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Developing Geographic Information System-Based Spatial System to Identify Safe Shipping Routes Based on Bathymetric Analysis in Port Sudan

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Abstract: This study concentrates on the development of an integrated system for determining safe shipping routes between anchorage areas and Port Sudan, based on bathymetric analysis using Geographic Information System (GIS) techniques. Bathymetric data were collected and processed from nautical charts, and 3D seabed topography models were created, enabling the identification of shallow areas and marine hazards, and the design of safe shipping routes. Changes in bathymetric depth during the period 2019–2024 were also analyzed to assess the impact of environmental and human factors. The results demonstrated the effectiveness of the proposed system in improving navigational safety, regulating vessel traffic, reducing waiting times and marine hazards, thereby contributing to increased port operational efficiency and supporting navigational decision-making.

Keywords: Maritime, Depth, Sea, Routes, Geographic Information Systems, 3D Model.

I. INTRODUCTION

Ports are vital to the global economy, serving as key points of contact for maritime trade that significantly contribute to the movement of goods and merchandise between countries. Ports play a fundamental role in promoting economic growth by contributing to the development of local industries, increasing job opportunities, and achieving economic sustainability through facilitating trade. The development of modern ports and the use of advanced technologies also contribute to improving operational efficiency and increasing cargo handling capacity, which has a positive impact on both the national and global economies.

Port Sudan is a maritime port located on the western coast of the Red Sea and plays a pivotal role in Sudan's economy and regional trade. The port's strategic location is of great importance, situated at the crossroads of vital routes between Africa, Asia, and Europe, making it one of the major ports in North Africa. Port Sudan offers direct access to one of the world's busiest maritime routes and serves as a gateway for global trade, not only for Sudan but also for neighboring landlocked countries, connecting them to global trade networks.

The port's proximity to the Suez Canal enhances its importance in international shipping, linking Africa, the Middle East, Europe, and Asia Port Sudan contributes to the movement of Sudanese exports of oil, minerals, and grains, in addition to the import of consumer goods and industrial materials. It also plays a pivotal role in facilitating international trade, as it is an important transit point for goods destined for neighboring countries, as well as a link between the Sudanese market and the markets of the region and the world.

Remote sensing technologies and geographic information systems play a prominent role in improving port management and maritime transport. Remote sensing helps in collecting accurate data on sea depths, ship movements, and environmental changes that affect navigation. Geographic information systems help in analyzing this data. These technologies contribute to monitoring changes in the marine environment and updating information related to depths and navigational conditions, which enhances the safety of maritime operations and the efficiency of trade.

1.1 Research Problem

Port Sudan is a vital port, but it relies on a traditional navigation system that does not keep pace with modern developments in maritime management. This system lacks

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advanced tools for determining shipping routes, leading to increased risks to vessel safety, especially in shallow areas and the waiting area.

1.2 Significance of the Research

Designing shipping routes is a crucial step in enhancing the safety and efficiency of maritime navigation, as it contributes to guiding vessels through safe passages, thus reducing the risks of collisions and groundings. To ensure the efficiency of these routes and their suitability to the maritime reality, the design includes an analysis of temporal changes in depth and the marine environment between 2019 and 2024, enabling the routes to be updated according to the latest navigational conditions. This contributes to enhancing the Automatic Identification System (AIS) by improving the reliability of data used in vessel tracking, strengthening traffic management, and facilitating information exchange between vessels and the relevant authorities. It also improves the organization of the waiting area and updates nautical charts, thereby enhancing the port's efficiency and its economic and strategic position.

1.3 Research Objectives

This study aims to analyze the topographic characteristics of the seabed using bathymetric map data to create a comprehensive model reflecting the distribution of depths and shallow areas, thereby improving navigation operations in the port. The research objectives can be summarized as follows:

1. Designing safe navigation routes for ships.
2. Analyzing temporal changes in the marine area between 2019 and 2024 using satellite imagery to understand the impact of human activities and environmental factors.
3. Improving the ship waiting area to reduce waiting time and increase efficiency.
4. Integrating modern technologies such as photogrammetry analysis with navigational data to provide innovative solutions that enhance port management.
5. Creating an up-to-date database to support future research and ensure the sustainability of marine resources and long-term planning.

II. SEAPORTS

Seaports are among the most vital facilities, playing a fundamental role in global trade and the local and international economy. They represent the gateway through which goods and commodities are transported between countries and serve as a major hub for connecting local and global markets. In addition to their vital role in facilitating the movement of ships and goods, ports also contribute to providing numerous jobs and enhancing international cooperation.

2.1 Types of Seaports

Seaports vary in type depending on their purpose, geographical location and the scale of economic activities that take place within them. The most prominent types of seaports include:

- Commercial Ports

These ports are the most common, used for receiving and unloading commercial goods, whether exports or imports. These ports include container loading and unloading terminals, as well as extensive storage facilities.

- Industrial Ports

These ports serve major industries such as oil refineries or heavy metal plants. They are equipped to receive ships carrying raw materials and semi-finished products.

- Cruise Port

These ports specialize in receiving cruise ships and provide high-quality services to passengers. They include recreational facilities and amenities for receiving tourists

- Military Ports

Used to provide logistical support for warships. These ports typically have heavy security and facilities specifically for military vessels.

2.2 Importance of Seaports

The importance of seaports lies in several key aspects:

Connecting global markets: Seaports represent the main corridors of global trade, with approximately 90% of global goods being transported by sea.

Impact on the national economy: Ports play a significant role in supporting the local economy, both through trade and by providing numerous jobs in the fields of loading, unloading, maintenance, and logistics.

Impact on the marine environment: Seaports also manage

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environmental pollution caused by ships and provide solutions to reduce the effects of pollution on the marine environment.

2.3 Components of Seaports

Seaports consist of several key components aimed at facilitating the movement of ships and goods. Among the most prominent of these components are:

- Sea berths

These are the areas where cargo loading and unloading operations take place. Sea berths are equipped with advanced equipment such as cranes and the necessary logistical equipment to operate efficiently.

- The anchorage

This is the location where ships dock upon arrival at or departure from the port. The anchorage requires a design that is compatible with the types of ships that the port receives.

- Warehouses

Ports provide areas for storing goods after they have been unloaded, and warehouses include refrigerated storage facilities to preserve sensitive goods such as foodstuffs.

- Logistics Facilities

Seaports include networks of roads and facilities that facilitate the movement of goods from the port to various parts of the country

2.4 The Impact of Technological Development on Seaports

"Ports now use technologies such as Geographic Information Systems (GIS) and remote sensing to analyze maritime data and manage T operations more efficiently. These technologies have helped improve vessel traffic management, port organization, and the identification of shipping routes more accurately and safely. Moreover, telematics technologies enable global ports to collaborate faster and more flexibly in managing shipping and maritime transport operations." (Tomsak, 2000). The most prominent technologies that have changed the face of seaports are:

- Smart Port Management Systems

These systems use remote sensing technologies and artificial intelligence to accurately track the movement of ships and their cargoes, contributing to improved vessel traffic management and reduced waiting times.

- Tracking and Monitoring Systems

Remote sensing technologies and electronic systems contribute to tracking ships as they enter and leave the port, providing accurate information about weather and marine conditions

- Automation in Handling

Modern ports increasingly rely on automation in loading and unloading operations. Robots and digital technology are used to reduce human error and increase the speed of operations.

2.5 Challenges Facing Seaports

Despite the importance of seaports to the global economy, they face several challenges that affect their efficiency. The most prominent of these challenges include:

- Ship congestion and operational delays

Ports face the challenge of managing ship traffic efficiently, especially with the increasing demand for maritime trade. Poor organization leads to congestion in the waiting area and delays in loading and unloading operations.

- Lack of accurate navigational data

Some ports rely on out-dated charts or navigational systems, which increases the risk of collisions and groundings, especially in shallow areas

- Environmental and Climatic Changes

Changes in sea level and ocean currents affect depths and shipping lanes, making it difficult to maintain accurate and sustainable data.

- Infrastructure Challenges

Some ports suffer from a lack of or outdated infrastructure, such as berths and equipment for loading and unloading ships, which weakens their operational efficiency.

- Maritime Security

Ports face increasing threats from maritime piracy and smuggling, requiring enhanced security measures to protect ships

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and cargo.

- Global Competitiveness

With more developed ports in other regions, ports need to improve their operational efficiency and invest in technology to remain competitive.

- Shortage of Specialized Personnel

Operating modern ports requires trained and qualified personnel to manage advanced technological equipment, a challenge faced by some ports.

Seaports play a pivotal role in global trade and the economy, but with the increasing challenges of maritime traffic volume, environmental risks, and climate change, countries and seaports must develop technological and management strategies to keep pace with these challenges and ensure the sustainability of future operations. Remote sensing technology is one of the effective tools that can contribute to improving port management and efficiency.

2.6 Monitoring Devices in Hydrography

In hydrography, a range of devices are used that have evolved over time to improve the accuracy and quality of data. One of the oldest devices used is the acoustic sonar device, which is used to measure sea depths

By sending a sound pulse and then listening for the returning echo. The time it takes for the echo to arrive is used to calculate the depth, since the speed of sound in water is about 1500 meters per second. (Webb, 2019)

Tide gauges were also important traditional instruments, used to determine the effect of tidal levels on measurements, which is essential for improving the accuracy of data taken during surveys.

Later, the introduction of the Global Positioning System (GPS) greatly improved the accuracy of positioning during surveys, compared to traditional methods that relied on reference markers or visual observation.

With the advancement of technology, side-scan sonar emerged, a sophisticated addition that enabled detailed images of the seabed by sending lateral sound pulses to illustrate the seabed topography and various obstacles.

Then acoustic velocity sensors appeared as a complementary tool to improve the accuracy of data collected using acoustic echo gauges. These sensors measure the speed of sound in water to correct readings and ensure the accuracy of results.

In more recent stages, marine lidar technology has emerged, which uses lasers to measure depths with high accuracy, especially in shallow and coastal areas. This technology is often used from aircraft or drones to survey areas quickly and efficiently.

Finally, remotely operated underwater vehicles (ROVs) have been introduced, which are used to access deep or hard-to-reach areas. These robots enable the collection of multiple data sets with high accuracy, making them among the latest technologies used in the maritime domain.

2.7 AIS (Automatic Identification System)

This is a system used in maritime navigation to enable ships to exchange information with each other and with coastal stations. This system helps in accurately determining positions, which enhances navigational safety and reduces the risk of collisions, especially in congested areas. To ensure the effective operation of the system, AIS requires frequent updates and the transmission of successive messages at short time intervals. To achieve synchronization of updates, a self-organizing communication mechanism has been adopted for distribution.

The AIS system consists of three main components: Assembly, through which data such as position and speed are collected; Display, which enables the display of this data on navigation systems; and finally, Communication, which allows the exchange of this data between ships and coastal stations. Data exchange between ships and coastal stations is one of the most prominent features of the AIS system. The system sends periodic reports on ships that include position, speed, and direction, which helps to improve the organization of ship traffic within ports and shipping lanes. This research aims to improve the Automatic Identification System (AIS) and increase its effectiveness in determining the safest routes for ships by integrating data on sea depth and on-going environmental changes.

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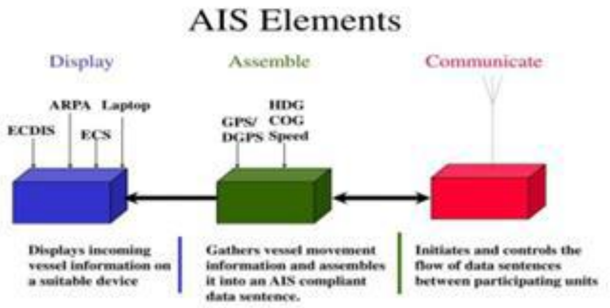

Figure 1: Basic elements of the AIS System

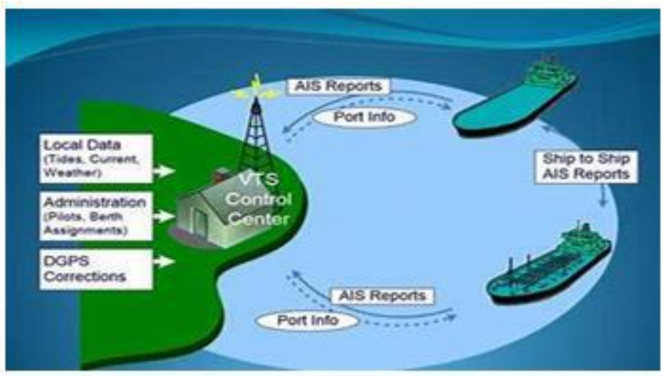

Figure 2: Illustrates the Mechanism of Data Exchange in the AIS System between Ships and Ports

III. MATERIALS AND METHODS

3.1 The Study Area

The study area chosen is Port Sudan, located between longitudes 36.5° and 37.2 and latitudes 19.3° and 19.8°.

Figure 3: Nautical Map of the Study Area

A nautical chart provided by the Port Sudan Maritime Transport Authority was used, containing data including sea depths, coral reef locations, shallow areas, ship waiting areas, and other details related to seabed characteristics.

Sea depth chart taken from the GEBCO (General Bathymetric Chart of the Oceans) website was also used. This is a global source that provides comprehensive data on the depths of the seas and oceans.

3.2 Data processing

3.2.1 Preparing the Sea Depth Chart

The satellite image of area (WGS_1984_UTM_Zone_37N) was Geo-referencing using ArcMap software

3.2.2 Digital Modeling (Digitalizing) of Marine Elements

The geo-referenced map was used as the basis for the digital modeling process, ensuring that the features drawn correspond to the correct geographic coordinates.

- Independent digital layers were created for each of the following

(Shallow areas, Waiting area and Anchorages or moorings)

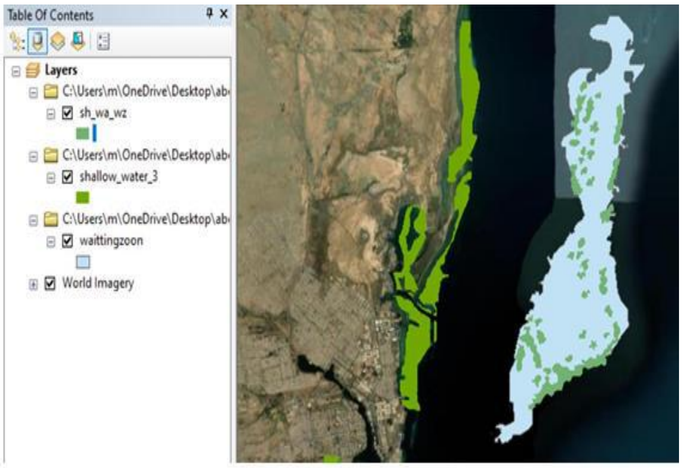

Figure 4: Distributions of the Waiting Area and Shallow Areas within the Study Area

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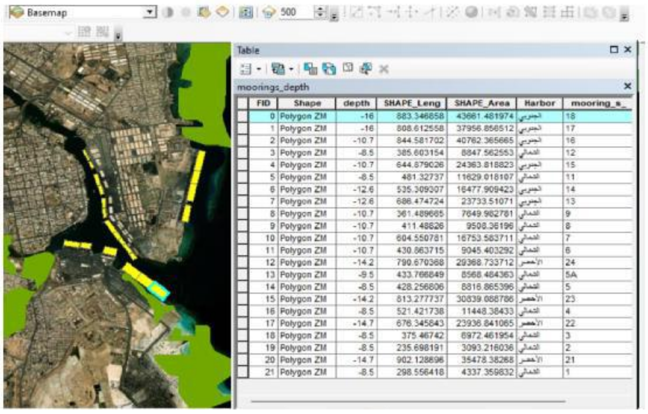

Figure 5: Distribution of Marinas in the Study area It also displays the Detailed Data associated with Each Marina

3.2.3 Representing Depth Data as Geo-data Points

Depth data was extracted from the geo-referenced map worked on in the previous steps.

Figure 6: Depth Distributions in the Study Area

Apply Spatial Interpolation Using the Spline Tool to Transform Data into a Continuous Digital Elevation Model

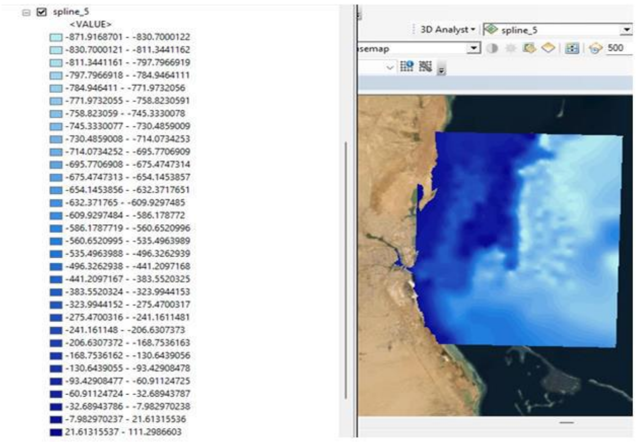

Figure 7: Variation of Depth Values using Color Gradients

3.2.4 Drawing Marine Routes Based on Depth Data and Defined Points

Areas where vessels can navigate safely were identified, taking into account sufficient depth for vessels from the waiting area to the berths. It was ensured that the route extends through areas with suitable depths, avoiding shallow areas.

Figure 8: Vessel Routes Starting from the Waiting Area and Heading towards the Different Berths

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Figure 9: Vessel Routes within the Port

3.2.5 Conducting Network Analysis to Determine Routes

The data required for network analysis were prepared, including the marine ro between the starting points in the waiting area and the ending points at the berths, as ch well as depth data representing the depth along earoute

3.2.6 Creating a 3D model of the routes and depth data using Arc Scene

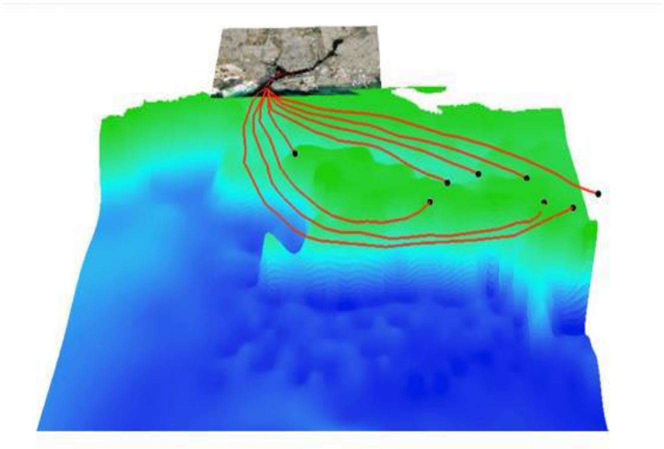

Figure 10: 3D Model of the Study Area and Routes

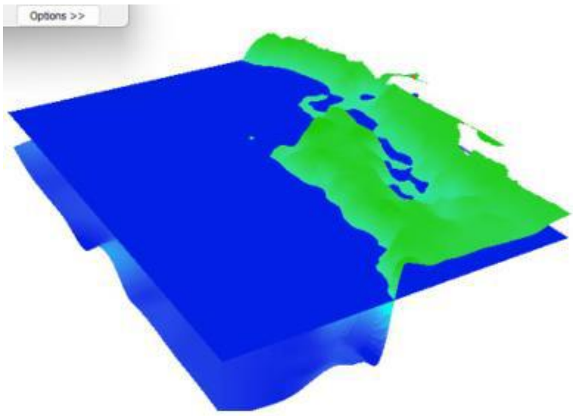

Figure 11: 3D Model of the Study Area, with a level View of the Water Surface

3.3 Detecting Changes in Sea Depth between 2019 and 2024 Using Arc Map

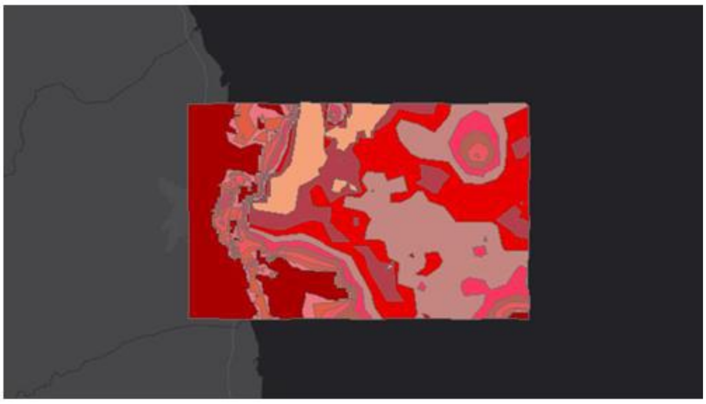

Figure 12: Represents the Sea Depth Data for the Study Area for the year 2019

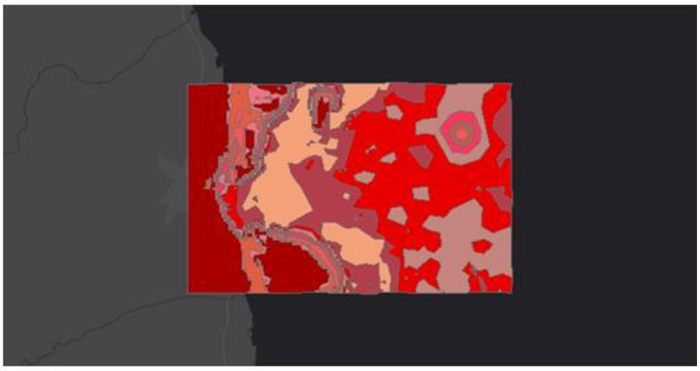

Figure 13: Represents the Sea Depth Data for the Study Area for the year 2024

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IV. RESULTS AND DISCUSSIONS

4.1 Determining Maritime Routes

- A comprehensive navigation network was constructed using bathymetric charts, which helped determine safe routes for vessels, taking into account shallow areas and waiting areas.
- Depths were also analysed to ensure the reduction of maritime hazards, especially in areas with heavy traffic.
- A digital environment based on coastal and seabed depth data was created to determine vessel data in a way that is
  - Safe: by avoiding shallow areas.
  - Efficient: by reducing distance and operating costs
  - Interactive: by providing a user-friendly interface for displaying and analyzing routes.

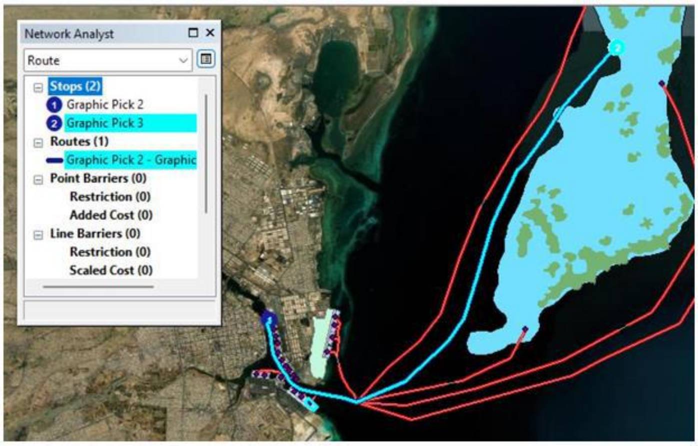

Figure 14: Vessel Routes within the Port

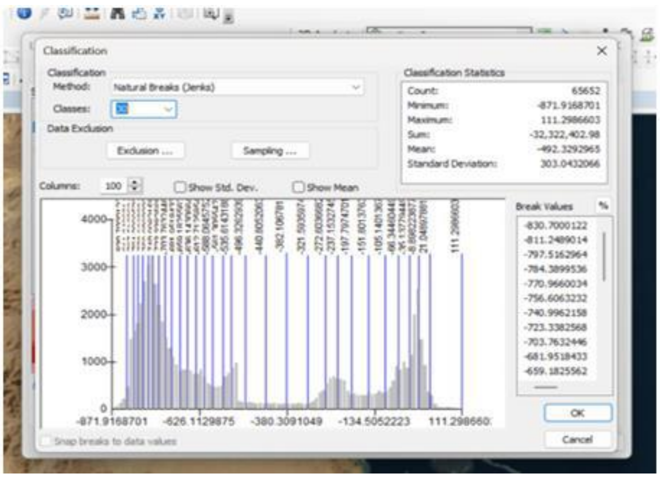

Figure 15: The Depth Classification of the Study Area

V. CONCLUSION

- Satellite imagery analysis revealed clear changes in the port's surrounding environment, including
- Changes in water depth due to sedimentation or dredging.
- Significant changes in seabed, where analysis showed variations in depth due to sedimentation or natural factor.
- Create. . A bitmap image was produced showing the the changes, providing a direct visual reference locations of to the affected areas.
- Charts were prepared showing the changes in numbers and areas, and classifying the changes according to their impact.

REFERENCES

[1] W. S. Brown. Elements of Physical Oceanography‹ School for Marine Science & Technology University of Massachusetts Dartmouth, 22 September (2020).

[2] Bushinak, Renaud, Lyubko, Kavran-Zvonko - Automatic Identification System in Maritime Traffic and Error Analysis - 2012 - Journal of Maritime Science Transactions.

[3] Rino Bošnjak, Ljupko Šimunović, Zvonko Kavran. Automatic Identification System in Maritime Traffic and Error Analysis. REGULAR PAPERS.Trans. Maritime Science, 2012; 02:77-84.

[4] Abbas Harati, Mohktari AIS, A human factors approach. Abbas Harati Mohktari, available at: http://www.mendeley.com/research/automatic-identification-system-ais-data-reliability-human-error-implications/#page-1, (2007) [accessed 16 March 2012].

[5] AIS, (2012), available at: http://wikipedia.org/wiki/AIS, [accessed 17 February 2012].

[6] Badurina, E., (2002), Pomorski Zbornik 40, pp. 79-94.

[7] Baljak, K., Vidan, P, Global ship reporting system and automatic identification system, GIS Applications and Development/Zagreb; Katowice: Hrvatski Informatički Zbor- GIS Forum; University of Silesia., (2006), pp. 77-83.

[8] Thomas Lillisand, Ralph W. Kiefer, Jonathan Chipman - Remote Sensing and Image Interpretation - 2015 - Wiley Publishers.

[9] Lucas L. F. Jans, Wim Humbaker - Principles of Remote Sensing: An Introductory Book - 2001 - International Institute of Aeronautics.

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