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COASTAL BATHYMETRY OF THE UNITED ARAB EMIRATES USING SATELLITE-BASED REMOTE SENSING DATA

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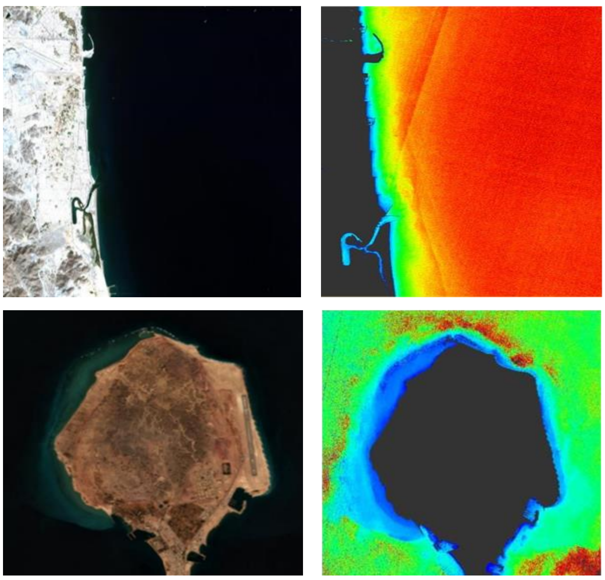

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This thesis is submitted in partial fulfilment of the requirements for the degree of Master of Science in Space Science

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Cover: Coastal Bathymetry of UAE using satellite-based remote sensing data.

(Photo: By Naser Salem Mohamed Salem Aldahmani)

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Declaration of Original Work

I, Naser Salem Mohamed Salem Aldahmani, the undersigned, a graduate student at the United Arab Emirates University (UAEU), and the author of this thesis entitled "*Coastal Bathymetry of United Arab Emirates using Satellite-based Remote Sensing Data*", hereby, solemnly declare that this is the original research work done by me under the supervision of Dr. Mritunjay Kumar Singh, in the College of Science at UAEU. This work has not previously formed the basis for the award of any academic degree, diploma, or a similar title at this or any other university. Any information borrowed from other sources (whether published or unpublished) and relied upon or included in my thesis has been properly cited and acknowledged in accordance with appropriate academic conventions. I further declare that there is no potential conflict of interest with anyone with respect to the research, data collection, authorship, presentation and/or publication of this thesis.

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Abstract

Bathymetry is the study of the bed under the water's surface, giving us the water's depth. The Thesis will be about studying the coastal area of the UAE by using satellite images that can help access large regions of the UAE Coast. Also, by using a history of 5 years of satellite visible bands and NIR images, we can see the change of depth near the coastal. The benefit of that study will help to build ship baths through shallow water and to go in and out of ports of UAE. Early warnings of the sea level increasing near the urban areas near the coastal zone by Global warming is the main reason for the increase of sea level, which will change the depth of the location of fishing in the UAE sea. A coastal bathymetry study will help clarify the best place for fishing areas. All these studies can be done by remote sensing satellites in the visible range and NIR (Near Infrared).

Knowledge of bathymetry is crucial for maritime applications, such as shipping, dredging, navigation, and engineering constructions. Marine applications have received help from recent advancements in satellite navigation technology, which can use multispectral bands to retrieve water depth information. Hence, this proposes to develop a coastal bathymetric map of areas of the UAE coast using optical satellite data and analyze the quality and accuracy of the derived bathymetric map. To derive the bathymetry of water areas, different algorithms are used in mapping the bathymetry. This project will use the linear band ratio (Ratio of Green and Blue bands) to derive the bathymetry map for Al Fujairah port and Delma Island using sentinel 2 Level 1C imagery. Multiple tools were used in the Sentinel Application Platform (SNAP) to derive the bathymetry of the two areas. The bathymetry derivation process implemented A set of procedures, including atmospheric correction, resampling, land masking, sun de-glint, and dark object subtraction. The Sen2coral processor was then used to manually confirm the steps using the software's sun de-glint and bathymetry deriving plugins.

Keywords: Remote sensing, coastal bathymetry, bathymetry, sentinel-2, optical satellite, UAE.

Title and Abstract (in Arabic)

قياس أعماق سواحل دولة الامارات باستخدام بيانات الاستشعار عن بعد

الملخص

قياس الأعماق هو دراسة الطبقة تحت سطح الماء، مما يعطينا عمق الماء. ستدور الأطروحة حول دراسة المنطقة الساحلية لدولة الإمارات العربية المتحدة باستخدام صور الأقمار الصناعية التي يمكن أن تساعد في الوصول إلى مناطق واسعة من ساحل الإمارات العربية المتحدة. وأيضا باستخدام تاريخ 5 سنوات من صور الأقمار الصناعية يمكننا رؤية تغير العمق بالقرب من الساحل. الفائدة من تلك الدراسات ستساعد في بناء موانئ السفن من خلال الدراسة للعمق ، مما سيساعد السفن على الدخول والخروج من الموانئ. دولة الإمارات العربية المتحدة، يعتبر الإنذار المبكر بارتفاع مستوى سطح البحر بالقرب من المناطق الحضرية القريبة من المنطقة الساحلية بسبب ظاهرة الاحتباس الحراري هو السبب الرئيسي لزيادة مستوى سطح البحر والذي سيغير العمق، وموقع الصيد في بحر الإمارات. ومن خلال زيادة عدد السكان في دولة الإمارات العربية المتحدة، ستساعد دراسات قياس الأعماق الساحلية في توضيح أفضل مكان لمناطق الصيد. ويمكن إجراء كل هذه الدراسات عن طريق أقمار الاستشعار عن بعد في النطاق المرئي والأشعة تحت الحمراء القريبة.(NIR) تعد معرفة قياس الأعماق أمرًا بالغ الأهمية للتطبيقات البحرية، مثل الشحن والتجريف والملاحة والإنشاءات الهندسية. وقد تلقت التطبيقات البحرية المساعدة من التطورات الحديثة في تكنولوجيا الملاحة عبر الأقمار الصناعية، والتي يمكن أن تستخدم نطاقات متعددة الأطياف لاستعادة معلومات عمق المياه. ومن ثم، يقترح هذا تطوير خريطة الأعماق الساحلية لمناطق ساحل الإمارات العربية المتحدة باستخدام بيانات الأقمار الصناعية الضوئية وتحليل جودة ودقة خريطة الأعماق المشتقة. لاشتقاق قياس الأعماق للمناطق المائية، يتم استخدام خوارزميات مختلفة في رسم خرائط قياس الأعماق. سيستخدم هذا المشروع نسبة النطاق الخطي (نسبة النطاقين الأخضر والأزرق) لاشتقاق خريطة قياس الأعماق لميناء الفجيرة وجزيرة دلما باستخدام صور(2) Sentinel المستوى(C1). تم استخدام أدوات متعددة في منصة تطبيق Sentinel (SNAP)لاشتقاق قياس الأعماق في المنطقتين. نفذت عملية اشتقاق قياس الأعماق مجموعة من الإجراءات، بما في ذلك تصحيح الغلاف الجوي، وإعادة أخذ العينات، وإخفاء الأرض، وإزالة بريق الشمس، وطرح الأجسام المظلمة. تم بعد ذلك استخدام معالج Sen2coral لتأكيد الخطوات يدويًا باستخدام المكونات الإضافية المشتقة من برنامج إزالة بريق الشمس وقياس الأعماق.

مفاهيم البحث الرئيسية: الاستشعار عن بعد، قياس الأعماق الساحلية، قياس الأعماق، سنتينل-2، القمر الصناعي البصري، الإمارات العربية المتحدة.

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Dedication

To my beloved parents, my family, and my Country

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List of Abbreviations

BOA	Bottom-of-Atmosphere
CHARTS	Compact Hydrographic Airborne Rapid Total Survey
DEM	Digital Elevation Models
DOS	Dark Object Subtraction
EAARL	Experimental Advanced Airborne Research Lidar
ELD	Empirical Line Depth
EMODnet	European Marine Observation and Data Network
EOF	Empirical Orthogonal Functions
ESA	European Space Agency
GEBCO	General Bathymetric Chart of the Oceans
GPL	General Public License
GPS	Global Position System
GSD	Ground Sampling Distance
IOC	Intergovernmental Oceanographic Commission
LADS	Laser Airborne Depth Sounder
LiDAR	Light Detection and Ranging
MAE	Mean Absolute Error
MBES	Multi-Beam Echo Sounder
MCS	Monte Carlo Simulation
MSI	Multi-Spectral Instrument
NIR	Near Infrared
NOAA	National Oceanic and Atmospheric Administration
NWLR	Normalized Water-Leaving Radiance
PEM	Physical-Empirical Model
RMSE	Root Mean Square Error
RTM	Radiative Transfer Model
RWD	Relative Water Depth
SAR	Synthetic Aperture Radar
SAWRM	Semi-Analytical Water Radiance Model

SBCP	Sea Bottom Control Points
SBES	Single-Beam Echo Sounders
SHOLAS	Scanning Hydrographic Operational Airborne Lidar Survey
SNAP	Sentinel Application Platform
TOA	Top of Atmosphere
UAE	United Arab Emirates

Chapter 1: Introduction

1.1 Overview

Bathymetry analyzes underwater depth, forming the primary data source on seafloor morphology. Lines of equal depths called isobaths, are the most popular type of bathymetric map. Multiple types of instruments are used in in-situ measurements, such as: Single-Beam Echo Sounders (SBES) send and receive sound pulse vertically down from a ship. The depth below the ship is computed by counting the time it takes for a sound beam to cross from a sounder to the seafloor and be recollected back to the sounder and knowing the speed of sound in water. This method provides depth information in single scan lines of data along the track of the ship movement. There is no information about the depth on either side of the ship's track. An SBES survey usually uses parallel lines or tracks at a set spacing. Undetected and dangerous features can exist between these lines (Jagalingam et al., 2015).

Another type is the Multi-Beam Echo Sounder (MBES). Multi-beam echo sounders emit pulses of sound in fan shape, known as a swathe, which is narrow along the track but wide across the track. The depth is like SBES, but the depths are calculated through different angles and ranges across the swathe. This allows each pulse to generate hundreds of depth measurements (Figure 1). MBES can measure the seafloor, provide bigger area depth information, and object detection (Jagalingam et al., 2015).

Recently, various advanced types of Light Detection and Ranging (LiDAR) systems that can obtain topographic and bathymetric measurements more rapidly, such as Scanning Hydrographic Operational Airborne Lidar Survey (SHOLAS), Compact Hydrographic Airborne Rapid Total Survey (CHARTS), Laser Airborne Depth Sounder (LADS), and Experimental Advanced Airborne Research Lidar (EAARL). Although large areas can be covered quickly and the general depth and shape of the seafloor can be determined, small but significant objects may be missed. Also, these techniques are expensive (Jagalingam et al., 2015).

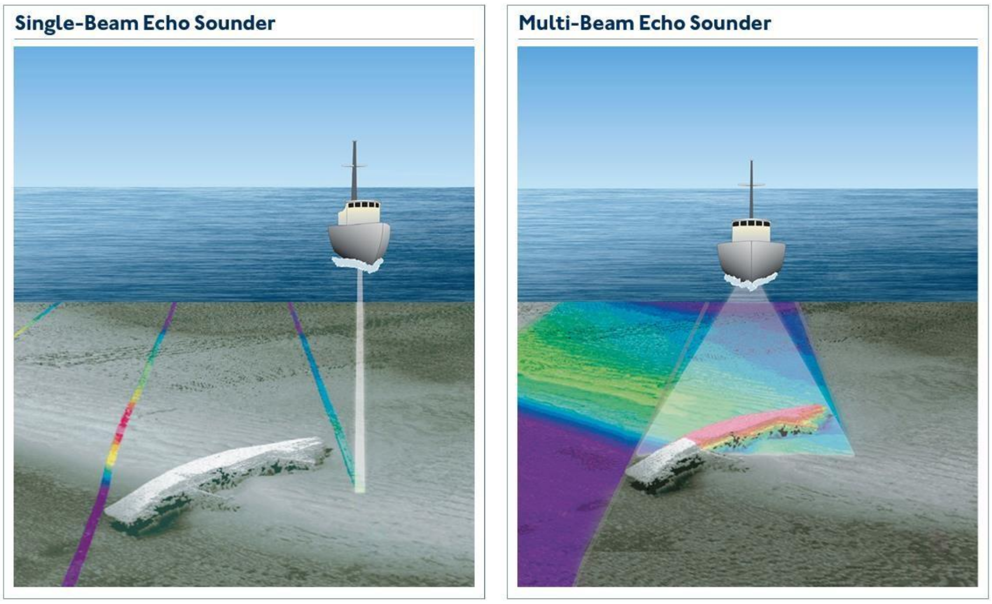


Figure 1: The difference between the way of working of Single Beam Sounders (SBES) and Multiple Beam Sounders (MBES), in that the wreck has been entirely missing in the SBES.

The primary advantage of image-based methods over physics-based methods is that the image-based method can provide bathymetry information for a larger area in a comparatively extremely low cost with minimum in-situ observations. For that, in this research, we will use the empirical method that derives the bathymetry by regression using in-situ data using known depths, specifically, the linear ratio model by Stumf (Stumpf et al., 2003).

1.2 Background

Studying underwater depth dates to ancient times when sailors used ropes and sounding leads to measure the depths of harbors and waterways. In the 19th century, technological advances led to more sophisticated tools for measuring water depth, including echo-sounding and single-beam sonar.

Using sonar technology during World War II marked a significant step in studying bathymetry. After the war, technology was adapted for scientific and commercial use, creating more detailed maps of the world's oceans and other bodies of water.

In the latter half of the 20th century, satellite technology revolutionized bathymetry. Satellite altimetry, which uses radar and laser technology to measure the depth of ocean surfaces, has provided new and improved data for bathymetry maps (Panayotov, 2019). Remote sensing techniques, including multibeam and side scan sonar, have also been developed and used to map the seabed in more detail.

Today, bathymetry is essential for many applications, including oceanography, navigation, environmental monitoring, and resource exploration. The continued development of modern technology and techniques promises to advance further our understanding of the depths of the world's oceans and other bodies of water (Panayotov, 2019).

However, the term "bathymetry" was derived from the Greek words "bathus" (deep) and "metron" (measure) and was first used in the 19th century to describe the measurement of underwater depth (Panayotov, 2019). The science of bathymetry has a long history, dating back to ancient times when sailors used ropes and sounding leads to measure the depths of harbors and waterways.

Over the centuries, various scientific institutions and organizations have contributed to the development and study of bathymetry. Today, bathymetry is a field of study within oceanography and geology and is essential for a wide range of applications, including navigation, environmental monitoring, and resource exploration. Many institutions and organizations worldwide, including universities, government agencies, and private companies, are involved in studying and applying bathymetry. The study of underwater depth is used for a wide range of purposes in several fields, including Oceanography: Bathymetry data provides information about the topography of the ocean floor, which is essential for understanding ocean currents, tides, and other oceanographic processes. Navigation: Bathymetry data creates charts that help sailors navigate safely in shallow waters and avoid underwater hazards. Environmental monitoring: Bathymetry data can be used to monitor the health of marine ecosystems and track changes in underwater landscapes over time. Resource exploration: Bathymetry data searches for oil, natural gas, and minerals in the deep ocean. Disaster response: Bathymetry data can support disaster response efforts, such as search and rescue operations, by providing information about underwater terrain and depth.

An example of bathymetry data in oceanography is described in " Geomorphology of the oceans " by (Harris et al., 2014) This paper comprehensively analyzes global bathymetry data and its relationship to oceanographic processes and geomorphology.

Overall, bathymetry plays an essential role in various fields and applications, and its continued development and improvement will help advance our understanding of the world's oceans and other bodies of water.

There are several sources for bathymetry data. Government agencies: National oceanic and atmospheric organizations, such as the National Oceanic and Atmospheric Administration (NOAA) in the United States, often make bathymetry data publicly available on their websites. University websites: Some universities, such as the University of Hawaii, have bathymetry data available on their websites for research purposes. Commercial sources: Commercial providers of bathymetry data, such as "Ocean Wise", sell data products and services. Open data portals: Some organizations, such as the European Marine Observation and Data Network (EMODnet), provide access to open bathymetry data through data portals.

One example of a reference for accessing bathymetry data is "GEBCO: The General Bathymetric Chart of the Oceans, which is a global bathymetry data set produced by the Intergovernmental Oceanographic Commission (IOC) of UNESCO and the British Oceanographic Data Centre.

It is important to note that the quality and accuracy of bathymetry data can vary depending on the source, so it is important to evaluate the suitability of a data source for a specific application.

1.3 Relevant Literature

To derive the bathymetry of water areas, different algorithms rely on two main categories. The empirical bathymetry (image-based) (Stumpf et al., 2003; Su et al., 2008) and analytical methods (physics-based) such as (Lyzenga, 1978, 1981; Lyzenga et al., 2006; Philpot, 1989). The empirical methods derive bathymetry by regression using in-situ data using known depths, while the analytical method uses radiative transfer model inversion using multispectral and hyperspectral data.

The Ratio Transform Algorithm (Linear band ratio) developed by Stumph is one of these methods that relies on using the ratio of two bands to reduce the number of parameters that would be used in the derivation of the ocean's bathymetry. Another standard algorithm is the Lyzenga algorithm (Lyzenga et al., 2006). The Lyzenga algorithm is a simple method that can estimate the water depth from the data source, namely multispectral images, or optical images. This algorithm is based on a physical model to figure out shallow water reflection. Another Algorithm is the(Van Hengel & Spitzer, 1991) developed by W. Van Hengel and D. Spitzer in their study conducted in 1991. This algorithm uses imagery data as a data source to generate bathymetry. This algorithm uses red, green, and blue bands (bands 4, 3, and 2) in its processing.

Many research studies have been conducted to derive the bathymetry maps of selected areas using the mentioned algorithms. For instance, a study done by Abdul Gafoor (Abdul Gafoor et al., 2022) for Abu Dhabi Island and Sir Bani Yas Island using gradient boosting and linear regression for estimating coastal bathymetry based on Sentinel-2 Images. Abdul Gafoor's study utilized deep learning techniques with satellite-based observations to improve the estimation of satellite-based bathymetry. It was found in this study that the gradient boosting method provides better estimates of bathymetry than linear regression. Also, it is found that the chlorophyll-a (Chl-a) concentration, sediments, and atmospheric dust do not affect the estimated bathymetry (Abdul Gafoor et al., 2022). However, tidal oscillations significantly affect satellite estimates of bathymetry (Abdul Gafoor et al., 2022).

Jagalingam had done a study to generate the bathymetry map of the coastal areas of southwest India by applying the ratio transform algorithm on the blue and green bands of Landsat 8 satellite imagery. Statistical indices such as R2, Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) are computed between the algorithm-derived value and the hydrographic chart-sounding value. The result shows a good correlation between the algorithm-derived and hydrographic chart-sounding values (Jagalingam et al., 2015).

Another study by (Setiawan et al., 2021) conducted on the Putri, Melintang, Macan, Dolpin islands, and Seribu Islands of Jakarta, aimed to extract rapid bathymetry using the

Sen2Coral algorithm available in Sentinel Application Platform (SNAP) image processing software. The study focused on the deriving bathymetry in shallow marine waters using Sentinel 2A data. The results found in this study show that the accuracy of the calculated bathymetric using Sentinel 2A is 68%.

Although all the studies used different algorithms, the linear band ratio would be used to derive the bathymetry map for Al Fujairah port and Delma Island as this method is applied in the SNAP application and it is the simplest method of bathymetry estimation.

1.3.1 Remote Sensing Satellite and Techniques

Bathymetry can be obtained from satellite images using several methods. Synthetic Aperture Radar (SAR) Interferometry: SAR interferometry uses the phase information from radar images to generate digital elevation models (DEMs) of the Earth's surface (Gupta et al., 2014; Singh, et al., 2015), including the seafloor. This method has been widely used and has been the subject of many studies, such as " Interferometric synthetic aperture sonar for high-resolution 3-D mapping of the seabed" (Griffiths et al., 1997) and " Coastal wave field extraction using TerraSAR-X data" (Bruck & Lehner, 2013). Light Detection and Ranging (LiDAR): LiDAR systems on satellites can measure the time taken for laser pulses to bounce off the sea surface and return to the satellite, allowing for calculating the sea surface height and bathymetry. An example of the use of LiDAR for bathymetry is " Schematic of space-borne lidar surveying neritic seabed terrain" (Dou et al., 2013). Altimetry: Satellite altimetry measures the time delay between transmitting a radar signal from the satellite to the sea surface and the echo’s return. This information can be used to measure the height of the sea surface and calculate bathymetry. A well-known application of satellite altimetry for bathymetry is "Modelling bathymetry by inverting satellite altimetry data" (Calmant & Baudry, 1996). Optical Remote Sensing: Optical remote sensing techniques such as multispectral and hyperspectral imaging can also extract bathymetric information by analyzing how light penetrates and interacts with the water column. An example of hyperspectral remote sensing for bathymetry is " A Combined Machine Learning and Residual Analysis Approach for Improved Retrieval of Shallow Bathymetry from Hyperspectral Imagery and Sparse Ground Truth Data"

(Alevizos, 2020). Each method has strengths and limitations. The choice of method depends on factors such as the desired resolution and accuracy, the availability of suitable satellite data, and the specific requirements of the study.

By applying models to explain the physical characteristics of light as it enters and interacts with the water column, physical techniques are used to process optical satellite images and derive bathymetry data. To determine the apparent brightness of the water and retrieve bathymetry, specific standard physical techniques, such as the Radiant Transmission Model (RTM), employ models of the radiative transmission of light in the water column. (Wang et al., 2022) provide "Bathymetry retrieval from RS data using a radiative transfer model" as an illustration of this technique. MCS, or Monte Carlo Simulation: The Monte Carlo Simulation (MCS) technique determines the apparent brightness of the water and retrieves bathymetry by using computer simulations of light scattering and absorption in the water column. Physical-Empirical Model (PEM): To determine bathymetry and compute the apparent brightness of the water, the Physical-Empirical Model (PEM) combines physical models with empirical relationships. (Ma et al., 2020) provided "datasets" to illustrate this technique. The conventional empirical models (i.e., the linear model and the band ratio model) were trained using bathymetric points from the spaceborne ICESat-2 lidar instead of the in-situ auxiliary bathymetric points. With the help of empirical models based on the most recent ICESat-2 lidar data and Sentinel-2 multispectral imaging, this innovative method allows for producing bathymetric maps in shallow waters using only satellite remotely sensed data (Ma et al., 2020).

Each of these methods has its strengths and limitations, and the choice of method depends on factors such as the desired resolution and accuracy, the availability of suitable satellite data, and the specific requirements of the study area.

Empirical methods commonly process optical satellite images to retrieve bathymetry information. Some standard empirical methods, like the Empirical Line Depth (ELD) method, estimate the depth by comparing the apparent radiance of the water to a set of empirically derived relationships between the apparent radiance and the depth. An example of this method is described in " The Remote Sensing of Ocean" by

(Balch et al., 1992). Semi-Analytical Water Radiance Model (SAWRM) uses a combination of theoretical models and empirical relationships to calculate the apparent radiance of the water and retrieve bathymetry. An example of this method is " Shallow Water Bathymetry Retrieval by Optical Remote Sensing Based on Depth-Invariant Index and Location Features" (Zhu et al., 2022). Empirical Orthogonal Functions (EOFs) method involves transforming the satellite imagery data into a set of orthogonal functions from which the bathymetry can be retrieved. An example of this method is " Using empirical orthogonal functions derived from remote-sensing reflectance for the prediction of phytoplankton pigment concentrations" (Bracher et al., 2015).

Each of these methods has its strengths and limitations, and the choice of method depends on factors such as the desired resolution and accuracy, the availability of suitable satellite data, and the specific requirements of the study area.

Optical remote sensing techniques such as multispectral and hyperspectral imaging can extract bathymetric information by analyzing how light penetrates and interacts with the water column. Some standard methods for processing optical satellite images to obtain bathymetry. Normalized Water-Leaving Radiance (NWLR) inversion: This method involves calculating the Normalized Water-Leaving Radiance (NWLR) from satellite imagery and using it to retrieve bathymetry by inversion. An example of this method is described in "Retrieval of shallow bathymetry from remote sensing data" by (Alevizos, 2020). Band ratio analysis: Band ratio research involves using the ratio of two or more bands of satellite imagery to retrieve bathymetry like bule and green bands. An example of this method is "Shallow water bathymetry retrieval from multispectral remote sensing data" (Zhang et al., 2020). Machine learning techniques: Machine learning techniques like artificial neural networks and decision trees can process satellite imagery to retrieve bathymetry. An example of this method is shallow bathymetry retrieval using hyperspectral imagery and machine learning algorithms (Alevizos, 2020).

Each of these methods has its strengths and limitations, and the choice of method depends on factors such as the desired resolution and accuracy, the availability of suitable satellite data, and the specific requirements of the study area.

Knowledge of measuring water depth in coastal areas faces several difficulties. Water quality is the clarity of the water, which can affect the accuracy of the bathymetry measurements, as suspended particles and algae can interfere with satellite imagery. Sun glint: The sun's reflection off the water surface can also affect the accuracy of the bathymetry measurements. Wave disturbance: Waves can cause the water surface to become rougher, leading to inaccuracies in the bathymetry measurements. Shadows cast by objects in the water, such as ships or oil platforms, can also interfere with the accuracy of the bathymetric measurements. Resolution of the satellite imagery can limit the accuracy of the bathymetry measurements, as more minor features in the water may not be captured in the image. Satellite coastal bathymetry can be expensive, requiring specialized satellites and equipment.

Despite these difficulties, satellite coastal bathymetry is still a helpful tool for studying and monitoring coastal areas, as it provides large-scale data and can be used in areas where traditional bathymetry methods are difficult or impossible.

De-glint an image from a satellite or other remote sensing device, typically needs to use a combination of image processing techniques. Glint occurs when sunlight reflects off a smooth surface on the Earth's surface or an object in orbit and appears as a bright spot in the image. Here are steps you can take to reduce or eliminate glint effects in satellite images:

Image Preprocessing:

- Radiometric Calibration: Using available calibration data, correct the image for radiometric artifacts, such as sensor sensitivity and atmospheric effects variations.
- Geometric Correction: Correct for geometric distortions and misalignment in the image.
- Glint Detection: Use image analysis techniques to identify areas in the image affected by glint. This can be done by looking for high-intensity spots or areas with unusually high reflectance values.
- Shadow Detection and Removal: Glints often occur in areas where there are shadows as well. Detect and remove shadows separately to further improve the quality of the image.

Multispectral or Hyperspectral Data:

- If you can access multispectral or hyperspectral data, you can use information from multiple spectral bands to differentiate between glint and natural features, making isolating and removing glint easier. Consider using machine learning or deep learning techniques to detect and remove glint artifacts automatically. Training a model to recognize glint patterns can be a powerful approach. In some cases, manual correction may be necessary, especially if glint areas are complex or subtle. Image analysts can use image editing software to edit and remove glint effects carefully. After applying the above techniques, validate the results to ensure that the glint has been adequately removed without introducing other artifacts or degrading the image quality.

It is important to note that the specific techniques and tools you use may vary depending on the type of satellite data you have, the characteristics of the glint, and the desired level of image quality. Additionally, having access to metadata and ancillary information about the satellite and the environment during image capture can be extremely helpful in the de-glinting process.

Sentinel-2 is a series of Earth observation satellites developed by the European Space Agency (ESA) as part of the European Union's Copernicus program. These satellites are designed to provide high-resolution optical imagery and data for various applications, including agriculture, forestry, land use, environmental monitoring, and disaster management.

Sentinel-2A was the first satellite in the Sentinel-2 series. It was launched on June 23, 2015. The satellite has been collecting valuable Earth observation data since then. The second satellite in the series, Sentinel-2B, was launched on March 7, 2017. It joined Sentinel-2A in orbit, doubling the data acquisition ability and coverage. The Sentinel-2 program was planned to include more satellites in the future to ensure continuity.

The Sentinel-2 satellites have advanced optical instruments to capture high-resolution multispectral imagery of the Earth's surface. Sentinel-2 satellites carry a Multi-Spectral Instrument (MSI) that captures imagery in 13 spectral bands, including visible, near-infrared, and shortwave infrared bands. This multispectral capability allows for various applications, including vegetation monitoring, land cover classification, and water quality assessment. The spatial resolution of Sentinel-2 imagery varies between 10 meters, 20 meters, and 60 meters, depending on the spectral band. The 10-meter resolution bands are particularly useful for detailed land cover analysis. Sentinel-2A and Sentinel-2B, when used together, provide global coverage of the Earth's land surface every five days, making them suitable for monitoring changes and events often. The two Sentinel-2 satellites provide a short revisit time, allowing for rapid monitoring of changes and natural disasters. The Sentinel-2 data is freely and openly available to users worldwide through the Copernicus Open Access Hub and other data distribution channels. The expected operational lifespan of each Sentinel-2 satellite is approximately seven years. Sentinel-2 data is processed and distributed in various formats, including Level-1C (top-of-atmosphere reflectance) and Level-2A (surface reflectance) products.

Sentinel-2 data has been invaluable for various applications, including agriculture, forestry management, disaster monitoring, urban planning, and environmental studies. It has contributed significantly to understanding Earth's dynamic processes and has been a valuable resource for researchers, government agencies, and commercial users worldwide. Please check with the European Space Agency or other authoritative sources for the latest updates and developments about the Sentinel-2 program beyond September 2021.

- European Space Agency (ESA) Publications: ESA often publishes technical documents, user guides, and scientific papers related to the Sentinel-2 mission. These can be found on their publication’s website of ESA.
- Copernicus Open Access Hub: The Copernicus Open Access Hub provides access to Sentinel-2 data, related documentation, and user guides.

1.3.2 SNAP Tool

SNAP (Sentinel Application Platform) is a software tool designed to analyze and process Earth observation data, including data from the Sentinel satellites and other remote sensing missions. SNAP provides a user-friendly environment for accessing, processing, and analyzing satellite data, making it a valuable tool for many applications in Earth sciences, environmental monitoring, agriculture, and more.

Here is some general information and specifications about ESA SNAP, an open-source software platform freely available to users and developers. It is distributed under the GNU General Public License (GPL), making it accessible to a broad community of users and allowing for customization and extension by developers. SNAP primarily supports data from the Sentinel missions, including Sentinel-1 (radar data), Sentinel-2 (optical data), and Sentinel-3 (ocean and land data). It also supports data from other Earth observation missions and various file formats commonly used in remote sensing. SNAP provides an intuitive and user-friendly graphical interface that allows users to perform multiple tasks without extensive programming or command-line skills. It includes a range of tools and wizards for data processing and analysis. SNAP offers a wide range of processing capabilities, including data calibration, atmospheric correction, image fusion, and data fusion. It supports optical and radar data processing and provides terrain correction and image manipulation tools. SNAP includes powerful visualization tools for exploring and interpreting Earth observation data. Users can display, overlay, and compare multiple data layers and create custom visualizations. SNAP allows users to create custom workflows and processing chains using the Graph Processing Framework (GPF). This enables advanced users to automate repetitive tasks and develop custom processing solutions. SNAP can be integrated with other software tools and libraries for further analysis and data processing. It supports integration with Python and the Orfeo Toolbox, among others. Users can export processed data in various formats, including Geo TIFF, JPEG, and more, making it easy to share results with others. Snap has an active user community, and users can find documentation, tutorials, and support on the ESA STEP (Scientific Exploitation Platform) forum and other online resources. SNAP is designed to work on multiple platforms, including Windows, macOS, and Linux.

To get the most up-to-date information about ESA SNAP, including downloads, documentation, and tutorials, you can visit the official SNAP website on the ESA STEP platform. The ESA STEP forum is also a valuable resource for asking questions, sharing knowledge, and seeking assistance with SNAP-related topics.

1.4 Statement of the Problem

This project aims to produce a bathymetry map of two areas on the coast of UAE, Al Fujairah Port and Delma Island. Major reasons for choosing the Arabian Gulf for this study, in addition to the availability of bathymetry data, are that it is among the saltiest waters in the world and has a high evaporation rate, making it vulnerable to climate change and coastal erosion (Ibrahim et al., 2020). Additionally, the coastal morphology of Abu Dhabi is complex, as the shoreline is exceptionally shallow, with many inshore and nearshore islands. Most of the coastal zones have been affected by reclamation and dredging activities. Therefore, having an accurate bathymetry map of this zone for safety and management would be significant.

Chapter 2: Study Area and Data Used

2.1 Study Area

The United Arab Emirates is situated in the Middle East and southwest Asia, bordering the Gulf of Oman and the Arabian Gulf, between Oman and Saudi Arabia. The UAE stretches for more than 650 km along the southern shore of the Arabian Gulf and extends for about 90 km along the Gulf of Oman. Most of the coastal areas consist of salt pans that extend far inland (Wikipedia contributors, 2023).

The United Arab Emirates (UAE) is home to several significant ports due to its strategic location along the Arabian Gulf and the Gulf of Oman. These ports are crucial to the UAE's economy as they facilitate trade, import, and export activities. While the number of ports may vary depending on how one classifies them, here are some of the most significant and well-known ports in the UAE:

- Port of Jebel Ali: Dubai’s Jebel Ali port is one of the biggest and busiest ports in the world. It is a major cargo container shipping and industrial activity hub.
- Port Rashid: Also situated in Dubai, Port Rashid handles general cargo cruise ships and has a long history as one of the UAE's primary ports.
- Port Khalifa (Khalifa Port): Located in Abu Dhabi, this deepwater port is one of the most modern and advanced ports in the region, handling a wide range of cargo types, including containers, bulk cargo, and industrial projects.
- Port Zayed (Mina Zayed): This port, also in Abu Dhabi, has historically been a critical point for trade and commerce. It continues to handle general cargo and some cruise ships.
- Fujairah Port: Located on the Gulf of Oman, Fujairah Port is crucial for the export of crude oil from the UAE. It also handles various other cargo types, including containers.

- Sharjah Port: This port in the emirate of Sharjah handles general cargo and has been expanding to accommodate container traffic.
- Ajman Port: Located in the emirate of Ajman, this port handles general cargo and has undergone developments to increase its ability.

The United Arab Emirates (UAE) is a country in western Asia, situated on the Arabian Peninsula's southeastern tip, and boasts a significant coastline along the Arabian Gulf. This coastline is indispensable to the country's history, economy, and culture (Wikipedia contributors, 2023).

From a geographical perspective, the UAE's coastline is marked by sandy beaches, coastal plains, and many islands. This coastal strip has seen the rise of major urban centers like Dubai, Abu Dhabi, Sharjah, and Fujairah (Subraelu et al., 2022). Historically, the coast has been vital for the UAE. Activities like pearl diving were once the lifeblood of coastal communities, shaping much of the country's cultural and societal norms. The dhow, a traditional sailing vessel, stands as a symbol of the maritime heritage of the UAE (Wikipedia contributors, 2023).

Several emirates and cities lie along the coastline, like Abu Dhabi. The capital city and largest emirate has a mix of modern skyscrapers, traditional architecture, and significant coastal developments, like the Corniche. Dubai is Known for its iconic skyline, manufactured islands (Palm Jumeirah, World Islands), and famous beaches. Sharjah has a rich history and a scenic waterfront. Ajman, Umm Al Quwain, and Ras Al Khaimah are smaller emirates with significant coastlines, each offering distinct cultural and natural attractions. Fujairah Lies on the eastern coast facing the Gulf of Oman and boasts scenic beaches and diving spots (Wikipedia contributors, 2023).

The coast has been vital for trade, fishing, pearl diving, tourism, and real estate development. Coastal regions draw tourists to luxurious hotels, beaches, and water-based activities. Some coastal and offshore areas are crucial for oil and gas extraction.

Mangroves are found in various parts of the UAE, particularly in Abu Dhabi. They play an essential role in the local ecosystem, breeding grounds for many marine species and protecting the coastline from erosion. Coastal waters, especially near the emirate of

Fujairah, house coral reefs, which are critical marine ecosystems but face climate change and development threats. The UAE relies on desalination for its freshwater needs. While essential, the process can pose environmental challenges, such as increased salinity in nearby waters due to brine discharge (Subraelu et al., 2022).

Before the discovery of oil, the UAE's economy heavily depended on pearl diving. This activity has deep cultural roots and has shaped the identity of many coastal communities. Traditional boats like dhows have been used for trade, fishing, and transport for centuries.

The coastal areas of the UAE are vital in the cultural and economic activities of UAE residents. Enormous growth of its coastal cities, infrastructure development and climate change induced flashflood activities in the past decades these areas are influenced by erosion, sediment deposition, and formation of barrier islands. So, it is quite important to find an economical way to check the considerable extent of these costs' sedimentation activates and sea floor depth in the coastal areas. Considering all these reasons two (2) prominent coastal areas of UAE have been selected as the test/study area for this research.

The first area used for bathymetry derivation is Al Fujairah Port, shown in Figure 2. The subset area is 24.657°N, 56.288°E and 25.143° N, 56.627°E.

Delma Island in Abu Dhabi is the second area for bathymetry derivation, as shown in Figure 3. The bond of the subset area is 24.367° N, 52.221° E and 24.57° N, 52.46°E.

Figure 2: Al Fujairah port on the UAE coast.

Figure 3: Delma Island in Abu Dhabi.

2.2 Data

2.2.1 Satellite Data

Copernicus Open Hub is a platform the European Space Agency (ESA) supports the Copernicus program, which focuses on Earth observation and satellite data. The Copernicus Open Hub offers free, complete, free access to sentinel satellite data. The Sentinel satellites are a family of satellites launched as part of the European Union's Copernicus Program, one of the world's most extensive Earth observation programs.

These are a fleet of satellites designed to collect data about Earth through various instruments. For instance, Sentinel-1 provides radar imagery, Sentinel-2 provides high-resolution optical imagery and others with specific focuses like monitoring atmospheric conditions or ocean and land surfaces. These satellites' vast data can be used for various applications, from agriculture, forestry, urban planning, disaster management, environmental protection, and more. The platform is designed for users to instantly search, view, and download the vast troves of data generated by Sentinel satellites. This data is available to the public, businesses, and researchers.

Sentinel-2 is an Earth observation mission from the European Union's Copernicus Program that provides multispectral imagery. The Sentinel-2B satellites (Sentinel-2A and Sentinel-2B) carry a Multispectral Instrument (MSI) that captures data in 13 spectral bands with a varying spatial resolution (Thayyen et al., 2020). Table 1 presents the main spectral bands for Sentinel-2 and their respective resolutions.

Table 1: Sentinel-2 Spectral and Spatial resolution specification. (ESA, 2015).

S. No.	Band No	Band Description	Central Wavelength	Spatial Resolution
1.	Band 1	Coastal aerosol	0.443 µm,	60 m
2.	Band 2	Blue	0.490 µm	10 m
3.	Band 3	Green	0.560 µm	10 m
4.	Band 4	Red	0.665 µm	10 m
5.	Band 5	Vegetation Red Edge	0.705 µm	20 m
6.	Band 6	Vegetation Red Edge	0.740 µm	20 m
7.	Band 7	Vegetation Red Edge	0.783 µm	20 m
8.	Band 8	NIR	0.842 µm	10 m
9.	Band 8A	Narrow NIR	0.865 µm	20 m
10.	Band 9	Water Vapor	0.945 µm	60 m
11.	Band 10	SWIR (Short wave infrared) -Cirrus	1.375 µm	60 m
12.	Band 11	SWIR 1	1.610 µm	20 m
13.	Band 12	SWIR 2	2.190 µm	20 m

The Sentinel-2 satellite data is processed at various levels, each suitable for diverse types of applications. These processing levels range from raw data to processed images and include below given processing levels:

1. Level-1C (L1C): Data at this level are ortho-image products; they have been projected onto a cartographic system (UTM). They are made of 100 km x 100 km tiles and are provided in actual color.
2. Level-2A (L2A): These are atmospheric corrected products, meaning they account for atmospheric conditions when the data was captured. The Level-2A product provides surface reflectance values (ESA, 2015).

The imageries of the studied areas are collected from Level 1C, Sentinel-2 MSI of the UAE (United Arab Emirates) coast. The images are available online on the Sentinel2 website. The Level-1C is distributed in 100×100 km^2 tiles (ortho-images in UTM/WGS84 projection). The Level-1C orthorectified product was generated using a Digital Elevation Model (DEM) to project the image in cartographic geometry (Singh et al., 2016). Per-pixel radiometric measurements are used to measure the Top of Atmosphere (TOA) reflectance and then atmospheric parameters were used to transform TOA into the radiances image. Level-1C products are resampled with a constant Ground Sampling Distance (GSD) of 10, 20, and 60 m, depending on the native resolution of the different spectral bands (Baillarin et al., 2012).

2.2.2 Bathometric Points

I-Boating is an open-source app provided by GPS Nautical Charts. It is related to digital marine and lake charts for boating. Such charts are critical for navigational safety and are commonly used in devices and applications to help boaters, fishers, and other maritime enthusiasts navigate bodies of water. GPS Nautical Charts typically offer marine charts for boating and fishing. These charts often display details about water depths, obstructions, aids to navigation, channel markers, and other valuable information that can help boaters in safely navigating waters. Many GPS nautical chart services cover a vast range of regions, including but not limited to the USA, Canada, Australia, and European waters. Depending on the specific service or app, features can include offline chart access, route planning, tide prediction, current prediction, and overlays of different chart types (like satellite imagery). These services are available on various platforms, including web browsers, iOS, and Android apps. It helped me to get points of depth wader with the exact location (GPS Nautical Charts, 2022).

The data sets used for this thesis work have the in-situ measured points (Table 2). Only points with a maximum depth of 25.5 m have been used for algorithm calibration, as this can be assumed as the maximum depth to which the retrieval from satellite data is possible.

Table 2: Bathymetry points used in the regression process for Delma Island

S. No.	Id.	Depth	Longitude	Latitude
1.	1	1.8 m	52.316115 E	24.417522 N
2.	3	2 m	52.317886 E	24.417583 N
3.	5	10 m	52.319339 E	24.42424 N
4.	10	6.2 m	52.321041 E	24.427324 N
5.	11	16.5 m	52.286911 E	24.405652 N
6.	12	13.7 m	52.283088 E	24.422784 N
7.	13	23.5 m	52.278026 E	24.429666 N
8.	14	26 m	52.293029 E	24.45613 N
9.	15	19.7 m	52.301372 E	24.46751 N
10.	16	14.6 m	52.340663 E	24.430791 N
11.	17	25.5 m	52.339855 E	24.461313 N
12.	15	5 m	52.351222 E	24.508623 N
13.	19	3 m	52.343051 E	24.506982 N
14.	20	0.9 m	52.332633 E	24.491205 N
15.	21	4.2 m	52.290882 E	24.538059 N
16.	22	7.4 m	52.316528 E	24.542264 N

Chapter 3: Methodology

In this research, the application for bathymetry derivation is the SNAP (Sentinel Application Platform) application. The SNAP application (created by the ESA) is an open-source application with several toolboxes commonly used to process Sentinel data. Some functions are available on this tool for data visualization, band exploration & combinations, masking, resampling the pixels, AOI (area of interest) clipping, and many other functions, including several plugins developed by other developers.

The algorithm to be used in this project is the Stumph method. Two ways of implementing the Stumph method would be applied in this project to derive the bathymetry by regression using in-situ data using known depths. This aims to confirm the manual derivation (Multiple steps) with the automatic derivation (By processor module).

The Stumpf Relative Water Depth (RWD) algorithm offers an innovative approach to deriving water depth from spectral band values. By linearizing the relationship using a log transformation and employing a log-band ratio, the algorithm minimizes the parameters in the equation to generate classes of relative water depth. This can then be aligned with actual bathymetric data.

One of the primary benefits of the RWD algorithm is its resilience against errors stemming from radiation fluctuations in the atmosphere and water columns. Furthermore, its ability to remain unaffected by seafloor variations, like the contrast between dark seagrass and bright sand, is noteworthy. Thus, areas with these different compositions but at the same depth are represented uniformly (Pushparaj & Hegde, 2017).

The core principle of the model hinges on the fact that distinct bands undergo varying degrees of absorption in a water body. The algorithm is represented by the equation (1):

$$z = m_1 \frac{ln(nRw(\lambda i)}{Ln\left(nR_w(\lambda_j)\right)} - m_0 \qquad \text{(eq. 1)}$$

Here, 'Z' stands for the derived depth in meters. 'm_1' is a scaling constant, while 'n' is a constant selected to ensure the ratio remains positive for any reflectance value. 'm0' stands for the offset for a depth of zero meters, and 'Rw' is the observed radiance for the bands $\lambda_i\lambda_i$ and $\lambda_j\lambda_j$.

This model was implemented using SNAP software (Ouwehand, 2015). An enhanced method tested the potential of newer yellow and coastal-blue spectral bands present in satellite multispectral sensors. By comparing various pairs of wavelengths, specifically focusing on the coastal blue, the best solution for the study area was figured out. Traditional blue/green ratios served as the comparison baseline (Pushparaj & Hegde, 2017).

Initial outcomes displayed relative water depths, scaled from zero to one. While these results grant a basic understanding of bathymetry, they are not suited for navigational purposes. To offer a bathymetric map, calibration with genuine seabed depth values was essential. This involved computing a density slice at spectral reflectance intervals and aligning it with actual depth surveys. Multiple Sea Bottom Control Points (SBCPs) were tested during this calibration process (Pushparaj & Hegde, 2017).

Firstly, to derive the bathymetry from Level 1C sentinel imagery, a processing workflow is implemented to derive the bathymetry map. The process workflow would be as follows:

3.1 Atmospheric Correction

Solar radiation reflected by the Earth’s surface to satellite sensors is affected by its interaction with the atmosphere. The aim of applying an atmospheric correction is to figure out actual cover Bottom-of-Atmosphere (BOA) reflectance values from the Top-of Atmosphere (TOA) reflectance values by removing atmospheric effects. I was done by plugin used on SNAP to generate level 2A.

3.2 Spatial registration (Resampling) & Spatial Subset

The 13 spectral bands in Sentinel-2 products have three different spatial resolutions (10 m, 20 m, 60 m). While the Sen2Coral toolbox supports products with bands of varied sizes, many other operators, such as Subset, do not. Therefore, we need to resample the bands to equal resolution first. We will use band two as a reference band from the source imagery for resampling the bands at 10 m resolution.

3.3 Land Mask

Another essential pre-processing step is the masking of the land, white caps (sea foam crest over the waves), clouds, and cloud shadows in all four bands (B2, B3, B4, B8). Therefore, we must create a land mask with 0 for land and 1 for sea. The NIR (Near Infrared) band will mask land from the image since the water appears dark and eases the discrimination of water from land, which looks much brighter. The mask can be created using a threshold value of the NIR band that separates land from sea or a polygon that describes the land.

Using the following expression in the "Band math" tool will allow you to mask the land pixels from water pixels.

Land mask math expression: " if B8 > 0.05 then NaN else 1"

To apply the land mask in each of the rest bands (B2, B3, B4, B8), we need to work with multiplying the land mask math expression with each interested band.

- ⇨ B2*Land mask math expression
- ⇨ B3*Land mask math expression
- ⇨ B4*Land mask math expression
- ⇨ B8*Land mask math expression

3.4 Sun-glint correction

A common phenomenon in satellite images that takes place because of the specular reflection of the sun on water surfaces is known as Sun glint. The water-leaving reflectance can be difficult to see due to the reflection of direct sunlight on the air-water interface (sun glint) in the direction of the satellite. The viewing geometry of the Sentinel-2 satellite for image acquisition makes it vulnerable to sun glint contamination. In the presence of sun glint, we must apply a glint removal algorithm to see the sea floor for bathymetry derivation. Several sun glint removal methods are available for high-resolution images and coastal applications. The Sen2Coral algorithm developed by (Hedley et al., 2005) and implemented in the Sen2Coral toolbox has been used in this research work for Sun-glint correction of sentinel-2 images.

Hedley described the following equation (eq. 2) for the deglinting of a multispectral image.

$$R'_i = R_i - b\,(R_{NIR} - MinNIR) \quad \text{(eq. 2)}$$

Where (R'_i) is the deglinted pixel in band i, (R_i) is the reflectance from visible band i, (b_i) is the regression slope, (R_{NIR}) is the NIR band value and the (Min_{NIR}) the minimum NIR value of the sample.

The following graph (Figure 4) illustrates the parameters of the Hedley method.

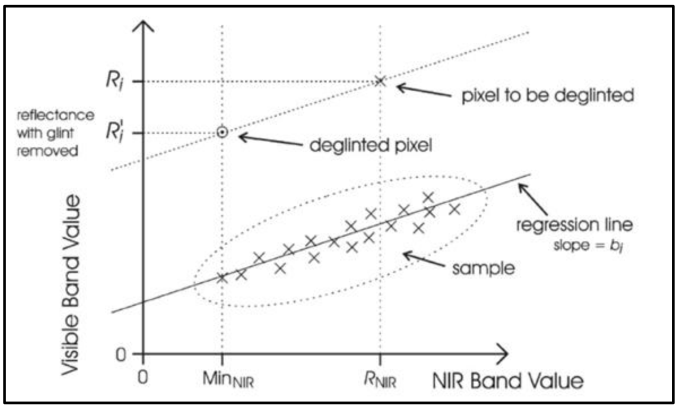


Figure 4: Graph illustrates the parameters of the Hedley method.

To deglint a visible wavelength band, a regression is performed between the NIR brightness and the brightness in the visible band using a sample set of pixels, which would be homogeneous if there is no sun glint (Hedley et al., 2005).   This could be achieved through ROI polygons drawn over areas of the image having sun glint in the imagery. These should be over deep-water areas where no bottom reflectance is expected, and all NIR reflectance is attributed to sun glint.

3.5 Dark-Object Atmospheric correction

Dark Object Subtraction (DOS) is an empirical atmospheric correction method that assumes that reflectance from dark objects includes a substantial part of atmospheric scattering. This atmospheric offset generated from the image can be removed by subtracting this value from every pixel in the band. However, this value is different for each band and can also be estimated as the value of the histogram's cut-off point at the lower end.

3.6 Empirical Bathymetry

Estimating bathymetry by empirical regression is commonly used for mapping shallow water areas. However, this method only applies if in-situ data are available for the interest area. These typically come from boat sonar systems and combined with cloudless and calm water images, can be used as an input to simple regression methods and calibration of the bathymetry retrieval algorithm. The Stumph algorithm is based on the principle that the water attenuation coefficients differ between wavelengths (bands), and we can figure out the ratio between the two bands, which will change with depth, and hence calculate the depth (z) using the following equation (eq. 3):

$$z = m_1 \frac{ln(nRw(\lambda i)}{Ln\left(nR_w(\lambda_j)\right)} - m_0 \quad \text{(eq. 3)}$$

Where, (m_1) is a tunable constant to scale the ratio to depth, (n) is a fixed constant for all areas, (R_w) is the reflectance of water for bands i or j, and (m_0) is the offset for a depth of 0 m (z=0). The fixed value of (n = 1000) is chosen to assure that the logarithm will be positive under any condition and that the ratio will produce a linear response with depth. Bands 2 (Blue) and 3 (Green) are commonly used for Sentinel-2 as these offer the best combination of penetration depth and spatial resolution.

3.7 Sen2Coral

Secondly, the steps done in the earlier section could be confirmed again using the Sen2coral algorithm on SNAP, which can speed up the derivation of bathymetry information from satellite images. Sen2Coral includes automatic processing for sun glint correction and Empirical Bathymetry Estimation. Also, the Sen2coral algorithm on

SNAP uses the ratio of blue and green channels. The algorithm implemented in the Sen2Coral toolbox follows the method developed by Stumpf.

Chapter 4: Result and Discussion

The process workflow to obtain the satellite bathymetry includes six steps, as discussed in the method. Mainly, as suggested by the Stumph method, we have used three bands in deriving the bathymetry (B2, B3, B8), which stands for, in sentinel, the Blue, Green, and Near Infrared, respectively. The Near-infrared (NIR) band is the best band to be used to distinguish between the water and land as the land has a high reflection in NIR (appears bright) while the water has an extremely low reflection in NIR (appears dark). Meanwhile, the blue and green bands are used in calculating depth as they offer the best combination of penetration depth and spatial resolution.

As the imageries collected are of level 1C, they must be atmospherically corrected to level 2A before going ahead. The Sen2Cor tool has been used for level 2A data product generation and performing terrain, atmospheric and cirrus corrections over TOA Level 1C input data. Then, the data is resampled to 10 m resolution and subset to the interested area from the imagery. The next step is land masking; applying the land mask in each band will create a masked image having only the aquatic elements. See Figure 5 and Figure 6.

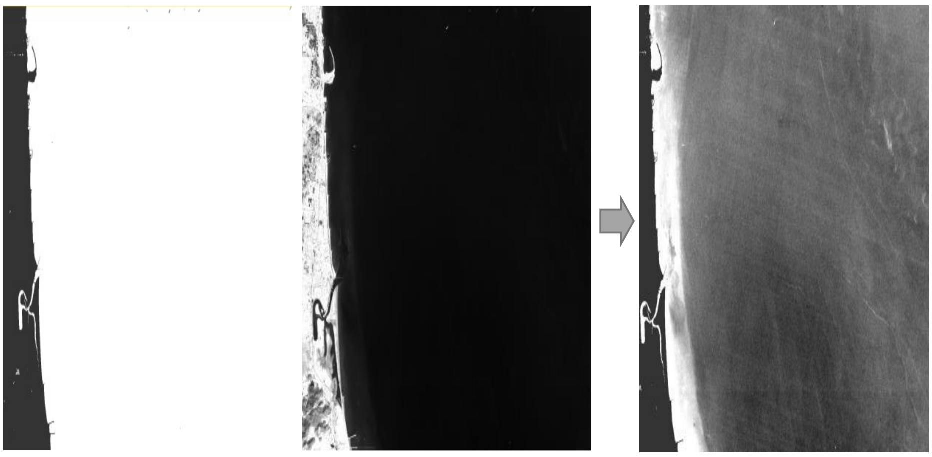


Figure 5: The land mask of Al Fujairah Port (Left), B2 image of Al Fujairah Port before applying the land mask (Middle), B2 image of Al Fujairah Port after applying the land mask (Right).

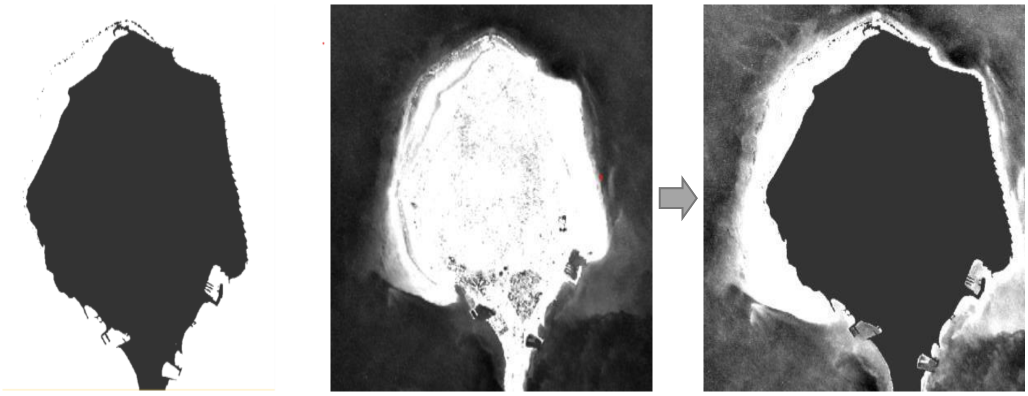


Figure 6: The land mask of Delma Island (Left), B2 image of Delma Island before applying the land mask (Middle), B2 image of Delma Island after applying the land mask (Right).

The scatterplot presented in Figure 7 shows that the values of (b_i) and (Min_{NIR}) are 1.2787 and 0.12, respectively.

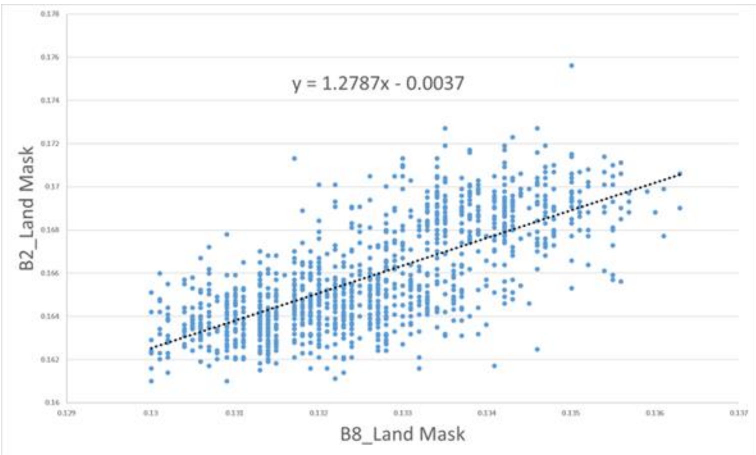


Figure 7: Scatter plot of pixels of the polygons in Al Fujairah port imagery.

The regression slope is then used for other pixels to predict the brightness in the visible band that would be expected if those pixels had an NIR value of (Min_{NIR}). The results of the B2 sun-deglint imagery are shown in Figure 8.

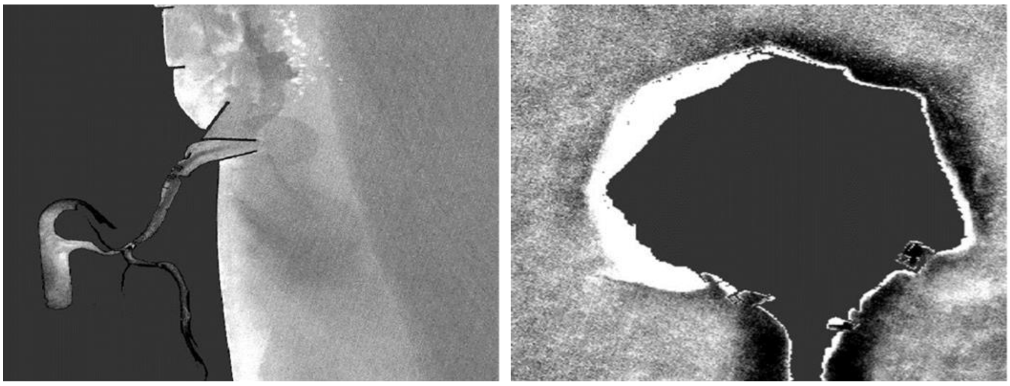


Figure 8: B2 Sun-deglint imagery of Al Fujairah Port (Left), and Delma Island (Right)

Figure 9 and Figure 10 show the histogram of the B2 deglint of Al Fujairah port and Delma Island imagery. The histogram of AL Fujairah port has been shifted for about 0.1445, while for Delma Island, the shifted value of the histogram is about 0.025. Therefore, these values will be subtracted from each pixel in B2. The same approach would be used to find the lowest value in the B3 histogram. The DOS method would be applied only for B2 and B3 as these are the only bands used in the next step (Empirical Bathymetry). Also, it is noticed that the histogram shifting is more in B2 than B3 as the sun's light is scattered down to the earth in the blue end of the spectrum.

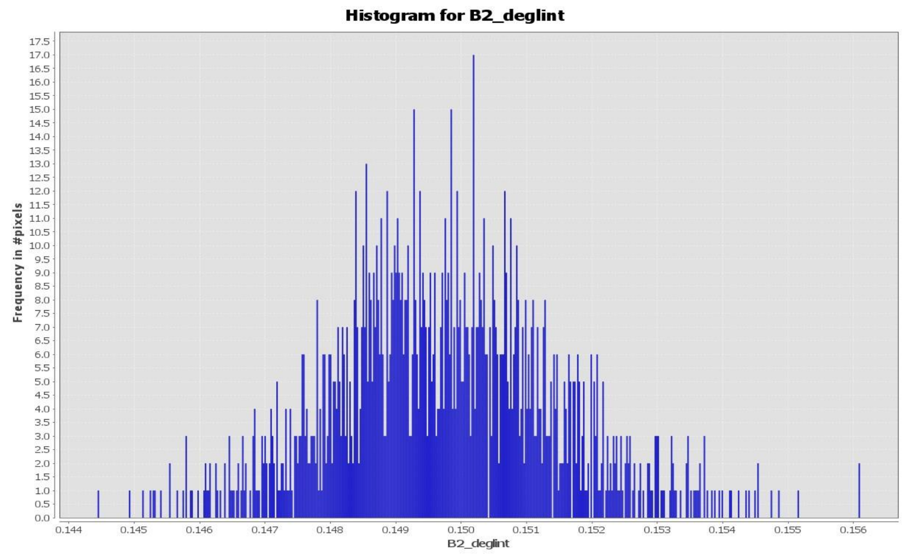


Figure 9: Histogram for B2_Deglint of Al Fujairah port imagery.

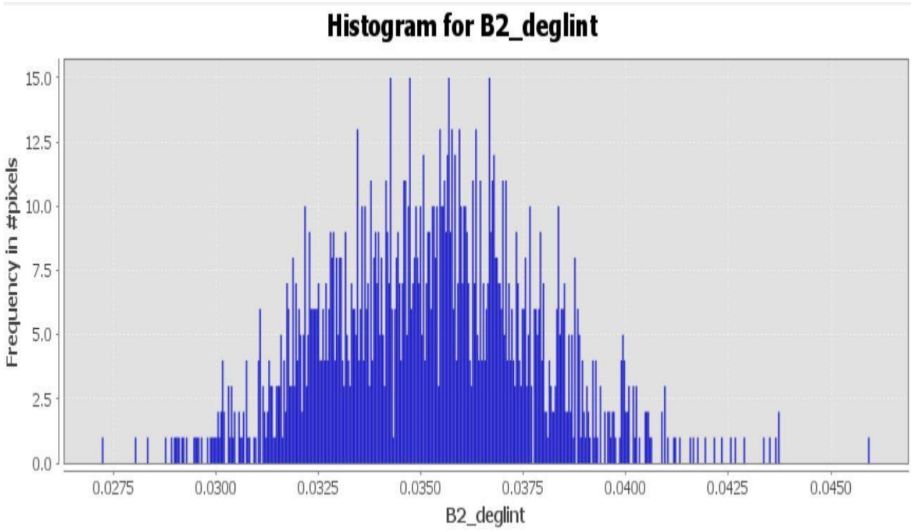
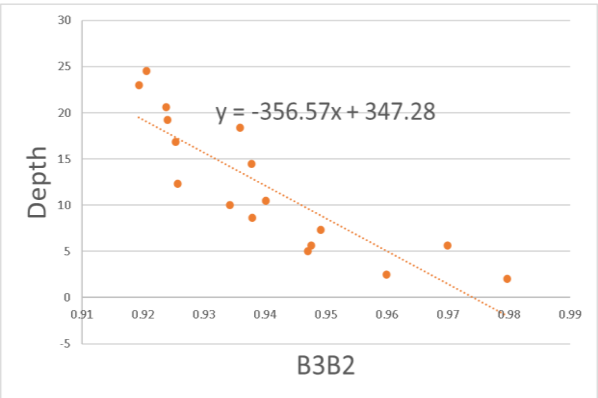


Figure 10: Histogram for B2_Deglint of Delma Island imagery the results of the B2 DOS process.

Finally, to derive the bathymetry map of Al Fujairah Port and Delma Island, we have calculated the values of $\boldsymbol{m_1}$ and $\boldsymbol{m_0}$ in both equations. As shown in Figure 11. From the Al Fujairah port regression equation, we have the value of $\boldsymbol{m_1}$ = -356.57 and $\boldsymbol{m_0}$ = +347.28. Similarly, for Delma Island, we have the value of $\boldsymbol{m_1}$ = -40.687 and $\boldsymbol{m_0}$ = +45.453. These values are used in equation 2 to calculate the depth z for both imageries' rest of the points.



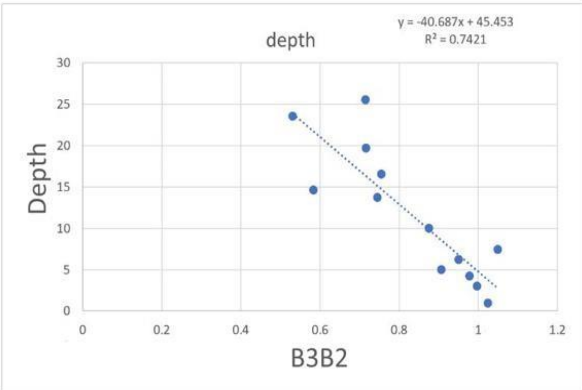


Figure 11: B3/B2 Regression graph for Al Fujairah port imagery (Left) and for Delma Island imagery (Right).

Eventually, the bathymetry maps for Al Fujairah Port and Delma Island were produced, as seen in Figure 12 and Figure 13, respectively. The depth values range from 0 m up to the maximum depth of 24 m.

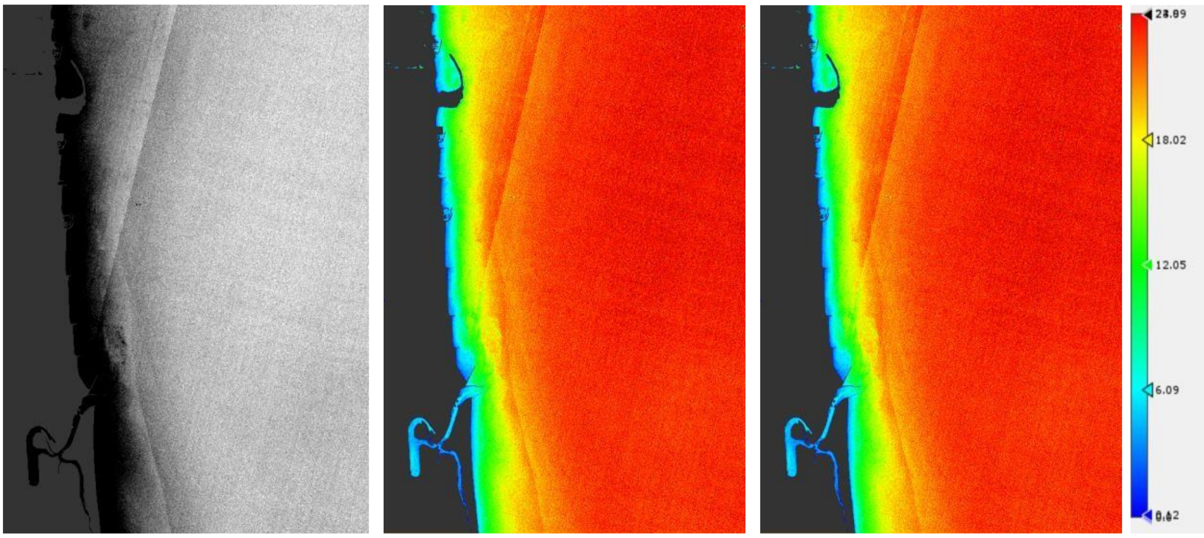


Figure 12: Bathymetry map of Al Fujairah Port before color manipulation (Left) and after the color manipulation (Middle). Sen2coral produced a bathymetry map of Al Fujairah Port (Right).

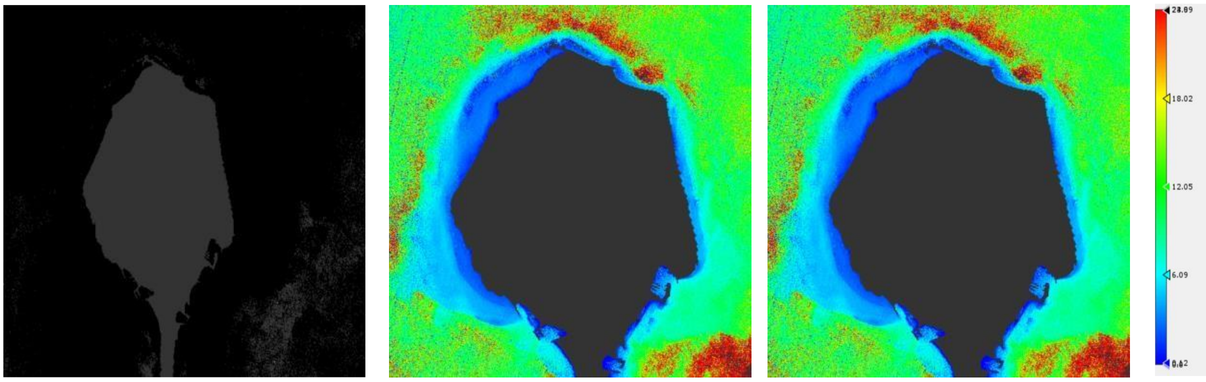


Figure 13: Bathymetry map of Delma Island before color manipulation (Left) and after the color manipulation (Middle). Sen2coral produced bathymetry maps of Delma Island (Right).

The clarity of the water, or water quality, can impact the bathymetry readings' accuracy since suspended particles and algae can skew satellite-based imaging. The accuracy of the bathymetry measurements can also be affected by the water's surface reflection of sunlight. Additionally, waves can make the water's surface rougher, which might skew bathymetry results. Accurate bathymetric measurements can also be hampered by shadows cast by submerged objects, such as oil platforms or ships. Because more minute structures in the water cannot be seen in the image, the satellite images' resolution can impact how accurate the bathymetry readings are. Coastal bathymetry measured by satellite can be costly and necessitates certain satellites and equipment. Despite these challenges, since satellite coastal bathymetry may be utilized in places where traditional bathymetry methods are impractical or impossible, it remains a valuable tool for researching and monitoring coastal environments. Figure 14 shows some other area in Unit Arab Emirates with lots of activities ships and natural effects to satellite images like mangroves and algae and some other particles under water.

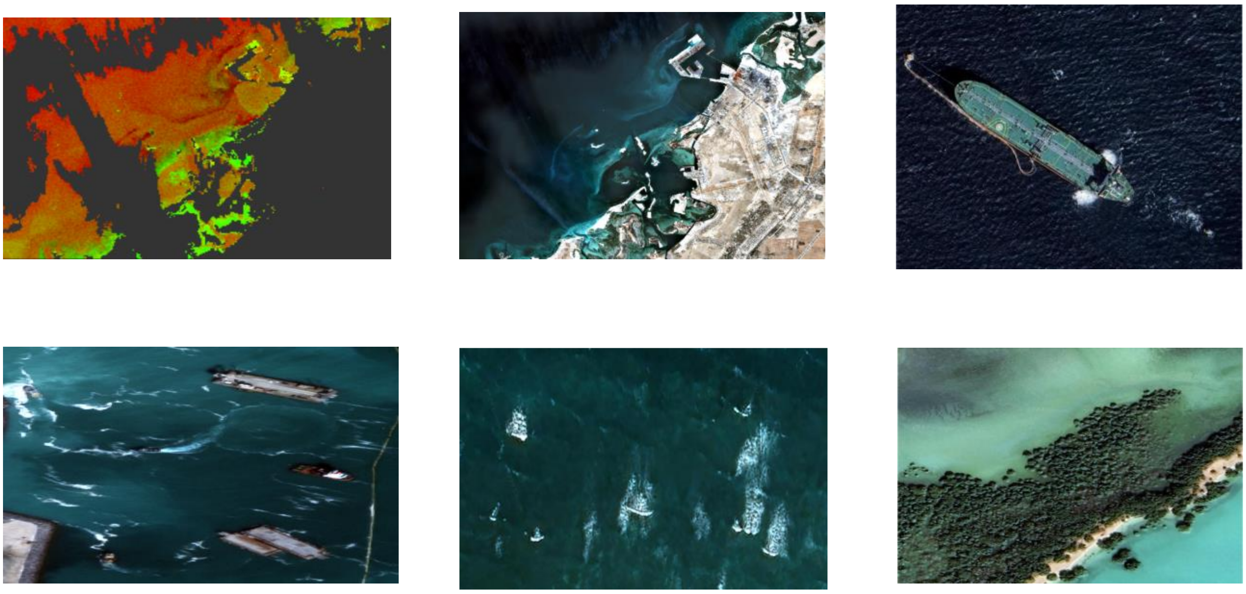


Figure 14: The clarity of the water, or water quality, can impact on the bathymetry readings' accuracy in other areas.

Chapter 5: Conclusions

Despite the enormous advances that have been made in mapping the floors of our oceans and seas, we still do not have any information about vast areas of the oceans. Empirical Bathymetry- image-based methods are low-cost and large spatial scales over which bathymetry information can be obtained based on readily available imagery that derives the bathymetry by regression using in-situ data using known depths, specifically, the linear ratio model by (Stumpf et al., 2003).

The 13 bands in Sentinel-2 products do not all have the exact resolution. Therefore, the input data bands must be resampled to equal resolution (10 m). Only bands with 10-meter spatial resolution were used. The visible Blue (band 2), Green (band 3), Red (band 4), and Near Infrared (NIR) band (band 8). These are the most common SDB applications with a strong linear correlation with depth. The mask can be created using a threshold value of the NIR band that separates land from sea or a polygon that describes the land. The NIR band is used for masking land and distinguishing water from land because the light at wavelengths above 700 nm has an extremely low transmittance in seawater.

Satellite coastal bathymetry uses satellite imagery to measure water depth in coastal areas, which faces several difficulties. Water quality is the clarity of the water, which can affect the accuracy of the bathymetry measurements, as suspended particles and algae can interfere with the satellite-based imagery. Sun glint reflection of the water surface can also affect the accuracy of the bathymetry measurements. Also, Waves can cause the water surface to become rougher, leading to inaccuracies in the bathymetry measurements. Shadows cast by objects in the water, such as ships or oil platforms, can also interfere with the accuracy of the bathymetric measurements. Resolution of the satellite imagery can limit the accuracy of the bathymetry measurements, as more minor features in the water may not be captured in the image. Satellite coastal bathymetry can be expensive, requiring specialized satellites and equipment. Despite these difficulties, satellite coastal bathymetry is still a helpful tool for studying and monitoring coastal areas, as it provides large-scale data and can be used in areas where traditional bathymetry methods are difficult or impossible.

The Empirical Bathymetry processor maps sea floor depth based on the regression of the log band ratio. Ancillary data are needed for known bathymetric observations. Sen2Coral plugin for SNAP toolbox is based on exploiting the Sentinel-2 mission for mapping (habitat, bathymetry, and water quality) and detection change for coral reef health assessment and monitoring. Sen2Coral includes automatic processing for sun glint correction and Empirical Bathymetry Estimation. The bathymetry map was derived using the empirical method. It was found that the manual method was better for learning the process of bathymetry derivation from the imagery data, and it gave precisely the same results. Also, the Sen2coral processor partially confirmed the results obtained in the empirical method.

In 2018, a group of research organizations, universities, and companies launched a project known as "Oceans 2030" (Seabed 2030, 2022). The goal of this collaborative project is to combine all available bathymetric data to produce the definitive bathymetric map of the world's ocean floor by 2030. It is a massive project that will require a lot of work. The seabed is constantly changing due to the movement of soil by water currents, earthquakes, and faults, which lead to the eruption of volcanoes. It is possible to map these changes but by doing in-situ observation back to the exact sites where those such events (e.g., earthquakes) occurred to see the changes on the water floor. Mapping all parts of the ocean might seem like massive work, but considerable technological changes have been made over the past few decades. This means getting accurate bathymetric maps within relatively less time (Lyzenga et al., 2006).

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This thesis uses 5 years of satellite imagery to explore UAE coastal areas. The research proposes a coastal bathymetric map for some areas of the UAE, utilizing optical satellite data and the linear band ratio algorithm. Sentinel 2 Level 1C imagery was processed in SNAP, involves atmospheric correction, resampling, land masking, sun de-glint, and dark object subtraction, applying Stumph method and the effect of human activities and agriculture near coastal on the satellite imagers.

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