iJRASET
International Journal For Research in Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 6 **Issue:** I **Month of publication:** January 2018

DOI: http://doi.org/10.22214/ijraset.2018.1285

www.ijraset.com

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor :6.887
Volume 6 Issue I, January 2018- Available at www.ijraset.com

Sediment Transport Rate and its Impact on Coral Reef Health – Palk Bay and Gulf of Mannar

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Abstract: ***Coral reefs act as natural barriers and protect the shorelines of islands and land masses against natural calamities. The natural parameters such as light, temperature, salinity and settlement of silt influence the growth of corals. Siltation is one of the major factors influencing the growth and survival of corals. South east coast of India consist of rich diversity of coral reefs are influenced by A both southwest and northeast monsoons. Sedimentation rateis calculated from the selected study sites of Palk Bay and Gulf of Mannar reef ecosystem is between the 14.6 and 38.54 mg.cm-^{2}d^{-1}. And the sedimentation rate of Palk bay and Gulf of Mannar is compared and found that,the sedimentation rate of the Palk Bay is ~2 times higher than that of Gulf of Mannar. The model predictions also clearly indicating that the suspended sediments due to high magnitude of coastal currents will allow the deposition of suspended mud on the coral environment. Significant Positive correlation of the model predicted sedimentation value with the collected value is observed from regression equation. Biophysical status of corals and its associated life-form communities (mean cover %) of the corresponding study sites are assessed.Due to high sedimentation rate, the corals presented in Gulf of Mannar and Palk Bay are negatively impacted in the present study (r = -0.47), which requires continuous monitoring in both physical (Sedimentation rate) as well as biological status(Ground truthing on coral reef cover) of the coral reef.***

Keywords: ***Coral reef, sediment transport, palk bay, coastal resource***

I. INTRODUCTION

Coral reef ecosystem is also called as the “Rainforests of the sea”. It is one of the most diverse ecosystems on the earth. Coral reef is the ridge of rock in the sea formed by the growth and deposit of coral. Coral reefs are built by colonies of tiny animals found in marine waters that contain few nutrients. Coral reefs require warm temperature, ample sunlight, less turbidity and sedimentation rate. Therefore they are restricted to shallow waters of tropical and subtropical regions. Coral reefs deliver ecosystem service to tourism, fisheries and shoreline protection. Now a days, this ecosystem are under threat from climate change, ocean acidification, blast fishing, sedimentation and harmful land use practices including urban and agricultural runoff which harm reefs by encouraging excess algal growth. Sedimentation is the tendency for particles in suspension to settle out of the fluid in which they are entrained and come to rest against the barrier. It is due to their motion through the fluid in response to the forces acting on them. Sedimentation rate is one of the vital factors in coral reef monitoring study .Sedimentation is a major controlling factor in the distribution of reef organisms and in overall reef development (Hubbard, 1986).

II. NEED FOR THE STUDY

Coral reefs provide many ecosystem services that support human populations’ economy, culture and aesthetics. They also provide ecological support for other associated organisms. The sedimentation rate is measured as one of the important stresses of pollutants on the reefs. Sedimentation from dredging and runoff constitutes one of the biggest threats of reef degradation from human activities (Anthropogenic Impacts). Sedimentation is a major controlling factor in the distribution of reef organisms and in overall reef development. Sedimentation and suspended sediments in the water column may affect the coral population and community structure by smothering adult corals or imposing physiological stress by reducing the light availability for photosynthesis or increasing the need for active sediment removal. Therefore, this study helps to identify how the sedimentation rate on corals affects their health.

III.STUDY AREA

The total coral reef area in India is 5790km^{2}, distributed in five major regions: Andaman and Nicobar Islands, Lakshadweep group of Islands, Gulf of Mannar, Palk Bay and Gulf of Kuchchh. Corals are also found near Gaveshani Bank about 100km offshore from Mangalore, and several areas along eastern and western coast of India, e.g. the Malvancoral reef sanctuary near Mumbai (Kumaraguru, *et al.*, 2006). Reef structure and species diversity are depends on the environmental conditions.

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A. Palk Bay

Palk Bay, named after Sir Robert Palk (1717-1798) the Governor of Madras Presidency (1755-1763), which is situated in the Southeast coast of India encompassing the sea between Point Calimere (Kodikkarai) near Vedaranyam in the north and the northern shores of Mandapam to Dhanushkodi in the south.

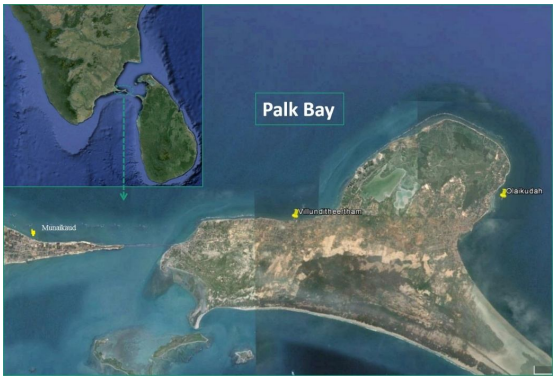


Figure 1 Location of Palk Bay

B. Geographical Location

It is situated between Latitude 9º 55’ - 10º 45’ N and Longitude 78º 58’ - 79º 55’ E. The Palk Bay itself is about 110 km long and is surrounded on the northern and western sides by the coastline of the State of Tamil Nadu in the mainland of India (Cathcart, 2003).

C. Coral reef Ecosystem

The coral reefs of Palk Bay runs parallel to the land in an east-west direction between Lat.9°17’ N and Long.79°17’ E - 79°8’ E. The Bay is a shallow flat basin and its depth hardly not exceeds 9 m.

The coral reefs in the Palk Bay starts from Munaikadu, as a wall like formation and runs east up to Thonithurai to a distance of about 5.5 km. East of Pamban Pass, the reef again starts near Thangachimadam and runs, although not continuously, up to Agnitheertham in the Rameswaram eastern side covering a distance of nearly 18 km. Twenty species of corals were reported in the Palk Bay region in the late 1960s.This number increased to 25 by the late 1990s. However, a thorough survey of the coral reef areas in the Palk Bay brought the number of species occurring in the region to 50 by the year 2004. They belong to 27 genera of 11 families (Kumaraguru, *et al.*, 2006). The reef area of the Palk Bay has been divided in to five zones viz., shore, lagoon, shoreward slope, reef crest and seaward slope.

D. Gulf Of Mannar

The Gulf of Mannar, situated along the southeast coast of India, is one of the richest marine ecosystems with nearly 3600 species of living flora and fauna. It has been recognized as a marine biosphere reserve mainly because of its possession of a rich variety of flora and fauna. It also has one of the important Marine National Parks of India.



Figure 2 Location of Gulf of Mannar

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E. Geographical Location

It is situated between Latitude 8º 47' - 9º 15' N and Longitude 78º 12' - 79º 14'E. It extends from Kanyakumari in the south to Rameswaram in the north. The importance of the Gulf of Mannar lies in the fact that it has a chain of 21 islands along a stretch of 140 km in between Rameswaram and Tuticorin.

F. Coral Reef Ecosystem

The coral reefs of the Gulf of Mannar are developed around a chain of 21 islands that lie along a 140 km stretch between Tuticorin and Rameshwaram. The islands lie on an average about 8 km from the mainland. They are a part of the Mannar barrier reef, which is about 140 km long and 25 km wide, between Pamban and Tuticorin. Different types of reef forms such as shore platform, patch, coral pinnacles and atoll type are also observed in the Gulf of Mannar.

The islands have fringing coral reefs with patch reefs located on them. Narrow fringing reefs are located mostly at a distance of 50 to 100 m from the islands. On the other hand, patch reefs arise from depths of 2–9 m and extend to 1–2 km in length with width as much as 50 m. Reef flat is extensive in almost all the reefs in the Gulf of Mannar. Reef vegetation is richly distributed on these reefs. The total area occupied by the reef and its associated features is 94.3 km^2. Reef flat and reef vegetation including algae occupies 64.9 and 13.7 km^2respectively.

The reefs are more luxuriant and richer than the reefs of the Palk Bay. There are about 96 species of corals belonging to 36 genera in the Gulf of Mannar. The most commonly occurring genera of corals are Acropora, Montipora and Porites (Kumaraguru, et al., 2006).

IV. METHODOLOGY

Corals are known to flourish in various turbid environments around the world. The amount of sediments in suspension and rates of sedimentation used to evaluate the condition of the reef environments. The sedimentation rate is calculated by field experiment method (English *et al.*, 1997) and Modelling software, then interpreted the results to assess how the coral reef health is affected by sedimentation.

A. Field Measurement

1) *Sediment Traps:* We used the cylindrical traps to collect the sediments (English, *et al.*, 1997). The size of the trap is chosen after considering the size of traps used by the various researchers along the reef ecosystems of India.

Table1. Trap size used by various researchers

Year	Literature	Author	Study Period	Trap Size	Sediment rate ($mgcm^{-2}$ d^{-1})
2005	Sedimentation of silt in the coral reef environment of Palk Bay	Wilson *et al.*,	May – Oct 2004	5 cm dia; 11.5 cm height	1 - 42
2010	Reef status in the Mandapam group of islands, Gulf of Mannar	Marimuthu *et al.*,	2006 – 2008	7.5 cm dia; 11.5 cm height	2- 30
2012	Bleaching and secondary threats on corals of Palk Bay: A Survey and Proactive conservation needs	Ravindran *et al.*,	May & June 2010	5 cm dia; 20 cm height	82- 153
2013	Coral Reef Recovery Status in South Andaman Islands after the Bleaching Event 2010	Marimuthu *et al.*,	June – Nov 2010	7.5 cm dia; 11.5 cm height	0.27- 0.89
2014	Seasonal Changes of Sediment Rates & Sediment Characteristics Status in the Gulf of Mannar Coral Island, India	Kumar *et al.*,	July 2007– June 2008	5 cm dia; 11.5 cm height	1.97-12.31

From considering pervious study of the sedimentation rate, sediment trap of size 7.5 cm diameter and 11.5 cm height is taken for my study as recommended in English et al. Sediment traps are covered with the baffles in order to prevent clogging of the mouth by the

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entry of fishes, large organism and large particles. These traps were deployed at the bottom vertically in the selected study sites to determine the rate of sedimentation.



Figure 3. Sediment trap

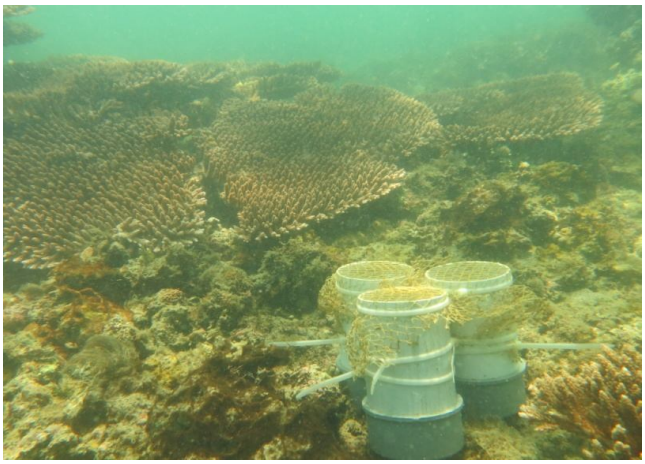




Figure 4 Erected sediment trap in the coral reef ecosys

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B. Collecting The Sediments

The sediment traps were collected for *a* period of three months from December 2015 to March2016. The mouth portion of the traps were closed with a cap, within the water itself, to avoid sediment loss from the trap while bringing up. The collected sediment traps were labelled immediately and transported to the laboratory.

C. Separation Of Sediments

In the lab, sediments were transferred into clean beakers and allowed to settle. The supernatant water was filtered with Whatman No.1 filter paper and the sediment was washed twice with clean tap water and then with distilled water to remove all the salt content in the sediment. Then the washed sediment was dried in a hot air oven at 60°C and weighed to the nearest milligram (English et *al.*, 1997).

D. Sediment Rate

The sedimentation rate was expressed in $mg.cm^{-2}.d^{-1}$. This was calculated by dividing the collected sediment weight by the number of days of immersion and again divided the surface area of the cylinder. The rate of sedimentation was calculated from the collected samples for every month by the following procedure. The average weight of sediment from each site was divided by the total surface area of cylinder and converted for a day using the following formula.

Cylinder bottom surface area $= \pi r^2$

$= 3.14 \times (3.75)^2$

Cylinder surface area $= 44.156\ cm^2$

Rate of sedimentation = Weight of sediment/Cylinder surface area x No. of days

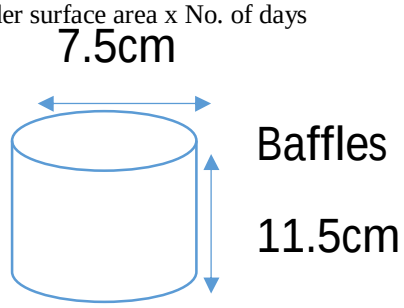


Figure 5 Sediment trap dimension

E. Modelling Studies

MIKE21 by DHI is a comprehensive and potential modelling capable of applying a flexible mesh over the area of interest. Because of this the accuracy of model is increased. It is also capable of extracting the bathymetry and tidal data, analysing spectral waves, calculating hydrodynamic conditions at required time steps and determining the details of sediment transport at particular location.

The modelling studies represents the hydrodynamic conditions at the site in Gulf of Mannar and Palk Bay in Rameshwaram and evaluating the sediment transport patterns.

For this study area the soil particle size is calculated and it is known as silt. So the Mud Transport Module is integrated with MIKE Flow Model FM is used.

Wind parameters are given using NCSCM weather gauge station located in Mandapam, near Rameshwaram. The 6-hours wind data obtained from ECMWF model is also been used. The Tide prediction of heights is based on the global tide model data extracts from the MIKE 21 Tools. Prediction of tidal heights based on from the eleven major tidal constituents like M2, O1, S2, K2, N2, K1, P1, Q1, Mf, Mm, Ssa.

Table 2.Tidal constituent symbols and names

Constituent Symbol	Name
M2	Principal lunar semidiurnal
O1	Principal lunar diurnal
S2	Principal solar semidiurnal
K2	Luni-solar semidiurnal

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N2	Larger lunar elliptic semidiurnal
K1	Luni-solar diurnal
P1	Solar diurnal
Q1	Larger lunar elliptic diurnal
Mf	Luni-solar fortnightly
Mm	Lunar monthly
Ssa	Solar semiannual

1) Model Input:N The generic nature of cohesive sediment dynamics revels a numerical model that will always call for tremendous field work or calibration due to measurements performed. The following input parameters have to be given:

a) Setting velocity
b) Critical shear stress for erosion
c) Critical shear stress for deposition
d) Erosion coefficients
e) Power of erosion
f) Suspended sediment
g) Concentration at open boundaries
h) Dispersion coefficients
i) Thickness of bed layers or estimate of total amount of active sediment in the system
j) Transition coefficients between bed layers
k) Dry density of bed layers

2) Model Output

The main output possibilities are listed below:

a) Suspended sediment concentrations in space and time
b) Sediment in bed layers given as masses or heights
c) Net sedimentation rates
d) Computed bed shear stress
e) Computes settling velocities

F. Biophysical Status Of Corals

Coral reef status of the region will be studied by using the method of English *et al.*, (1997). The live coral cover on the area is studied by using the benthic surveys. The suitable method adopted for the measuring the live coral cover is line intercept point transects.

G. Line Intercept Transect

Transect is laid out (10 - 50m long) which is marked at set intervals (10 - 100cm) along transect. At each interval the substratum type underneath each interval is recorded.



Figure 6 Line Intercept Transect method

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The live coral cover of that area is determined and it helps to correlate with the sedimentation rate to observe the relation between the live coral cover and sedimentation in the selected study area.

V. RESULTS AND DISCUSSIONS

The sediment traps were collected from the study sites on 12 March 2016. Then the amount of sediment deposited on the sediment traps are calculated and found out the sediment deposition rate for per day.



Figure 7 Exposed sediment trap for 80 days

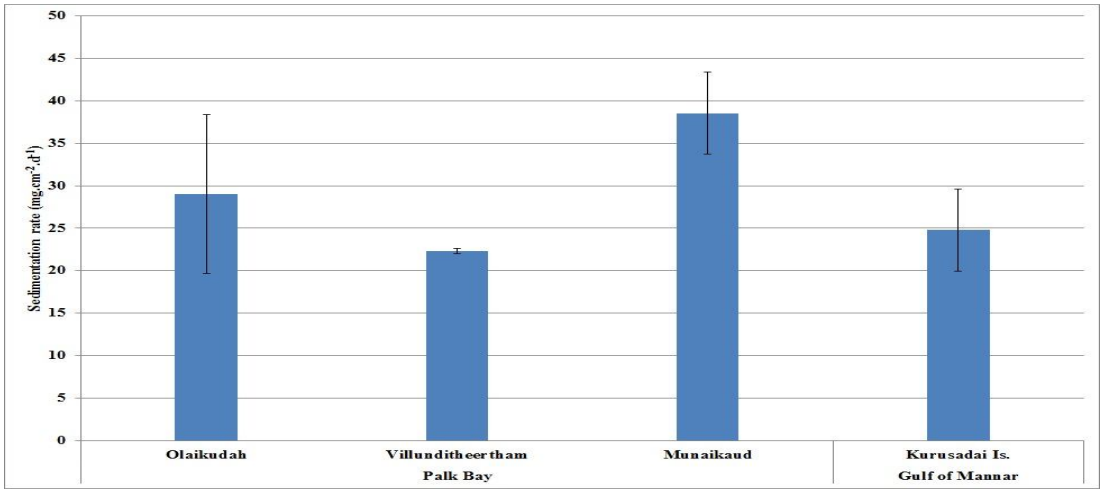


Figure 8 Sediment deposition rate of Palk Bay and Gulf of Mannar

The sediment deposition rate in the various sites of Olaikudah, Villunditheertham, Munaikaud in the Palk Bay and Kurusadai Island in the Gulf of Mannar is shown in the fig 8. The quantity of silt collected in the present study varied from one location to another. The live coral cover was 39.75% in Olaikudah region, 11.4% in Villunditheertham, 12.55% in Munaikaud, 39.67% in Kurusadai Island are shown in Figure 5.3. Olaikudah and Kurusadai Island are rich in the coral cover.

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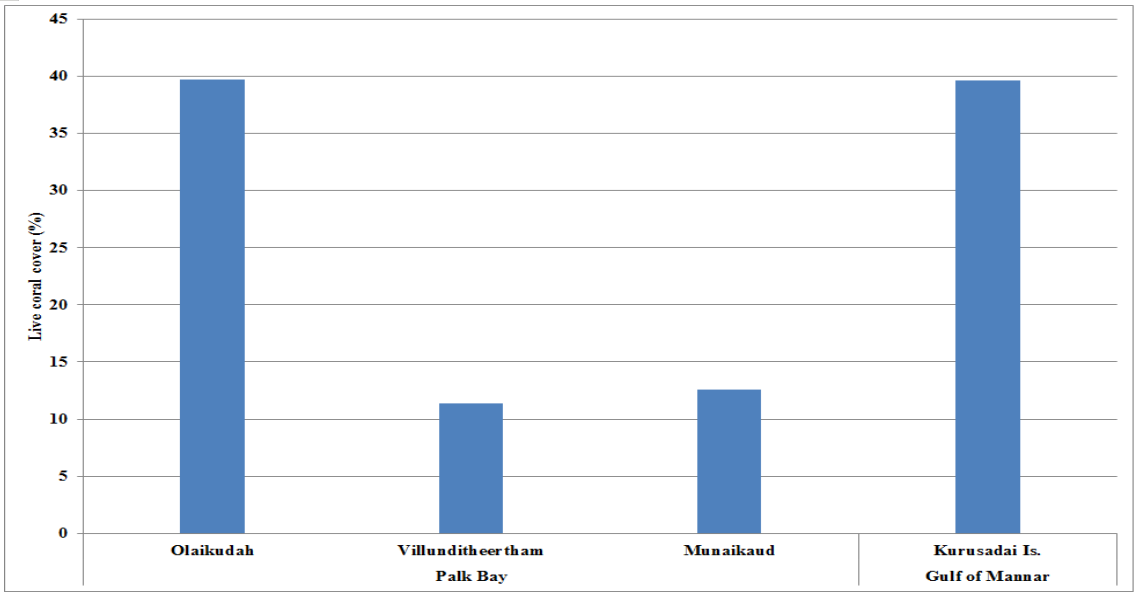


Figure 9 Live coral cover (%) of the Palk bay and Gulf of Mannar

Among the 4 sites, the maximum mean cover of live corals observed in this study was 39.75% at Olaikudah in Palk bay present in the eastern part of Rameswaram Island followed by Krusadai Island have (39.67) whereas the minimum cover (12.55%) was recorded at Villinditheertham.

A. Interpretation Of Coral Reef Cover With Sedimentation Rate

The values of the coral reefs and the live coral cover are given below. To calculate the relationship between the live coral cover with the sedimentation rate.

Table 3. Relationship between mean live coral cover (%) and Sedimentation rate ($mg.cm^{-2}.d^{-1}$.)

Site	Live Coral cover* (%)	Sedimentation Rate ($mg.cm^{-2}.d^{-1}$.)
Olaikudah	39.75	28.99
Villunditheertham	11.40	22.27
Munaikaud	12.55	38.54
Kurusadai	39.67	24.79

*NCSCM Sentinel site program

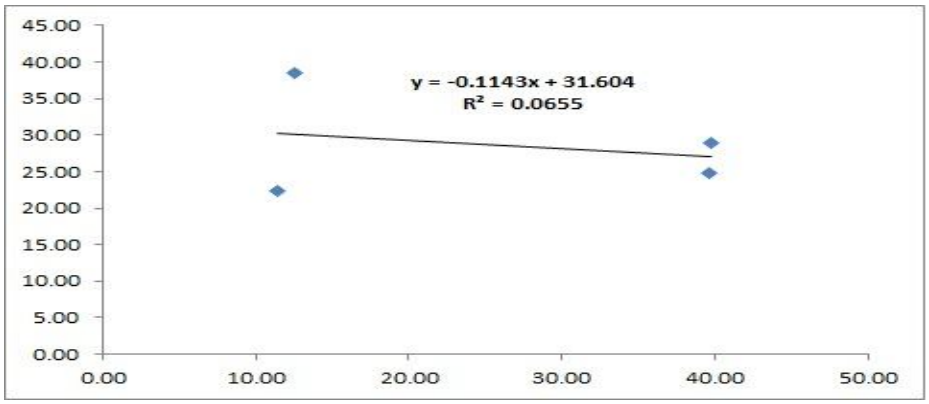


Figure 10 Relation between Sedimentation rate and the Live Coral cover.

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The relation between Sedimentation rate and the Live Coral cover observed from the selected study sites are shown in the Figure 5.5. Based on the coefficient of determination value (r = -0.255); it was evident that almost all the dependent variable, that is % of live corals is explained by the derived regression equation, (y = -0.1143x + 31.604). A very poor negative correlation of the live corals with the Sedimentation rate is observed, which indicating that there are factors other than sedimentation affecting the live coral cover in the region.

The coral reef cover and the sedimentation rate have the inverse relationship. If the sedimentation rate is increases then the growth of the corals are get affected and reduce the percentage of the coral growth in the region.

B. Modelling Results

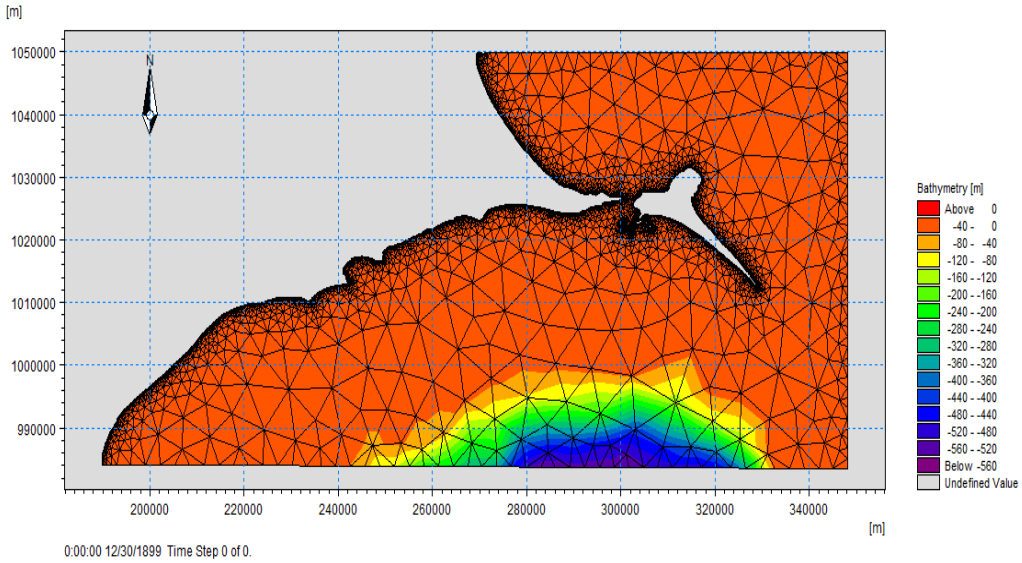


FIGURE 11 MESH GENERATION FOR SELECTED STUDY SITES

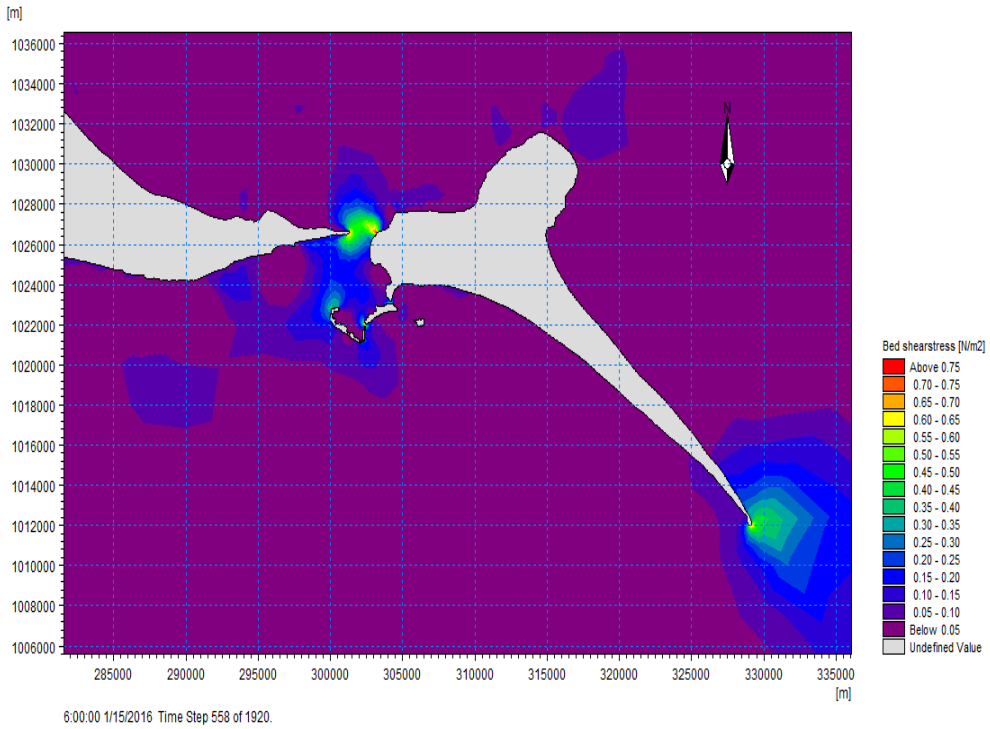


Figure 12 Variation of bed stress at the Palk Strait and Islands of Rameshwaram

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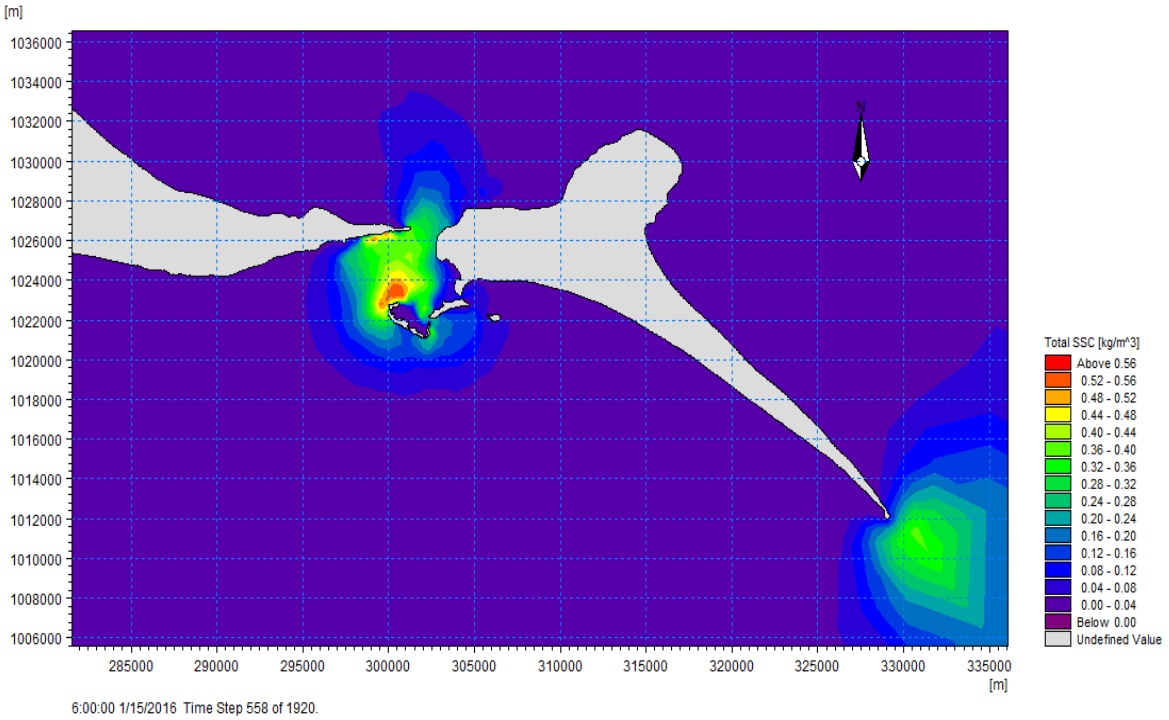


Figure 13 Total Suspended Sediment Concentration in the Gulf of Manner and the Palk Bay region of southern Tamil Nadu region

C. Interpretation Of Field Value With Model Predicted Value

The comparison between the field based measurements and model predicted values of suspended sediment concentration correlation is shown through a regression graph (Figure 5.11).

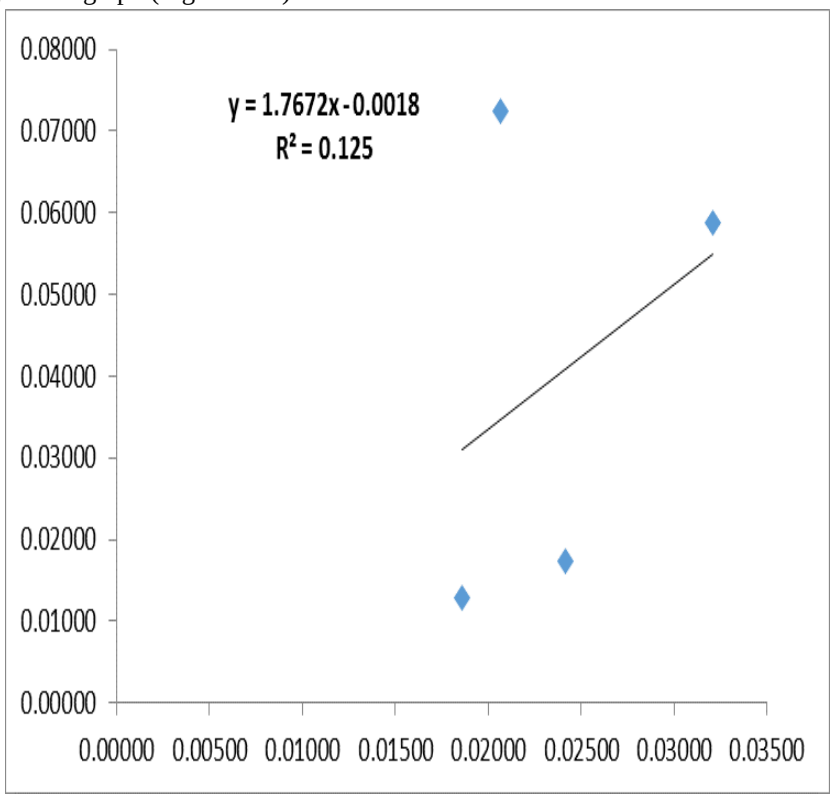


Figure 14 Relation between Field Sedimentation rate and the Modelling Value

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Table 4 Comparison of field valve with Modelling value

Area	Field value ($mg.cm^{-3}.d^{-1}$)	Field value ($kg.m^{-3}.h^{-1}$)	Modelling Predicted Value ($kg.m^{-3}.h^{-1}$)
Olaikudah	8.99	0.02415	0.01746
Villunditheertham	2.27	0.01858	0.01280
Munaikaud	8.54	0.03211	0.05880
Kurusadai	4.79	0.02065	0.07248

The comparison between the field based measurements and model predicted values of suspended sediment concentration correlation has shown through the regression graph (Figure 5.11). It showed the coefficient of regression value (r = 0.3536); hence it was evident that all the dependent variable, which are calculated from field based sedimentation rate are explained by the derived regression equation (y = -1.7672x -0.0018).

A Significant Positive correlation of the model predicted sedimentation value with the collected value is observed from regression graph. There are certain uncertainties are observed in the model predicted values due to the lack of high resolution bathymetry data in the study area. It will be incorporated in the further studies to make the prediction more reliable and accuracy.

VI. CONCLUSIONS

In the present study, the sedimentation rate observed in the field is between 14.6 and 38.54 $mg.cm^{-2}.d^{-1}$ in the Palk Bay and the Gulf of Mannar which affecting the health of corals. It is also observed that the sedimentation rate of the Palk Bay (29.94 $mg.cm^{-2}.d^{-1}$) is higher than that of Gulf of Mannar (24.79 $mg.cm^{-2}.d^{-1}$) due to the circulation pattern.

In modelling, it shows that the bed stress predicted to vary from 0.05 m to 0.75 Nm^2 and it is more in the Palk Strait as compared to the Rameshwaram Island. Because it is directly connected to the flow conditions so it affected the tides to form the sediment in the channel. The magnitude of the suspended sediment has varied in the range of 0.04 – 0.56 kg/m^3 and is high in the Palk Strait and west side of the Kurusadai Island as compared to the offshore regions.

The comparison between the field collected suspended sediment concentration and model predicted values clearly indicate that the model prediction is highly comparable and well matched with the field observations. Hence the numerical model simulations are highly reliable to the measure the health of the coral reef and estimation of the suspended sediment concentration and accumulated sediment concentration in the complex Islands region. The model predictions clearly indicate that the suspended sediment is more in the Kurusadai Island which is in the Gulf of Mannar is due to the complex flow exchange in the channel between the Palk Bay and Gulf of Mannar. But its accumulation is less comparable to the other Islands. Hence Kurusadai Island corals are comparatively healthier than the other Islands.

The percentage of the live coral cover was low at both Villunditheertham and Munaikaud compare to the Olaikudah and Kurusadai Island. As a result of sedimentation, the corals of the family Acroporidae were observed to be stressed severely. Due to high sedimentation rate, the corals in the Gulf of Mannar and Palk Bay reefs are negatively impacted in the present study (r = -0.47) which requires continuous monitoring both in physical (Sedimentation rate) as well as biological status (Ground truthing on coral reef cover) of the coral reef. The model predictions also clearly indicating that the suspended sediment is more in the Kurusadai Island which is in the Gulf of Mannar is due to the complex flow exchange in the channel between the Palk Bay and Gulf of Mannar. But its accumulation is less comparable to the other Islands due to high magnitude of coastal currents will not allow the deposition of suspended mud on the coral environment. Hence Kurusadai Island corals are comparatively healthier than the other Islands.

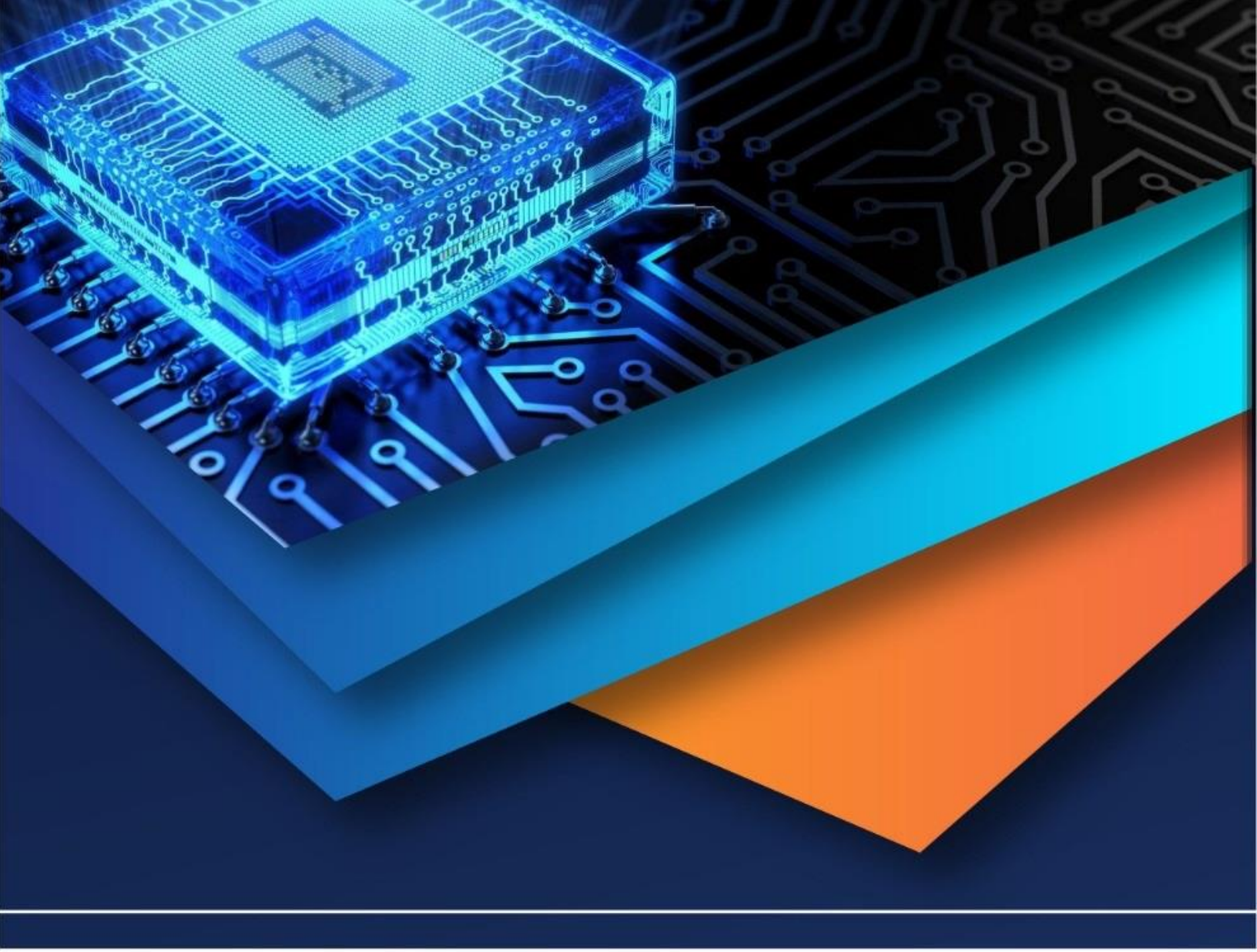
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