



The Challenges of River Bathymetry Survey Using Space Borne Remote Sensing in Bangladesh

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Abstract: Over the last two decades there has been a revolution in our ability to map and monitor large areas of subaerial topography using technologies such as radar and near-infrared Light Detection and Ranging. The Multispectral Remote Sensing (RS) Satellite 'WorldView-2' imagery has the ability to measure water depth up to 25m. Studies have been conducted based on the band ratio algorithm to determine water depth in the study area the Ganges River in Bangladesh. This method is able to generate accurate depth measurements at points or along transects, and also offer more flexible, efficient and cost-effective means of mapping bathymetry over broad areas. There are two methods are available to derive bathymetry from remote sensing imagery which are "linear method" and "ratio method". The linear method is depended upon bottom type albedo. While different bottom types at the same depth would be incorrectly calculated for one of these two substrates. The accuracy of the retrieved bathymetry varies with water depth, with the accuracy substantially lower at a depth beyond 12 m. Other influential factors and challenges include water turbidity and bottom materials, as well as image properties.

Keywords: Remote Sensing, Bathymetry, Ratio Algorithm, Worldview-2, Linear Regression

1. Introduction

Accurate determination of water depth is important both for the purposes of monitoring underwater topography and movement of deposited sediments, and for producing nautical charts in support of navigation. Such information is also critical to port facility management, dredging operations, and to predicting channel infill and sediment budgets. Remote sensing of bathymetry takes several forms, each having its own detection depth, accuracy, strengths, limitations and best application settings. These forms into two broad categories. There are two methods are available to derive bathymetry from remote sensing imagery which are "linear method" and "ratio method". The linear method is depended upon bottom type albedo. While different bottom types at the same depth would be incorrectly calculated for one of these two substrates. The ratio method compares the attenuation of two bands against one another. Consequently different bands attenuate at different rates at different albedo; one band will be different than the other. Therefore, the ratio between two bands will change with depth and difference of the albedo

type on the mathematical equation would be accounted. The change in the type of the bottom layer on the reflectance should be similar to both of the two bands. Hence, the ratio of the reflectance of the two bands will remain unaffected with the change of albedo types over different substrates at the same depth [1]. Airborne optical sensing of bathymetry is by far the most frequently used for a wide range of water bodies, including inland lakes, shallow estuaries, coastal areas, and open seas.

The direct approach Bathymetric survey precisely represents underwater terrain. However, sometimes it is not cost-effective in the risky navigational area and when less accuracy is required. "Remote Sensing is the art and science of obtaining information about an object without being in direct contact with the object" [2]. Satellite based remote sensing is the large spatial coverage, greater availability, capable to acquire meaningful information from the Earth Surface. It has the ability to derive bathymetry (water depth) up to 25 m. Remote sensing technology is civilizing rapidly and capable to observe the Earth's surface from detection of an atmospheric property to the ocean floor mapping. The information extraction depends on the purpose of uses for

every case. The image processing and classification is the method of information extraction. Surface water depth has a strong correlation with reflectance of optical bands. Hence, measurement of reflectance can benefit the subject as an alternative state-of-the-art solution while, Echo-sounding technique and hydrographic survey are costly, slow and has certain limitations. Since the launch the World View-2 (WV-2), ocean floor has become much clearer. It is a high-resolution multispectral satellite given that a coastal Blue bands (400-450 nm). The coastal blue band is enabled to see 25-30 meters depth of underwater. It has revolutionized bathymetric studies. Now, analysis can see deep into the water and distinguish features of the terrain clearly. This eventually increases the application of remote sensing. It also facilitates navigational security as well as detailed mapping and water modeling applications [3]. The main objective of this study is to investigate remote sensing to estimate water depth using the multispectral satellite imagery and major challenges over the methods.

2. Space Borne Remote Sensing

The World View 2 Multispectral Remote sensing image is Half-meter panchromatic and 2 meter multispectral high resolution satellite remote sensing image launched on October 2009. Eight spectral bands, 4 standard colors: Red, Blue, Green, and NIR-1 and 4 new bands: Red-Edge, Coastal Blue, Yellow and NIR-2. Worldview-2 combination of increased altitude, advanced agility, bi-directional push broom sensor detector and multiple ground station allows remarkable collection rates. Worldview-2 satellite orbit is 770 km altitude, 11-bits per pixel dynamic range and swath width of 16.4 kilometers at nadir view [4]. New bands the coastal blue (400-450nm) and yellow band (585-625 nm) of the WV-2 imagery are more potential for estimating water depth among new 4 bands. The coastal blue band is least absorbed by water and has the potential to improve atmospheric correction techniques. Therefore, it is useful in bathymetric studies. The yellow band is very important for feature classification. This band detects the “yellowness” of particular vegetation, both on land and in the water [5]. The conventional blue band (450-510nm) also provides better penetration of water. [6] investigated that to determine the water depth using the [1] ratio algorithm, yellow/green and yellow/blue ratios improve the accuracy of depths compared to the green/blue ratio, particularly in shallow waters. The Coastal blue is the new spectral band the band range is 400-450 nm. It can detect healthy plants as it is absorbed by chlorophyll. Coastal blue is least absorbed by water thus, the coastal blue is very useful in bathymetric studies. The coastal blue is potential to improve atmospheric correction as it is significantly influenced by atmospheric scattering. The green band range is 510-580 nm (narrow than the green band of Quick Bird). It has ability to focus more precisely on the peak reflectance of healthy vegetation. Therefore, perfect estimation plant energy and supportive discrimination of the plant material is possible when combination with the yellow

band. Yellow band is important for feature classification. Near Infrared 1 (NIR1) can separates water bodies effectively from vegetation while NIR2 (new band) is less affected by the atmospheric influence.

3. Methods

There are two methods are available to derive bathymetry from remote sensing imagery which are “linear method” and “ratio method”. The linear method is depended upon bottom type albedo. While different bottom types at the same depth would be incorrectly calculated for one of these two substrates.

3.1. Linear Method

[16] Developed water depth measuring Equation 1

$$z = g^{-1}[\ln(A_d - R_{\infty}) - \ln(R_w - R_{\infty})] \quad (1)$$

Where,

g = Function of scatter attenuation coefficient

A_d = Bottom Albedo

R_{∞} = Reflectance of the water Column

R_w = Observed Reflectance

In the linear method single band uses for defining relationship between reflected radiance and water depth.

3.2. Ratio Method

In order to overcome limitations of the linear method, the Water depth measuring equation [2] developed “ratio method”. The ratio algorithm is described mathematically by Equation 2.

$$Z = m_1 \frac{\ln(nR_w(\lambda_i))}{\ln(nR_w(\lambda_j))} - m_0 \quad (2)$$

Where,

m_0, m_1 = Offset (where $Z=0$) and Scale factor;

n = Chosen constant e.g. 1000 for overcoming negative values;

R_w = Reflectance of water;

λ_i, λ_j = wavelength of two different bands

The ratio method compares the attenuation of two bands against one another. Consequently different bands attenuate at different rates at different albedo; one band will be different than the other. Therefore, the ratio between two bands will change with depth and difference of the albedo type on the mathematical equation would be accounted. The change in the type of the bottom layer on the reflectance should be similar to both of the two bands. Hence, the ratio of the reflectance of the two bands will remain unaffected with the change of albedo types over different substrates at the same depth [2].

3.2.1. Determine Relative Bathymetry

The ratio algorithm has been used to determine the relative bathymetry which is the beginning steps of water depth derivation while absolute bathymetry is the next step. The

ratio algorithm used the natural log transform of the ration of the short wave length reflectance to the long wave length band reflectance value. The reflectance values are multiplied by 1000 to ensure that the logarithms remain positive for all

reflectance values. According to the ratio algorithm, here Coastal blue and yellow band have been used to determine the relative bathymetry. It is found that the relative value is incasing when depth is increase.

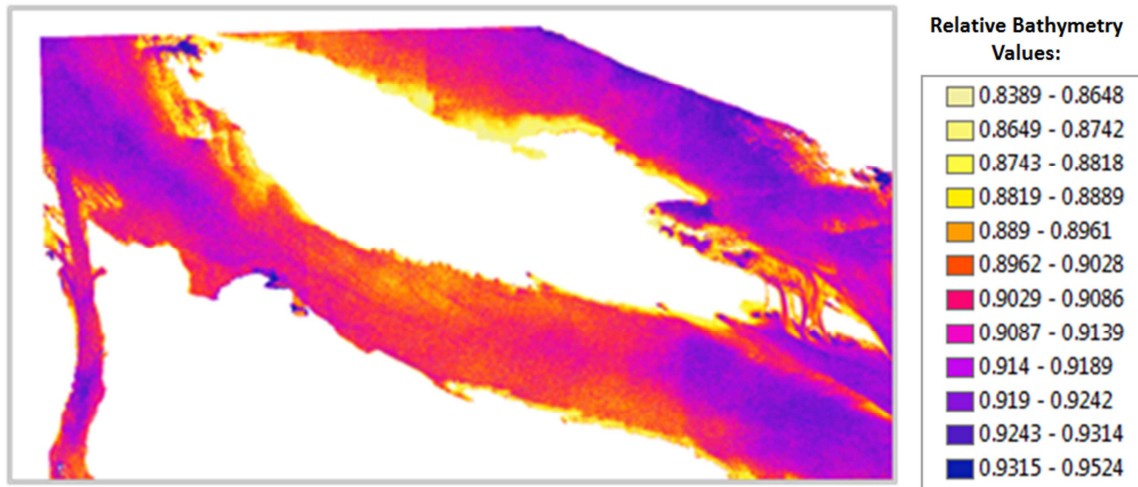


Figure 1. Relative bathymetry of Coastal blue and yellow band reflectance.

3.2.2. Filtering the Relative Bathy

The reflectance is always contaminated by the atmospheric particles (Water vapor, dust, gases, etc.) Therefore, the effects of atmospheric components remain a noisy data is not impossible. The low pass filtering may be applied to eliminate noise data of the relative bathymetry to enhance the data quality.

3.2.3. Determine Absolute Bathymetry

Based on the direct surveyed bathymetric data, calibration has been performed of the relative bathymetry to estimate the absolute bathymetry. The calibration factor m_1 and offset m_0 of the equation 2 has been determined using an optimized best fit curve plotted to estimate the absolute bathymetry. A linear regression between relative bathy (reflectance ratio of CB & Y bands) and the actual depth of different transects have been plotted. Among them the linear regression of the transect ID XS-03 (Ganges River) has been selected based on high correlation values found in this section. The obtained equation from the linear regression is $y = -110.3X + 97.96$. Therefore, calibration factor, $m_1 = -110.3$ and offset, $m_0 = 97.96$. X is the relative bathymetry results.

The following Equation has been used to determine the absolute bathymetry while the component of the equation has described earlier in in Equation 2.

$$Z = m_1 \frac{\ln(nR_w(\lambda_i))}{\ln(nR_w(\lambda_j))} - m_0 \quad (3)$$

The direct bathymetry survey has been conducted of the Ganges River during November 2012 to March 2013. For the Gorai river direct bathymetry survey has been conducted on 6th February 2013 while the investigated area worldview-2 remote sensing imagery was acquired on 5th February 2013. IWM provided bathymetry data including point position corresponding to the river bed elevation of the Ganges River.

Therefore, based on the recorded time series water level data of the study area the water depth has been calculated for the date of 5th February 2013 on the Ganges River.

3.2.4. Analyzing Relative Bathymetry

Different Band ratio has been used to estimating the relative bathymetry using the Equation 2. Among three band combinations, Coastal blue/Blue, Coastal Blue/Green and Coastal Blue/Yellow, the costal blue/Yellow band ratio fount high correlation between relative bathy and actual depth.

3.2.5. Analyzing Linear Regression Curve

The linear regression between relative bathymetry for the band ratio Coastal blue and yellow band in different transect has been plotted for both the Ganges and the Gorai River. The linear regression curve at transect ID XS-03 is optimum fit curve which R-squared value is 0.72. Therefore, the coefficient of the linear regression equation of transect XS-03 have applied for estimation absolute bathymetry. An R-squared value varies between 45% to 72% among the all transects of the study area.

3.2.6. Absolute Bathymetry Analysis

The estimated absolute bathymetry calculated from the relative bathymetry by using the calibration factor and offset values obtained from the linear regression equation. The absolute bathymetry Equation have described in equation 2.

3.2.7. Absolute Bathymetry Compared to the Actual Bathymetry

It is visualized that the derived bathymetry from the Worldview-2 Remote sensing is fairly good except a particular segment of the Ganges River. The segment is flow dominating channel during the period. Based on actual depth the estimated water depth has been classified in three classes considering the quality achieved. i) Satisfactory result; ii)

Reasonable and iii) Not-satisfied result. Comparison DEM and foreground colored transect lines shown all three classes result. The transect lines with blue color is satisfactory result, the transect line pink color is represented reasonable results and the transect lines red color represent not satisfied results. Same color transects lines used as overlay for both actual and estimated DEM in order to easily identify DEM location. The Ganges river flow dominating segment shows that the water

depth is maximum 16 m while the estimated water depth is 2-3 m. Nevertheless, remaining areas of the study area the estimated water depth is satisfactory or reasonable. It is assumed that the particular channel segment is with high water velocity, contaminated by the suspended sediment which may not be suitable for light wave water penetration during the time of image acquisition.

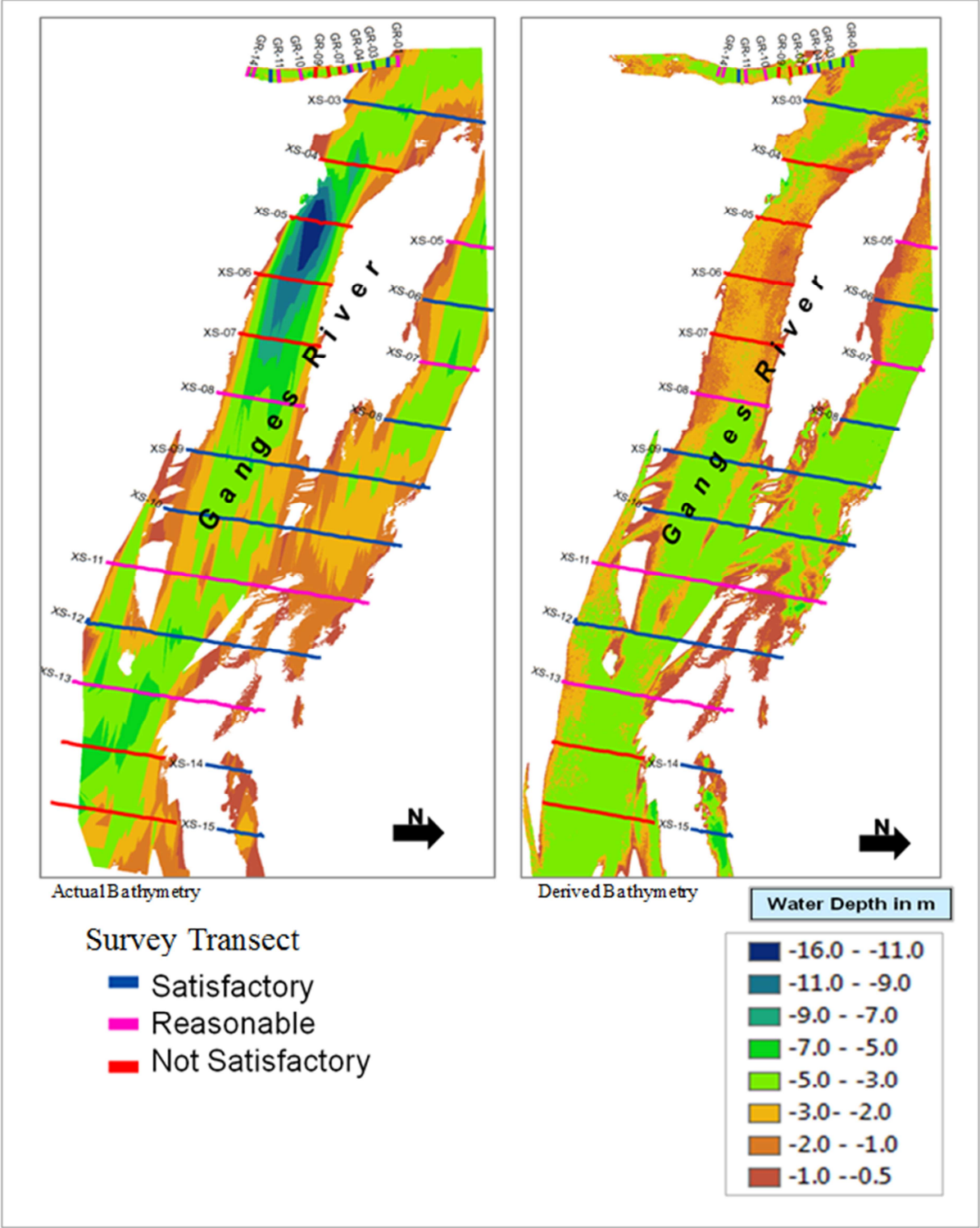


Figure 2. DEM comparison between actual Vs estimated bathymetry.

Following superimposed cross sections profiles between actual and estimated water depth one can visualize the quality achievement of Worldview-2 remote sensing bathymetry mapping for all three classes (satisfactory, reasonable and Not-satisfied results) of the Ganges river as well as the Gorai River. The dark blue color points denoted actual water depth and the pink color are derived depth.

4. Mapping Challenges and Contributing Factors

The challenges that effect the results such as evaluation of atmospheric correction, because in the lower portions of the atmosphere where larger particles like water vapor, dust, pollen, salt partials are more abundant which are causes of Mie Scattering and affect the actual earth surface reflectance. Hence, the proper atmospheric correction is necessary at the preprocessing steps. Farther more, the impact of suspended sediment concentration and water velocity can be analyzed for more satisfactory results. Sun glint, Wave crest may also deviate results. In the ratio method, two different wavelengths were used instead of two different spectral reflectance from different albedo, which may misinterpret the phenomenon. Hence, the ratio of the reflectance of the two bands will remain unaffected with the change of albedo types over different substrates at the same depth. Both types of methods are limited in that it is very difficult to calibrate the detected depth. All analytical models require radiometric calibration to account for the atmospheric effect irrespective of their specific format. The analytical implementation is more accurate, but very complex, and requires the input of more parameters related to the water and even the atmosphere. Thus, it is highly complicated, but can yield highly accurate bathymetric information. By comparison, Ratio is much simpler and easy to use. This regression-based model is able to take into account the local set of conditions of the study area, and the atmospheric effects on the electromagnetic waves path in its structure [7]. Therefore, it is not always vital to calibrate the remote sensing imagery radiometrically.

The varied optimal wavelengths are explained by water clarity and the sensing environments. In pure and clear waters, little backscattering takes place and radiation is able to penetrate the deeper water. Nevertheless, the short wavelength algorithms advocated for bathymetric measurements in clear water cannot be applied to turbid productive waters. Turbid waters shift the optimum wavelength of sensing bathymetry towards longer radiation, away from the vicinity of $0.45 \mu\text{m}$ that tends to have the maximum penetration in clear waters [8] (Siegal and Gillespie, 1980). In this environment, water depth is strongly correlated with the red band of the $0.746\text{--}0.759 \mu\text{m}$ range, but not the blue end of the spectrum [9].

The accuracy of the retrieved water depth is subject to the influence of the sensing environments, atmospheric absorption and scattering, water surface conditions (e.g., roughness,

waves and currents), scattering by in-water constituents, and substrate reflectance properties that might affect the characteristics of the returned electromagnetic radiation. In addition to image properties, the accuracy of remotely sensing bathymetry is affected by a variety of water-related factors, such as water clarity, attenuation, depth, bottom reflectance if present, and bottom materials. The retrieved bathymetry may be made more accurate by considering a number of relevant factors. For instance, errors are reduced considerably after correction for the solar and view-angle effects [10]. Mapping can also be made more accurate by taking into account water quality and bottom reflectance.

4.1. Accuracy

In bathymetric mapping, the most accurate results reported so far have a standard error of 0.648 m [11]. The accuracy of optically sensing bathymetry is subject to image spatial, spectral, and radiometric resolutions that may have a confounding effect. The spatial resolution of early systems is too coarse for bathymetric mapping, especially over shallow estuarine environments. Contemporary sensing systems (having a spatial resolution measured in meters) hold great potential for the derivation of accurate bathymetric data. Regression of logged depth bands yielded an R^2 value over 0.87 (Muslim and Foody, 2008), much higher than the maximum R^2 value of only 0.35 achieved from MSS and TM bands of $30\text{--}79 \text{ m}$ resolution [12]. This suggests that a finer spatial resolution is conducive to more accurate bathymetric information. On the other hand, the inverse depth had a correlation coefficient of 0.56 with TM band 1 (30 m resolution), but only 0.51 with band 1 (20 m resolution) [13]. The best results obtained from the Geophysical Environmental Research Hyperspectral Imaging Spectrometer data have an r of 0.974 with water depth, highly similar to simulated Landsat TM ($r = 0.964$) [14]. Thus, a fine spectral resolution is not always critical in generating highly accurate bathymetric information.

4.2. Impact of Water Turbidity

Water turbidity is the most important factor affecting the accuracy of optically sensed bathymetry. Turbidity obstructs the path of electromagnetic radiation, and reflectance from suspended particles becomes confused with bottom reflectance. Waters of different turbidity levels scatter the incoming radiation differently. Both the form and accuracy of the empirical model are affected by water turbidity that exerts a varying impact on the accuracy and depth of remotely sensed bathymetry. On the one hand, it enables sensing of depth in highly turbid Case waters. On the other, it considerably lowers the detectable water depth. The regression relationship varies slightly with water clarity [9]. Thus, the same regression model established from turbid waters cannot be applied to clear waters. In fact, if water turbidity is rather low (e.g., clear water), the results could be encouraging from TM data [15]. If the water has too high a

turbidity, the sensible depth will be drastically reduced. The depth of highly turbid water is difficult to determine by the optical bathymetry method [16]. The influence of turbidity on depth measurements can be compensated for by applying a correction factor to the reflectance [17].

4.3. Impact of Water Depth

Bottom reflectance is the reflectance from the sea floor that is not indicative of water depth directly. It occurs in shallow waters or in relatively deep clear water when the solar radiation is able to penetrate the water column to reach the floor. The exact depth at which bottom reflectance ceases, however, is a function of the in-water constituents and the sensing wavelength. Depth-independent bottom reflectance can be retrieved from remote sensing reflectance using bathymetry and tables of modelled water column attenuation coefficients [18]. Bottom reflectance is a major factor in comparison with water column scattering in the radiance emergent from water in very shallow and turbid waters. This enables the development of a water column scattering based remote bathymetric model which can be applied to turbid and deeper coastal waters [17]. Bottom reflectance must be factored in by radio metrically modifying the reflectance prior to regression analysis. Bottom reflectance is related to bottom type. The regression coefficients deteriorate with mixed bottom types because the variability in brightness values from a heterogeneous bottom has a deleterious effect on the correlation coefficient. A uniform type of bottom reduces this variability and leads to a strong correlation between depth and brightness value, thus improving the accuracy of estimated depths [19]. In order to guarantee the validity and accuracy it is imperative that separate models be constructed for differing types of floor material. The best way of handling bottom reflectance is to measure it and then subtract this from the total reflectance if the water insufficiently clear. More precise processing involves retrieving depth-independent bottom reflectance from the sensed reflectance using bathymetry and tables of modelled water column attenuation coefficients [20]. Otherwise, a scattering coefficient needs to be applied. One method of ascertaining the relative substrate reflectance is to exponential influence of depth in each pixel of multi-spectral imagery under a mathematical constraint [21]. Derivation of bathymetry from multi-spectral data is problematic if the substrate reflectance varies appreciably [22]. This requires the removal of the distorting influence of the water column on the remotely sensed signal with the assistance of the mechanistic radiative transfer approach [23]. The superimposition of substrate reflectance from multi-spectral bands allows the distinction of different bottom materials.

5. Conclusion

There are two broad types of methods used in the remote sensing of bathymetry linear & Ratio Method. The former method is able to detect spot heights at sensed points, but this method did not find wide applications until recently due to

technical constraints of low sampling density and slow scanning. The successful overcoming of these limitations, in conjunction with the use of kinematic GPS, has considerably increased the popularity of this method. This method has the advantage of being able to detect a large range of depths up to 70 m in clear open waters at accuracy close to 15 cm. Depth determination performed in two steps, relative depth and absolute depth. The linear regressions between relative depth and actual depth obtain the factor and offset to produce the predicted bathymetry. A statistical analysis has been performed in order to assess coastal blue and yellow band reflectance ratio. The correlation between ratio result and actual depth of Coastal blue and yellow is in between 0.6 and 0.8 all through the study area. Among these sections a single cross section has been used for ground truth (XS-03 on Ganges River) where correlation value was 0.8 between relative depth and actual depth. The important challenges is atmospheric correction, because in the lower portions of the atmosphere where larger particles like water vapor, dust, pollen, salt partials are more abundant which are causes of Mie Scattering and affect the actual earth surface reflectance. Hence, the proper atmospheric correction is necessary at the pre-processing steps. Furthermore, the impact of suspended sediment concentration and water velocity can be analyzed for more satisfactory results. Sun glint, Wave crest also deviate results. This analysis will be important both for the purposes of monitoring underwater topography and movement of deposited sediments, as well as river monitoring, River morphological analysis.

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