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SATELLITE-DERIVED BATHYMETRY USING LANDSAT-8 IMAGERY FOR SAFAGA COASTAL ZONE, EGYPT

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Satellite-Derived Bathymetry (SDB) modeling is used to derive bathymetric data needed for enriching several applications including nautical charting. The nautical charts of Safaga port, Egypt, contains significant gaps as they are based on 50-years old hydrographic survey data and it needs an update. We applied the SDB algorithm (log-ratio approach) using multispectral Landsat-8 OLI images for extracting bathymetry to update the nautical charts of SAFAGA port. The results are verified against the old nautical chart of SAFAGA with a coefficient of determination (R^2) varies between 0.42 to 0.71 in areas where hydrographic data are old, unavailable or costly to obtain.

Keywords: Algorithm, Bathymetry, Landsat-8, nautical charting, Safaga port, satellite imagery.

1. Introduction

Coastal Zone consists of various biodiversity natural mechanisms that can accentuate the biological ecosystem products such as mangroves, coral reefs, seagrasses, sand dunes, and many species and genetic diversity fish. economic activities are mainly concentrated on the coastal areas to the detriment of the littoral ecosystems[1].These ecosystems are under pressure as a result of the high usage of modern trade, tourism, globalization, and different industries. It is a fundamental issue to protect the coastal ecosystems to help achieving sustainable development. Targeted intervention can reverse this demise using tools ranging from marine protected areas to reef restoration, but to be effective, it is necessary to understand the location of Earth's reefs and their status [2].This requires monitoring of the marine environment to develop marine awareness and "thereby encourage the sustainable growth of the marine economy in different industries, such as offshore oil and gas or coastal and maritime tourism, water quality, natural hazards and calculating rates of erosion, evaluating processes that shape coastal landscapes, and predicting how the coast will respond to future sea-level rise on repetitive monitoring" [3].

Near-shore bathymetry is one of the most relevant criteria for coastal cycle investigations and hydrodynamic models in coastal regions. As such,

a field of growing importance in coastal management and study is the potential to extract near-shore bathymetry utilizing remote sensing techniques. The extremely complicated existence of near-shore regions contributes to regular shifts in bathymetry that need to be tracked at intermittent intervals and thus using standard shipboard instrumentation and sampling techniques which is a time-consuming process that can be performed regularly and almost cumbersome.[4]. Bathymetry measured by an airborne lidar system is called airborne lidar bathymetry (ALB), and is appropriate for use in shallow waters[5].

However, the target area must be in a flight capable area, and the cost of ALB is still extremely high. Thus, insufficient bathymetric data have been collected for coastal areas which cannot be easily accessed by ship and airplane for these measurements.[6]

Remote sensing is considered an option for the measurement of near-shore bathymetry because a vast number of multi-constellations, multi-spectral and multi-spatial satellites are used as open data sources. However, only a few open databases with a global reach are suitable for this purpose.[6] Therefore, optical remote sensing-based near-shore bathymetry has been a cost-effective complement to Sound Navigation and Ranging (SONAR) and Light Detection and Range (LiDAR) surveys. However, many optical remote sensing methods have been suggested to supplement field-dependent approaches.[7].

During the 21st century, major advances of remote sensing technology have occurred. Through Space agencies Laboratories and research centers, also by different Domain researchers. Following improvements in the spatial resolution of optical sensors, SDB has been the focus of hydrographic associations worldwide [8]. So, We aim to utilize these innovations to advance knowledge of coastal environments and their threats.

Remote sensing satellite launches such as GeoEye-1, Spot (5, 6, 7), GF-8 and all GF-5&6, OceanSat-3, Scatsat-1, Pleiades, RapidEye Worldview-2 and Worldview-3 provide high-spatial and spectral-resolution imagery, but all such data need to be commercially procured. Since collecting publicly accessible imagery is proving costly for most developed countries. Usage of the free and accessible images to the public such as Landsat 8 and Sentinel-2 imagery data were used in the present research to chart the ocean bathymetry.

Satellite-Derived Bathymetry (SDB) models were intended to capture coastal sea bottom reflection from satellite imagery and use this knowledge efficiently to produce coastal bathymetry. Over the past 30 years 9 Corporate political activity: The good, the bad, and the ....(https://www.sciencedirect.com/science/article/abs/pii/S0007681312000092), researchers have examined SDB algorithms and developed estimation methods which fall into classifications such as spectral rationing and models of radiative transfer.

Single spectral band and multispectral band models were suggested in case of radiative transfer. The single band algorithms supposed a constant coefficient of attenuation and homogeneous form of the bottom.

Reliable SDBs are effective where the water is lucid and water content and forms at the bottom are homogeneous. Single-band water depth models may provide a fair approximation of depth when certain specifications are reached. However, coastal water ecosystems hardly provide these ideal conditions. Therefore, radiative transfer models utilizing linear multispectral band regression have provided strong results.[7]

Therefore, this research aims to apply and check the radiative transfer models using linear regression of multispectral bands to collect bathymetric data from deeper waters and delineate remarkable benthic features such as reef formations and shoal batches of the coastal region of Safaga, Egypt. Safaga area is located at (26°44' 24.25" N and 33°58' 8.88" E). The ratio transform algorithm was applied on Landsat 8 (OLI) satellite images supported with a spectral range of sunlight that penetrates seawater to appreciable depths between (350 nm to700 nm) [9]. In addition, the method of linear regression with statistical tests such as R2 is used with other methods for validating the satellite generated values in deeper waters with depth contours and limited spaced surveyed areas of the coastal region of Safaga. The findings indicated a good enough deal of agreement between them.

So, the study objectives are to assess and examine the overall adequacy of Landsat-8 OLI satellite data for the derivation of coastal bathymetry in the port environment of Safaga, using a blue / green ratio and statistical practice using reference points.

2. STUDY AREA

The study area is Safaga port which is located in the Red Sea Governorate on the western coast of the Red Sea (26° 44’ N, 33° 56’ E). It is a broad bay (natural gulf) on a distance of 60 km south of Hurghada city and on a distance of 225 km south of Suez port. The bay is naturally protected from the east and the north sides by Safaga Island, and protected from the prevailing western winds by mountains (http://www.emco-shipping.com/Safaga.aspx) (Fig. 1). Yet, for a short period, it is affected by south winds (El-Azeeb) which cause disturbances and waves inside the port. The port has Capacity Specifications with drafts are deep and safe draft through the entrance is 15.29 m or less, thus enabling the accommodation of large vessels (Table1).

(http://mts.gov.eg/en/content/203-Description-And-Specifications)

This study area was selected according to the IHO publication C-55 and UKHO charts that identified the nautical charts of Safaga. The charts of Safaga port contain significant gaps as they are based on old inaccurate hydrographic survey data (about 50 years old) and nautical charts were not updated. Therefore, the charts were used to investigate the potential applications for satellite-derived bathymetry in an attempt to fill the gaps and recheck the existing soundings and bathymetry in the nautical charts of Safaga port and surroundings.

Table 1: Port Specifications (http://mts.gov.eg/en/content/203-Description-And-Specifications)

Total port Area	57 km^2(56,968,000 m^2)
Water Area	56.5km^2(56,490,000 m^2)
Land Area	0.5km^2(478,000m^2)
Total Warehouses Area	15,000m^2
Maximum Capacity	6.37 million tons/year
Maximum Ship Depth	14m

Fig. 1: ARCMAP Satellite imagery base layer of Safaga port coastal area.

3. Data sets Collection

3.1. Satellite imagery:

The coastal area of Safaga is characterized by a low wave energy environment with a tidal range of about 0.1 m to 0.8 m [10]. So, the satellite imagery selected for this research was acquired by the constellation of Landsat satellites.

Landsat 8 was selected because of being one of the most available, freely-used optical satellite images with respect to its spatial resolution (30 m) and different spectral resolutions. In addition, the satellite images were taken in a cloud-free Atmosphere (3% cloud cover) and the images were also chosen to be recent (Dec-2019).

In this study NIRGB (Near-infrared, Green and Blue) bands are used because of the radiance of blue band, and green bands (0.450 to 0.515 µm, 0.525 to 0.600 µm and 0.845 to 0.885 µm respectively) decreases more rapidly with depth and wavelengths above 700 nm has a very low transmittance in sea water

(https://core.ac.uk/download/pdf/82292507.pdf)

Therefore, water appears dark relative to the land that appears bright As the fact that NIR (near-infrared wavelengths) do not penetrate into water (especially into Deepwater) as shown in Fig2 (b). For this reason, the infrared band (845 – 885 nm) is used for distinguishing water from land (https://core.ac.uk/download/pdf/82292507.pdf). In Fig. 2 ((a) True color and (b) NIR) shows the blue, green and infrared bands of Landsat 8 satellite imagery[11].

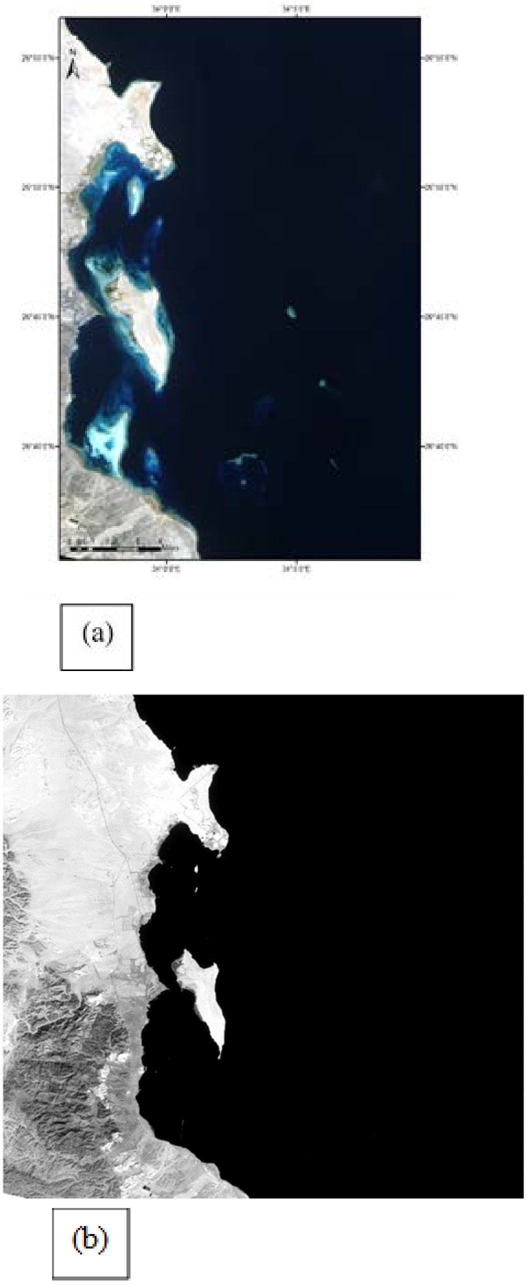

Fig 2: (a) THE study area of Safaga coastal true color and (b) EFFECTS of NIR wavelength for distinguishing Water from land respectively.

3.2. Bathymetric Data:

The reference soundings of Water Depth (WD) data used in this paper were collected during 2016 after coordination with Safaga Port Authority as a surveying program. Most Data used for this research was obtained by using single beam echo sounders applying depth tidal corrections supported with Differential GPS and primary for initial bottom coverage along sounding profiles. Depths were reduced to LAT (Lowest Astronomical Tide) and deemed ideal for charts of hydrography. With a vertical accuracy of less than 20 cm RMS (Root Mean Square) and a horizontal positioning accuracy of less than 1 m, the full system was able to calculate water depths between 0 and 30 m. In our research models these data are used as the answering variable (Calibration data for SDB Extraction).

Listed soundings have been used to compare satellite-derived bathymetry to the chart datum. Such soundings are used as control points (ground truth).

The gain and offset that is added to the ratio transform for the algorithm results was determined. The instantaneous water level is unlikely to correlate with the satellite image capture time (Lowest Astronomical Tide [LAT]). There is no need to determine tidal height during image processing as this is automatically compensated when using control points chosen from a nautical chart to establish the process parameters. Differences in water levels over limited spatial scale are typically well approximated as a vertical offset and do not conflict with the linear correlation between chart soundings and the algorithm ratios.

The adopted technique thus removes both the need tide-coordinated imaging and for tide correction.[12]

1. Methodology:

Previous approaches were emphasized on applying a correction for atmospheric effects and sea surface reflections to eliminate the spectral contributions from the water column in order to retrieve accurate depth information. The approaches developed for satellite-derived bathymetry fall into two categories: spectral rationing and radiative transfer models. Also, there are two subcategories of radiative transfer (single band and multiband) models that had been developed. And each has its conditions for usage. Single-band algorithms assume a homogeneous seabed and constant attenuation physical characteristics of the study area water. But, for acceptable depth results, those algorithms need clear water and some specific water column specifications.

On the other hand, these conditions are difficult to be available in real Ecosystems. So, Radiative transfer models using linear regression of multispectral bands have yielded good results.[7], [12]

By comparison with other scientific and statistical methods (ex. Look-up tables based on large database on many RTModels) [13], empirical methods utilizes fewer parameters and therefore, they are simpler and easier for mapping the bathymetry. We used a ratio transform algorithm that could retrieve the depth of deeper than 25 m in a clear water in the present work. Also, the algorithm can predict the depth to a certain extend in the turbid water environment which depends on the suspended sediment intensity and rate of deposition, which varies according to location. The adopted procedure is using ArcGIS 10.5 Geographic Information System (GIS) software. Hydrographers could use the procedure and marine surveyors to produce mapping the bathymetry effectively [11].

2. SATELLITE DERIVED BATHYMETRY PROCEDURE

2.1. Preprocessing

Download Satellite imagery based on the geographic location (study area) and environmental conditions (e.g., cloud coverage and sun glint).

Satellite imagery in the U.S. Geological Survey (USGS) data archives includes imagery from current and previous Landsat missions through USGS Website. In the current Landsat 8 mission, an Operational Land Imager (OLI) has been operational since mid-2013. The swath width of the Landsat imagery is 185 km, with spatial resolution 30 m. The number of bands and their spectral range differs between Landsat missions, but this study focus on Landsat 8 (OLI/TIRS) imagery with 11 spectral bands.[14]

Selected satellite bands were loaded into ArcGIS 10.5 for reassembling spectral bands data and focus on study area which is SAFAGA port concerning Band (4) with scale 1:22000 as shown in Fig. 3

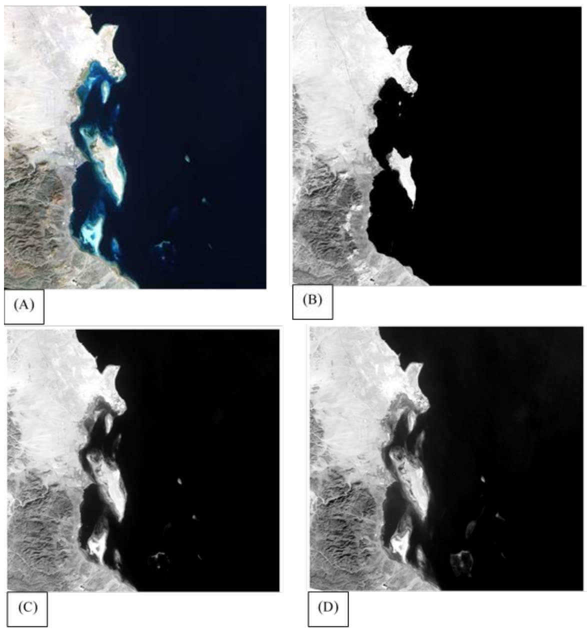

Fig 3: (A) MULTI true color of Landsat image of Safaga; and (B) Infrared Landsat image (band 6) of SAFAGA, Egypt; (C) Green band of Landsat image (band 3) of SAFAGA ; and (D) Blue Band of Landsat image (band 2) of SAFAGA.

Although a radiometric correction of the imagery is one of the most essential preprocesses for clearing satellite images from radiometric errors (e.g. speckle noise), this step will not be applied here. The reason is that the quality control on the imagers produced from the current operational satellite is good enough to provide a bathymetric product and does not require this step anymore.[14]

2.2. Land/Water Separation

The average threshold value for land/water separation was calculated using the Near-infrared band (B6) in Arcmap 10.5, and the results are given through the profile graph of both land and water areas of pixel values as shown in Fig .4

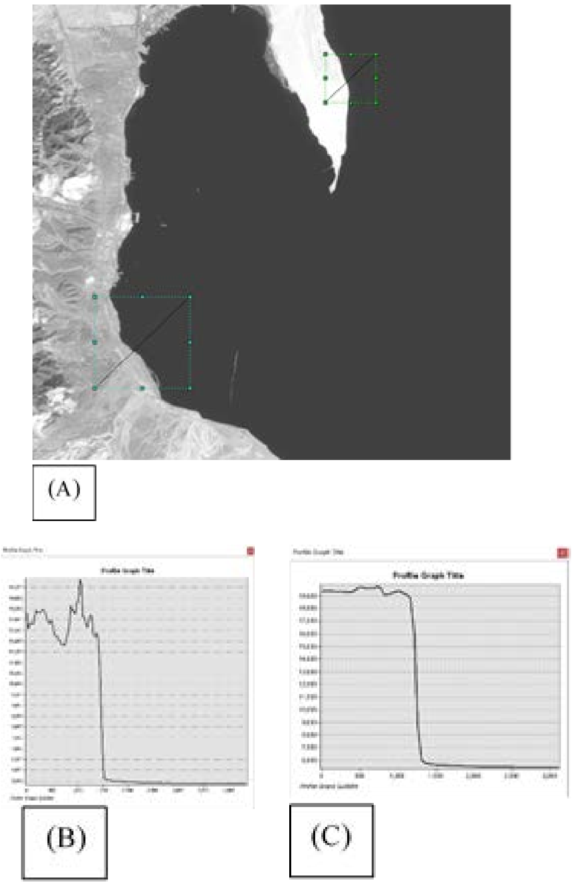

Fig 4: (A) INTERPOLATE lines created for Neari-nfrared band (B6); (B) and (C) Profile graphs for getting the average threshold value of SAFAGA satellite image for processing Water/ land separation.

2.3. Spatial filtering

Float, filter processes for each (B6, B2 and B3) was applied for increasing precision of each pixel value and enhancing the reliable transfer of every feature geometric from every pixel to another and remove the speckle noise. Then, finally applying separation tool depending on the threshold value of Band 6 as shown in Fig .5

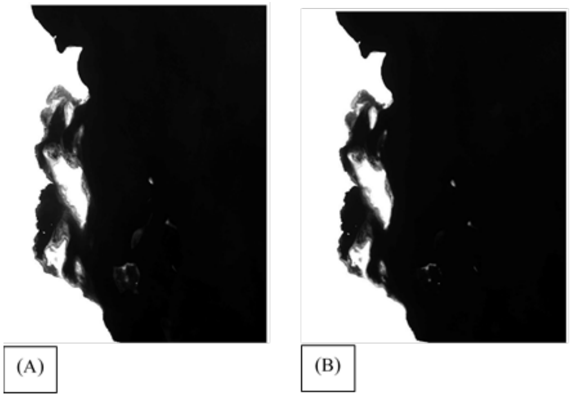

Fig 5: (A) and (B) APPLYING water body extraction for both Band (2) and Band (3) respectively using threshold values extracted previously for SAFAGA satellite image using Arcmap 10.5.

2.4. Applying the Bathymetry Algorithm

According to earlier studies, using the Band Ratio Method for depth estimation does not necessitate applying the atmospheric correction. Water appears dark with its physical property of light absorption compared to dry land, which is clear by Low digital values in band 6 (NIR band) of Landsat 8 imagery. Also, clouds were removed by NIR band.

Using NIR histogram and profiles on different sampled coastal areas in the study area, we could find a threshold value manually for separating water from both land and cloud cover.

By the way, using reference soundings contribute to Extracting bathymetry vertically corrected to the chart datum at the acquisition time of the Landsat imagery.

Applying the SDB algorithm (log-ratio approach) as shown in (Fig .6) by using both outputs of extraction waterbody layers of λi (blue band) and λj (green band) which is typically best in coastal areas, based on the ratio will maintain the diffuse attenuation coefficients of different wavelengths which are digital number needing calibration as shown in (Equation 1) where Lobs (observed radiance), m1(gain), m2 (offset) [15].

$$z = m1\left(\frac{\ln(Lobs(\lambda i))}{\ln(Lobs(\lambda j))}\right) - m0, \qquad (1)$$

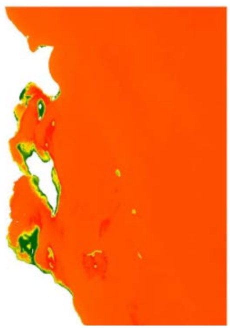

Fig 6: BATHYMETRIC algorithm output layer after applying on both floated and filtered Band2 and Band3 using spatial statistics tools of Arcmap 10.5.

6. Results and discussion

6.1. Validation

Recommendations from previous studies and according to this research; both the survey period and the survey technology have its significance for selecting reference soundings. Also, a visual correlation and Linear regression has been applied between the extracted bathymetry and the soundings of calibration.

Several procedure configurations were Performed, and from the cartographical technical point of view that those sampled soundings are not enough for mapping the whole desired area by traditional field surveys but here are sufficient to the empirical or theoretical and statistical bathymetric calculations [16].

These soundings collected using single beam echo sounders and corrected to chart datum (Lowest Astronomical Tide) will be overlaid on the satellite image using Arcmap 10.5. Depth points in the soundings and the corresponding pixel values from the satellite image are obtained by using spatial analysis extraction tools in Arcmap 10.5. as shown in Fig .7
The coincidence pixel value of the satellite derived bathymetry image is obtained with the referenced soundings point value, and so there is no need to measure the tidal height during the image acquisition. Into Excel spreadsheets, for each depth value of soundings, corresponding pixel value from Satellite derived bathymetry (SDB) image is obtained and averaged and the same process is continued for obtaining the remaining depth values. In order to validate the model, the statistical index or the coefficient of the determination (R^2) is computed between the algorithm derived value and the soundings showed R^2 of 0.5738 between the Satellite Derived Bathymetry Value (SDBV) versus Bathymetric Soundings Value (BSV) as shown in Fig .8[11]

Using Band ratio approach and deriving the extinction depth was the most important priority for determining the algorithm limitation of acceptable derived bathymetric value. Thus, values shallower than the extinction depth value showed an agreement with the reference bathymetric data according to statistical analysis by using linear regression. In the contrary, values deeper than the extinction depth value did not show any correlation with the reference bathymetric data**.**

Assessing the procedure reliability and practicality, contours derived by the algorithm with other small areas reference data sets were compared with the source satellite image as shown in Fig 8.

The derived bathymetric data extracted varies between depth values 5 m for many areas and less than 20 m but we cannot confirm any results deeper than 20 m because of light attenuation and diffusion also turbidity that may be caused by currents and waves. This may occur especially close to different rocky islands, sandy shoal patches formed by potential sedimentation and suspended organic materials above seabed (algae, and disposed coral reefs) in front of harbor entrance which cause false indication of bathymetry.

The high cost of hydrographic surveying operations, especially that depend on acoustics and the inability to enter intertidal areas, shoal patches and very shallow water areas, present difficulty and require many calibration data cover the area of interest. So, satellite-derived bathymetry is a practical method for providing reasonable depth values for areas like ports that need periodic Dredging operations or significant areas Filling with gaps or areas with old surveying operations that aren't easily to be surveyed from both the financial and safety point of view.

By Applying band ratio method and statistical linear regression method after Atmospheric and radiometric Noises removal we got some residuals readings which may be relates to benthic type characteristics, relation between Satellite derived bathymetry and Seabed type need more research.

It is worth mentioning that when getting bathymetry from shallow water, it is important to perceive the environmental conditions (e.g., water clarity, cloud cover, and sun glint) that may diminish the depth accuracy. From a reasonable perspective, the procedure for exploring coastal areas is successful. The satellite imagery and nautical chart are the two essential informational parameters utilized all through the adopted methodology. Tidal corrections or tide-coordinated images are not required as reference soundings are utilized to change the algorithm execution to realistic depths and compare them with the outline information simultaneously on chart. The fundamental constraining element influencing the performance of satellite-derived bathymetry is the environment. Water clarity is a key factor that decides the penetration of light in water. The depth of the sea-area floor must be evaluated to the penetration extent. Specifically, this procedure has restricted application in turbid waters compared with clear waters. Other environmental variables include the presence of cloud cover in satellite images, atmospheric transmittance, sun glint, and substrate type. Cloud cover is frequently predominant in tropical zones, and exertion should be made to choose just imagery with under 10% cloud cover without sun glint. Another test is the choice of dependable reference soundings that might be faulty because of the age of the hydrographic surveying or the obsolete procedure and hardware used to lead the surveying. In such circumstances, it is suggested that the reference soundings are chosen from those zones where the seafloor morphology appeared on the outline and that derived from algorithm results are comparative.

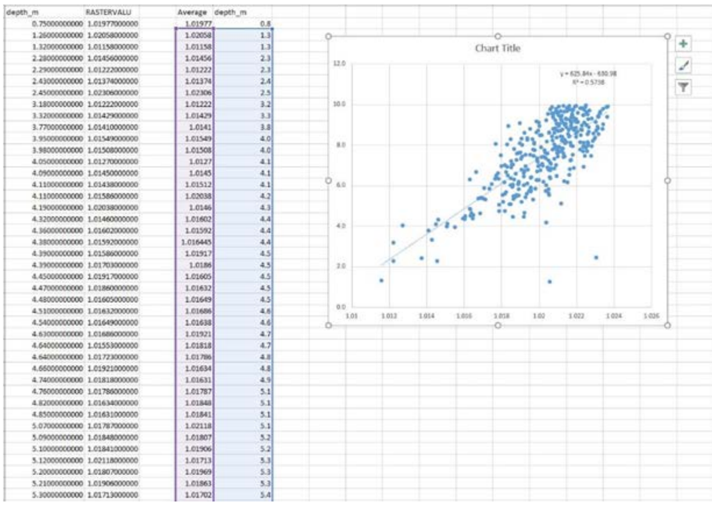

Fig 7: BATHYMETRIC data (soundings) layer overlaid on satellite image with applying spatial analysis extraction tools in Arcmap 10.5 on both for calibration.

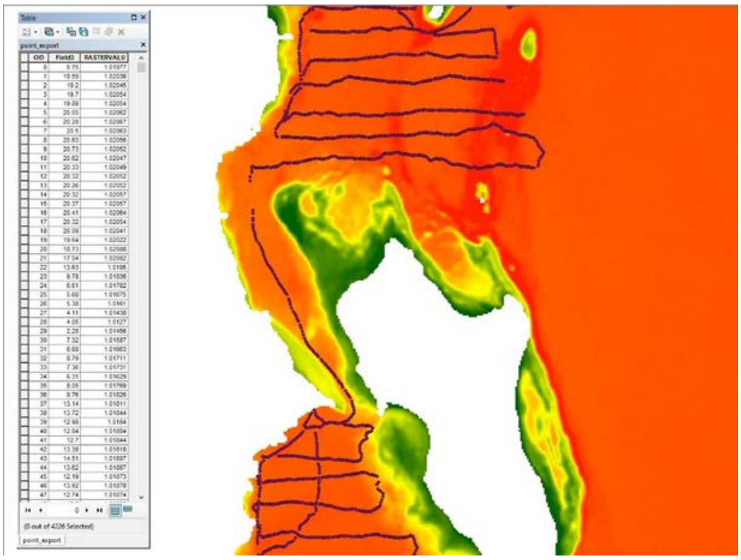

Fig 8: TABLE and graph of corresponding pixel value with bathymetric data (soundings) showing extinction depth and both R2 value and the equation of both gain and offset as parameters of regression analysis.

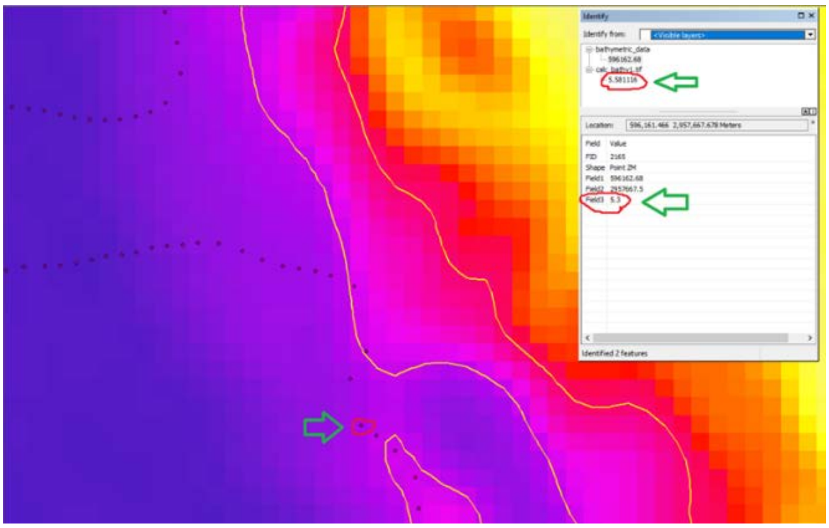

Fig 9: COMPARING contours derived by the Algorithm with other small areas reference data sets and also with the Source satellite image.

7. Conclusion and Recommendations

This investigation showed that utilizing the satellite-derived bathymetry modeling using the log-ratio algorithm is promising, provided that the model is validated using accurate recent ground truth data. The present study results indicated that the determination (R^2) between the algorithm derived value and the soundings is R^2 of 0.5738 with standard error of estimate in the range which indicates a suitable initial assessment of bathymetry on same-existing nautical chart coverage based on Landsat-8 OLI images. It is worth mentioning that Thesis and the running project will continue looking for higher accuracy using other recent Sentinel satellite missions that might provide better accuracy.

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