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Author: W.A.A.P. Wijesundara

National Aquatic Resources Research and Development Agency, Sri Lanka

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Author: - W.A.A.P. Wijesundara
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DERIVATION OF NEARSHORE BATHYMETRY BY USING LANDSAT 8 IMAGES: A NEW APPROACH FOR COASTAL RESEARCH IN SHALLOW AREAS

W.A.A.P. Wijesundara
National Aquatic Resources Research and Development Agency, Crow Island,
Colombo 15, Sri Lanka.
anusha@nara.ac.lk

ABSTRACT

Bathymetric information is of fundamental importance to coastal and marine planning and management, nautical navigation, and scientific studies of marine environments. Traditionally, nautical charts were produced by collecting the bathymetry from conventional methods of employing ships or boats with sonar which are often inaccessible in shallow water areas. Then the techniques have been developed to use the remote sensing technology to infer the bathymetry in shallow water areas which are inaccessible by hydrographic ships due to rocks, coral reefs or simply the shallowness of the water. This study is focused to obtain the satellite-derived bathymetry maps of near shore in Hambanthota by using freely and easily accessible Landsat 8 imageries. The speckle noise of the image is removed using spatial filtering and land and water area separated by identifying the threshold value of the infrared band. The radiometric correction was applied for clouds and sun glint and bathymetry is calculated using the linear transform algorithm on the blue and green bands. The regression analysis was used to reference the algorithm results in to the chart datum. The extracted isobaths were compared with the available bathymetric data collected via traditional techniques using Single Beam Echo Sounder. The statistical index of root mean square is 0.942 and it demonstrated the good correlation between the soundings and the algorithm values. The results show the medium resolution (30m), freely available satellite images provide reliable estimations for retrieving bathymetry for shallow water areas up to 10m depths. Satellite derived bathymetry using remote sensing techniques can be used for coastal monitoring and research in shallow areas to get the valuable information efficiently and cost effectively. Finally, the accuracy of SDB maps are directly related to the quality of multi spectral images, water clarity, reference depth and wave climate. *Keywords: Shallow water, Satellite derived bathymetry, Hydrographic ships, Sun glint, and Threshold value*

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1.0 INTRODUCTION

Bathymetric information is of fundamental importance to coastal and marine planning and management, nautical navigation, and scientific studies of marine environments. Traditional bathymetric charts are based on individual soundings accumulated during decades of ship-borne surveying operations. Ship borne surveys with single-beam or multi-beam echo sounders can operate to depths in excess of 500 m by sensing and tracking acoustic pulses. However, mapping shallow water bathymetry from conventional methods of employing ships or boats with sonar is a quite an expensive task and comparatively inefficient. Many shallow water areas are not accessible by hydrographic ships due to rocks, coral reefs or simply the shallowness of the water. Monitoring navigation channels for shipping traffic safety and mapping underwater sand bars, rocks, shoals, reefs and other hazardous marine features relies on accurate and up-to-date water depth measurements (Jupp et al., 1989).

With the expansion of coastal modelling, monitoring and marine economic activities, the accurate bathymetry of near shore regions became to play a vital role to describe the physical features of the sea bottom and adjoining coastal areas (Su et al., 2008). Then, the technology was enhanced to use active or passive remote sensing from aircraft and/or satellites. In recent decades, airborne bathymetric LiDAR (Light Detection and Ranging) systems have been developed to map shallow coastal waters. While maximum penetration of LiDAR systems is heavily dependent upon water clarity, these systems commonly achieve depth measurements of up to 30 m, with 4 m spatial resolution and 20 cm vertical accuracy. Though, these airborne bathymetric LiDAR systems provide a rapid and precise means for mapping shallow coastal waters, their use is inadequate by the high cost of operations and logistical difficulties. The feasibility of deriving bathymetric estimates from remote sensing imagery was first demonstrated using aerial photographs over clear shallow water. The technique has been expanded to include the use of multi-spectral satellite imagery including Land sat, IKONOS, and Worldview and Quick Bird images. The main advantages over the conventional echo sounding methods are including the wide data availability, surface coverage, and high spatial resolution. Furthermore, the only requirement is that remotely sensed images need to be carefully calibrated to ensure the accuracy of extracted depth information.

The present work explores the retrieval of Satellite-Derived Bathymetry (SDB) for shallow coastal areas in Hambanthota by using freely and easily accessible Landsat 8 imageries by taking the several improvements of latest generation of Landsat 8 mission launched in early 2013. The processing steps include the pre-processing, water separation, spatial filtering, glint/cloud correction, applying the bathymetry algorithm, identifying the extinction depth, and vertical referencing. The procedure was developed with GIS tool for the corrections of the image and the bathymetry is calculated using the Stumpf et al. (2003) algorithm on the blue and green bands.

1.1BATHYMETRIC MAPPING USING MULTI-SPECTRAL SATELLITE IMAGES

The physical principle of extracting the bathymetry by using multi spectral imageries is that when light passes through the water, it becomes attenuated while interacting with the water column. The Light attenuation and penetration is wave length dependent. Shallow water areas appear as bright in the image as it's less absorbed the reflected light and deep areas appear as dark since it's absorbed much more reflected lights.

The observed radiance in shallow water can be expressed as (Philpot et al.,1989) , (Maritorena et al., 1994) :

$$L_{obs} = (L_b - L_w\ ).e^{-2K(\lambda).Z} + L_w \quad (1)$$

Where, k(**λ**) is the attenuation co-efficient, z is the depth, Lobs is the radiance observed at the sensor's detector, Lb is the radiance contribution from the bottom, and Lw is the observed radiance over optically deep water with no bottom contribution.

Fig. 1 : Study Area

2.0 MATERIALS AND METHODS

2.1 Study Area

Sri Lanka is situated along the key shipping route between the Malacca Straits and the Suez Canal, which links Asia and Europe. The near shore coastal waters in Hambanthota area was selected for this study which has a natural harbor and is located on the southern tip of Sri Lanka close to international shipping routes. Further, the port of Hambanthota is known as the largest port after port of Colombo in Sri Lanka and it will serve ships travelling along the east-west shipping route which passes south of Hambanthota. Therefore, the understanding of the sea bottom in near shore is important for the safety of navigation.

3.2 Landsat 8 Images

The Operational Land Imager (OLI) aboard Landsat 8 has been operational since mid-2013 with the several improvements of latest generation. The swath width of the Landsat imagery is 185 km, and the image resolution is 30m. Each image contains 11 bands at different spectral ranges. For this study, blue (450-515 nm), green (525-600 nm) and infrared (IR) (845-885 nm) bands were selected respectively

3.3 Ground Truth Data

Bathymetric ground truth data are required for the depth calculations and statistical analysis. Bathymetry was collected in this area by using the single beam echo sounder and it was reduced to the Lowest Astronomical Tides (LAT) as per the standards of International Hydrographic Organization. The acquisition dates of soundings and images were selected to close to each other. Therefore, both data can be co-registered correctly and use for the estimation of bathymetry. Further, both data were referenced to a common chart datum.

3.4 Methodology

Freely available Landsat 8 images in Hambanthota area were selected and downloaded from United States Geological Survey (USGS) website, acquired on 19 March 2013. The procedure for estimating bathymetry is processed by using ArcGIS 10.2. The infrared band is used to calculate the threshold value for land/water separation due to the appearance of water in dark and land in bright. Though there are different approaches to assess the threshold value, methods of profile graph and the histogram were used. In the infrared histogram it represents two peaks where one represents the land values (very large values) and the other represents the water very close to 0.

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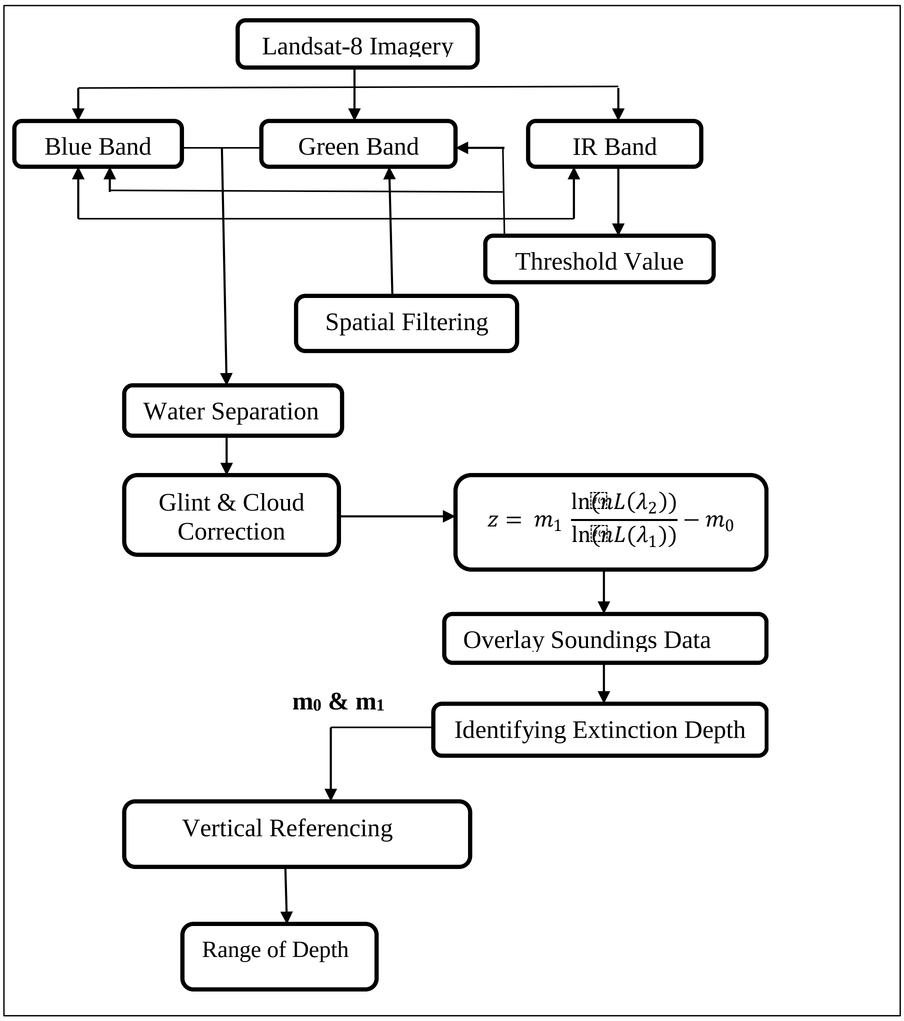

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Fig. 2: Flow chart for derivation of near shore bathymetry

In this image the identified threshold value was used to generate the water subset mark. In this water subset, the blue and green layers contain areas only the water areas.

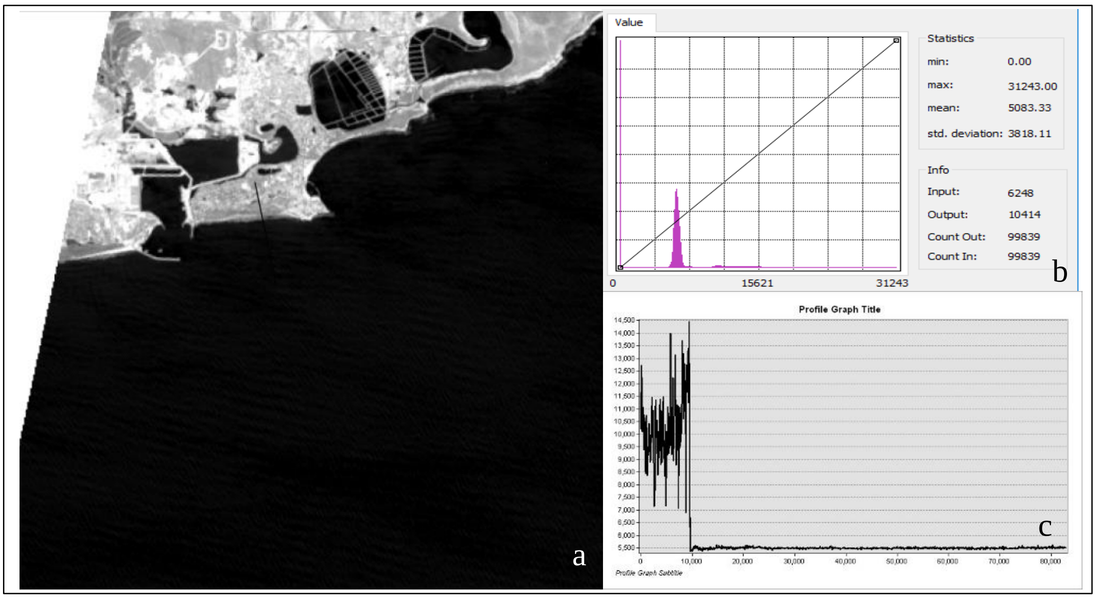

Fig.3: (a) Infrared Landsat Image; (b) Histogram of Landsat Image; (c) Profile plot of section A-B in infrared band of Landsat image

The Hedley et al. (2005) algorithm is used to correct radiometric contributions from sun glint and low clouds from the blue and green bands. By selecting the sample polygon in infrared band over the dark areas in the water, extracted it using extract by mask tool in ArcMap software and repeated the same command for both blue and green bands. The linear relationship between the IR and visible bands is performed using linear regression and calculated the slope of the trend for the blue and green layers by using the following equation;

$$Slope = \frac{y_2 - y_1}{x_2 - x_1} \quad (2)$$

The equation for removing the sun glint and low clouds is shown below;

$$R_i' = R_i - b_i(R_{NIR} - Min_{NIR}) \quad (3)$$

Which simply means: reduce the pixel value in band i (Ri) by the product of regression slope (bi) and the difference between the pixel NIR value (RNIR) and the ambient NIR level (MinNIR). This gives Ri' , the sun-glint corrected pixel brightness in band i. MinNIR essentially represents the NIR brightness of a pixel with no sun glint and can be estimated by the minimum NIR found in the regression sample (Hedley et al., 2005).

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The bathymetry is calculated using the Stumpf et al. (2003) algorithm which utilizes the log ratio approach on the blue and green bands. The equation is as follows;

$$Z = m_1 \frac{\ln(nL(\lambda_i))}{\ln(nL(\lambda_j))} - m_0 \tag{4}$$

Where n is observed radiance of bands, m_1 and m_0 are offset and gain, $L(\boldsymbol{\lambda}_i)$ and $L(\boldsymbol{\lambda}_j)$- observed radiances (after atmospheric and sun glint corrections) for spectral bands i and j.

The optic depth limit for inferring bathymetry is calculated with the results of plotted graph. The algorithm results need to reference to the chart datum. For this purpose, the linear regression analysis was performed after fitting a linear trend through the scatter plot. The R^2 value, gain and the offset values were calculated. The statistical analysis was done for the quality assurance for assessing of the relative accuracy of the results by calculating the correlation coefficient and the standard deviation of the data sets.

4.0 Results and Discussion

The procedure evolved to estimate the near shore bathymetry based on the log inversion model. The threshold value is identified as 10, 500 which is between water values and land values. The smooth section with low values represents water, whereas the fluctuation high value areas represent land. This threshold value was used to separate land and water areas on blue and green bands.

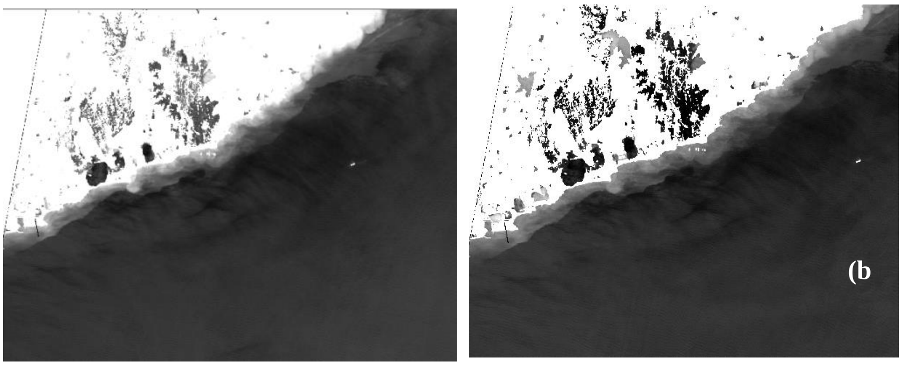

Fig.4: Land/water separated (a) blue band (b) green band

The Hedley et al. (2005) algorithm is adopted for the removal of glints and clouds of blue and green bands. The slope of trend for the blue band is -1.318 and green band is -1.799. These values were applied to obtain the results of radiometric corrected blue and green bands.

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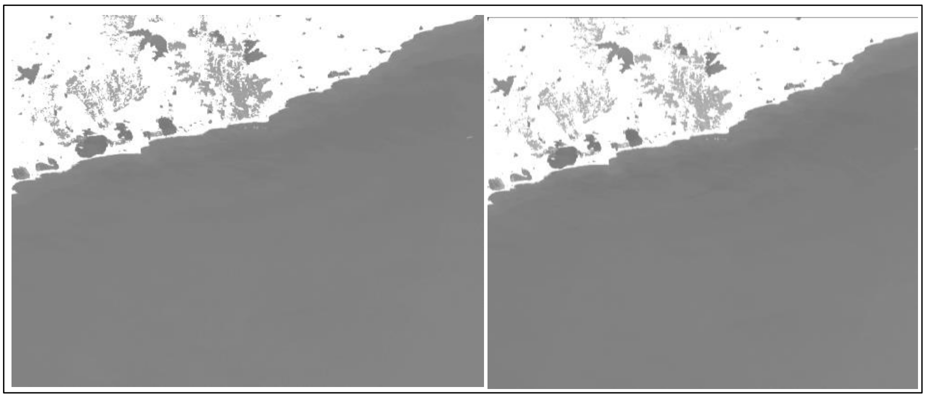

(a) **(b)**

Fig.5: Glint/Cloud corrected (a) blue band (b) green band

The algorithm of $\ln(Band_{blue})/\ln(Band_{green})$ was applied for deriving bathymetry in near shore ocean in this study area. The derived bathymetry is overlaid with the existing SBES data to obtain the m1, m0 and the extinction depth.

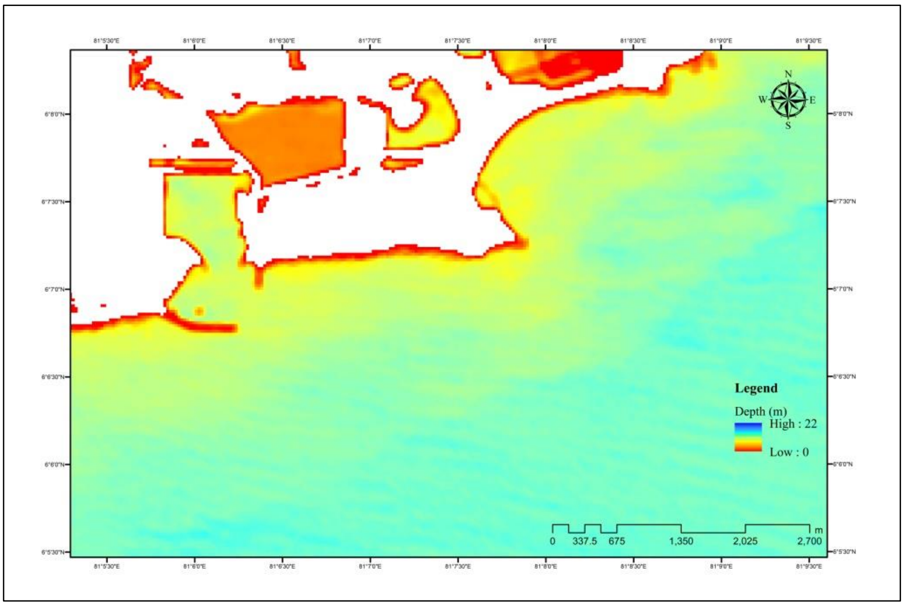

Fig.6: Bathymetric image for algorithm results

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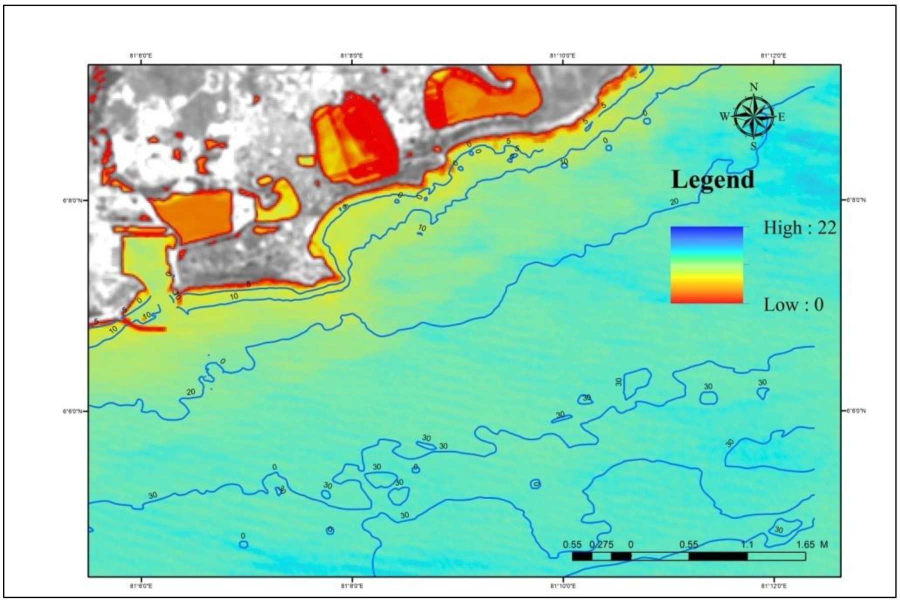

Fig. 7: Existing depth contours overlaid with algorithm results

The pixel values of the bathy image and the corresponding bathymetric data values were obtained and plotted them in a scatter plot diagram. The available soundings data were plotted against the algorithm values and the resulting graph show a linear line at the lower depths and a break. The break represents the extinction depth which is around 9 m and beyond this depth there is a less correlation between the soundings data and the algorithm values. Then, the algorithm results need to reference to the chart datum. For this purpose, the linear regression analysis was performed after fitting a linear trend through the scatter plot and calculated R^2 value, gain and offset values.

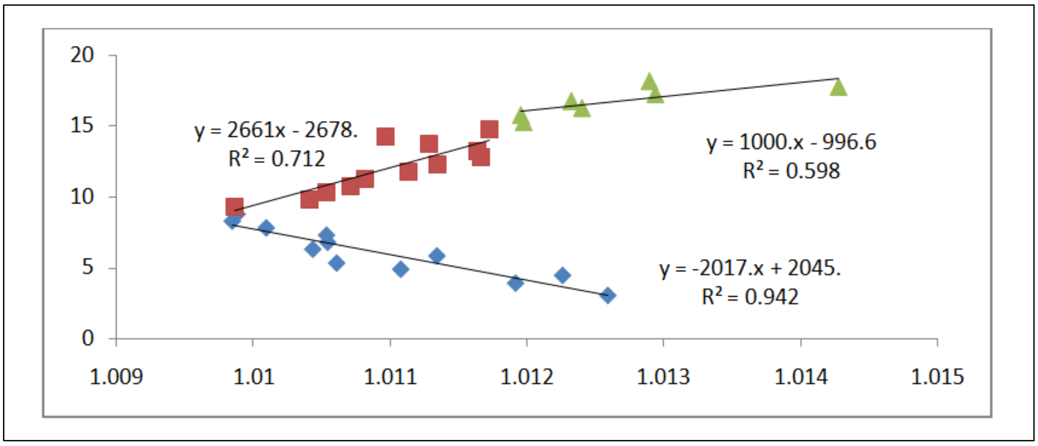

Fig. 8 : R^2, gain and offset values

The scatter plot of depth soundings against the algorithm values shows that Root Mean Square Error (RMSE), R^2 value is 0.942

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and that's indicated there is a good correlation up to 9 m depth. The R^2 value is 0.712 up to 10-15 m depth and that's indicated there's a medium correlation between the depth soundings data and the algorithm values. The R^2 value is 0.598 indicated that there's a less relationship up to 15-18 m depths between the algorithm values and the available soundings data. The resulting equation of the trend line provides the gain and offset values. The gain and offset is obtained as -2017 and 2045 respectively.

These values applied for (4) to obtain the satellite derived map by using freely available Landsat8 imageries.

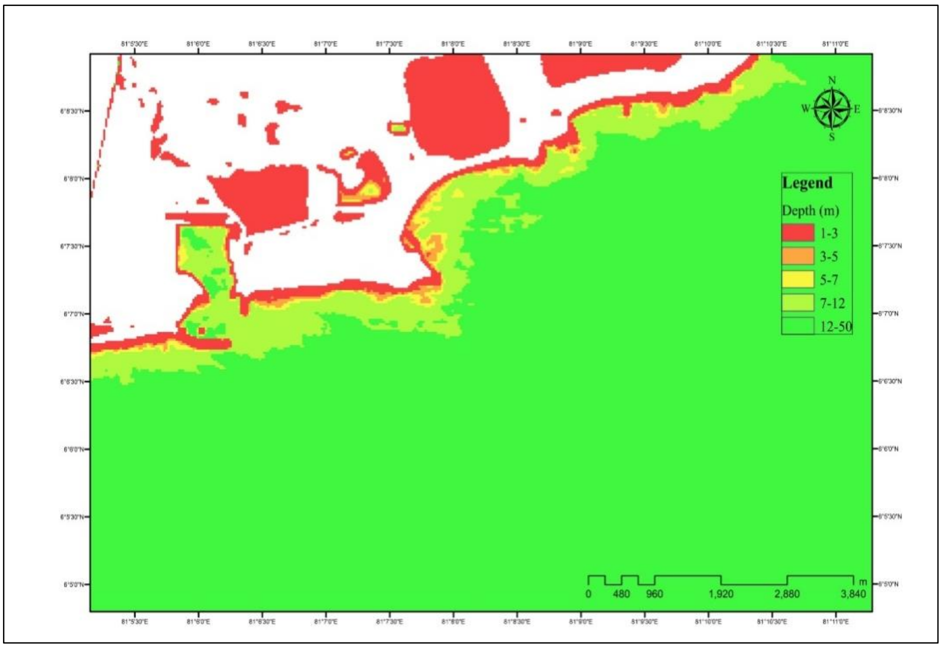

Fig. 9 : Satellite Derived map of the study area

The statistical analysis is performed to check the quality assurance of the data and to assess the absolute accuracy of the results. The mean and the standard deviation were calculated between the final bathymetry product and the soundings. The derived depths are in the accuracy of ± 4 m and the minimum depth uncertainty are occurs at 3-10 m depths.

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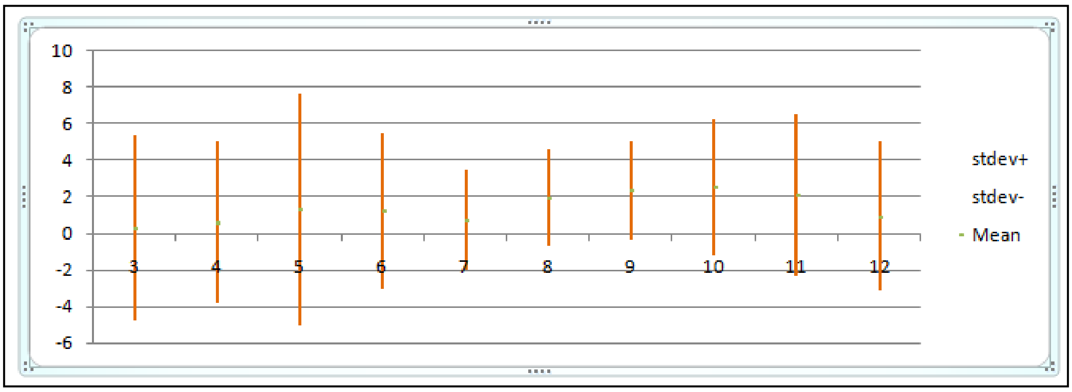

Fig.10: Uncertainty estimation

This technique can be easily apply to understand about the sea bottom nature especially in remote areas where it's too timely and costly to collect the near shore bathymetry due to undersea disturbances.

4. CONCLUSION

The procedure of log transform algorithm for the satellite derived bathymetry by using medium resolution, freely available Landsat 8 images indicates, that as a best investigation tool for infer the bathymetry of near shore coastal region. The results specified that this technique provide a quick and reliable estimation for deriving shallow water bathymetry up to 10m depths. As well as there exist a good liner correlation between the retrieval depths and the hydrographic survey data up to 10m depth. This technique can be applied to national hydrographic offices for the purpose of chart adequacy to evaluate the bathymetry of available nautical charts. Further, the environmental conditions of the image such as water clarity, cloud cover and sun glint are needed to be considered as it's directly affect to degrade the accuracy of the retrieval depths. Finally, Satellite derived bathymetry using remote sensing techniques is a valuable tool for coastal monitoring and research in shallow areas. Also this technique can be used as a reconnaissance tool to get the shallow water bottom information efficiently and at low costly especially for the remote areas where the acoustic surveys are limited.

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