3D BATHYMETRIC MAPPING FOR NEAR SHORE USING LANDSAT-8 IMAGES; A CASE STUDY AT USWETAKEIYAWA, SRI LANKA

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ABSTRACT: The bathymetric information of water features are important when initiate different activities such as sedimentation monitoring, fisheries, voyages, recreation and many reservoir base constructions. In such works, sedimentation and multi temporal environmental changes are prejudicial for consistent volume of water level. For studying such changes, 3D bathymetric map can be used as a beneficial descriptor with different bathymetries.
Sounding techniques based on survey vessels are obviously time consuming, the cost of survey and the method to determine the bathymetry is based on specific equipment, which considerably limits frequent repetition. Satellite Derived Bathymetry (SDB) is a growing approach to infer bathymetry using a band ratio of satellite imagery as a supplementary approach for traditional hydrographic surveys. The calibration information by the energy attenuation due to the depth of the water column and the backscatter due to suspended loads in the water has contributed to create an image of shelf areas understandable.
The study area was Uswetakeiyawa of western coastal region of Sri Lanka. First the water features were identified and the coastal region is extracted by the use of two normalized factors (NDWI and MNDWI). Coastal Aerosol and green is identified as the best band combination for bathymetric depth extraction and blue-green, Coastal Aerosol-red, blue-red combinations are also given significantly high accuracy, indicating that those ratios are also competent for extractions of near shore bathymetry based on Landsat 8. When transforming the relative bathymetry to absolute bathymetry, the accuracy is improved by different samples and obtained a high correlation of nearly 0.9 for all samples tested. The resulting depths are converted to a 3D surface map affirming the shape of the bathymetries for further analysis.

1. INTRODUCTION

1.1 Background

Bathymetric mapping with satellite data is a new field of application of satellite data. Some literatures are available about this type of applications.

A valuable work on bathymetric charting was done at the Penang Strait in Malaysia where the signal reflectance data were corrected using sound signals (Abdullah, Matjafri, & Din, 2000). They commenced a survey to measure the new survey points using a boat equipped with sonar and survey locations were collected with a GPS system. Landsat TM and SPOT data acquired between January 1997 and February 1997 were used by them for study. The pixel values of the same locations were extracted and were used as independent variables and the topographic points measured as dependent variables. In algorithm to study the depth of the multiband water was used in the comparative analysis. Regression techniques were used for the calibration of satellite signals to measure the depth of water. From the regression equation they examined the correlation and root mean square deviations coefficient for each data set. Thereafter, the accuracy of each calibration algorithm was further verified using other known points. Finally, the calibration algorithm has been applied to the corresponding image to generate the map of depth of water.

A notable work could be referred on mapping benthic habitats and bathymetry near the Lee Stocking Island of the Bahamas (Louchard et al., 2003). The depth was not more than 10 meters and they used multispectral data as it included identifying sea grass where bathymetry was a factor. To correct the error due to the low availability of light was offset using a mobile hyperspectral imager for low light spectroscopy. For quick identification of benthic features in coastal environments they used a spectral library of remote sensing reflectance generated by radiative transfer calculations to classify the pixels of the image depending on the type of substance and depth of water. Later, they tested the library classification method on hyperspectral data collected using a portable hyperspectral imager for low light spectroscopy airborne sensor near Lee Island storage, Bahamas. In their paper, they showed a comparative technique that is used to estimate the bathymetry from remote sensing data. According to them an individual band is not suitable to extract bathymetry which is in the form of multispectral data generally do not contain enough information to differentiate spectral types of complex substance; in this case, hyperspectral data will give good results. The detailed spectral information available in hyperspectral imaging offers the possibility of developing a new approach for analysis and modeling of the benthic reflectance.

Another distinctive research was done by (Stumpf, Holderied, & Sinclair, 2003). In their research, two standard naming linear algorithms transform and transform the new ratio transform were compared by analysis of satellite imagery IKONOS against LIDAR bathymetry. The coefficients for the ratio algorithm were manually adjusted to some depths of a nautical map, still performed and the linear algorithm set by using multiple linear regressions against the LIDAR. Both algorithms compensate type of background and variable albedo (sand, pavement, algae and corals) and collect bathymetry in water depths of less than 10-15 m. However, the linear transformation did not distinguish depths of 15 m and is more prone to variability in the studied atolls. The ratio transform was performed well in clear water, recovering 25 m water depths and shows greater stability between the different zones. It has also been performed slightly better in the distribution of the turbidity that the linear transformation. The ratio algorithm was much more noisy and could not always adequately address the fine morphology (smaller structures that 4-5pixels) in water depths of 15 to 20 m. Generally, at the end of this transform study report identified more robust than the linear transform

Another comparative study of derivation of bathymetry from multispectral imagery was done by (Bramante, Raju, & Min, 2006).where highly turbid waters of Singapore’s south islands. In this paper, four algorithms were used to determine the depth of the water column using multispectral satellite images. Due to the high turbidity of Singapore water, the investigation was limited to the study and derives depths less than two meters. In the narrow band of depth, it was difficult to get accurate results due to the low level type variable, instrument error, and incorrect assumptions about the water column.

The new study using Landsat 8 imagery was done by (Pacheco et al., 2015) in near shore region in Ria Formosa system in southern Portugal. This subscription was focused on the application of the linear transform algorithm to attain satellite-derived bathymetry (SDB) maps of the near shore, at medium resolution (30 m), from freely available Landsat 8 imagery. The algorithm was tuned with available bathymetric LIDAR data for a 60-km-long near shore stretch of a highly complex coastal system that comprises barrier islands, exposed sandy beaches, and tidal inlets. A comparison of the derived depths is presented, enabling the configuration of near shore profiles and extracted isobaths to be explored and compared with sounding techniques .The results illustrated that the linear algorithm was efficient for retrieving bathymetry from multi spectral satellite data for shallow water depths (0 to 12 m), showing a mean bias of 0.2 m, a median difference of 0.1 m, and a root mean square error of 0.89 m.

The primary objective of this research is to create near-shore 3D bathymetric map using Landsat 8 satellite derived bathymetry using ratio method. Specific objectives of the study were water feature extraction, find the best band ratio for bathymetry extraction and compare the predicted bathymetry with ground truth. The study area is Uswetakeiyawa coastal region which is located in western coastal belt of Sri Lanka. This region is highly changing area due to currents effects and sedimentation of Kelani river mouth. This kind of application will be important for knowing the rapid changes in bathymetry of this region. The upper left Universal Transverse Mercator (UTM) co-ordinates and lower right UTM coordinates of the study area are 780413.00 N, 369156.00 E and 776389.00 N, 374688.00 E respectively.

1.2 Bathymetry Derivation using remotely Sensed Data

Although there are various methods available to derive bathymetry from remotely sensed images generally segregated into “linear methods” and the “ratio methods”. Both methods are based upon the principle that light is attenuated through interaction with the water column, and the depth to which light penetrates water is dependent upon the light’s wavelength (Stumpf et al., 2003). The linear methods make two primary assumptions. The first assumption, common to both methods, is that light will pass through water to a degree dependent upon its wavelength. The second assumption is that water quality is homogeneous throughout the image. Additional assumptions exist depending on the method used. For example assume that the substrate albedo is homogeneous. (Stumpf et al., 2003) proposed a “ratio method” that, to some extent, overcomes the limitations of varying substrate albedo. The method builds upon the principle of light attenuating exponentially with depth, but proposes that by using two bands to derive depth, the effects of substrate albedo are minimized. The ratio method addresses this imperfection by comparing the attenuation of two bands against one another rather than using albedo as a variable in depth calculation. Different bands attenuate at different rates; therefore, one band will be less than the other. The ratio between the two bands will change with depth. The change in bottom albedo should affect both bands similarly, but the change in attenuation with depth will be greater than the change attributable to bottom albedo so that the ratio between the two bands should remain similar over different substrates at the same depth (Stumpf et al., 2003). The first step to derive bathymetry from the image is to determine relative bathymetry using the natural log transform of the reflectance values. Equation (1) shows the ratio expression used for relative bathymetry:

$$B = \frac{\ln(n.R_{b1})}{\ln(n.R_{b2})} \text{ --- Eqn (1)}$$

Where; B: Relative bathymetry, R_{b1}: Band 1 reflectance value, R_{b2}: Band 2 reflectance value

Normally the reflectance values are multiplied by 1000 (the *n* value in equation (1)) to ensure that the logarithms remain positive for all reflectance values. The next step is to calibrate the relative bathymetry to absolute bathymetry. Equation (2) helps to derive absolute bathymetry for the entire image (Stumpf et al., 2003).

$$Z = m_1 \frac{\ln(n.R_{b1})}{\ln(n.R_{b2})} + m_0 \text{ --- Eqn (2)}$$

Where; Z: Depth, m_1: Tunable constant to scale the ratio to depth, n: constant to ensure the ratio remains positive under all values, R_{b1}: Band 1 reflectance value, R_{b2}: Band 2 reflectance value, m_o: Offset for a depth of 0m

2. METHODOLOGY

The first task was synchronizing the image coordinate system and ground truth coordinate system. Thus, coordinates of the sounding data were converted in to image coordinate system which was WGS84 UTM 44N projected coordinate system. Radiometric correction allows the conversion of raw image digital value (DNs) to spectral Radiance (Wee & Pradhan, 2015). Normally in satellite imagery has numeric values called DN values for each pixel. It's the only identifier value for each pixel. According to the Landsat 8 Calibration guide suggested by USGS, OLI and TIRS band data can be converted to TOA (Top of Atmospheric) spectral radiance using the radiance rescaling factors provided in the metadata file. The calibration routine is expressed mathematically as in equation (3).

$$L_\lambda = M_L Q_{cal} + A_L \text{ -- Eqn (3)}$$

Where: L_λ : TOA spectral radiance, M_L: Band-specific multiplicative rescaling factor from the metadata, A_L: Band-specific additive rescaling factor from the metadata, Q_{cal} : Quantized and calibrated standard product pixel values (DN)

Thereafter Dark Object Subtraction (DOS) method was used as an atmospheric correction model. Then spatial sub setting and water feature extraction steps were done. This step is to remove land areas and other areas not required for the bathymetry calculation. Masks and classification techniques were used for this. A mask was manually created to remove areas outside of the study region. Identifying accurate feature boundaries was a challenging task.To get rid of this NDWI algorithm was applied.

NDWI = (Green – NIR) / (Green + NIR) ------------------------------------ Eqn (4)

However NDWI does not extract shallow parts of the water body and is unable to separate built-up structures from water feature. Therefore to increase the level of details in the result, used the summation of NDWI and a modified NDWI (MNDWI) and then did the binarization of result (Mishra & Prasad, 2015).

MNDWI = (Blue – NIR) / (Blue – NIR) ------------------------------------ Eqn (5)

The summation index used is where;

$$I = NDWI + MNDWI \text{ --- Eqn(6)}$$

Using the resultant I imagery a mask was created for water features. Then, using the mask, water area of subsetted image was masked. Out of the water feature values were converted to no data. Then resultant image radiance values were converted in to top of atmospheric reflectance values using equation (7).

$$\rho\lambda' = M\rho Q_{cal} + A_{\rho} \text{ -- Eqn(7)}$$

Where: $\rho\lambda'$: TOA planetary reflectance without correction for solar angle (Note that $\rho\lambda'$ does not contain a correction for the sun angle), M_ρ : Band-specific multiplicative rescaling factor from the metadata, A_ρ : Band-specific additive rescaling factor from the metadata, Q_{cal} : Quantized and calibrated standard product pixel values (DN).

TOA reflectance with a correction for the sun angle is then;

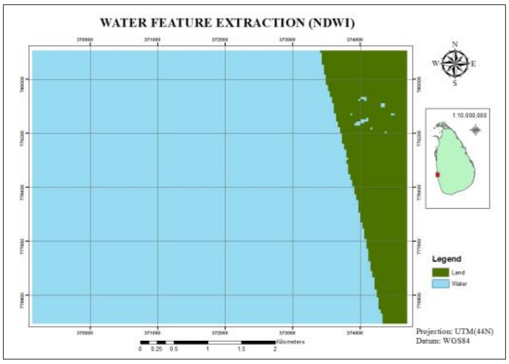
$$\rho\lambda = \frac{\rho\lambda'}{\cos(\theta_{SZ})} = \frac{\rho\lambda'}{\sin(\theta_{SE})} \text{ --Eqn(8)}$$

Where; $\rho\lambda$: TOA planetary reflectance, θ_{SE} : Local sun elevation angle in degrees is provided in the metadata, θ_{SZ} : Local solar zenith angle (θ_{SZ} = 90° - θ_{SE})

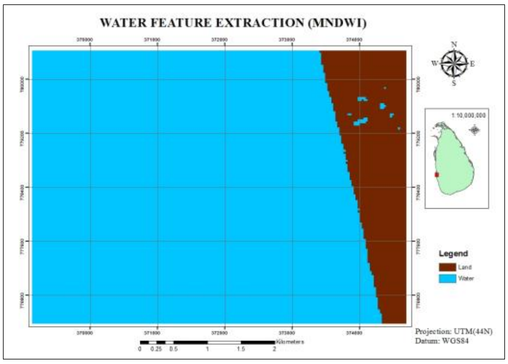
Thereafter relative bathymetries were calculated using the equation (1) . Finding best band ratio was a prime objective in this research and it was implemented by scatter plots which were drawn using relative bathymetry and respective ground truth values along a sample line. Tunable constants (m_0 and m_1) also determined using this scatter plots. After solving best band combination, absolute bathymetries were calculated using the equation(2). Further, using several sample lines, constants were fine tuned and applied for final bathymtry.

3. RESULT AND DISCUSSION

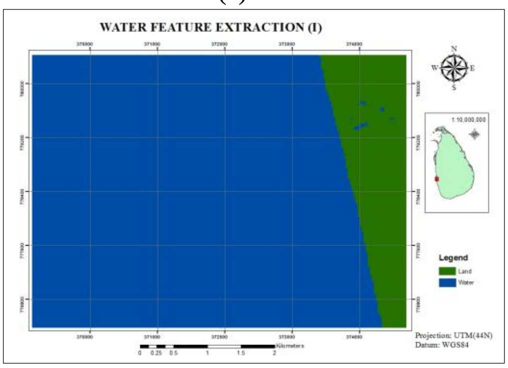
3.1 Water features extraction



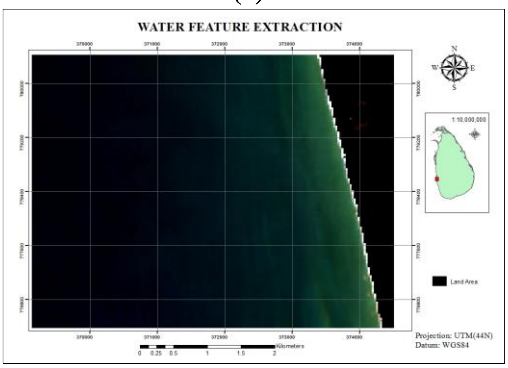
(a)



(b)



(c)



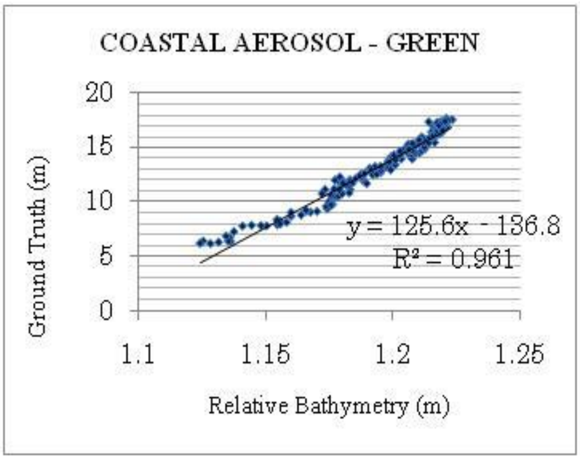
(d)

Figure 1: (a) NDWI result (b) MNDWI Result (c) Additive result of NDWI and MNDWI (d) Resultant satellite image masked by I

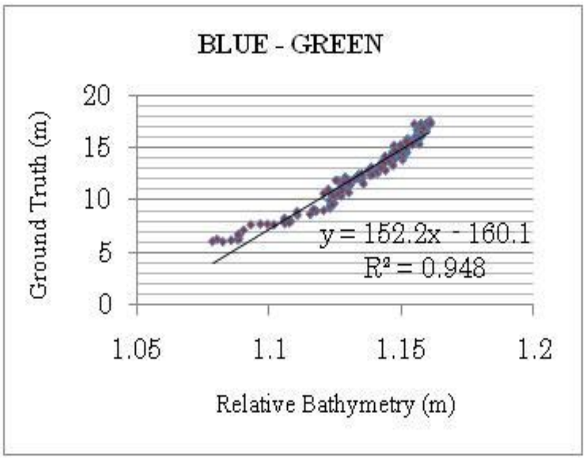
Figure 1 shows the results after applying normalized factors described in equations 4, 5 and 6, and result of water feature after applying mask. According to the obtaining results, current study puts forward an automatic approach to extract the water body from Landsat8 satellite imagery. Several approaches have been developed in many studies to delineate water bodies from different satellite imagery varying in spatial, spectral, and temporal characteristics. But this approach obviously better in water feature extraction.

3.2 Best Band ratio

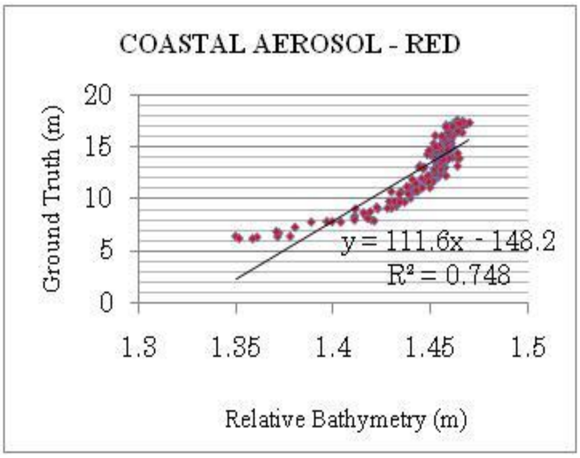
Correlation between relative bathymetry and ground truth of the regressions is given confidence about best band ratios for bathymetry extraction. Figure 2 shows four suitable band combinations out of 28 possible band combinations of Landsat 8 imagery.



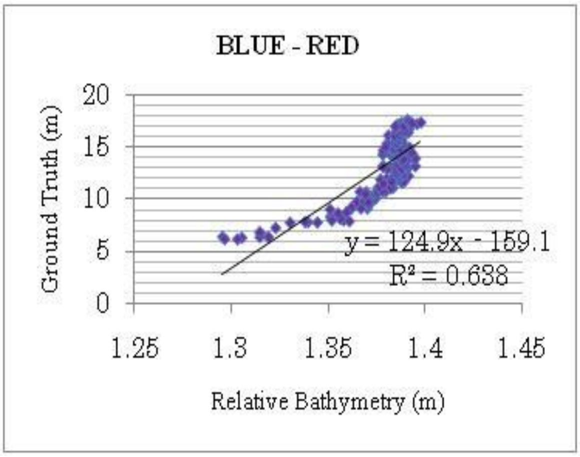
(a)



(b)



(c)



(d)

Figure 2: (a) Relative bathymetry vs. Ground Truth (Coastal Aerosol- Green) (b) Relative bathymetry vs. Ground Truth (Blue- Green) (c) Relative bathymetry vs. Ground Truth (Coastal Aerosol- Red) (d) Relative bathymetry vs. Ground Truth (Blue- Red)

Table 1: Correlation Factors of Band Ratios

Band Ratio	**Correlation Factor (R)**
Coastal Aerosol - Green	0.980
Blue-Green	0.974
Coastal Aerosol - Red	0.865
Blue -Red	0.798

According to the regression analysis results describes in Figure 2 and Table 1, Coastal Aerosol and Green band combination obviously taken the prominent suitability than other combinations in bathymetric derivation.

3.2 Satellite Derived Absolute Bathymetry

Figure 3 describes derived absolute bathymetry along a selected random line over study area using sample 1 constant values (m_0 and m_1) for coastal Aerosol- Green band ratio.

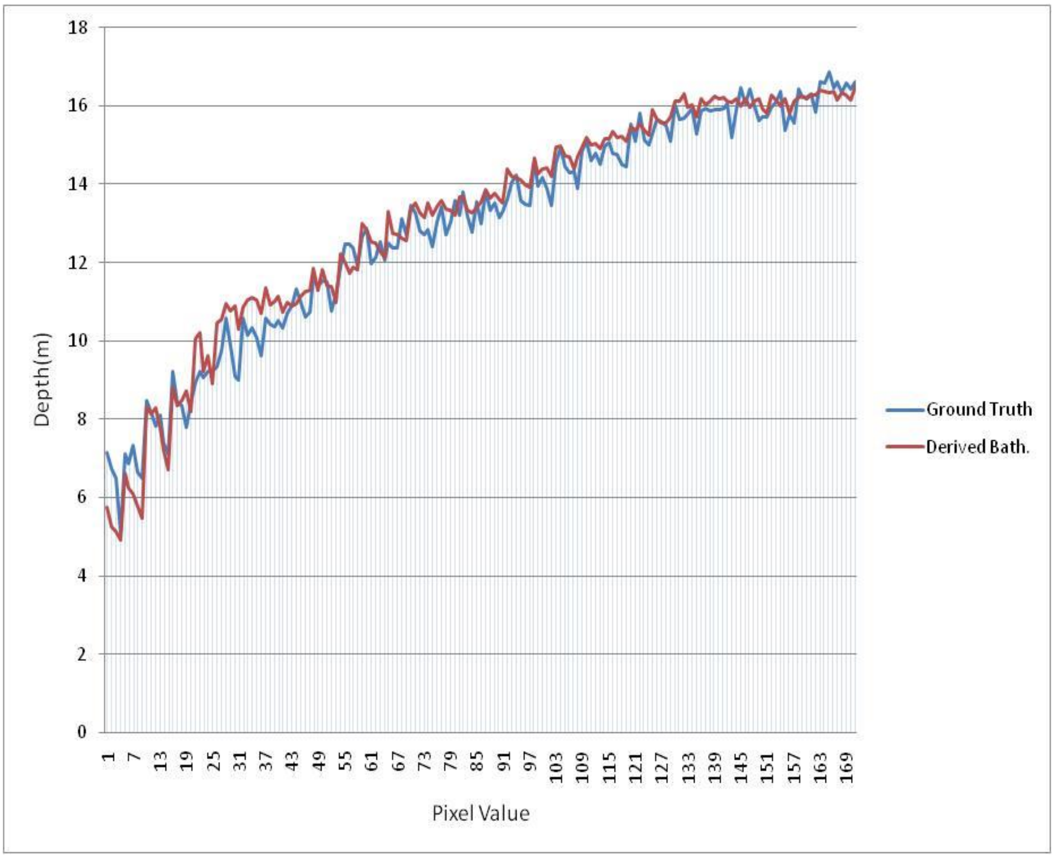


Figure 3: Derived Absolute Bathymetry for Coastal Aerosol and Green ratio using Sample 1 constant values

Table 2: Different constant values for each sample for Coastal Aerosol and Green band combination

Sample	**m_1**	**m_0**
1	125.6	-136.8
2	114.6	-123.9
3	130.1	-142.6
Average	123.433	-134.433

Figure 4 describes variation of derived bathymetries along a random line over the study region respect to different samples for Coastal Aerosol- Green band ratio. Figure 5 is a magnification of sample region (pixel 55- 70) illustrating its deviations.

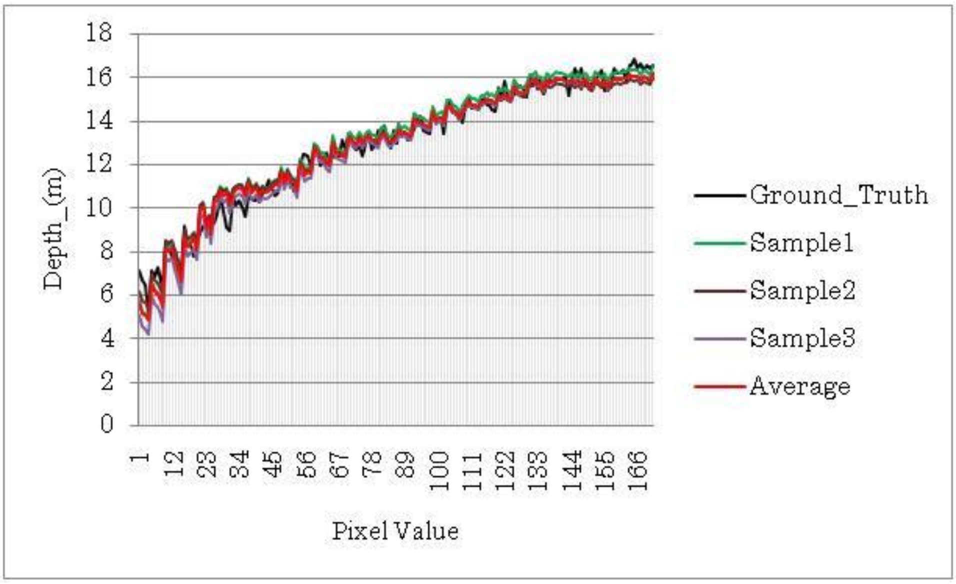


Figure 4: Absolute Bathymetry variation of Coastal Aerosol and Green ratio for different samples

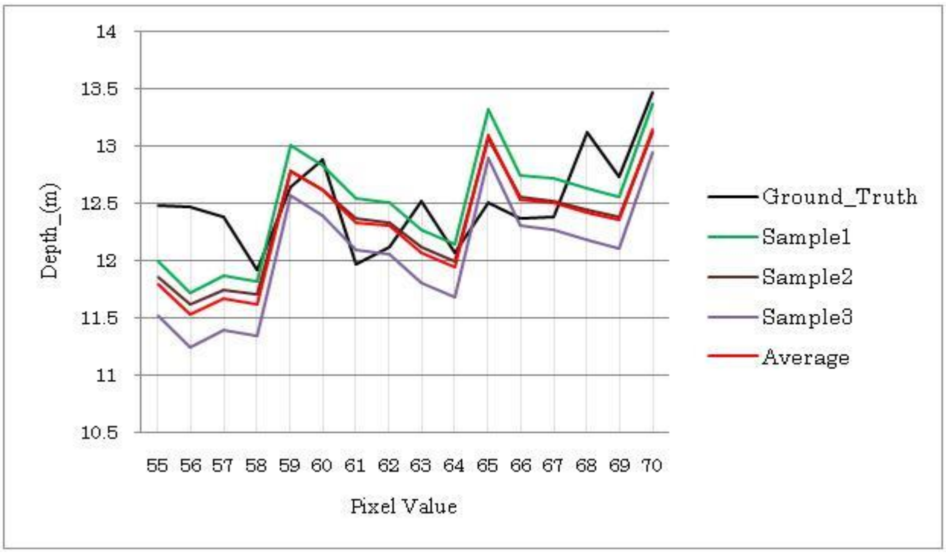


Figure 5: Absolute Bathymetry variation of Coastal Aerosol and Green ratio for different samples (Magnification of pixel 55 – 70)

Table 3: Total Depth Error for different Samples

Sample	Total Depth Error (m)
1	47.56
2	42.07
3	58.15
Average	39.95

Table 3 determines total error of depths along the random check line regarding each sample constants and average constants as well. Number of samples which is used to calculate tunable constants are affected significantly for the depth error. And averaging constants takes the better result than each sample.

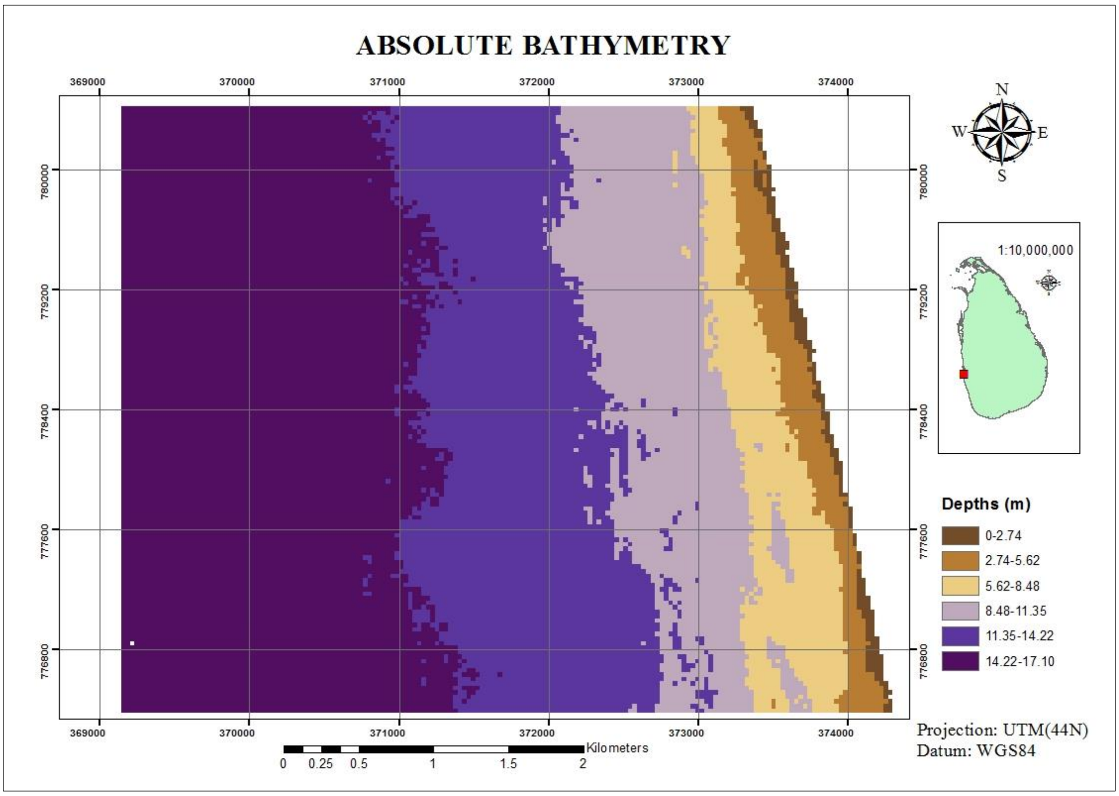


Figure 6: Absolute Bathymetry using average constant values for Coastal Aerosol - Green band combination

Figure 6 describes the final bathymetric map of the study region using Landsat 8 imagery which was fine tuning all conclusions of the entire research. End of this case; Maximum depth error =1.6m, Minimum depth error= 0.0076 m, Average depth error = 0.36m for (6-17m) depth range taken along a random check line, the results shown that bathymetry obtained from multispectral satellite data is more accurate for shallow water depths (0 to 10m) than for greater depths (10–16 m). In study of (Pacheco et al., 2015) get the similar result and they were proven that bathymetry obtained from multispectral satellite data is more accurate for shallow water depths (0- 8m) than for greater depths (8–12 m).

4. CONCLUSIONS AND RECOMMENDATIONS

Dark object subtraction (DOS) method is given good result in this study because possible DN values can be identified in the image. (0 values also seen in the image, if there is an atmospheric error, all DN values are more than an offset value; 0 is the possible minimum DN value that can be seen in imagery). Precise water feature extraction is challenging due to less spatial resolution. Combination of NDWI and MNDWI is given better result of water feature extraction especially in coastal region that can be much verified by spreading of spectral values of water area. Coastal Aerosol and Green band combination is the best band ratio in bathymetry extraction with highest correlation value nearly 0.9 for all samples in the study. Hence, equation (2) can be directly applied to find absolute bathymetry using Landsat 8 especially in shallow condition of coastal region. When calculating absolute bathymetry using relative bathymetry, m_0 and m_1 constants are the key components (Equation 2). Minimum of two sample lines are needed identify m_0 and m_1 values and verifying, but number of samples are improved the consistency of m_0 and m_1 and final bathymetry as well. If there are different samples, best way is averaging the constants and applies for the equation (2). Within the 0m-17m depth range of the study region, depth difference between actual ground and derived bathymetry was less than 1.6m and results shown that bathymetry obtained from multispectral satellite data is more accurate for shallow water depths (0 to 10m) than for greater depths (10–16 m). Accuracy of derived bathymetry may be decreased due to turbidity & salinity of water because this region is near the river mouth of Kelani. Most of Landsat 8 images which acquired in this region are covered with clouds. Error results may be appearing due to cloud patches. Acquisition date of satellite image and ground truth data has little difference. It may introduce poor correlation.

There are many recommendations to restrain the barriers discussed in above. Advanced atmospheric corrections methods can be applied to fine tune for best results. To enhance water feature extraction precisely, Artificial Neural Network based techniques can be used. (Blue/Green), (Coastal Aerosol /Red) and (Blue/Red) ratios are much suite for bathymetry when request less accuracy. Applying water turbidity corrections & salinity corrections will increase the accuracy of results. If it is possible to select cloud free images unexpected results can be omitted. Simultaneous observations of sampling of soundings and acquisition of satellite imagery will give best results.

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