

**In-Situ Observations of Mudbanks of Southwest Coast of India and Mapping of its Extent in 2016**

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**Abstract :**

Formation of mudbanks in Alleppey, south-west coast of India is an annual phenomenon which is widely discussed, and many hypotheses have been proposed on its formation. The presence of fluid mud in a levitated condition in the bottom is believed to be the cause of the formation. In this study, in-situ measurements of the Suspended Sediment Concentration (SSC) were carried out for five months in the year 2016 during the monsoon using the Laser interferometry instrument (LISST 100X). This observation was to determine the variations in the SSC in the water column and to delineate the zone of mudbanks. One station inside the mudbanks (M2) and other two stations outside the mudbanks (M1&M3) were considered. During the monthly observations, huge difference in the near bottom SSC from 600-700 mg/l in the mudbanks region and 300-400 mg/l in the outer regions indicates the extent of mudbanks region. The particle sizes were ranging from clay to sand. The concentration of clay particles has abruptly reduced from 50 mg/l to 15 mg/l in surface waters at the outer regions of mudbank. It was also found that these suspended particles have settled back after the monsoon. Observations for periphery demarcation was carried out during the mid of the monsoon (26 July 2016) with 30 stations in five different transects covering both inside and outside regions of the mudbank. Based on the variations in the concentration and the particle sizes, mudbanks periphery was demarcated. The mudbank periphery was identified here with the presence of high concentration of clay particles near the sea bottom. The total particle concentration level at near bottom varied from 600 mg/l in the mudbanks stations to 200 mg/l at outside regions. Fivefold increase in the concentration of clay particles at the near bottom in mudbanks stations revealed the extent of mudbank region. The presence of clay particles was more than fifty percent of the total concentration. The concentrations of clay near the bottom in stations 11, 12 and 29 have increased from 50 mg/l to 250 mg/l, 20 mg/l to 100 mg/l and 40 mg/l to 200 mg/l respectively. This abrupt increase showed the presence of mudbank and was used to demarcate its periphery.

**ADDITIONAL INDEX WORDS:** Mudbanks, Alleppey, LISST-100x, Particle size, suspended sediments.

## **INTRODUCTION**

The formation and the behaviour of mudbanks is a phenomenon peculiar to the southwest coast of India. They are unique in their formation as well as function (Moni 1970). Mudbanks are described to be in semi-circular shape, a region of calm and high turbid water that are formed close to the shore during the southwest monsoon time when there are strong wind and wave activity. This condition helps fishermen to easily access the sea during the rough weather and thus helps in increasing the fish landing resulting in economic benefits. The history of mudbanks started from a book “A new history of east indies” about the Alleppey mudbanks (Cope 1758). Theories and hypotheses quoted the existence of backwater and the transport of freshwater through underground channel could be the reason for Alleppey mudbanks. Later all the theories on the presence of subterranean flow at Alleppey were eliminated by quoting that it is impossible for the backwater to rise without flooding the lower parts of the land near the neck and at the same time, besides 5 feet of depth. Hence, there will not be enough pressure to overcome the frictional resistance of solids in suspension. So a new theory of the existence of water-bearing stratum at a good depth which is bringing water from hills and comes out under the sea resulting in levitating the bottom mud (Bristow R C 1938). On the contradiction, chemical analyses which showed that the mudbanks mud and backwater mud had different characteristics (Ducane *et al.*, 1938). Subsequently, another hypothesis proposed that the upwelling along the coast during the southwest monsoon could be the reason for lifting the mud (Ramasastry A A and Myrland P 1959). This theory was later questioned that, if upwelling is the cause then why the mudbanks are formed only in particular regions rather than all along the coast (Ramamirtham C P and Rao D S 1973). The region is calm in spite of the rough sea, due to the high sediment concentration which acts as a dissipator of gravity waves (Tatravati and Narayana 2006). Then the suspended matter was studied in detail to identify the turbidity level of the water column in the mudbank which could be a reason for the dampening of waves in the mudbank region. In April 1972 the concentration was around 100mg/l on the surface and 250 mg/l at 1m above the bottom. It increased to 1000mg/l at the surface and 1500 mg/l at 1m above the bottom in July and from September onwards it started decreasing gradually (Kurup P G 1977). A study was carried out in narakkal mudbanks, where the concentration varied from 100mg/l to 900 mg/l in the surface and 120mg/l to 3600 mg/l in the bottom waters. They have also concluded that the concentration increase from May to July- August months and decreases during September – December (Purandara B K and

Dora Y L 1991). A recent study about the suspended matter in Alleppey mudbank found that the mean suspended particulate matter concentration was low at the surface, whereas around 4-7 times higher at the bottom which gives strong evidence for the presence of fluid mud at the bottom and also the decrease in the concentration level during September was noticed. The difference in concentration levels throughout the column was supporting the presence of high sediment at the bottom waters in the mudbank region (Shynu *et al.*, 2016). All these studies discussed the possible theories of the formation of mudbanks and the difference in sediment concentration at the sampling locations only. No study in the past attempted to estimate the size and areal extent of the presence of the mudbanks by taking the samples in that whole region. This study is unique in that way and attempted to demarcate the mudbank region which is at the sea bottom using the in-situ measurements. The primary aim of this study is to demarcate the periphery of the Alleppey mudbank which occurred in the year 2016 and to analyse the sediment properties of the water column in both mudbank and non-mudbank region.

## **METHODS**

Alleppey is a persistent mudbank which appears every year during the onset of southwest monsoon. In 2016, the mudbank occurred at Punnapra, south of Alleppey, Kerala, India. The field observations to define the sediment characteristics of the Alleppey mudbanks in 2016 was designed as such to quantify the difference in the sediment distribution along the water column both inside and outside the mudbank. This observation was carried out with primarily two objectives, variations in the concentration of suspended sediments in the water column and to identify the periphery of the mudbank. The observation was a sensor based water column data (LISST-100X) and was of two types, i) a systematic time series observation and ii) Periphery demarcation. LISST-100x uses the technique of laser diffraction to obtain particle size-distribution (PSD). The laser diffraction method for sizing particle became the most widely used optical method. For laser diffraction, the composition or refractive index of the particle is not important. This method determines the size distribution of an ensemble of particles, as opposed to counting type devices that size one particle at a time. In the aquatic sciences, particle refractive index is poorly known because particles are often a mixture of mineral grains and organic particles. Thus, except for shape effects, laser diffraction offers an excellent method for size distribution. LISST-100X records the scattering intensity over a

range of small angles using a specially constructed multi-ring (32 rings) detector; then the multi-angle scattering is converted to size distribution with a mathematical inversion.

$$E = K N_v$$

Where,

E = angular scattering energy sensed by the 32 silicon rings.

K = scattering property kernel matrix.

$N_v$  = volume distribution.

Diffraction-based techniques have been used to obtain size-resolved PSD in situ by inversion of near forward scattering measurements made using LISST (Agrawal, Y C and Pottsmith 2000). This inversion is most sensitive to a particle's cross-sectional area. Hence non-spherical marine particles result in across size class as different orientation are displayed to the sensor while providing a useful measure of particle cross-sectional area (Karp-boss *et al.*, 2007). So, LISST instruments are designed to work in turbid environments and hence have a relatively low signal to noise ratio in clear waters (Boss *et al.*, 2015). The instrument is a Type-B with angular range corresponding respectively to size ranges from 1.25 $\mu\text{m}$  to 250 $\mu\text{m}$ . So, here the concentration limit is based on the optical transmission (OT) values and also the quality of the data depends much on it. The OT values ranges between 0 and 1, if the value is close to 1, the water is clear, and if the value is close to 0, the water is turbid. The turbidity level is limited by if  $OT > 0.995$ , then the water is too clear and the values are neglected and same if  $OT < 0.10$ , then the water is too turbid and sensor is not designed to detect it (SEQUOIA Scientific 2015).

The LISST-100x estimates the concentration of the suspended sediments after calibrated with the ISO standard natural particles. This instrument was calibrated at factory and calibration constants were provided along with the instrument firmware. The file provided (LISST.INI) contains the parameters, their multiplier and offset values along with reference data. This file which can be loaded into the software and then a background quality check is performed with deionised water before the field deployment. These values are unique to this instrument and were regularly checked for its laser strength. LISST-100X has a limit of 800mg/l for the standard 50mm optical path, but it

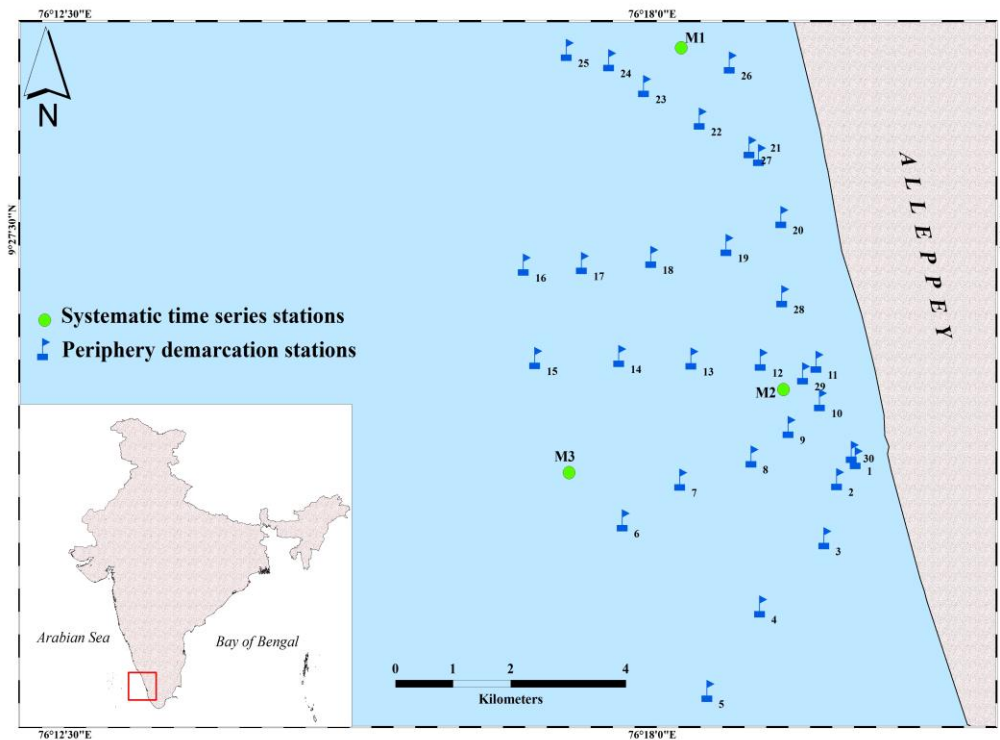
varies based on the grain size range. In Alleppey mudbank area, the instrument retained very less OT at some places which obviously indicated the presence of thick sediments in the laser path. The highest recorded values were considered throughout the study.

### **Systematic time series observation**

The systematic time series observation was planned for three stations M1, M2 and M3 (Figure 1) for five months from May to September, 2016. M1 is a station outside the mudbank with same depth on the northern side of the mudbank. M2 is the station inside the mudbank, and M3 is the station outside mudbank towards the sea with a depth of around 12m. These stations were planned in such a manner to identify the differences in the sediment distribution inside and outside the mudbanks. The total volume concentration of suspended sediments along the entire water column has been estimated and plotted for identifying the distribution level in all the three stations.

### **Periphery demarcation**

This observation was carried out on 26<sup>th</sup> July 2016 and planned in such a manner that a maximum number of points should be considered to get the precise boundary of the mudbank. So, a total of 5 transects containing 5 points in each transect which run through the mudbanks to the rough sea and a transect parallel and close to the coast was also considered to define the mudbank boundary near the coast. The transects were drawn to get a spatial variation of sediment distribution in the water column and based on the concentration values the periphery was defined. The first station was placed inside the mudbank, and further, the stations were numbered based on the trail of the boat.



**Figure 1.** Station location map for Time series observation and Periphery demarcation.

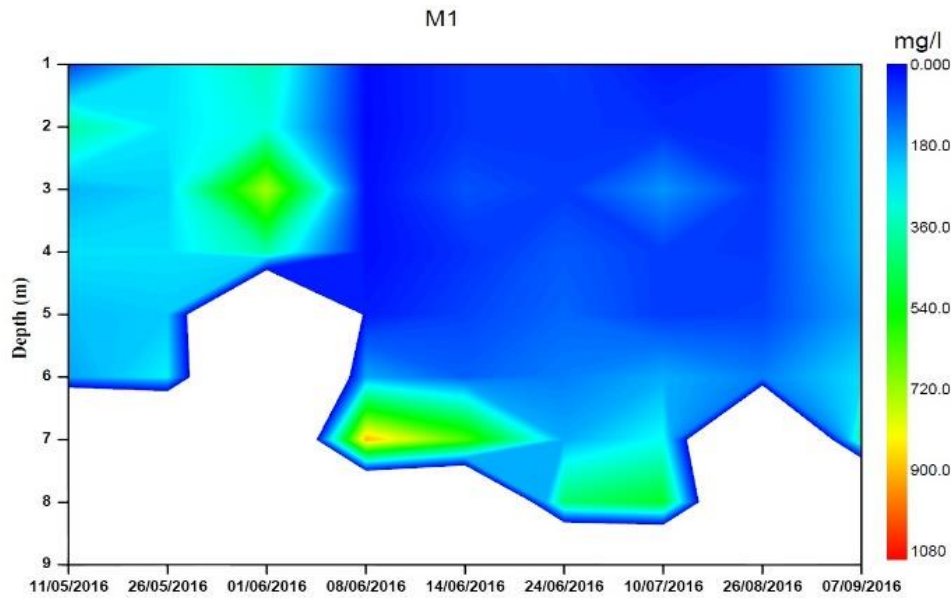
## RESULTS

The time series observation from May to September in stations M1, M2 and M3 revealed the variations in concentration of the sediments from inside and outside the mudbanks. Out of five months, the observation was carried out on nine different days starting from 11<sup>th</sup> May to 07<sup>th</sup> September 2016. The concentration variation along the profile has been plotted for the respective stations.

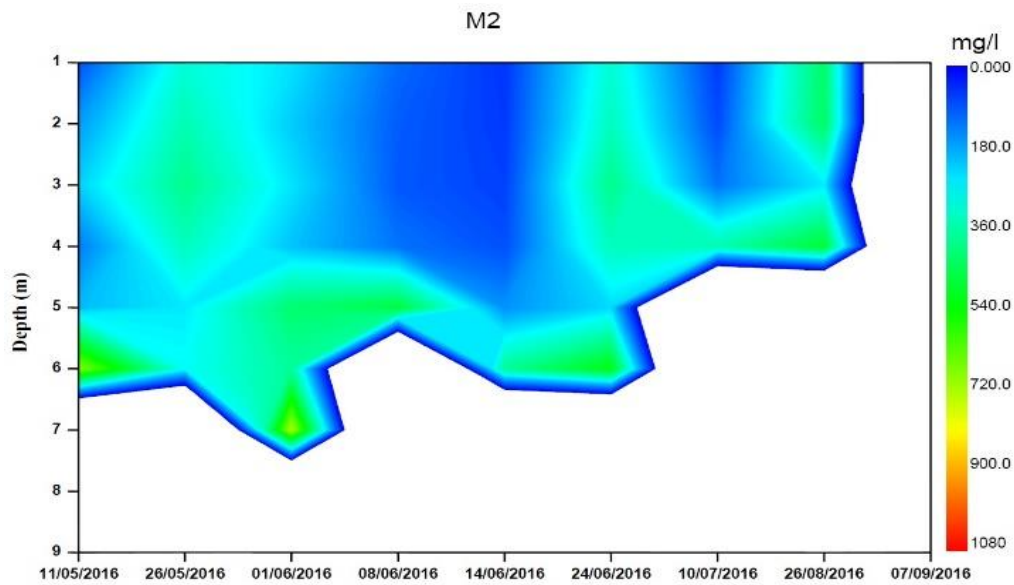
### Systematic time series observation

Station M1 which is on the northern side of the mudbanks, was showing a high concentration throughout the profile in May (Figure 2), with values ranging from 200 to 300mg/l and gradually falling back to the less concentration on the surface except the bottom waters for the upcoming months. The concentration near the bed was high nearing 900 mg/l in June. The concentration along the profile was invariably less until August, and the September values were around 200 to 300 mg/l on the surface when the mudbanks dissipated.

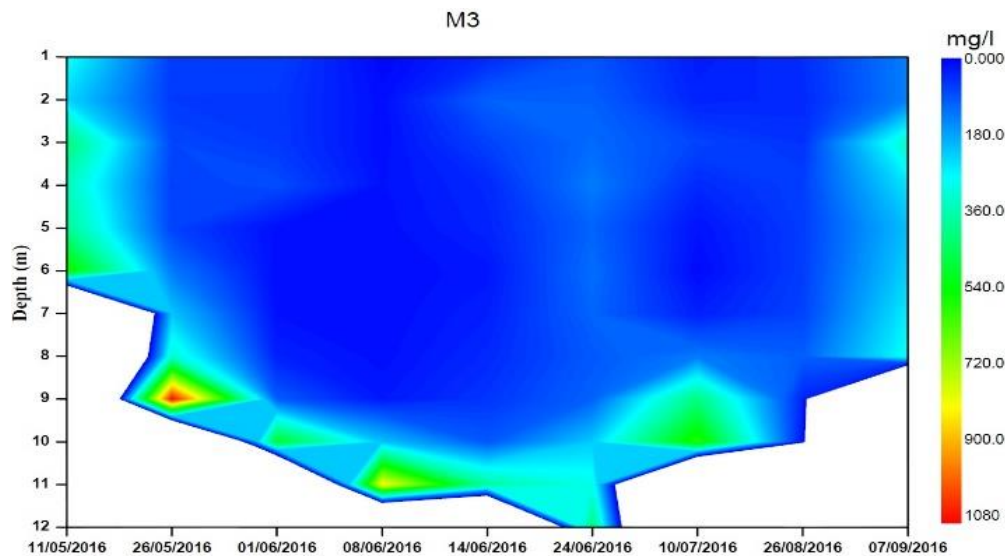
The mudbanks station M2 was constantly showing high suspended value throughout the event from May till August (Figure 3), the high concentration of suspended particles in the surface ranging 200-400 mg/l was found, and the bottom part was experiencing a high turbid environment with values reaching beyond 600 mg/l. This concentration level of sediments in the suspended form can be seen during the time of observations, and the values have reduced after August. The turbid environment was observed in the entire profile till the disappearance of the mudbank in September.



**Figure 2.** Volume concentration of suspended sediment at station M1.



**Figure 3.** Volume concentration of suspended sediment at station M2.



**Figure 4.** Volume concentration of suspended sediment at station M3.

Then the station M3, which is far away from mudbanks, was also experiencing a high value of around 200-300mg /l in the surface and around 500 mg/l in the bottom during May. It started decreasing to 50 – 150mg/l in the surface for the subsequent months and bottom water concentration

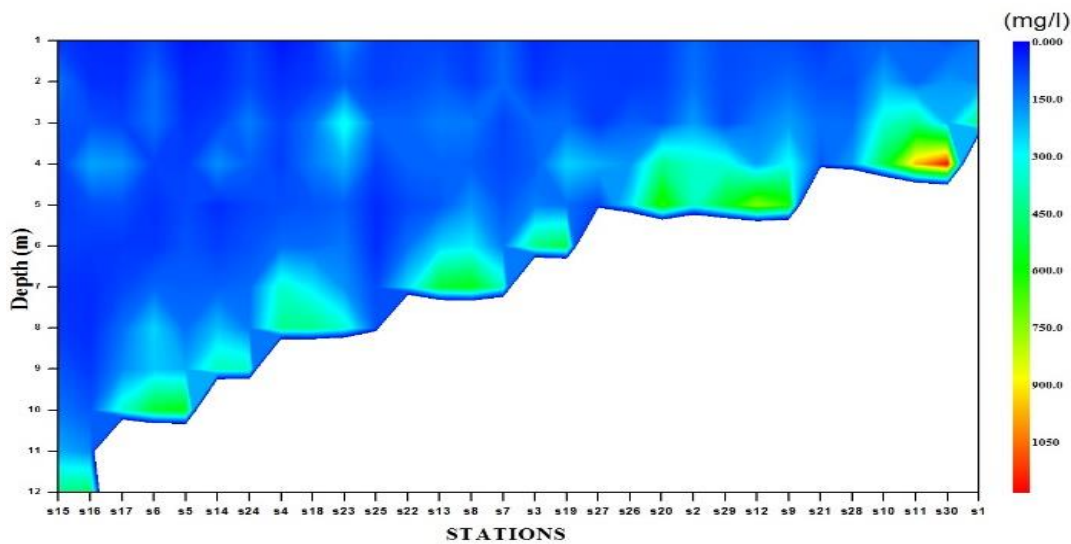


was 400-500 mg/l. Later it increased to around 150 – 300 mg/l in the surface during September (Figure 4).

### Periphery demarcation

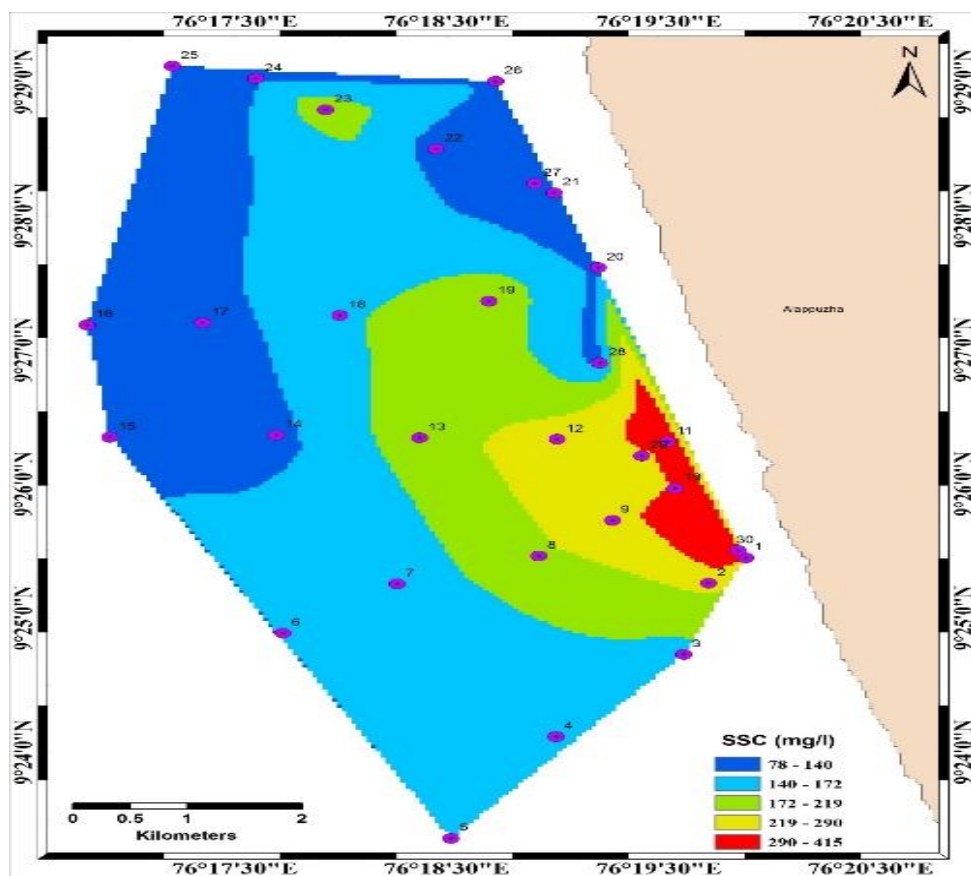
This observation for defining the boundary was carried out with a total of 30 stations in 6 different transects. So the concentration values are plotted with respect to the depth of the stations, from shallow to deep. The variation in the sediment suspension and then their concentration values were used to create a spatial map for demarcating the periphery of the mudbank.

The concentration plot (Figure 5) reveals high values in the mudbank and nearby located stations compared to the non-mudbanks stations. Further many stations close to the coast gave a high concentration in the surface. From the plot it is evident, the stations 1, 30, 10 and 11 give high concentration from the surface till bottom with values ranging from 600 to 1000 mg/l. The following stations 28 and 21 is not much turbid and further the stations 9, 12, 29 and 2 which are 6m deeper express high sediment concentration in the bottom waters with values around 500-700 mg/l. However, rest of the stations remained less turbid in the surface and along the profile. The concentration plot along with the variations in the profile was then taken into consideration to delineate the boundary of the mudbank. These values could be used to find the difference in the sediment conditions inside and outside the mudbank.



**Figure 5.** Volume concentration plot for periphery demarcation stations (Depth wise).

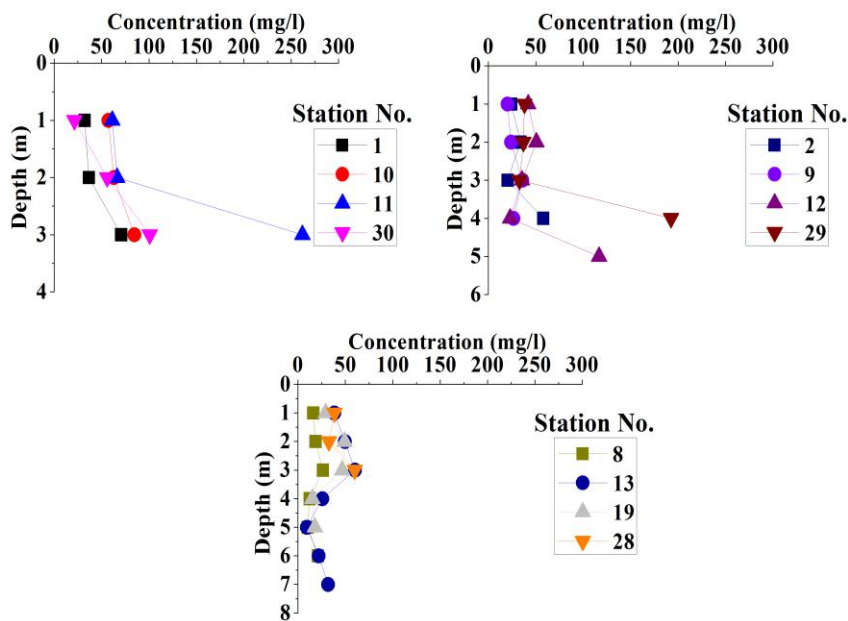
So in order to eliminate the non-mudbank region with mudbanks region, a spatial approach was attempted through geographical information system (ArcGIS) software. So, here the average of the concentration of the sediments in each station was calculated and that was considered as an attribute to interpolate and create a raster map to find the boundary of the mudbanks. In order to interpolate, the technique of Triangulated Irregular Network (TIN) was used to interpolate the points with respect to the average of the concentration values. The TIN surface after converting to the raster gave the concentration levels in the respective points (Figure 6). The stations with high concentration values (1, 2, 9, 10, 11, 12, 29&30) were found near the mudbank regions, and the turbidity level decreases for the stations away from the coast. Some stations which are closer to the coast also exhibit lesser concentration since they are outside the mudbank. However, stations 19, 13, 8 and 3 are also moderately turbid with average values around 172-219 mg/l, but these stations do not cover mudbank because of the absence of high concentration of clay which is the main attribute of the mudbanks.



**Figure 6.** Periphery map for Alleppey mudbank, 2016.

So the points falling under the mudbank region were validated with the points outside the mudbank to reduce the error in demarcation. Since the mudbank always consists of colloidal clay more in concentration and thick at the bottom waters, estimating the amount of the clay substances in the stations were carried out. Results showed that the stations located inside the mudbanks were having a high concentration of clay ( $1.25\text{-}1.48\mu\text{m}$ ) in the suspended form. It resulted in high turbidity along the entire profile and enormously high in the bottom water, whereas the stations outside were not having a concentration of clay in the suspended form (Figure 7). The stations 1, 30, 10 and 11 falls on a high concentration area which is at the center part of the mudbank and the stations 29, 12, 9 and 2 falls on the next layer which is also the part of the mudbank. The concentrations of clay near sea bottom in stations 11, 12 and 29 have increased from 50 mg/l to 250 mg/l, 20 mg/l to 100 mg/l and 40 mg/l to 200 mg/l respectively. This abrupt increase showed the presence of mudbank and was

used to demarcate its periphery. In this study, parameters such as more than fivefold increase in the clay particle concentration within one-meter depth difference at the near bottom were considered to identify the periphery of mudbank which may be followed at different mudbank regions of the world. The stations 8, 13 and 19 falling on the third layer do not fall in the mudbank region because of the less concentration of clay in the profile and also in the bottom waters.



**Figure 7.** Concentration variation of clay particle (1.25-1.48 μm) in mudbank stations.

## CONCLUSIONS

The sediment distribution pattern in the water column could be studied better with the LISST-100x, which helps in finding the particle size variations and the concentration levels with higher accuracy. The difference in the concentration of sediments in the water profile of the three stations (M1, M2, and M3) defines the turbidity level. Time series experiment reveals the presence of the fluid mud in the bottom waters of the station M2, whereas the other two stations (M1 & M3) were found to have a higher concentration in the bottom but not perpetually. At the same time, the sediment concentration

in the surface waters was found to be high in the mudbank station, with respect to time. The high concentration level in the non-mudbank stations during May and September and less concentration in the other months supports the formation and dissipation of mudbanks in the intermediate months (June - August). The mudbank periphery was identified here initially with the presence of high concentration of clay particles near the sea bottom. It is observed that the fivefold increase in the concentration of clay particles at the near bottom in mudbank stations. The presence of clay was more than fifty percent of the total concentration in that area. It confirms the presence of mudbank at those stations. This study thus revealed the existence and periphery of Alleppey mudbank in 2016 and should be attempted to demarcate in future to understand the migration dynamics of mudbank. This high turbid environment helps in various socio-economic benefits to the local community. It is essential to understand its shape, spatial extent also and earlier studies attempted only on its formation mechanism.

## **ACKNOWLEDGEMENT**

Authors are thankful to the Director, National Institute of Oceanography, Goa, for initiating this study. Authors acknowledge Scientist in Charge, Scientists, Staffs, Students of Regional Center, CSIR-NIO, Kochi and all the field participants for the support during the Mudbanks field campaign. The NIO contribution No is XXXX.

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