Monitoring Water Quality Parameters in Trivandrum Coast, Kerala using Sentinel Images

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Abstract: **Remote sensing has been played an important role in water quality monitoring. The Physiochemical parameters of water like Suspended sediments and Turbidity are an important determinants of water quality in coastal zones. Total suspended solids will increase the turbidity of water, which can affect the water quality. Turbidity is that just a cloudiness of fluid. Various parameters causing turbidity are phytoplankton, sediments from erosion, resuspended sediments, waste discharge, algae growth, urban runoff etc.Then,the naturally occurring events like storms, river flows, waves ,tides and activities like fishing, shipping and dredging operation also cause turbidity. This study aims to develop and implement regression models for estimating and mapping TSS and Turbidity concentrations from Sentinel 2A and 2B satellite images over the Trivandrum coast,Kerala.Concurrent complementary in-situ data for Turbidity were collected based on different latitude and longitude. By the collected turbidity values, TSS values can be determined. Using the secondary satellite data, giving latitude and longitude of field data and extracted reflectance values of each band and then regressed with their respective field data of TSS and Turbity.An algorithm was proposed to obtain the regression coefficient. This algorithm can beused to estimate the TSS and Turbidity concentration with a high correlation coefficient(R^2=0.86) for Turbidity and (R^2=0.82) for TSS. Finally, The map of Turbidity and TSS concentration was generated by using the proposed algorithm. This study found that TSS and Turbidity mapping can be conducted by using sentinel 2A and 2B images over the coast of Trivandrum ,Kerala. The predicted result from Sentinel 2A and 2B imagery exhibit that the predicted TSS and turbidity has a close agreement with the field data with the high R^2 values. Then, TSS and turbidity mapping has been done for validating the results with the in-situ data of turbidity (October 21, 2018 and November 10 and 15, 2018) and got 94% accuracy with mean difference error value of - 0.12903.**

Keywords: TSS, Turbidity, Sentinel 2A, 2B imagery, Flood, Trivandrum coast, Regression analysis and Validation.

1. INTRODUCTION

Water is an important major source for all living organisms in this world. When water quality is get poor,it affects not only the aquatic life but also surrounding ecosystem as well. A major key factor affecting water quality in coastal waters is the suspended sediments concentrations, which causes non-point source pollution in the area(Guan et al.2011).Turbidity is an optical property of water and describes the transparency of the water. It occurs in lakes, rivers and oceans. Turbidity isnot itself a pollutant ,but it indicates, how much sediment and organic matter present in the water. High turbid ocean waters have a large numbers of particulates like sediments and phytoplankton which reduce the visibility of the water. In addition, turbidity caused by humans also. These anthropogenic causes may originate from waste water discharges to beam trawling, propeller wash resulting from shipping as well as re-suspension caused by dredging.

Total suspended matter such as clay, silt and organic matter, as well as plankton and other microscopic organisms interfere with the passage of light through the water and thus cause turbidity.Although total suspended solids(TSS) and turbidity are not same.TSS is a measurement of the non-dissolved solids which are suspended in water.TSS is measured in mg/l. Turbidity is an optical property which scatters and absorbs the light rather than transmit it in a straight line. Turbidity is affected by TSS,but it also determined by the shape of particles, size distribution, refractive index, color and absorption spectra. TSS absorb more heat from solarradiation than water molecules. So, it increases water temperature and decreases DO (Dissolved Oxygen).

Various models have been used to correlate water quality in Remote Sensing measurements. Remote sensing studies on coastal waters have generally used regression analysis of satellite data and simultaneous measurements of field data. In the present study, the regression model was developed based on the reflectance value of all bands and the field TSS and Turbidity data. Then the algorithmwas proposed for both TSS and turbidity mapping.

2. STUDY AREA

The study area is the south-west coast of Kerala, Thiruvananthapuram **Figure 3.1.**The geographical coordinates of Trivandrum i.e. latitude and longitude is 8.524139ºN and 76.9770813ºE respectively. Kerala’s coast runs some 580 km in length and it varies between 35- 120km in width. The study area covers the Kovalam, Vizhinjam, Pachaloor, Shankumugham, Mulloor, Poovar, and edapaddu.The coastal Zone of Kerala is well known for its rich fisheries, placer mineral deposits, water resources, transport facilities and excellent backwater systems. Kovalam is a small coastal tourist village.it having the small sandy beach protected by rocky regions. Vizhinjam is known for its large harbor with rocky coast. Chowara beach is with sandy coast and Azhimala beach having rocky coast. Poovar beach with nice golden sand, very long and clean, only beach in kerala with sea on one side and river in other side. Due to the industrialization or the urbanization, terrestrial runoffs and tourist activities etc., where the large amount of sediment is introduced in Trivandrum coast and the adjacent areas.

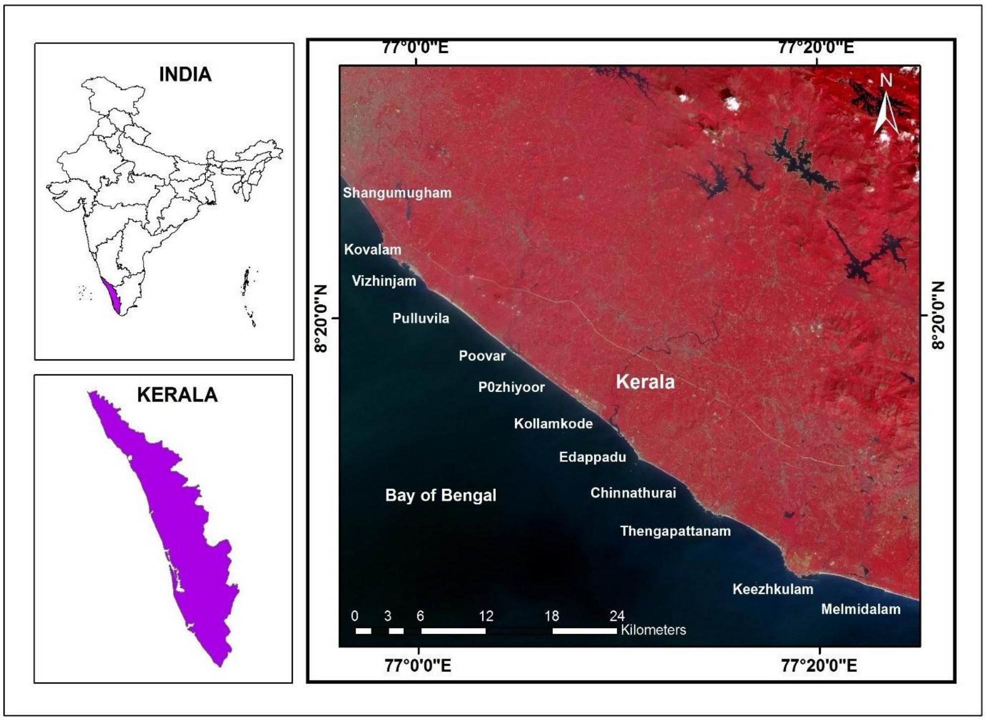

Fig 1. Base Map of Study Area

3. REVIEW OF RELATED WORKS

M.Moussavi Alashloo et al. (2012) estimated the total suspended sedimentsmapping by using ALOS imagery on 16 February 2010 over the coastal waters of Langkawi Island,Malaysia.This study aims to develop and implement regression models for estimating and mapping TSS concentrations.An algorithm was developed based on the water reflectance model.The in-situ sample of suspended sediment concentration was collected over the study area based on using handheld GPS(Global Positioning System)on 16 February 2010.Statistical techniques were used ,the extracted reflectance bands of satellite imagery were regressed with the in-situ TSS data by using SPSS 19.This study successfully applied a cost-effective method to obtain remote sensing data from the ALOS for remote sensing analysis and then the proposed algorithm proved to be a useful tool for water quality mapping in coastal water areas.

Saumi Syahreza et al. (2011) estimated the monitoring of Surface Water quality in Coastal area of Penang.They have used the Landsat TM data.Reflectance model was used.The digital numbers for each band corresponding to the sea-truth locations were extracted and converted into radiance and reflectance values.The algorithm was developed from optical model of water.The TSS algorithm produces high R and low RMS values.The water quality maps were prepared by using the TSS algorithm. The water quality image was geometrically corrected using the Cubic convolution method and smoothened to remove random noise.

Midyan D.I. Aldabash et al (2016) have analyzed the multi temporal satellite imagery for total suspended sediments in a Wave-Active Coastal area –Gaza strip Coastal water, Palestine.In this study,two Landsat TM5 images of 1999 and 2010 were used and then Landsat TM7 images of 2003,and 2014 and 2015 images of Landsat 2Oli were used for TSS mapping.Then 64 TSS in-Situ tested samples were used to calculate a correlation equation between DN in each image pixels and TSS values in the ground data.They used Linear Regression mathematical equation for highest correlation value.By this,TSS maps were generated by ILWIS 3.3(IntegratedLand And Water Information System) software.

Robabeh Asadpour et al (2012) have analyzed a statistical model for mapping of spatial distribution of TSS(Total Suspended Solids) from THEOS satellite imagery over Penang Island,Malaysia.Water samples were collected on 12 November 2009 from 13 sampling stations and location noted by using handheld GPS.Then satellite image was geometrically corrected.Reflectance values extracted corresponding to the in-situ location and TSS algorithm was developed based on high correlation .In this study, regression equation was calculated by using SPSS 18.0 statistical analysis and TSS maps were generated by PCI Geomatica 10.3 software.

T. Hariyanto et al (2017) have evaluated the total suspended sediments distribution using ASTER,ALOS and SPOT-4 satellite imagery in 2005-2013.Satellite data used in this study was 2005-2008 for ASTER,2010 for ALOS and 2009-2011 for SPOT-4.TSS algorithm were proposed separately for ASTER,ALOS and SPOT. Linear correlation analysis were calculated for TSS of satellite imagery and TSS of field data for 2009-2013.They concluded that high TSS value because of Lapindo mudflow to Porong River.It can fatal to ecosystems in research.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 02, February-2022

Apriwida Yanti et al (2016) have estimated the application of Landsat 8 OLI for Total suspended solid (TSS) mapping in Gajahmungkur Reservoir Wonogiri Regency 2016.In this study, empirical modelling ,it integrates the image pixel values and field data using correlation and regression analysis. The field value of 12 April 2016 was used and then May 8 2016 satellite images was used.The estimated band 4 have better accuracy in the estimation of TSS.

James Packman et al (1999) have analyzed the turbidity to determine total suspended solids in urbanizing streams in the Puget Lowlands. Data collected from 9streams. In this, a log- linear model used between TSS and Turbidity with the regression equation.

Nguyen Hao Quang et al (2017) have analyzed the spatiotemporal variation of turbiditybased on Landsat 8 OLI in Cam Ranh Bay and Thuy Trieu Lagoon, Vietnam. In this study, an algorithm for turbidity retrieval was developed based on the correlation between in –situ measurements and a Landsat band reflectance.

Bilgehan Nas et al (2010) have analyzed the application of Landsat -5 TM Image data for water quality mapping in Lake Beysehir,Turkey.In this study ,the in-situ samples of TSS, turbidity and chlorophyll-a from 40 sampling standards were collected on August ,2006.They have used spectral band data and sampling data for bivariate and multiple regression techniques for mapping.

Sajad Ahmad Hamidi et al (2017) have used MODIS remote sensing data for mapping the spatio-temporal variability of water quality in Michigan lake.In this study,the empirical relationship from 2011-13 have done between in-situ measurements of water quality parameters (Turbidity and TSS) with the MODIS reflectance values.Then the proposed equations was tested for summer 2014 data.

Bismay Ranjan Tripathy et al (2018) have used the Landsat OLI sensor for mapping and monitoring the seasonal variability and movement of suspended sediment concentrations along the Thiruvananthapuram coast, Southern India. In this study, they have determined the pre- monsoon (March 2017) and post- monsoon (September 2017) suspended sediments, for this they converted the DN values into TOA reflectance and they also mapped the mean significant wave height along the coast.

4. MATERIALS AND METHODS

4.1 SATELLITE DATA:

Table 1. Satellite Data

DATA	SATELLITE	PIXEL DEPTH	RESOLUTION	YEAR
Sentinel	Sentinel 2a and 2b.	32 bit	Four bands at10m resolution.	2018 and 2019.

Table 2. Datesets used for Primary and Secondary data

DATE	DATASOURCE	FIELD TSS AND TURBIDITY DATA
21/10/2018	SENTINEL 2B	TURBIDITY DATA USED
10/11/2018	SENTINEL 2B	TURBIDITY DATA USED
15/11/2018	SENTINEL 2A	TURBIDITY DATA USED
20/12/2018	SENTINEL 2B	TURBIDITY AND TSS DATA USED
25/12/2018	SENTINEL 2A	TURBIDITY AND TSS DATA USED
04/01/2019	SENTINEL 2A	TURBIDITY DATA USED
09/01/2019	SENTINEL 2B	TURBIDITY DATA USED
14/01/2019	SENTINEL 2A	TURBIDITY DATA USED
19/01/2019	SENTINEL 2B	TURBIDITY DATA USED
24/01/2019	SENTINEL 2A	TURBIDITY DATA USED
29/01/2019	SENTINEL 2B	TURBIDITY DATA USED
03/02/2019	SENTINEL 2A	_
10/03/2019	SENTINEL 2B	_
04/04/2019	SENTINEL 2A	_
15/05/2019	SENTINEL 2A	_
02/08/2018	SENTINEL 2B	_
06/09/2018	SENTINEL 2B	_
21/09/2018	SENTINEL 2B	_

4.2. SOFTWARE USED

SNAP 6.0-Sentinel Application Platform.
SeaDAS 7.5- ‘SeaWIFS’ Data Analysis System.
Qgis
Microsoft Excel.

4.3 METHODOLOGY

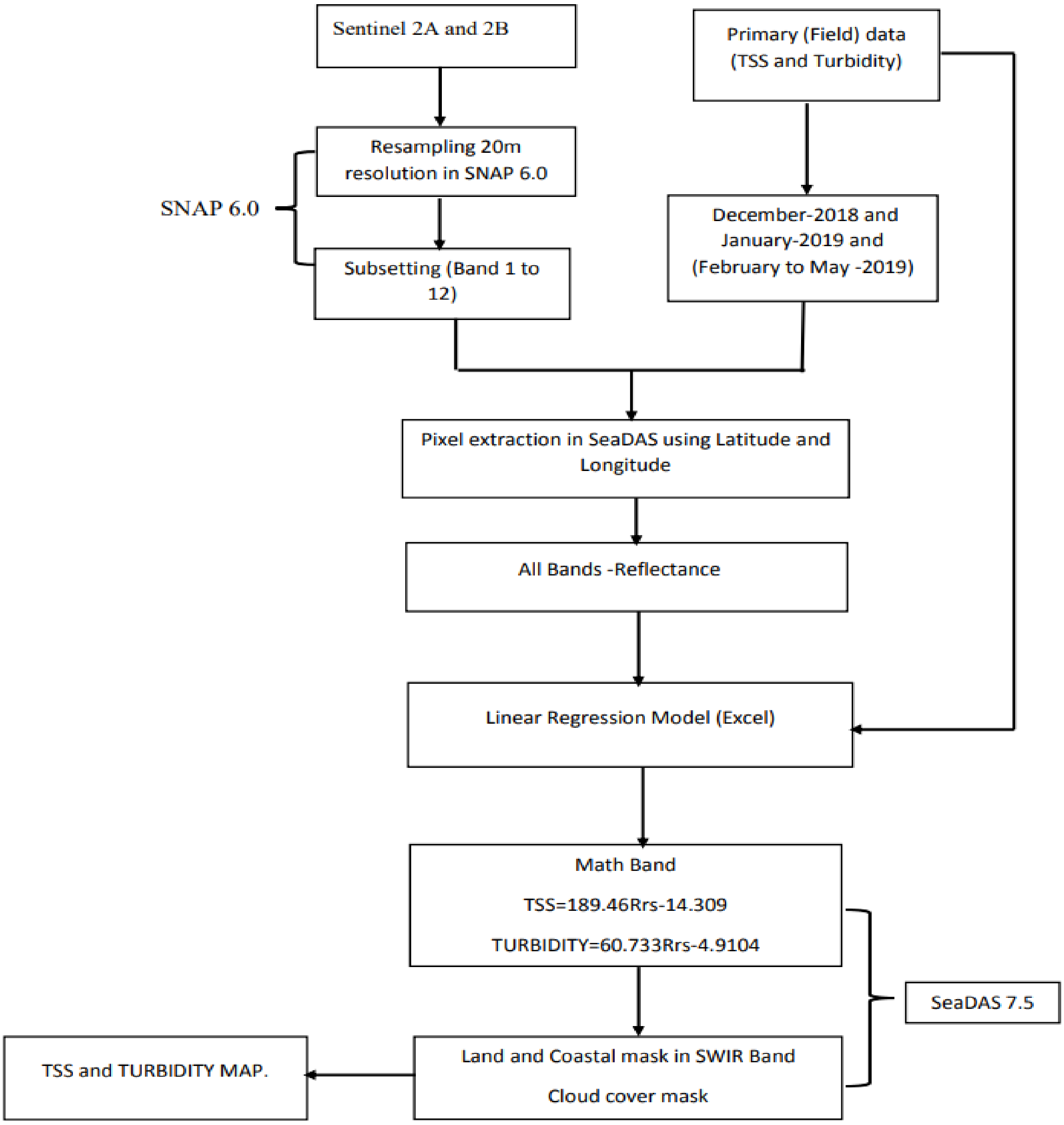

Fig 2. Methodology

4.4. RELATIONSHIP BETWEEN TSS AND TURBIDITY

Measuring the water transparency and TSS also used to predict turbidity values. .By, total suspended solids we can calculate sedimentation rate but turbidity can't. Normally, turbidity readings cannot be converted to TSS value. Because, turbidity is the measure of a sample's tendency to scatter light. While the scattering is produced by the presence of suspended particles in the sample, turbidity is purely an optical property. The pattern and intensity of scatter changes with the size and shape of the suspended particles as well as the with the material of which they are made. We can convert turbidity to TSS measurements is by correlation. That the correlation coefficient with an estimate of strong relationship.

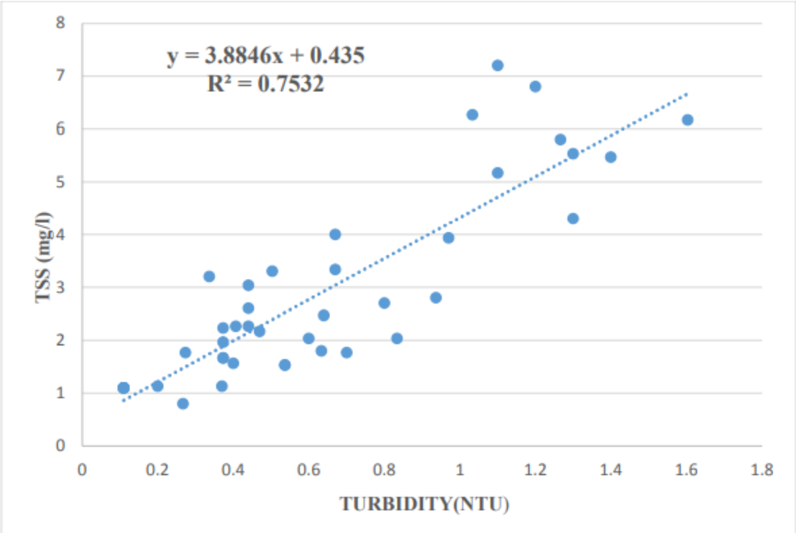

Fig 3. Scatter Plot of TSS vs Turbidity

Regressing the known values of TSS and Turbidity of Trivandrum coast, Kerala to get the TSSequation.

TSS=3.8846*(TURBIDITY) +0.435

By using this derived TSS equation, we can substitute the known turbidity values of Trivandrumcoast, Kerala

5. RESULTS AND DISCUSSIONS

5.1 REGRESSION ANALYSIS:

The plot of the relationship between the reflectance for each band with the TSS and Turbidity values shows the positive correlations between these two parameters in all bands. Different empirical equations were investigated. Finally, the best model was taken for TSS and Turbidity mapping based on the Highest R^2 values. The spectral band 2(490nm) have better accuracy in the estimation of Total Suspended Solids (TSS) and Turbidity along the Trivandrum coast, Kerala.

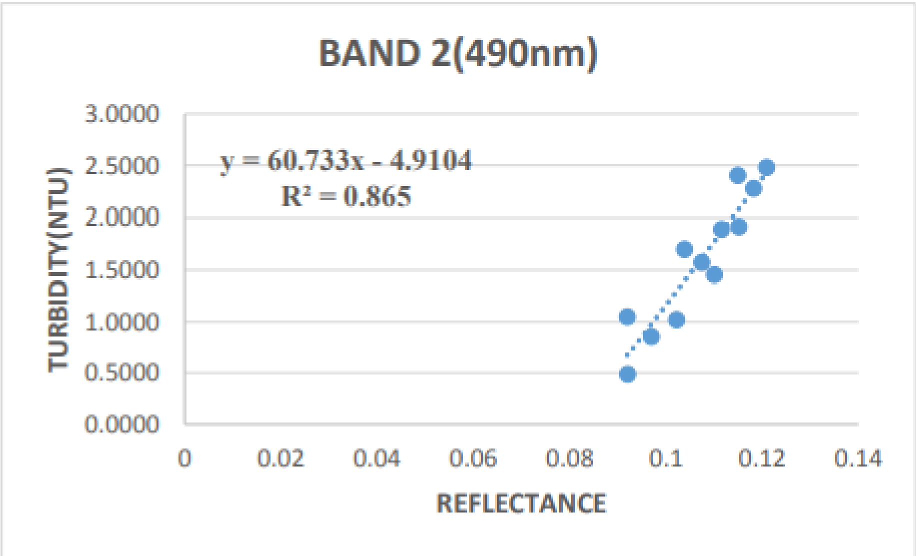

Fig 4. Scatter Plot of Band 2 (490nm) vs field Turbidity (NTU)

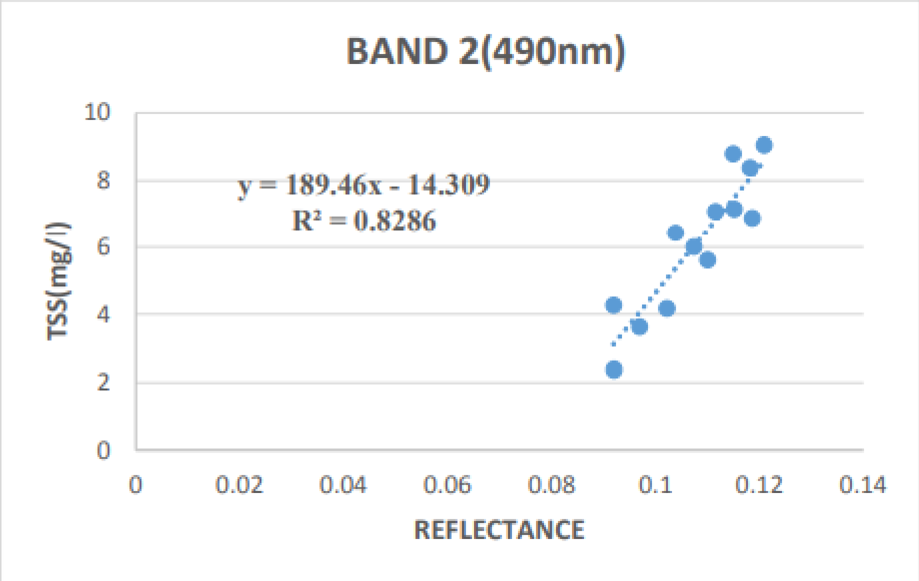

Fig 5. Scatter Plot of Band 2 (490nm) vs field TSS (mg/L)

Table 3. ALGORITHM DEVELOPED FOR TURBIDITY AND TSS.

TURBIDITY=60.733*Rrs (B2)-4.9104

TSS=189.46*Rrs (B2)-14.309

S.No	**Study area**	**Model**	**R^2**
1.	TRIVANDRUM,KERALA	TURBIDITY= 60.733*Rrs(B2)-4.9104	0.865
2.	TRIVANDRUM,KERALA	TSS= 189.46*Rrs(B2)-14.309	0.8286

By applying this model in SeaDAS 7.5, the following turbidity maps were generated.
The turbidity maps were generated for the following dates: December (20 and 25),2018, January (4,9,14,19,24 and 29), 2019, February 3,2019, March 10,2019 and April 4,.2019 and May 14,2019.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 02, February-2022

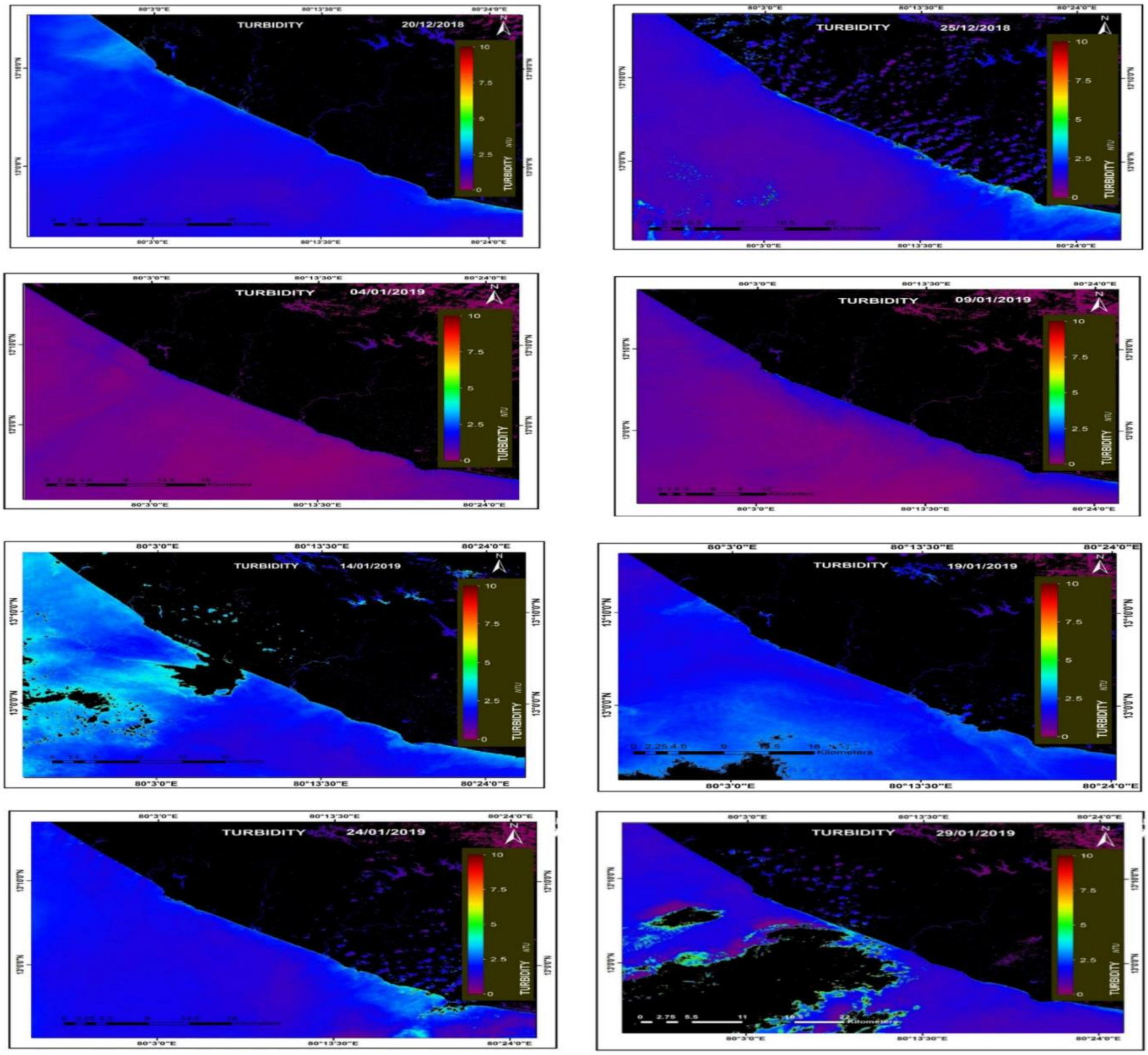

Fig 6. Turbidity Map of Dec 20th,25th 2018 and Jan 4th, 9th, 14th , 19th ,24th, 29th 2019

International Journal of Engineering Research & Technology (IJERT)
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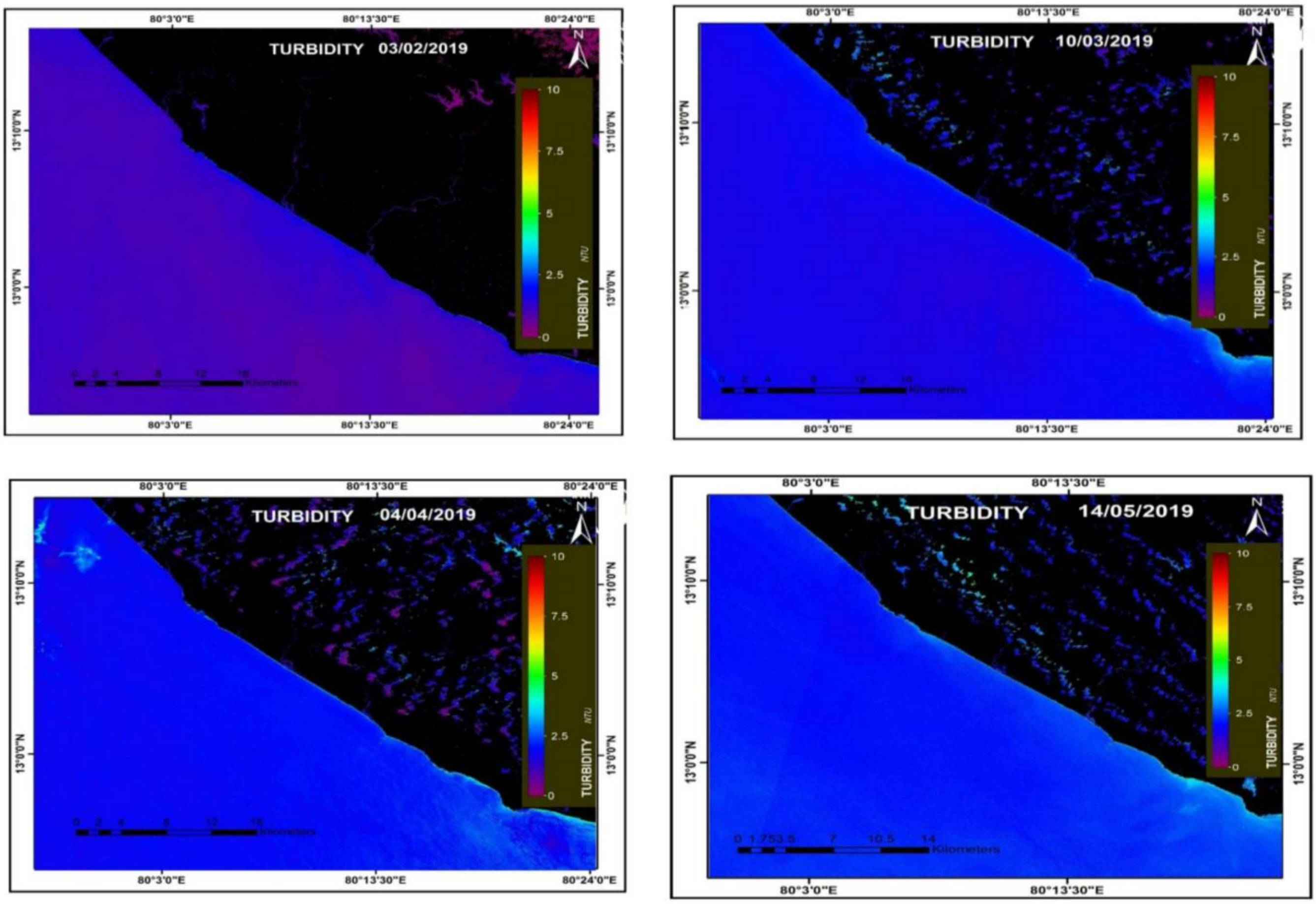

Fig 7. Turbidity Map of Feb 3rd , 5th 2019 , April 4th 2019, May 14th 2019

5.2 TOTAL SUSPENDED SOLIDS:

By applying these models in SeaDAS 7.5, the following TSS maps were generated. The TSS maps were generated for the following dates: December (20 and 25), 2018, January (4,9,14,19,24 and 29), 2019, February 3, 2019, March 10, 2019 and April 4, 2019 and May 14, 2019.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 02, February-2022

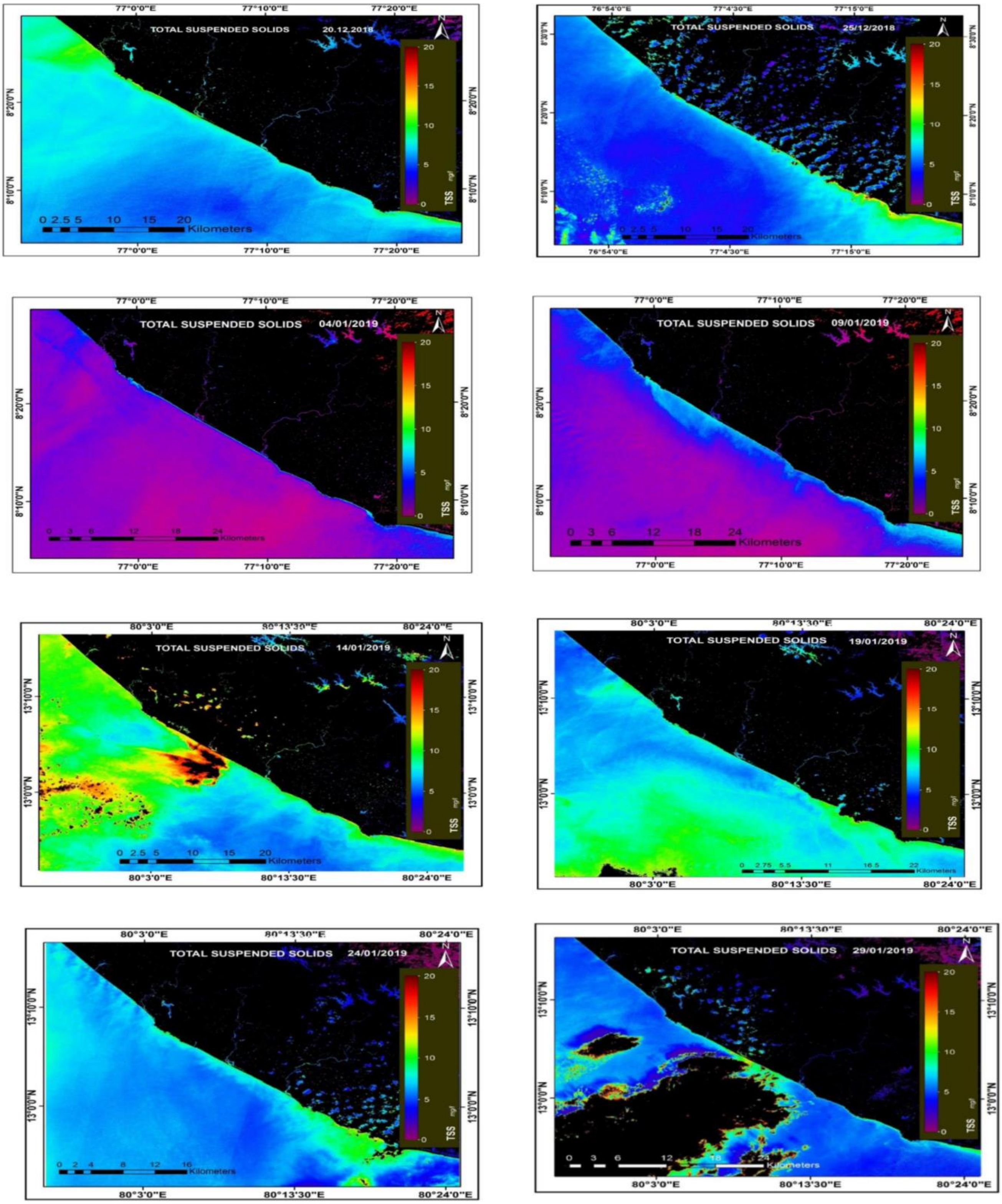

Fig 8. TSS Map of Dec 20th,25th 2018 and Jan 4th, 9th, 14th , 19th ,24th, 29th 2019

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 02, February-2022

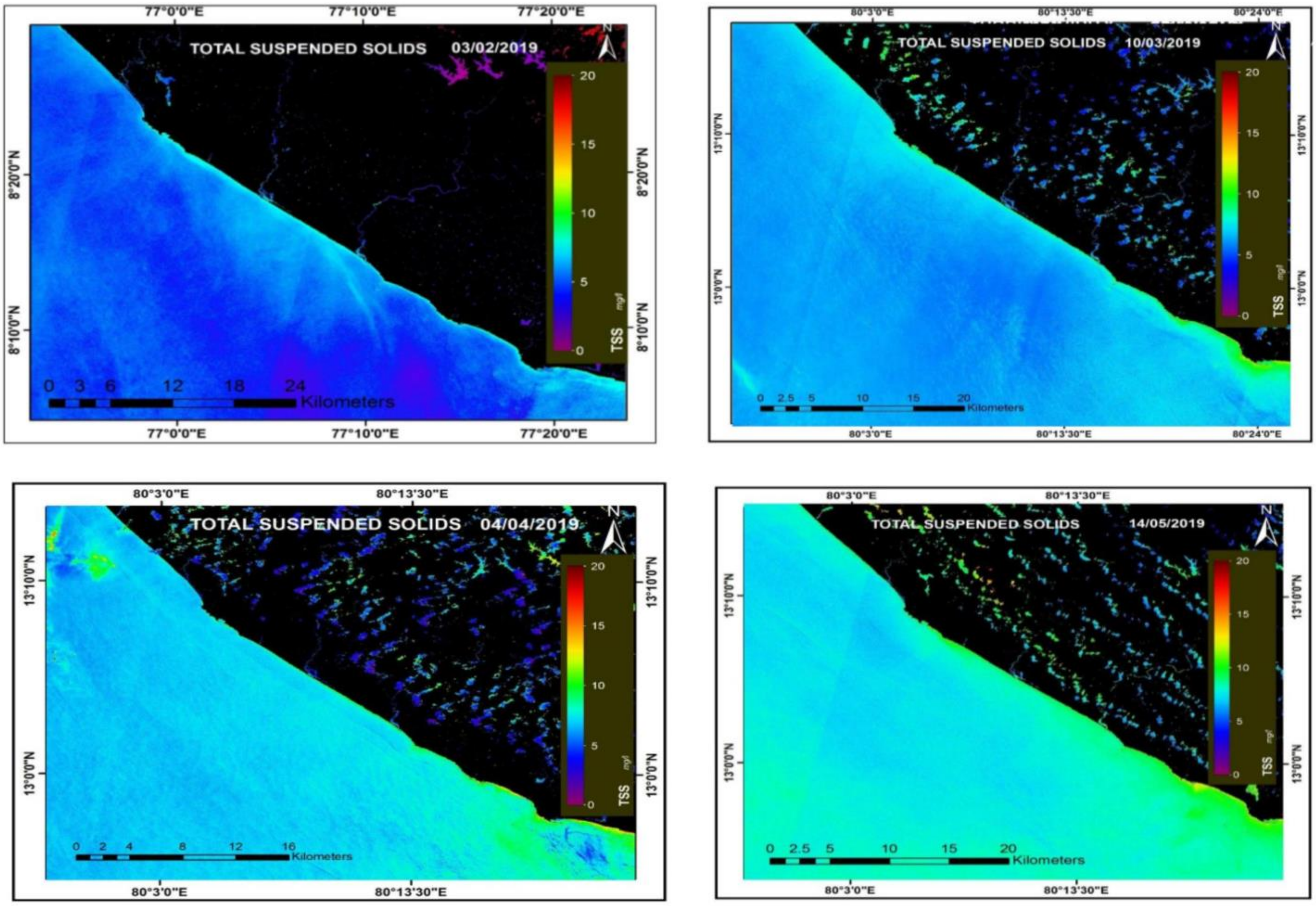

Fig 9. TSS of Feb 3rd , 5th 2019 , April 4th 2019, May 14th 2019

In this study, Sentinel - 2 images are used, it consists of two satellites developed to support vegetation, land cover, and environmental monitoring. It cover all Earth's land surfaces, large islands, inland and coastal waters every five days. Sentinel -2 imagery has a higher potential for coastline monitoring due to aspects like temporal and spatial resolutions as well as data availabilityand low coast of access. SWIR –Short Wave Infra-Red band having high sensitivity and high resolution, it provides imagery in day and night, it can penetrates thin clouds and atmospheric aerosols having lesser effect on SWIR bands.
The TSS (Total Suspended Sediments) and turbidity map was made, resampling and Subsetting were done using SNAP6.0. Then using math band in SeaDAS7.5 the proposed algorithm was givenusing SWIR band coastal land mask done, the map was made and after that cloud cover mask wasdone and it indicates black color in TSS and turbidity mapping.
From December to May, turbidity maps were generated. It was found that, in Trivandrum, the turbidity is like 2.5 NTU in December, (1.5-3.0) NTU in January 2019 –May 2019, then in that allimages the black color represents the cloud cover mask. For December 20 and 25, 2018, the turbidity value near Shankumugham beach and Keezhkulam was 3.0 NTU and all other areas having 2.0NTU and below.
In 4 January, 2019, all areas having turbidity of 2.0 NTU only. In 09January2019,from Shankumugham beach to Keezhkulam near shore, all areas having 2.5NTU and offshore the turbidity values are below 1.5 NTU.In14January.2019,near Shankumugham beach,Pachaloor,Mulloor,Kovalam up to Edappadu ,the turbidity is 3.0NTU.In 19.01.2019,all areas from Shankumugham to Keezhkulam is 2.5 NTU but near Edappadu beach, the turbidity is around 3.0 or 3.5 NTU. In January 24,2019,all areas having 2.5NTU but Edappadu beach only having 3.0 NTU. In January 29, 2019, it having cloud cover near Shankumugham beach the turbidity value is 2.5 NTU and below the south of kerala, near Edappadu and Keezhkulam is below 1.5 NTU.

In February 3, 2019, all areas having 2.5NTU.In March 10, 2019, all areas having 2.5 NTU only but near Keezhkulam coast, the turbidity is 3.0 NTU.In April 4, 2019, near Shankumugham and Edappadu beach only having more turbidity values of 3.0 NTU.In May14,2019, near Edappadu beach the turbidity is more of 3.0NTU.
In Trivandrum coast, from (December 20-25), TSS value was 6.5 mg/l and in (January 4-29), it was 6-10 mg/l then from 3 February to 14 May, TSS value increases up to 13 mg/l, the black colorin image represents the cloud cover mask. In December 20 and 25,2018 ,all areas like Shankumugham beach,Pachaloor,Kovalm ,Vizhinjam,

Poovar,Mulloor,Pozhiyoor,Kollamkode,Edappadu beach and Keezhkulam having the TSS(Total Suspended Sediments) of nearly 8-10 mg/l.
For January 4,2019 all areas having TSS up to 2mg/l and in January 9,2019 ,the onshore areas from Shankumugham to Keezhkulam TSS was 7mg/l.In January 14,2019, more amount of TSS ie.10 mg/l at Shankumugham coast, Pachaloor, Kovalam, Mulloor and Vizhinjam and at Edappadualso .In January 19,2019 all areas near shore is about 8.0mg/l but in offshore the TSS will be 10 mg/l.In January 24,2019, near Edappadu beach only TSS will be more. In January 29, 2019 all areas having less TSS like 5mg/l because of this cloud cover image.
In February 3, 2019 ,the onshore areas from Shankumugham to Keezhkulam TSS was 8mg/l .ForMarch 10 and April 4, 2019 all near shore areas from Shankumugham to Keezhkulam the TSS will be 10mg/l.In 14 May, 2019 near shore areas having 8mg/l and more amount of TSS like 11-12 mg/l at Edappadu and Keezhkulam.

In January (14, 19, 24, and 29) maps of TSS and turbidity, the black color indicates the cloud covermask.
The high TSS and turbidity were analyzed from February to May 2019, it may be due to thefollowing reasons:

- TSS (Total Suspended Sediments) is higher in rainy season because of high flooding towards sea.
- Wave’s activity suspended bed loads in water column increases TSS concentration.
- Higher and stronger waves leads to higher TSS and turbidity concentration.
- TSS variation was due to change in sea water depth, tidal phase and elevation of sea water sample collection.
- Fishing activities and dredging also one of the reason.
- The rocky headlands near the Kovalam was the another source of minerals as sediments into the coast.
- From this study, the high TSS and turbidity were identified near Kovalam, Shankumugham and Edappadu beach, all these were may be due to the anthropogenic contribution due to tourism. Because of tourism, mainly the coast will be polluted.
- Major water quality concerns at port include wastewater and leaking of toxic substances from ships, stromwater runoff and dredging.
- The rocky coast near Vizhinjam having less amount of TSS (Total Suspended Solids) and turbidity. But more amount of TSS and turbidity in Pachaloor, Poovar, Shankumugham and Edappadu because it’s all having sandy coastal area, the movement of suspended sediments will be more.
- Suspended sediment concentration decreased rapidly with increase in distance from the beach and the depth from the sea bed.

5.3. VALIDATING WITH IN-SITU DATA OF TURBIDITY - (OCTOBER AND NOVEMBER 2018).
The plot of the relationship between the field data turbidity of October 25-2018, November (10, and 15), 2018 with the satellite derived turbidity values by using the already proposed algorithm **TURBIDITY=60.733*BAND 2 - 4.9104** shows the positive correlations between these two parameters. It shows 94 % accuracy of validation result with the mean difference error value of - 0.12903.

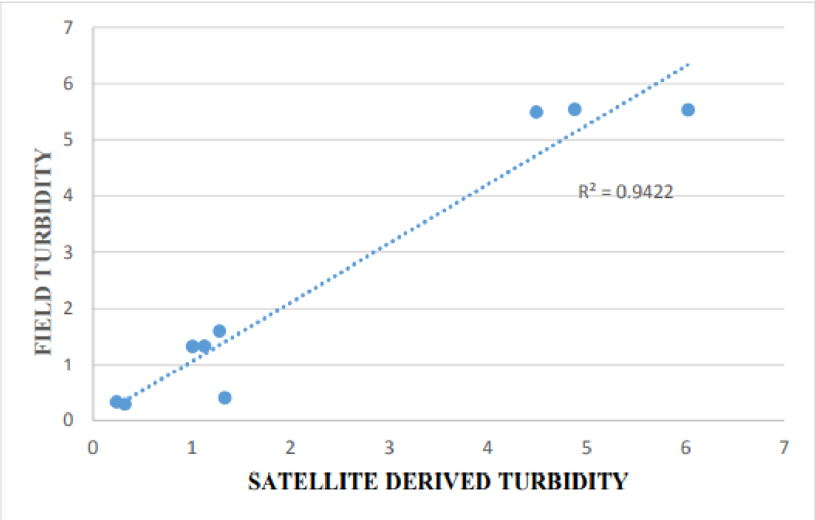

Fig 10. Scatter plot of field turbidity vs satellite derived turbidity

This validation helps us to know that the proposed algorithm for turbidity derived in this study helps us to derive the turbidity for past months like (October and November 2018) and upcomingmonths like (February – May 2019) also.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 02, February-2022

6. CONCLUSION

This study proposed developed algorithm for water quality parameters like TSS (Total Suspended Sediments) and turbidity. The predicted result from Sentinel 2A and 2B imagery exhibit that the predicted TSS and turbidity has a close agreement with the field data with the high R^2 value of 0.94 and with low mean difference error value of -0.12903 .The spectral band 2 (490nm) have better accuracy in the estimation of Total Suspended Solids (TSS) and Turbidity along the Trivandrum coastal area using SeaDAS 7.5.So, it is concluded that Sentinel 2A and 2B imagery and regression analysis can be used effectively to determine TSS and turbidity over Coastal areas of Trivandrum, Kerala. This proposed model in this study can be useful for mapping the turbidityand TSS concentration during before and after flood. Then, this proposed model also used to predict the turbidity and TSS during before and after dredging. Results from this study is expectedto be referenced in the development and utilization of the area in research and Coastal Zone Management in future.

ACKNOWLEDGMENT

The authors of this work, thank Dr. Basanta Kumar Jena, Scientist F and Ms. S. Shanmuga Priyaa, Project Scientist 1, National Institute of Ocean Technology, Coastal and Environmental Engineering Department, Chennai for their constant support, precious guidance and encouragement.

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