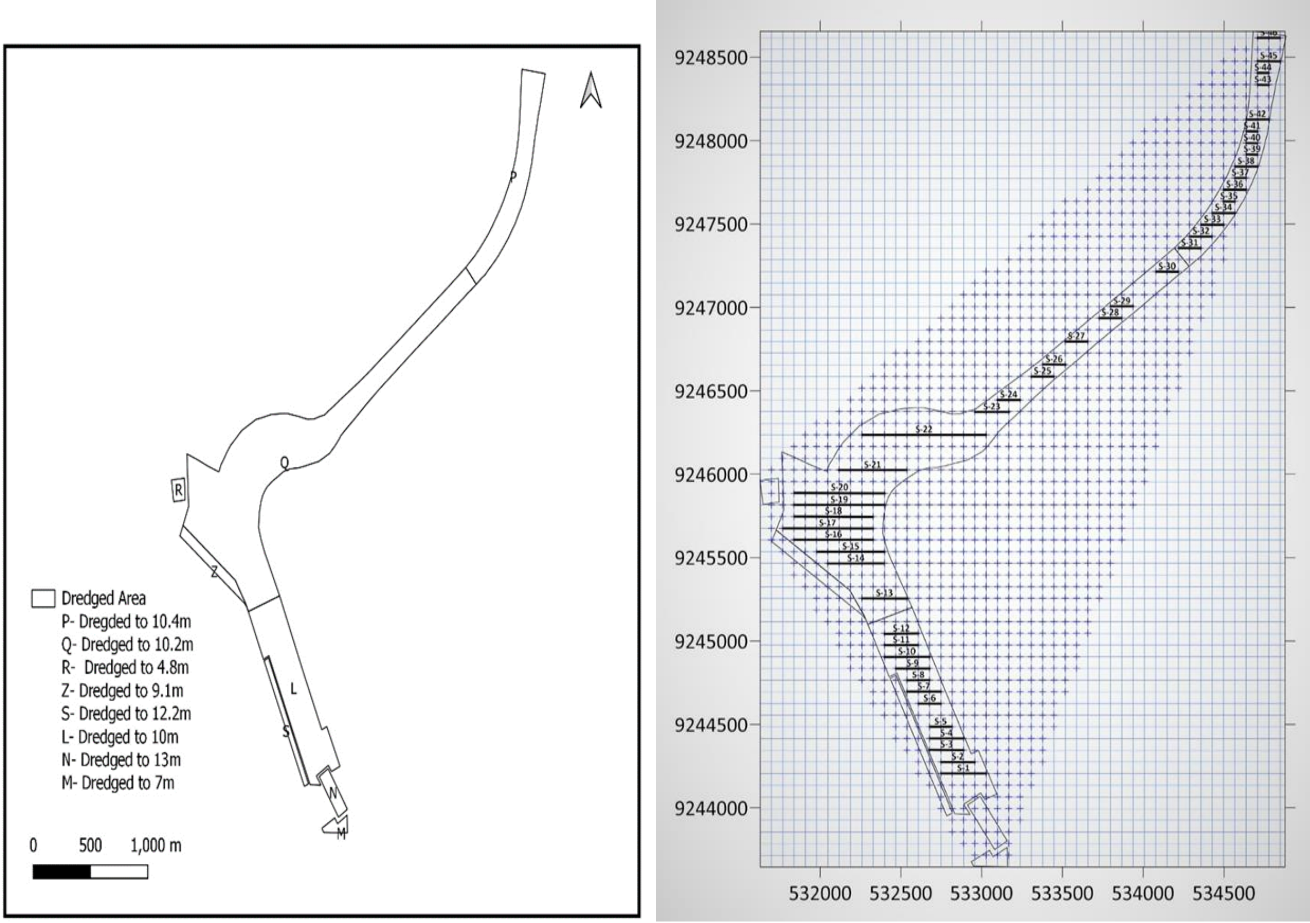
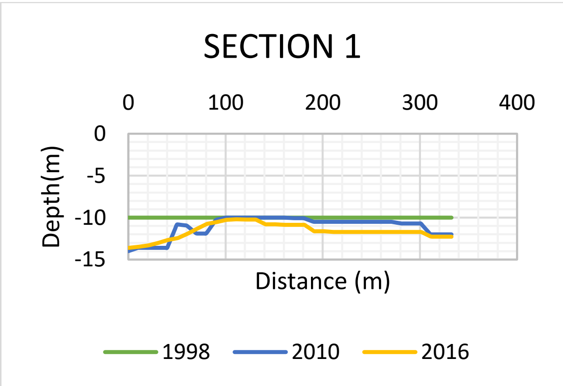
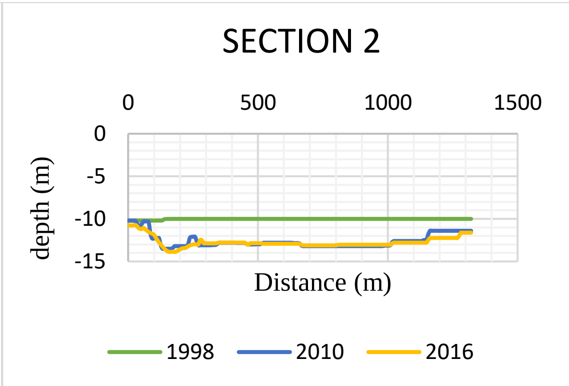
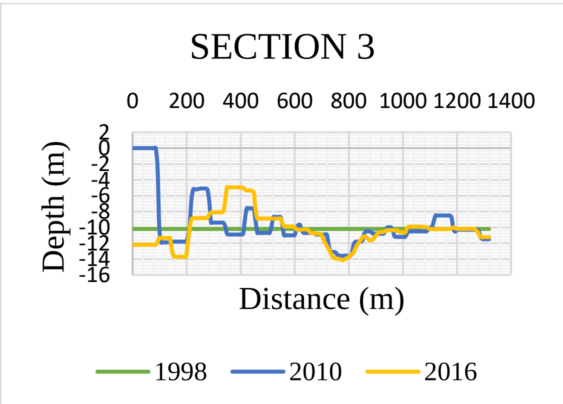
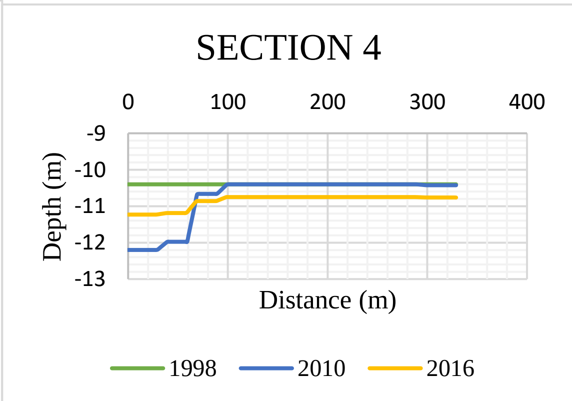


Figure 2: The Entrance area of the Dar-es-Salaam Harbour showing the dredged area in 1998 and sections taken at different parts of the entrance channel of the Dar es Salaam harbour, comparing depths after dredging in 1998, 2010 and 2016









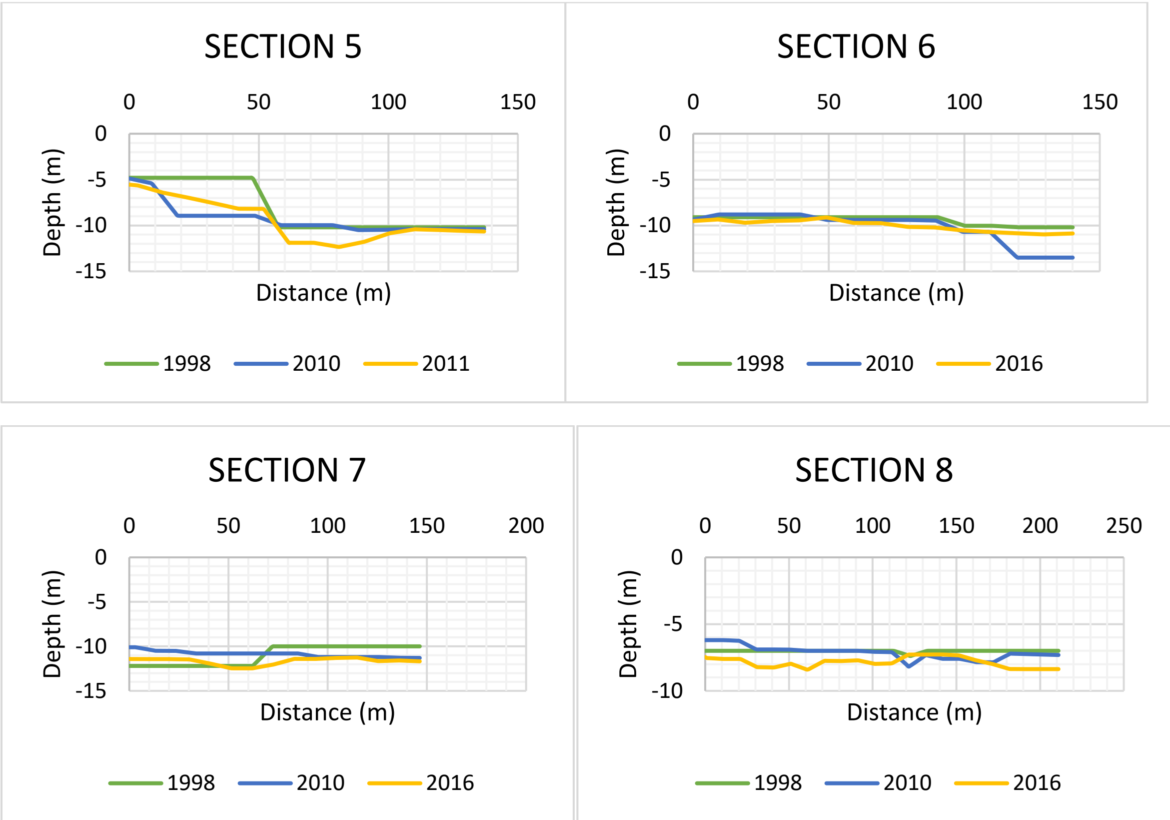


Figure 3: cross-section of the entrance channel of the Dar es Salaam harbour, comparing depths after dredging in 1998, 2010 and 2016.

3.3 Sediment Rate

Most of the parts in figure 4 (1998-2010) show that sediment build up within the entire channel appears to be significant over the 12-years assessment period. The sediment rate in the entire channel of the dar-es-salaam harbour is up to 3.3cm/year (0-4m total) where some of the places the rate is in order 20cm/year to 23.3cm/year (2.4m to 2.8m total) or less consistent with earlier assessment that is contributed as a result of scouring that happened on large part of the channel. The sedimentation rate in the main quay is in order of 3.3cm/year to 33.3cm/year (0.4-4m total)

Most of the parts in figure 4 (1998-2016) show that sediments build up within the entire channel appears to be relatively low over the 18-year assessment period. The sediment rate in the inner channel of the dar-es-salaam harbour are in order 2.2cm/year to 6.7cm/year (0.4m to 1.2m total) where at other area the rate is up to 40cm/year (2.8-4.8m total) in the segments n and m as seen in figure 4.4. The sedimentation rate in the main quay is in order of 2.2cm/year to 28.9cm/year (0.4-5.2m total)

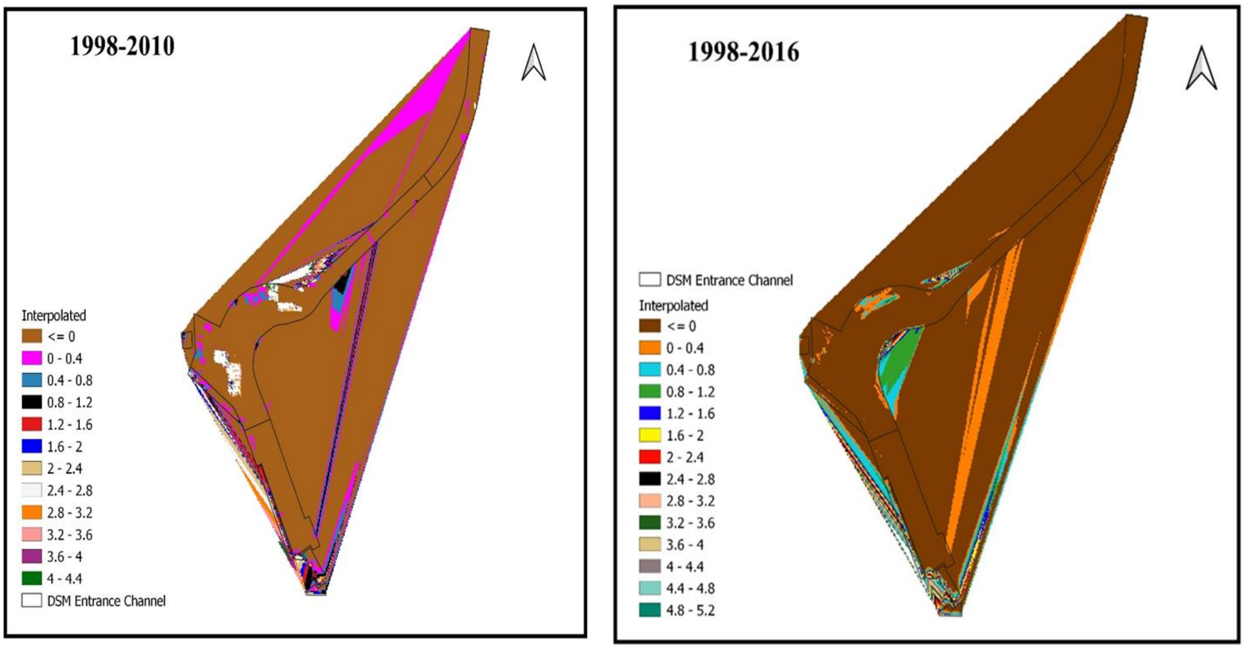
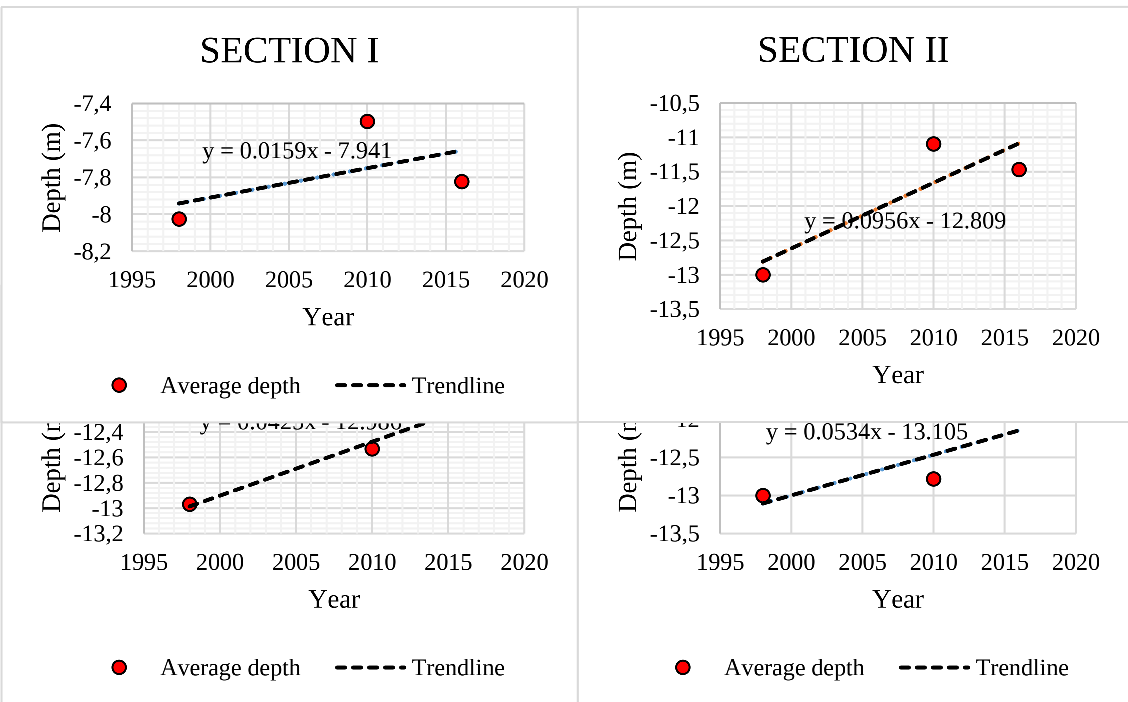


Figure 4: The difference in depth between 1998 and 2010 and 1998 and 2016 bathymetric plots for the dar-es-salaam harbour

3.4 Time series for the designed sections

Time series maps were drawn for each section at varying depth to show the rate of sedimentation and how it differs between the sections. From the time series maps drawn, it shows that the rate has been changing significantly from the time of dredging to 2010 and 2016. The rates are calculated from the main quay in which at each section average depth is taken in each year and the rate is determined from the best fitting line equation where the slope indicates the rate of sediment deposit at that year. The rate ranges from 1.59 to 12.25cm/yr. Most of the part has experienced scouring with exception for sections between S21 and S23 where the rate is between 10.18 and 10.15 cm/year.



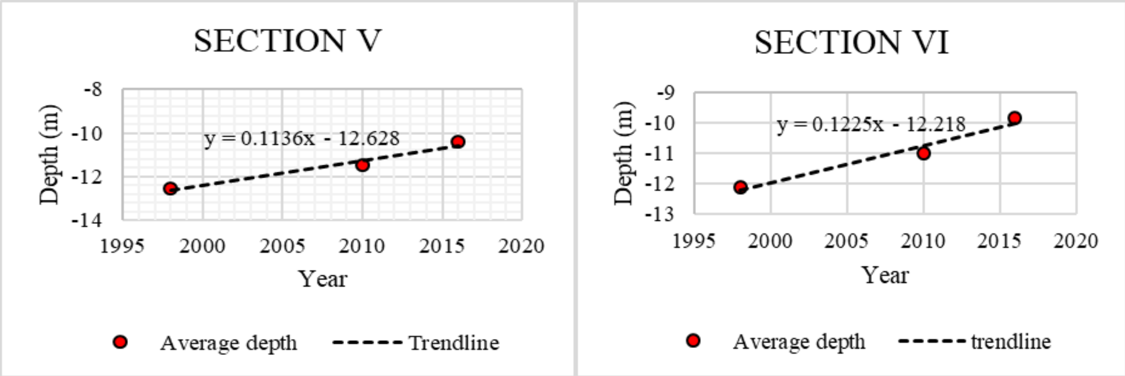


Figure 5(a): Time series maps indicating how the rate has changed at different sections at the main quay

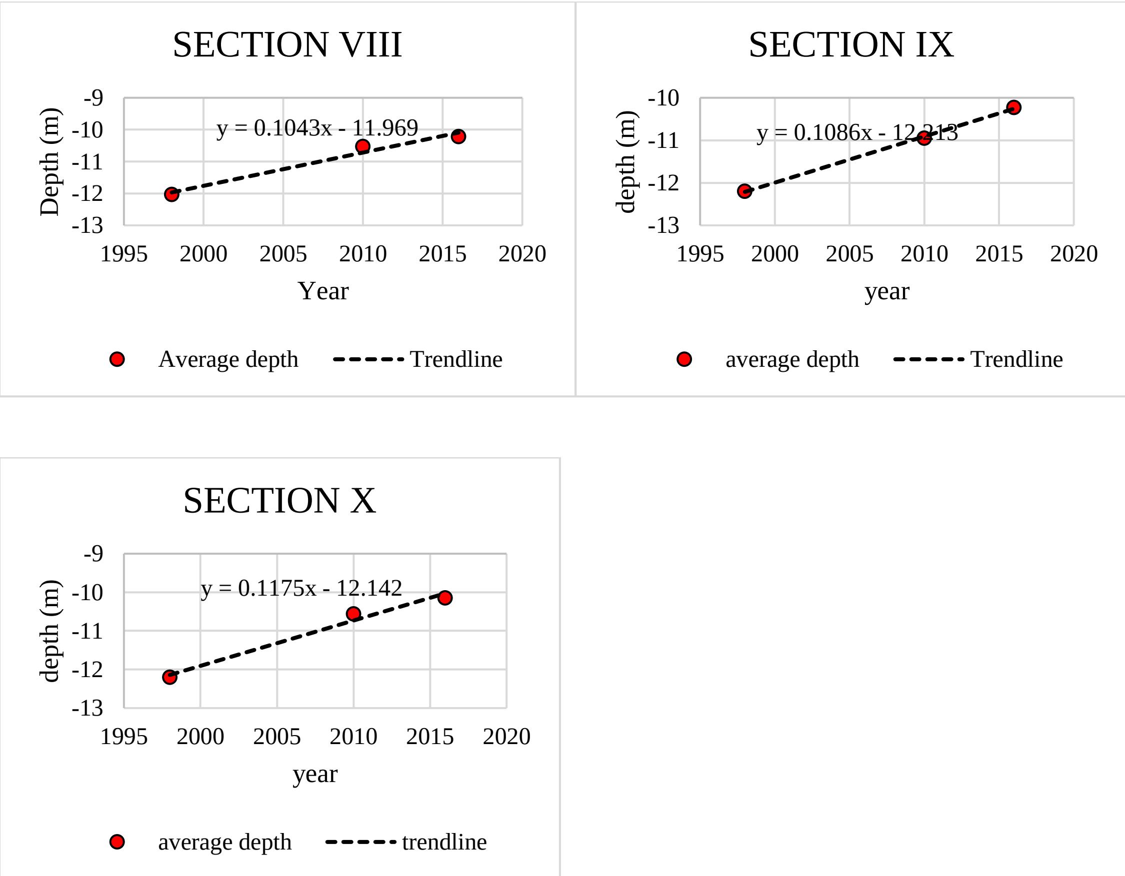


Figure 5(b): Time series maps indicating how the rate has changed at different sections at the main quay

4. CONCLUSION

This study involved the assessment of the entrance channel of the Dar-es-Salaam Harbour that is to investigate the impact of the improvement of the entrance channel with the aim of determining the sedimentation rate and to establish its pattern along the berth basin using recent data.

According to the results obtained, the rate of sedimentation is not constant over the entire channel that is it varies depending on the deposition of materials on the area.

From the results it is seen that the rate of sedimentation is not constant over the entire channel which varies depending on the deposition of materials on the area. The sediment deposition is much concentrated at the main quay which may be due to manoeuvers of the ships at the basin. In the year 2010, the sediment rate in the entire channel of the Dar-es-Salaam harbour from the residual plot is up to 3.3cm/year (0-4m total or less consistent with earlier assessment that is contributed as a result of scouring which happened on large part of the channel. In the year 2016, the sediment rate in the entire channel of the Dar-es-Salaam harbour are in order 2.2cm/year to 6.7cm/year (0.4m to 1.2m total).

The time series graphs drawn for each section showed the sedimentation rate ranges from 1.59cm/year to 12.25cm/year.

The pattern of sediment deposition at the harbour is cyclical pattern that it does not occur at regular interval that makes it to be difficult to predict if deposition or erosion will occur at that particular place. This pattern shows that there is scouring in the entrance channel where the magnitude differs from section to section and in the harbour basin for the year 2010 and 2016, sedimentation is seen closer to the quays.

5. ACKNOWLEDGMENT

First of all, I am grateful to The Almighty God for his abundant blessings and giving me the ability to complete this study successfully.

I would like to express my deep and sincere gratitude to my research supervisor, Mr. Bakari Mchila for his invaluable guidance and support throughout the research. It was a great privilege and honor to work and study under his guidance.

I am extremely grateful to Mr. Aggrey Nyete, Hydrographic Surveyor from Tanzania Ports Authority for the provision of necessary data and sharing his pearls of wisdom to complete my study.

6. FUNDING

No Funding.

7. AUTHOR CONTRIBUTIONS:

1. Edna William Machumu – Developing research title based on the statement of the problem, data collection and analysis.
2. Melchior Vitalis Shukuru – Participated in data collection and analysis.

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10. KEY TERMS AND DEFINITIONS

Sediment Rate: often referred to as the sedimentation rate, is the speed at which sediment particles settle and accumulate in a specific area, typically measured over a set period. This rate can be expressed in units such as grams per square meter per year (g/m^2/year) or centimeters per year (cm/year). It is an important parameter in fields like geology, hydrology, and environmental science, as it helps in understanding sediment transport dynamics, the formation of sedimentary layers, and the impacts of natural and anthropogenic activities on aquatic and terrestrial environments.

Dredging: Dredging is the process of excavating and removing sediment, debris, and other materials from the bottom of water bodies such as rivers, lakes, harbors, and oceans. This activity is often conducted to maintain or increase the depth of navigation channels, harbors, and ports to ensure safe passage for vessels.

Bathymetric Data: Bathymetric data refers to information about the underwater topography or depth of a water body, such as oceans, seas, lakes, or rivers. This data is typically collected using various methods, including sonar technology, satellite imagery, and hydrographic surveys. Bathymetric data provides valuable insights into the shape and features of underwater landscapes, including submerged mountains, valleys, ridges, and canyons.