BATHYMETRY ESTIMATION USING LANDSAT-8 OLI, CASE STUDY SAHL HASHESH, HURGHADA, RED SEA, EGYPT

M.HASSANI.MOHAMED

Civil Engineering, Suez Canal Economic Zone (SCzone)

Keywords: Landsat 8, Red sea, Linear, Ratio band algorithms, SDB, Sahl Hashesh, Hurghada.

ABSTRACT Bathymetry is an essential requirement for coastal zone safety, monitoring, and modeling. The conventional techniques for bathymetry retrieval are based on either sounding or LIDAR (Light Detection and Ranging). However, echo-sounders are cost-effective in measuring water depths with high vertical accuracy, they require extensive labor and have some limitations in accessibility for shallow regions and complex topography. Regarding LIDAR, it is costly for bathymetry updates and restricted to be used in some countries. Alternatively, the satellite-derived bathymetry (SDB) is an effective approach that estimates bathymetric information for large areas at low cost and covering wide areas. The SDB can be attained theoretically using water column, bed characteristics, and atmospheric properties or empirically using mathematical relationships between the measured water depths and image pixel reflectance values. The linear band and the ratio transform are the widely used empirical models for SDB, machine learning techniques are recent approaches for bathymetry estimating. The Landsat 8 OLI images are commonly used for the SDB due to the free access and reasonable spatial/temporal resolution for bathymetry mapping. The current study aims to assess the performance of Landsat 8 OLI derived bathymetry using the empirical methods including the linear band method and the ratio transform method. The two different methods have been applied along the Red Sea coast in Sahl Hashesh , Hurghada, the results were analyzed by two coefficients R^2 and root mean square error (RMSE), and it is found that the ratio transform method has RMSE equal 0.66 and 0.69 m for the linear method. Thus, the study presented that free Landsat 8- OLI images are effective with reliable and high accuracy for bathymetry estimating.

INTRODUCTION

Coastal zones play an essential and pivotal role in world economics and trade, Therefore coastal zones management and monitoring is very important, Egypt has important coastal zones along the Mediterranean Sea, the Red Sea, and Suez Canal which connects the western world with the eastern world. Consequently monitoring, management, planning, construction, and navigation of the coastal zones need a continuous measurement and a good knowledge of sea bathymetry and topography, Bathymetry and topography is the fundamental data in coastal hydrodynamic monitoring and the basic data in numerical modeling of circulation, sedimentation change of beach morphology detect of swash zone hydrodynamics which plays a significant role in design and maintenance of shore protection structures as it causes beach change morphology (Ruggiero et al 2001 Sallenger 2000), For marine resource assessment activities, coastal engineering sciences sustainable management and spatial planning of lakes which have changeable sediment movements due to tidal currents wave propagation and intensive human activities (Ceyhun and Yalcin 2010), bathymetry data is significant in dredging and navigation.

Modern techniques for estimating bathymetry from acoustics to the use of both the visible and radio wave portions of the electromagnetic spectrum. Measurements are through the water medium in the case of acoustics, through the water and air for visible light measurements, and through the air medium alone for radar altimetry remote sensing to obtain an estimate of the seafloor depth. Acoustics applies for determining centimeter- to kilometer-scale features and is the prevailing method used to validate optical and radar bathymetry. The penetration limits of visible light in a water medium is the reason for using active and passive light only applicable in shallow water. Techniques are like Single Beam Echo Sounders (SBES) and Multi-Beam Echo Sounders (MBES) with high-resolution measurements. But these techniques have disadvantages such as the time consuming, cost, and decreasing of swath width in shallow water. Acoustic techniques are not ideal for monitoring bathymetric changes and shoreline configuration changes caused by tidal currents, storm surge, and sea-level change. The most effective means to map shallow-water bathymetry is active sensors pulsed and sense stream of light (e.g., light detection and ranging, or LIDAR) but is highly costly and time-consuming.

The alternative effective technique is remote sensing, the use of remote sensing imagery in coastal and shallow water bathymetric mapping is considerably cost-effective (Mumby et al., 1999), and a vital to reach difficultly accessible regions. Remote sensing technique is depending on the fact that light exponentially attenuates with water depths.

Many trials have been presented to extract water depths from remote sensing and satellite imagery by having a relationship between water reflectance and measured bathymetry.

The most traditional algorithms for satellite-derived bathymetry are the linear band model(Lyzenga 1981,1985) which is exponential (log-linear relationship) between water reflectance and water depth assumption that water optical properties and bottom reflectance are uniforms and the log-transformed band ratio model by Stumpf (2003) depending on the fact that the depth increases, as the reflectance of bands decreases and the natural logarithm of the green band (the band with higher absorption) will decease proportionately faster than the natural logarithm of the blue band (the band with lower absorption).

The two algorithms are applied in Sahl Hashesh , Hurghada along the Red Sea coast using Landsat 8 -OLI imagery. Landsat 8-OLI satellite is a free source for images with a spatial resolution of 30 m and has 9 bands of light wavelengths. Table (1) describes the Landsat 8-OLI characteristics.

The current study presented a rapid, reliable, and non-expensive technique for deriving water depths with free accesses satellite images.

Table 1. Landsat 8 OLI bands characteristics

Bands description		Spatial resolution (m)	Wavelength (µm)
Band 1	Coastal /Aerosol	30	(0.43 – 0.45)
Band 2	Blue	30	(0.450 -0.51)
Band 3	Green	30	(0.53 – 0.59)
Band 4	Red	30	(0.64 – 0.67)
Band 5	Near-Infrared	30	(0.85 – 0.88)
Band 6	SWIR 1 Short-wavelength infrared	30	(1.57 – 1.65)
Band 7	SWIR 2 Short-wavelength infrared	30	(2.11 – 2.29)
Band 8	Panchromatic	15	(0.50 – 0.68)
Band 9	Cirrus	30	(1.36 – 1.38)

STUDY AREA

The study area at Red sea coast, Sahl Hashesh, Hurghada, Egypt is located in (27.0370° N, 33.8523° E), it has an area of 2.6 Km² as shown in figure (1) below, the study area has rough topography except below the shelves (Jokela (1963)). The coastlines of the Red Sea are remarkably straight and parallel with sand seafloor and Corel reefs, Water circulation in the Red Sea is driven by monsoonal wind patterns. Monsoon winds occur because of the different heating between the land surface and sea in the Indian Ocean and Asia, a northwesterly monsoon is controlled by the eastern Mediterranean weather systems. The water is mostly clear.

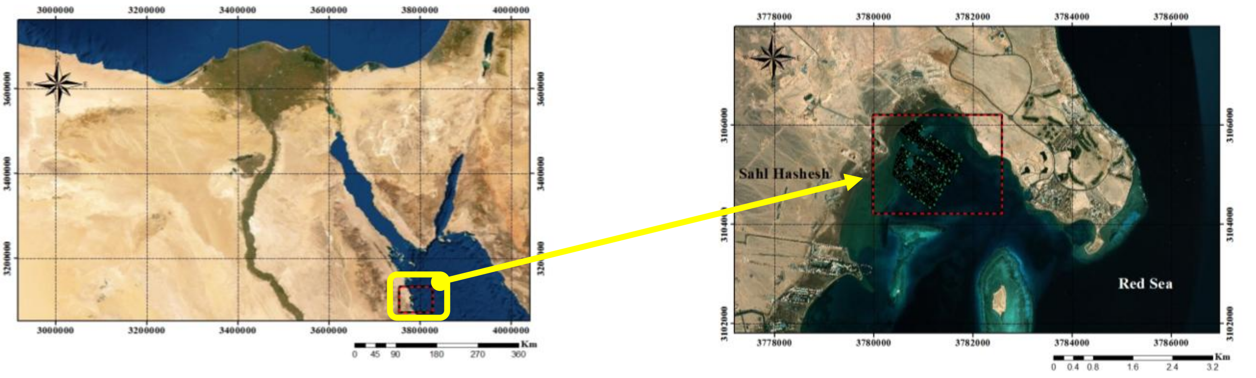

Figure 1: Sahl Hashesh study area

IN SITU DATA

It is necessary to have surveyed data by a Nautical chart or by in situ data measurement. Surveyed bathymetry was occurred during April 2017 by Single Beam Echo Sounder (SBES) with a range of depth from 0.59 m to 8.5 m which consist of 7235 points of field measurement, Figure (2) showed the path of field survey.

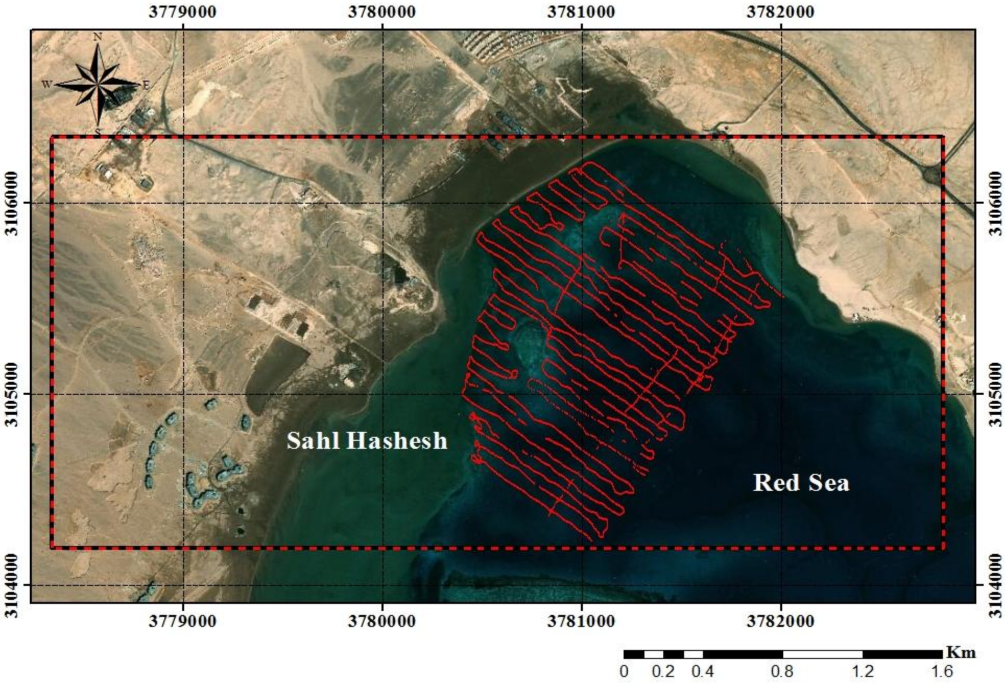

Figure 1 : Field measurement path in Sahl Hashesh study area.

SATELLITE IMAGES DATA

The satellite imagery downloaded from the US geological survey (USGS), since 1972 the beginning of the first mission Landsat 1 followed by the next missions from Landsat 2 to Landsat 8. Landsat 8 began the mission in 2013 until now, The Landsat 9 satellite will be launched at March 2021.Landsat 8- OLI will be used in this study with an acquired date on 26 April 2017 due to the approximate date of measured depths, with cloud cover 5.74 %.

METHODOLOGY

Firstly, the image georeferenced by ground control points with a projection of UTM zone 36, then satellite image radiometric calibration of Landsat image, then atmospheric corrections applied on satellite images to remove atmospheric artifacts as aerosols, *suspended* sediment particles of dust, water vapor, and water droplets using efficient and reliable methods. One of the atmospheric corrections methods applied is Fast Line-of-sight Atmospheric Analysis of Hypercubes (FLAASH) is a Physical method which uses the MODTRAN radiation transfer code with different Aerosol models Maritime model here which is included in ENVI software. Figure (3) represents the flow chart of the study which consists of two parts the first part is image preprocessing which is divided into three phases (geometric correction, radiometric calibration, and atmospheric correction).

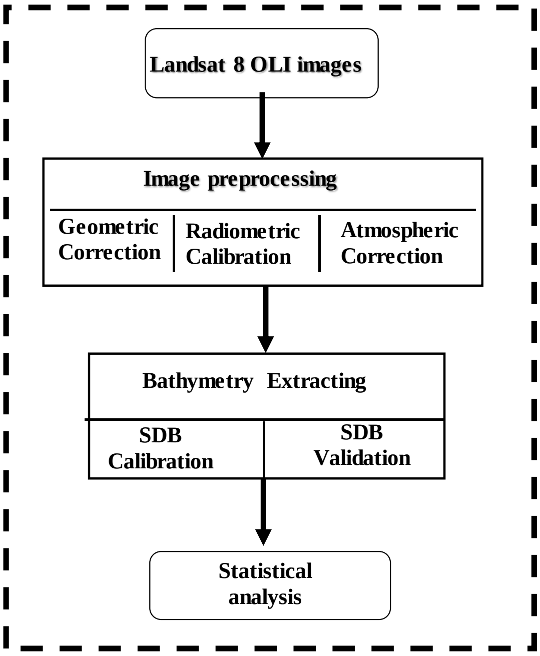

Figure 3: Flowchart of Bathymetry extraction

BATHYMETRY EXTRACTION

Bathymetry estimation is a correlation between measured water depths with predicted depths which can be implemented either analytically or empirically, or by a combination of both. Analytical or semi-analytical is based on the manner of light transmission in water and requires many parameters related to the properties of the atmosphere, water column, and bottom material of the seafloor otherwise but it is complex and difficult to use. Empirical methods are simple and have fewer parameters.

One of the empirical methods is a linear algorithm band model which is an exponential (log-linear relationship) between water reflectance and water depth with an assumption that water optical properties and bottom reflectance are uniforms

The models were implemented firstly in the 1960s by Polcyn and Sattinger then Brown in 1971 and Lyzenga in 1978,1983 followed by Benny and Dawson in 1983, Philpot in 1989. The following equation describes the linear model.

(1) $$Z = a + bi\ xi + bj\ xj$$

Where $xi = Ln(v_1 - vs_1)$
$xj = Ln(v_2 - vs_2)$
v_1, v_2 = Bands radiance
vs_1, vs_2 = Deep water signal value
a, bi, bj = Constant coefficients from bands linear regressions

The second model used is the ratio model algorithm which is depending on the fact that the depth increases as the reflectance of satellite bands decreases. The following equation describes the ratio model algorithm.

(2) $$Z=m_1*((\ln(n*R(\lambda_i) / \ln(n*R(\lambda_j)) \pm m_0$$

Where m1= constant to calculate the absolute depth
m0= offset for zero-depth
R (λi) = Reflectance of band i
R (λj) = Reflectance of band j

Field water depths points (7227 points) were divided into 60% (4267 points) to calibrate the functions of water depths extractions models and 40% o of measured points (2960 points) were kept for validated models. The equations for the ratio transform model and linear model are presented in table (2) .

Table2. Ratio and linear algorithms equations

Model Equation "Ratio algorithm "	R2	RMSE
$Z_{predicted}$ = 21.676*(B/G) -18.665	93.45	0.82

Model Equation "Linear algorithm "	R2	RMSE
Zpredicted =-3.83474+9.131255*(B) – 12.384(G)	94.17	0.775

RESULT ANALYSIS

Models were developed to extract water depths by a mathematical relationship between the Satellite images reflectance and in situ depths. For Landsat 8-OLI surface reflectance of blue and green bands are used namely band 2 and band 3 the reason behind the choice of blue and green bands is shorter wavelengths have strong penetration proficiency. So, the blue and green bands were utilized in bathymetry derivation of models (linear band model, and ratio model).

Band ratio algorithms are a traditional technique in water depths derived they reduced the errors caused by atmospheric corrections.

The validation data of the study area is shown for the ratio model and linear model in figure (4). All models give values of more than 0.9 (for the linear algorithm 92.59 and 93.37for ratio algorithm). In shallow water depths the linear algorithm gives a more accurate result. Predication measurements of linear and ratio algorithm are overestimated the measured data.

The linear algorithm prediction points have RMSE value lower than the ratio algorithm. The summary of the performance of different algorithms was compared based on correlations between measured and predicted water depths R^2 and RMSE values (high correlation and less RMSE) as presented in Table (3). The ratio model gives more accuracy.

Figure (5) shows that bathymetric maps by applying the linear and ratio algorithms using Landsat 8-OLI.

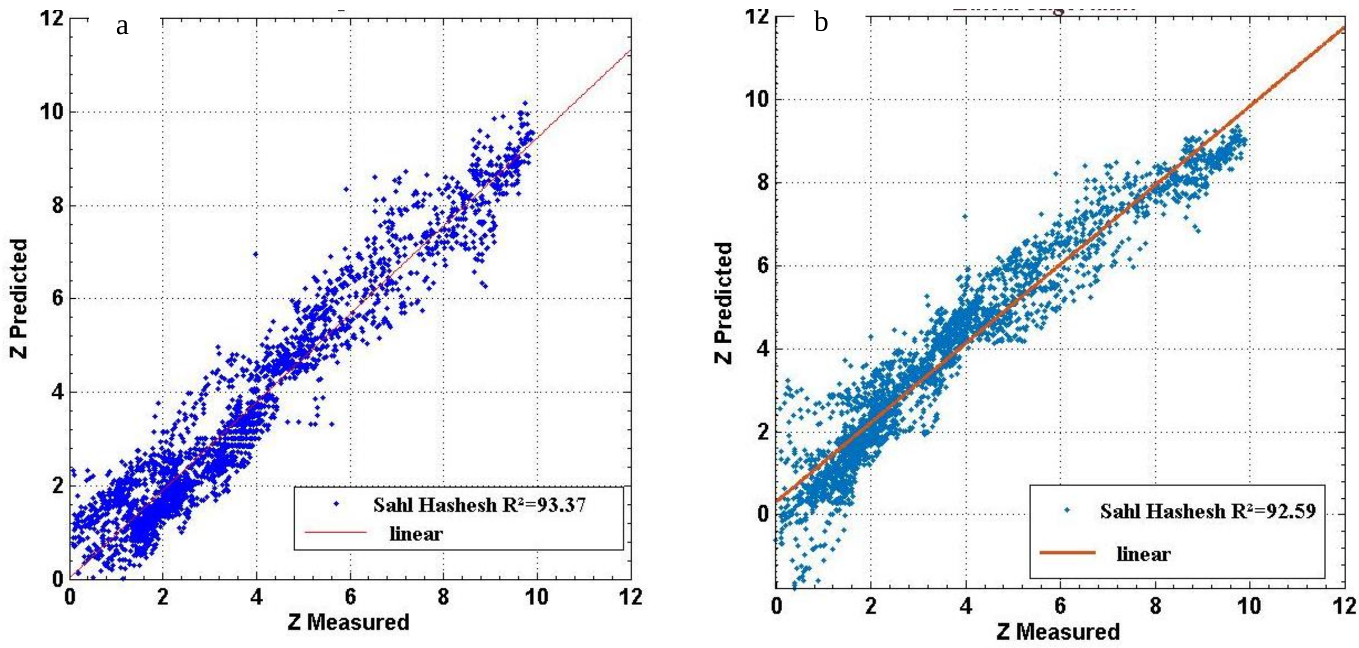

Figure 4 : Measured depths and satellite predicted depths a. Ratio Algorithm b. Linear algorithm

Table 3. R², RMSE Validation points for Ratio and linear algorithm

Ratio		**Linear**	
R^2	RMSE	R^2	RMSE
93.37	0.661521	92.59	0.69020379

a

b

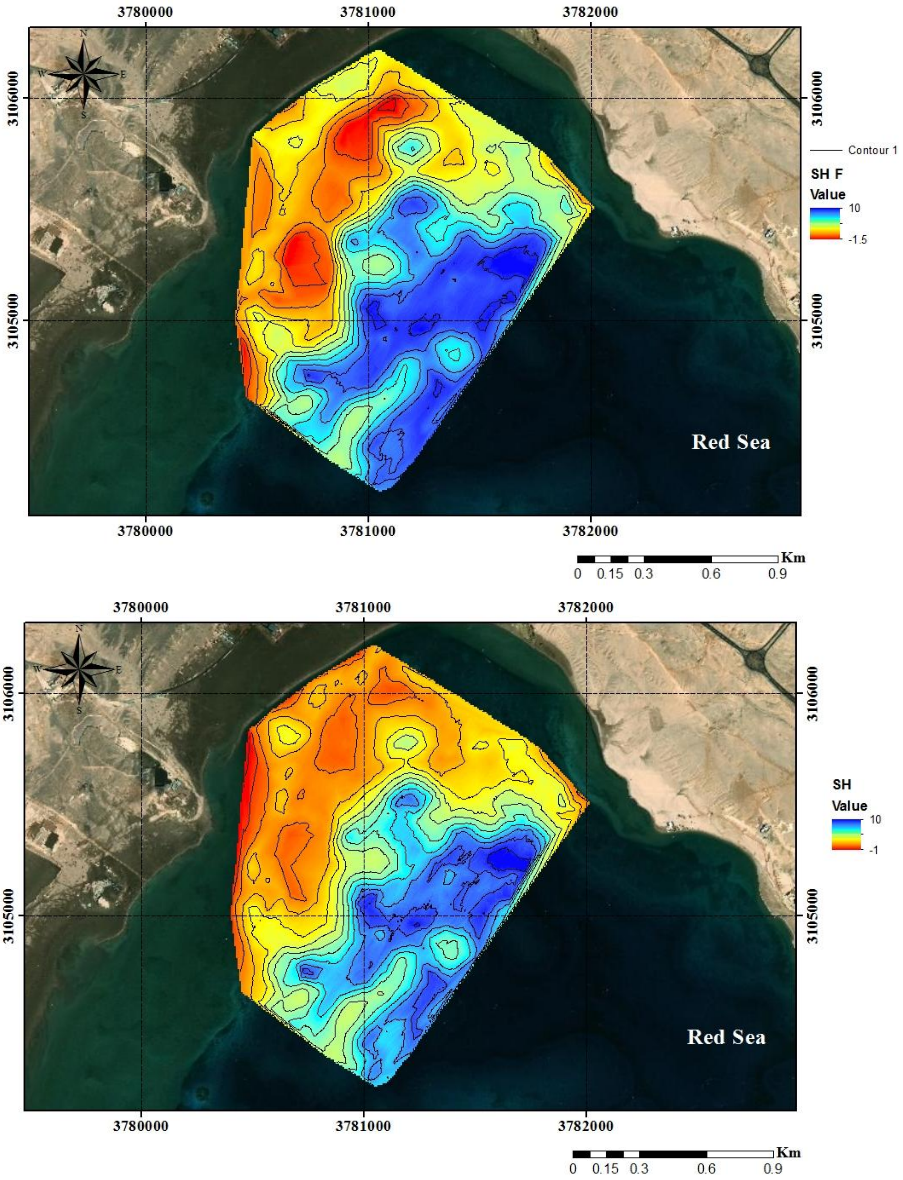

Figure 5 : Bathymetric map a. Ratio algorithm   b. Linear algorithm

CONCLUSIONS

This study presented two algorithms approaches for bathymetry extraction, these algorithms were applied in Sahl Hashesh , Hurghada, Red Sea coast, with clear water, Corel reefs bottom and water depths from 0.59 to 8.5 m using blue /green band ratio after applied FLAASH atmospheric correction in Envi software on Landsat 8-OLI of the study area, all results were compared with measured water depths gave R^2 and RMSE values of (92.59,0.69), for a linear algorithm (93.37,0.661521) and ratio algorithm in the study area. which gives a good result to use as a technique for bathymetry extraction and detecting morphology changes along the coast.

ACKNOWLEDGMENTS

The author would like to thank Dr. Moustafa Tawfik Taha assistant professor of coastal and harbor engineering, Irrigation and hydraulic department, engineering faculty, Cairo University for support, and for offering the tools and help needed for this study.

REFERENCES

1. Ruggiero.P D. Komar, William G. McDougal, John J. Marra and Reggie Wave Runup, Extreme Water Levels and the Erosion of Properties Backing Beaches A. Beach Journal of Coastal ResearchVol. 17, No. 2 (Spring, 2001), pp. 407-419
2. Lyzenga, D.R. Passive remote sensing techniques for mapping water depth and bottom features. Appl. Opt 1978, 17, 379–383.
3. Benny, A.H.; Dawson, G.J. Satellite imagery as an aid to bathymetric charting in the Red Sea. Cartogr. J. 1983 20, 5–16.
4. Lyzenga, D.R. Remote sensing of bottom reflectance and water attenuation parameters in shallow water using aircraft and Landsat data. Int. J. Remote Sens. 1981, 2, 71–82.
5. Lyzenga, D.R. Shallow-water bathymetry using combined lidar and passive multispectral scanner data. Int. J.Remote Sens. 1985, 6, 115–125.
6. Stumpf, R.P.; Holderied, K.; Sinclair, M. Determination of water depth with high-resolution satellite imagery over variable bottom types. Limnol. Oceanogr. 2003, 48, 547–556.
7. Elfatih.A.S. Wave and wind conditions in the Red Sea A numerical study using a third-generation wave model 2010
8. Bassam,G.M.Ahmed.Assessment of genetic algorithm in developing bathymetry using multispectral Landsat images. APAC 2019 pp 393-400
9. Bassam ,G; M.Ahmed .PlanetScope and Landsat 8 Imageries for Bathymetry Mapping. J. Mar. Sci. Eng. 2020, 8, 143.
11. Landsat 8 (L8) Data Users Handbook," America (NY). vol. 8, no. 1993.
12. Provisional Landsat 8 Surface reflectance Prod, vol. Version 2, pp. 1–27.
13. Dierssen, H. M., and A. E. Theberge. Bathymetry: Assessing Method Heidi," Encycl. Nat. Resour. Water, pp. 629–636.
14. Green, E.P, Mumby, P.J., Edwards A.J., Clark, C.D. 2000. "Remote Sensing Handbook for Tropical Coastal Management". Coastal Management Sourcebooks 3, UNESCO, Paris.
15. Benny. G. J. D. and, A.H., 1983, "Satellite Imagery as an Aid to Bathymetric Charting of The Red Sea.," Cartogr. J., vol. 20 (1), pp. 5–16.

17. M.Mohamed. Detection of the submerged topography along the Egyptian Red Sea Coast using bathymetry and GIS-based analysis. The Egyptian Journal of Remote Sensing and Space Sciences (2013) 16, 35–52.
18. Gholamalifard, M Bathymetric Modeling from Satellite Imagery via Single Band Algorithm (SBA) and Principal Components Analysis (PCA) in Southern Caspian Sea. Int. J. Environ. Res., 7(4):877-886, 2013.