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Bathymetry Mapping of Hikkaduwa Coral Reef Using Multispectral Satellite Imagery

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Abstract - **In previous era, bathymetry was determined by using conventional methods which retrieved the depth at a single point at one time. Later it was developed to many kinds developed systems which can determine water depth more accurately, but high in cost. In recent years, with remote sensing data it can be easily map at shallow water areas up to 25m. The idea behind this method is to use the reflection intensity of the various wavelengths captured by the satellite sensors. The ENVI Suite Relative Water Depth Tool empowers to create an item with relative water depths rapidly. As they do not appear actual depths (the relative depths are scaled from zero to one), the water depth comes about are relative, and the purpose is to deliver a large feel to the area's bathymetry. The yield must still be calibrated to field information to assess real depth. While coral reefs are found in Sri Lanka, the reefs around Hikkaduwa are among the most diverse and accessible which has a typical fringing coral reef with a shallow crest. The reef has suffered high degradation due to both natural and human activities. According to analysis, due to the relative significance changes of bathymetry comes about from the today, the coral reef has, by comparison, changed around 48.5% over the past 25 a long time (1995 to 2020) due to both natural and human exercises. By summarizing the real values for each bathymetry outline, it can be analyzed that between 2002 and 2019, the coral reef debased by roughly 5%, depending on the increasing of average depth within the study area. This has led to the creation of a new tool for the use of multispectral satellite image data to map shallow water bathymetry, referred to as satellite derivatives bathymetry. And there is no data available for evaluation to be used to assess the performance of the satellite-derived models. And with the lack of high resolution and undisturbed (i.e. without cloud disturbances) multispectral satellite imageries, it limits the derivation of bathymetry data.**
Keywords: **bathymetry, remote sensing, shallow water, multispectral, coral reef**

I. INTRODUCTION

The Hikkaduwa coral reef or National Park consists of a network of fringing reefs around the southern area of the island, specifically near the city of Hikkaduwa. The average depth of the reef is about 16 feet, perfect for coral growth as they harbour photosynthetic algae inside[1]. However, the popularity of Hikkaduwa has often been its greatest enemy, and irresponsible tourism has resulted in significant damage to the reef [2].

Estimation of the current situation of the coral reef can be achieved by referring the bathymetry maps. Bathymetric maps can be prepared using lots of conventional ways by measuring water depth using hydrographic surveying. In addition water depth can be extracted from the reflectance values of satellite images [3][4][5].

Remote sensing approach has more advantages because of the less time and cost consuming for the smaller scale studies[6]. Sensing instruments are not carried by a vessel, so that these techniques can be used in any type of water surfaces, although it cannot be reached by humans such as on-board depth measurement instruments [7][8]. There are various algorithms to determine depth at shallow water areas with different parameters. Stumpf *et al.* (2003) developed a water depth extraction model with use of two bands in order to reduce the number of parameters to determine bathymetry of the ocean[4]. With remote sensing data, it can be easily map at shallow water areas up to 25m[9].

II. METHODOLOGY

A. Data Requirement

In this process, optical images from Landsat 5, 7 and 8 (spatial resolution of 30m), and optical images of Sentinel 2 (spatial resolution of 10m) were used. It was needed several satellite images acquired in the desired time period. To determine the relative degradation of the coral reef six satellite images from Landsat series were used.

1. 17.01.1995 – Landsat 5 TM
2. 23.01.2000 – Landsat 7 ETM
3. 12.01.2005 – Landsat 5 TM
4. 26.01.2010 – Landsat 5 TM
5. 08.01.2015 – Landsat 8 OLI TIRS
6. 06.01.2020 – Landsat 8 OLI TIRS

To make the bathymetry maps with using existing bathymetry data, another four satellite images from Landsat and Sentinel series were used.

1. 13.02.2002 – Landsat 7 ETM
2. 17.03.2002 – Landsat 7 ETM
3. 30.07.2019 – Landsat 8 OLI TIRS
4. 17.11.2019 – Sentinel 2A

To calibrate the relative depths to actual depths, true depth values as mentioned below were used.

1. Bathymetry map issued by NARA (The National Aquatic Resources Research and Development Agency) which was created with surveying data collected from 07.02.2002 to 14.02.2002
2. The General Bathymetric Chart of the Oceans (GEBCO) 2019

For the tidal correction tide data of the study area at time when satellite image was captured is needed.

A. Study Area

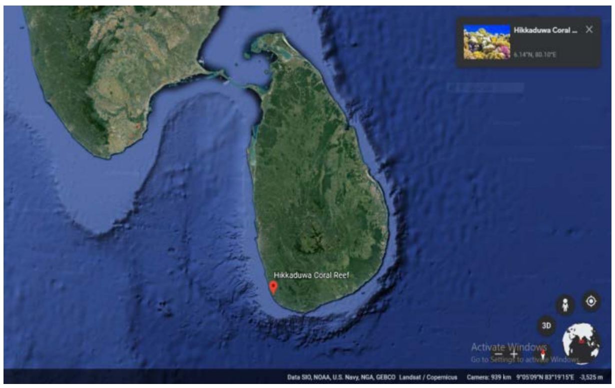

Fig 1 Study Area - Google Earth images showing Hikkaduwa costal area

The study area of this researchis Hikkaduwa coastal area (around 6 ° 8' 22.0848" N and 80 ° 6' 22.6260" E) with a high degree of biodiversity fringing coral reef. It is a coastal area near shore, with low tidal range.

B. Multispectral Satellite Images

A multispectral image captures the image data in a range of wavelength across the electromagnetic spectrum. Filters can separate or detect wavelengths using instruments susceptible to specific wavelengths, including light from frequencies outside the visible range of light, i.e. infrared and ultraviolet[10].

C. Atmospheric Correction

When solar radiation is transmitted to the earth, it is absorbed or dispersed by the atmosphere. The reflected energy from the target is absorbed or dispersed before reaching a sensor by the atmosphere[11].

D. Relative Water Depth

The SPEAR Relative Water Depth tool allows users to produce a product with relative depths quickly. This tool uses Stumpf and Holderied's (2003) Bottom-Albedo-Independent Bathymetry algorithm[4].The results of the water depth are related, since they do not display absolute depths (results are scale from zero to one), and their purpose is to give the bathymetry in the area a general feel. Relative water depth images can be generated and exported for use in reports or briefings in graphical files.

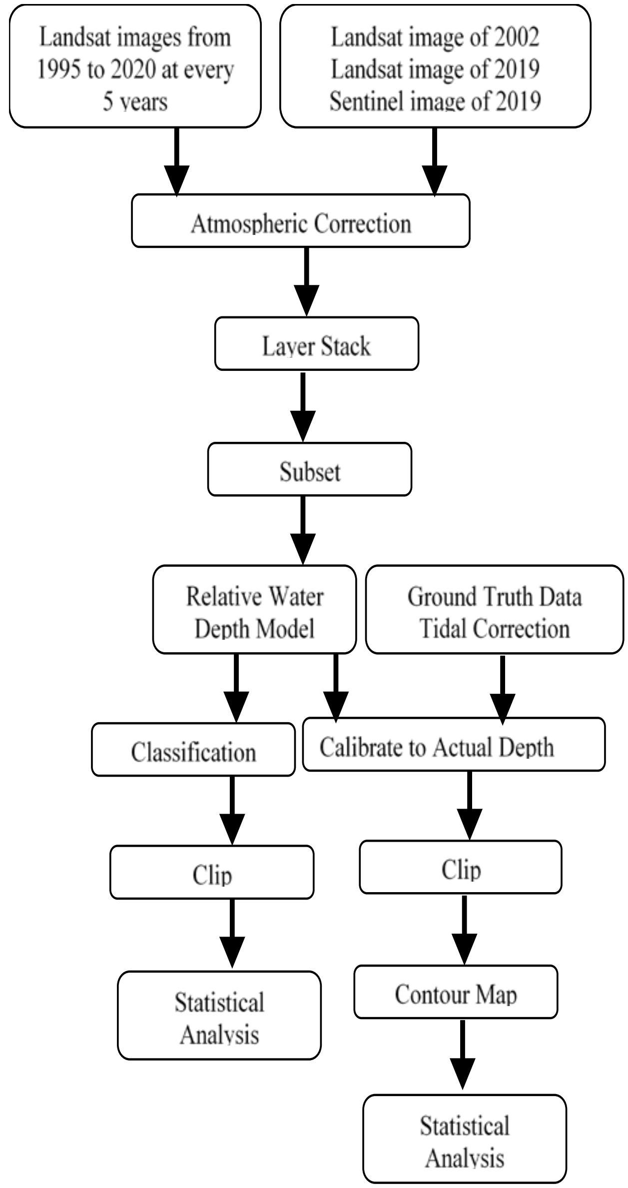

Fig.2 Methodology of the Research

III. RESULTS

Final bathymetry data derivation is done by using corrected satellite images. Derived depth information are visualized in a raster image, which represents depths by pixel values. In this study to gain primary results Relative Water Depth Index (RWDI) model integrated in ENVI software which is developed byStumpf and Holderied (2003)[9].

This model follow the fundamentals of water absorptivity vary spectrally from band to band. As the depth increases, the reflected irradiance decreases faster in the high absorptive spectral band (greenband) than in the low absorptive band (blue band). Based on that, developed a reflectance ratio model as in Equation 1.

$$Z = m_1 \frac{\left(\ln n\, R_w(\lambda_i)\right)}{\left(\ln n\, R_w(\lambda_j)\right)} - m_0$$

R_w is the observed reflectance of the wavelength for bands i and j, the ratio of which forms the basis for depth extraction. The blue (λ_i) and green (λ_j) bands were used for the ratio input as they have the greatest penetration though the water column. The constant, n, is a fixed value, chosen to keep the ratio positive given any reflectance value input.

A. Comparison of the Coral Reef from 1995 to 2020 by Depth Variation with the Relative Water Depth Measurements

So without estimating values for m_1 and m_0, the relative depth can be estimated. Then the relative depths vitiated with the input reflectance values and the wavelength of each band. Reflectance is the ratio of the amount of light leaving a target to the amount of light striking the target. It has no units. Below figures (figures from 3 to 8) show the classified relative water depth maps from accumulated results.

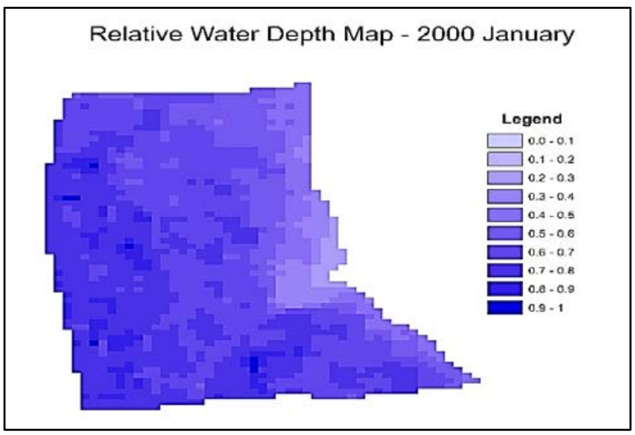

Fig.3 Relative Water Depth Map 1995 January

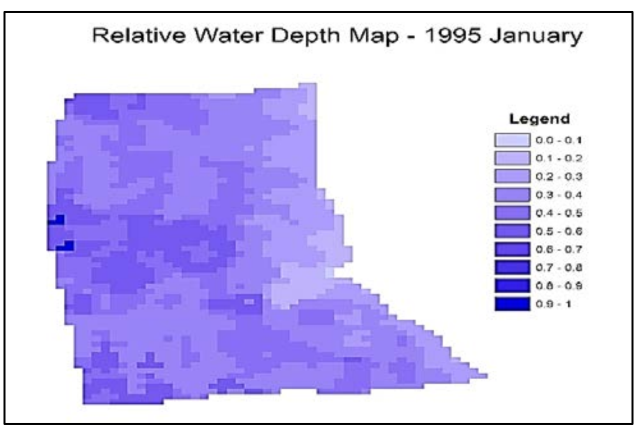

Fig. 4 Relative Water Depth Map 2000 January

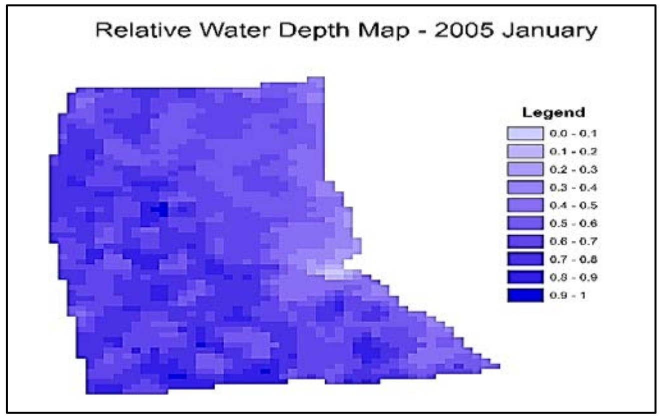

Fig.5 Relative Water Depth Map 2005 January

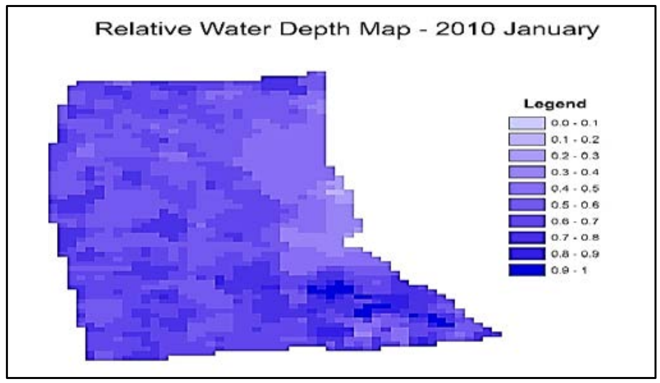

Fig.6 Relative Water Depth Map 2010 January

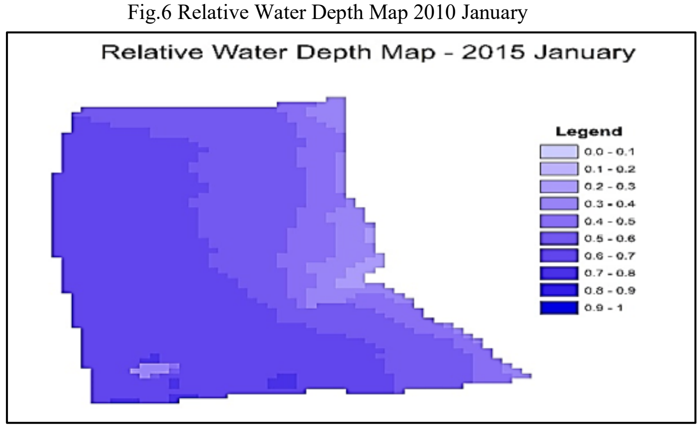

Fig. 7 Relative Water Depth Map 2015 January

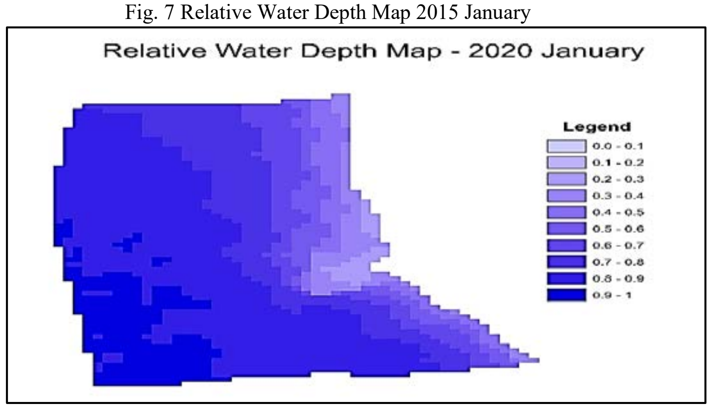

Fig. 8 Relative Water Depth Map 2020 January

B. Statistical Analysis of Degradation of the Coral Reef by Relative Depth Measurements

It can be analysed the relative water depth values over the study area statistically to get a numerical decision about the degradation of the coral reef by depth variation.

TABLE I STATISTICAL SUMMARY OF THE DERIVED RELATIVE WATER DEPTH VALUES

Bathymetry Map	Minimum Value	Maximum Value	Mean Value
1995 January	0.087238	1.000000	0.388792
2000 January	0.240058	0.925200	0.651051
2005 January	0.000000	0.995641	0.641442
2010 January	0.199866	1.000000	0.606689
2015 January	0.263008	0.722601	0.572290
2020 January	0.226402	0.944629	0.754028

C. Comparison of the Coral Reef between 2002 and 2019 by Depth Variation with the Actual Water Depth Measurements

Bathymetry maps with actual water depth values can be used to analyze the degradation of the coral reef area by variation of the actual depth values over the study area. Final results are classified for visualization as below (see figures from 9 to 12).

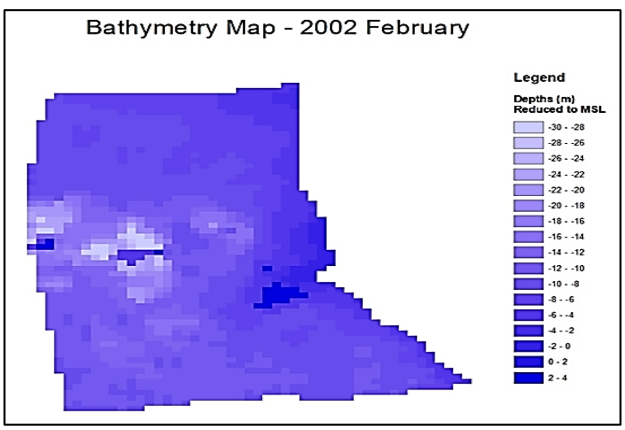

Fig. 9Actual Water Depth Map 2002 February

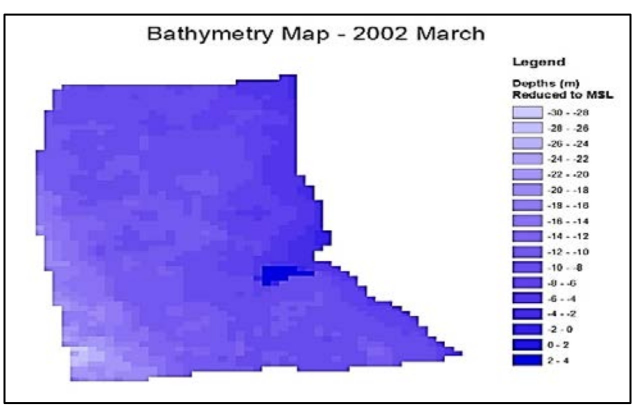

Fig.10 Actual Water Depth Map 2002 March

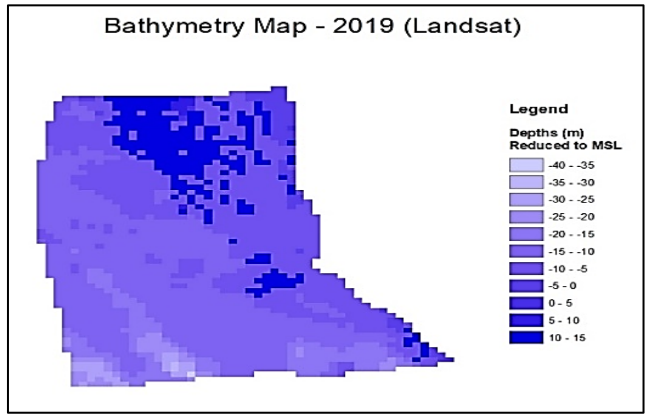

Fig.11 Actual Water Depth Map 2019 created with Landsat Satellite Image

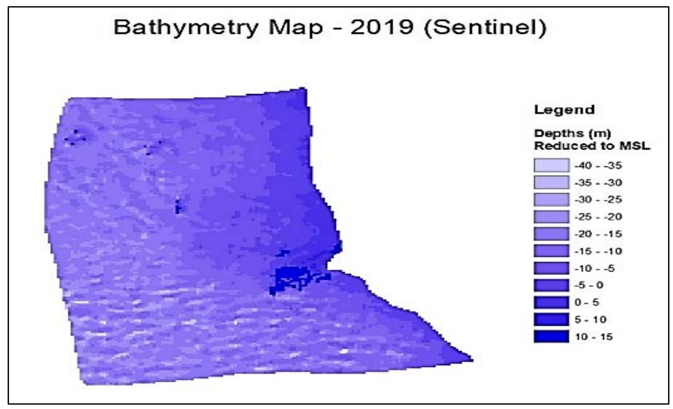

Fig.12 Actual Water Depth Map 2019 created with Sentinel Satellite Image

D. Statistical Analysis of Degradation of the Coral Reef by Actual Water Depth Measurements

In order to achieve a numeric decision on the degradation of the coral reef by depth variation, the values of actual water depths above the study area can be statistically examined.

TABLE II STATISTICAL SUMMARY OF THE DERIVED ACTUAL WATER DEPTH VALUES

Bathymetry Map	Minimum Value (m)	Maximum Value (m)	MeanValue (m)	Average Value of Mean Values (m)
2002 February	-28.78	2.88	-9.71	-9.90
2002 March	-28.66	2.88	-10.09	
2002 NARA	-21.00	2.00	-8.00	
2019 Landsat	-38.34	11.59	-8.18	-10.43
2019 Sentinel	-38.04	11.89	-12.7	
2019 GEBCO	-15.52	6.29	-8.53	

IV. DISCUSSION

The mapping and remote sensing services to acquire bathymetry data using multispectral satellite images seen in this case study can be used to provide benefits in different activities engaged with different purposes.

Optical satellite images obtain water depth information by analyzing marine floor spectral change. For shallow near shore waters, this approach is very effective. The idea behind this method is to use the reflection intensity of the various sunlight wavelengths captured by the satellite sensors. Two major developments in technology advanced this method further; firstly, an increased satellite resolution that allows for an adequate level of detail in the mapping of seashore and, secondly, the development of standardized and workflows

According to the relative and actual water depth results of the analysis it emphasizes that the current average depth of the study area in 2019 is about -10 meters which has been increased about 1 meter relevant to depth values of 2002. That means according to the increment of the depth values, degradation of the coral reef is about 5% in past 17 years from 2002 to 2019. According to relative water depth values coral reef's estimated degradation from 1995 to 2020 is about 40%.

Because of both human and natural activities are caused for this degradation. El Niño in 1998 and Tsunami in 2004 is the most affected natural events happened in past 25 years. Then because of the huge tourists attractions also been caused for the degradation of the coral reef. Glass bottom boats and walking of the divers mostly caused for the damages. Then other environmental pollution factors also affect the subsidence of the coral reef.

If the current procedure is happened for a long time in the future, coral reef may be completely destroyed within next 50 years. So then we should minimize the factors caused for the degradation of the coral reef. We can use safe tourism ways to watch beauty of the coral reef. Then we can replant the coral reef and make it a better place for various kind of water and plant species. Different government and private organizations take several precautions to conserve the coral reef.

In order to support various applications, such as navigational safety and recognition surveys, coastal zone management, or hydrodynamic modelling, bathymetric data are increasingly important in the low water area. A gap between data demand, costs and the ability to map with ship and airborne sensors has been identified. This has led to the creation of a new tool for the use of multispectral satellite image data to map shallow water bathymetry, often referred to as satellite derivatives bathymetry.

Limiting factors of bathymetry by satellite means how clearly and precisely the ocean floor is visible from space. Usually it means that only depths are resolved until the light is extinguished. Light extinguishing depth is about 20-30 meters under optimum conditions. In addition, all satellite derived bathymetries may be limited in shoreline areas with lots of bloom, suspended sediments or intense wave action. However, under the correct conditions, derived satellite bathymetry directly addresses the problems of coastal bathymetric mapping.

It is important to remember, that there is no data available for evaluation to be used to assess the performance of the satellite-derived models of bathymetry and sites for which adequate satellite and field information is available in conjunction with the development and evaluation of models are scarce. Consequently, it is difficult to estimate estimates of seafloor topography extrapolated from multispectral satellite data across broader regions.

And with the lack of high resolution and undisturbed (i.e. without cloud disturbances) multispectral satellite imageries, it limits the derivation of bathymetry data. And it is remembered that there are no multispectral satellite for free to gain results for any area covering the earth surface.

V. CONCLUSION

The methodology adopted in Stumpf and Holderied[9] was used for the calculation of the relative radiance of the satellite data. The ENVI Suite Relative Water Depth tool was used to extract the log ratio from the green and blue ribbons. In order to calculate satellite derived relative depth (SDRD), the algorithm uses a ratio of observation reflectance and two constants. The output must still be calibrated to field data to estimate actual depth. Therefore, the maximum depths are of 1 if the green is more reflective than the blue band. It emphasizes that deeper areas have greater reflection than shallow ones due to the higher reflectivity of the wavelength water surfaces according to the spectrum of the reflectance. By relative water depth results it emphasize that, the average relative depth value has increased rapidly between 1995 and 2000 (from 0.388792 to 0.651051). It highlights the increase in profundity and significantly the destruction of the coral reef relative to the study area's maximum average profile. Then from 2000 to 2005 (from 0.651051 to 0.641442), the mean relative depth value has been reduced. It emphasizes that due to its growth or sedimentation of the area studied, the depth is reduced and the coral reef has been changed. The profound variation compared to others between 2005, 2010 and 2015 has been substantially small. But the mean relative depth value is rapidly increased in 2020 (0.754028). This results in an increased relative depth of the study area and the destruction of coral reef by various factors. Finally it can say that from 1995 to 2000 coral reef has been degraded around 40.4% and from 2000 to 2005 coral reef has been differentiated about 1.5%. Comparably through the previous 25 years (from 1995 to 2020) coral reef has been changed about 48.5% according to the relative depth measurements variation from the satellite derived bathymetry results. According to the average actual depth value has overall increased from 2002 to 2019 (from 9.901060m to 10.43474m). It emphasizes the increase in depth and the destruction of the coral reef. Finally, the coral reef was degraded between 2002 and 2019 by around 5%, based on the average satellite derived depth in the study area. With the actual bathymetry data it can say that depth of the study area differentiate from -8m to -8.5m and the coral reef was degraded around 5.5%. As Landsat image has a spatial resolution of 30m, it shows a smaller variation in range of depth values and Sentinel image has a spatial resolution of 10m it shows a larger variation in range depth values. That emphasize that the most accurate results can be acquired with high resolution cloud free satellite images.

VI. ACKNOWLEDGEMENT

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