International Journal of Plant & Soil Science

23(4): 1-11, 2018; Article no.IJPSS.42151
ISSN: 2320-7035

Mangroves for Protection of Coastal Areas from High Tides, Cyclone and Tsunami

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Authors' contributions

This work was carried out in collaboration between both authors. Author SS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author SPK managed the analyses of the study. Author SS managed the literature searches. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2018/42151
Editor(s):
(1) Dr. Msafiri Yusuph Mkonda, Lecturer, Sokoine University of Agriculture, Tanzania.
(2) Dr. George Perry, Dean and Professor of Biology, University of Texas at San Antonio, USA.
(3) Dr. Marco Trevisan, Professor, Institute of Agricultural Chemistry and Environmental Research Centre BIOMASS, Faculty of Agriculture, Catholic University of the Sacred Heart, Italy.
Reviewers:
(1) Muhammad Luqman, University of Melbourne, Australia.
(2) Abdul Malik, Universitas Negeri Makassar, Indonesia.
Complete Peer review History: http://www.sciencedomain.org/review-history/25467

Review Article

Received 23rd April 2018
Accepted 2nd July 2018
Published 9th July 2018

ABSTRACT

Mangroves are salt-tolerant evergreen dense forests that grow in intertidal zones in tropical and subtropical estuarine regions and mud-flats. Additionally, mangrove forests provide many economical, ecological and environmental values to the people. The total mangrove forest area of the world in 2000 was 1, 37,800 square kilometres spanning 118 countries and territories [1]. According to state forest report of 2015 of Forest Survey of India, mangroves spread over 4,740 sq. km which is about 3 percent of world's mangrove vegetation and 0.14 per cent of the country's total geographical area. Ecological valuation of the mangroves is mainly for its important role of protection and stabilization of coastal lands and estuarine. Mangroves are important means to control coastal erosion. They not only reduce erosion along the coast but also enhance sediment deposition which is essential to maintain their ecosystems. Several studies have been conducted using remote sensing and GIS which show that there is increased erosion rate in coastal areas where mangrove forests have died. Root architecture of mangroves is such that it traps sediments and prevents erosion from waves and storms. Mangrove forests also play an important role in many

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other edaphic functions which includes nutrient cycling, facilitation of plant nutrition, disease suppression, water purification, and biological attenuation of pollutants. The paper discusses different studies on coastal erosion, physico-chemical properties of soil, soil nutrition, soil organic carbon and relationship of soil with species composition and structure of mangrove forests in tropical mangrove environment. The study will help in exploring future research for reforestation of deforested mangrove sites, their management and conservation.

Keywords: Mangrove forest; coastal erosion; sedimentation; soil nutrition.

1. INTRODUCTION

Mangroves, the only woody halophytes living at the confluence of land and sea, have been profoundly used traditionally for food, timber, fuel and medicine, and presently occupy about 1,81,000 sqkm of tropical and subtropical coastline [2]. In India Mangroves occupy 4740 sqkm, about 3% of the world's mangrove cover [3]. Sundarbans in India is the largest mangrove site in the world, colonized with many threatened animal species. About 58% of the mangroves occur on the east coast along the Bay of Bengal, 29% on the west coast bordering the Arabian Sea, and 13% on Andaman and Nicobar Islands [4]. The State forest report of 2015, states that out of total cover of mangrove, Sundarbans contributes about 44%, followed by Gujarat 23% and Andaman and Nicobar Islands 13% [3]. On the basis of density of mangrove cover about 40% area covered by the open mangrove, 29% by the moderately dense mangrove and 31% by the very dense mangrove. In Gujarat, the highest mangrove cover is recorded in Kutch district which is about 71% of total Gujarat's mangrove cover, followed by Jamnagar (15%).Whereas, South Gujarat comprising of 5 districts has 7% mangrove cover of Gujarat's [3]. About 69 species in 27 genera, belonging to 20 families are considered as true mangrove species given by M.S. Swaminathan Research Foundation [5] Table-1. The tree species of Mangrove forest belong to various families such as *Avicenniaceae, Rhizophoraceae, Euphorbiacea, and Combretaceae* [6].

Table 1. List of common mangrove plant (MSSRF)

Avicennia marina	*Avicennia officinalis*
Bruguiera cylindrica	*Ceriops decandra*
Ceriops tagal	*Excoecaria agallocha*
Rhizophora apiculata	*Rhizophora mucronata*
Sonneratia apetala	*Xylocarpus grantum*

Although the occurrence of mangrove is limited, its ecological role has been recognized [7]. Out of many ecological, socio-economical services by the mangroves one of the major services is in protecting the coastal region from the natural calamities like Coastal erosion, Cyclone and Tsunami [8]. However, sufficient mangrove forest width needs to be present to maintain sediment balance; to prevent erosion and it may encourage active soil build-up. Complex aerial root systems help slow water flows, allowing sediment to settle and causing sediment to accrete rather than erode. It is observed that young trees enable soils to build up [9].

2. PHYSICO CHEMICAL PROPERTIES OF MANGROVE SEDIMENTS

The study of physico chemical properties of mangrove sediments is important as they are highly productive and play an important role as breeding and nursery grounds for many commercially important fishes especially shrimps [10]. Nutrients status of the sediments determines the fertility potential of a water mass [11].

The study conducted by Sahoo et al. [12] highlighted the physicochemical properties (pH, Conductivity, Organic carbon/OC, Salinity and Total phosphorous) of sediments from mangrove of Odisha from five different sampling sites such as Bhitarakanika(SITE-I), Dhamra (SITE-II), Mahanadi (SITE-III), Devi(SITE-IV) and Budhabalanga (SITE-V). Physico-chemical characters were analysed (Table 2). Mangrove sediments of Bhitarakanika was nutrient rich due to the amount of organic carbon content, whereas the Budhabalanga sediments has less organic carbon content. The sediments of Bhitarakanika were having slightly neutral pH which indicates that the better growth and survival of highly diverse organisms.

Bhitarkanika of Odisha is the one among the two mangrove genetic paradises of the world [13]. Similar results were found by other researchers [14,15,16]. [17] compared physical chemical properties of mangrove and non mangrove sites (Table 3.) and found that mangroves sediments are more productive than the non mangrove

Table 2. Physico-chemical sediment properties of mangroves of Odisha [12]

Sr. no	Physico-chem. Property	Site-I	Site-II	Site-III	Site-IV	Site-V
1	pH	6.91 to 7.7	6.23 to 7.75	6.27 to 8.3	4.32 to 7.54	8.22 to 8.77
2	Conductivity (µS/cm)	2087 to 2199	1782to 2236	2095 to 2564	1327 to 1675	2312 to 2457
3	OC (mg/g)	51.86 to 36.42	13.88 to 24.68	14.1 to 44	10.98 to 48.48	6.7 to 21.3
4	Salinity (PSU)	0.86 to 4.63	0.75 to 3.73	0.78 to 3.18	1.15 to 3.15	0.39 to0.67
5.	Total P (mg/ml)	58.94 to 42.52	18.9 to 44.48	22.12 to 32.96	14.23 to 25.5	6.68 to 14.34

Table 3. Chemical characteristics and major nutrients in the soil collected from mangrove and non mangrove areas of Bhitarkanika Conservation area, India

Sr. no	Physico-chemical sediment properties	Mangrove site	Non-mangrove site
1	pH	7.58	7.03
2	EC (mho)	2.64	2.30
3	Organic Carbon content (kg/ha)	25236	18323
4	Nitrogen (kg/ha)	2907	2057
5.	Phosphate (kg/ka)	28.11	20.08
6.	Potassium (kg/ha)	7564	1222

Table 4. Comparison of selected soil chemical properties between WSSM and AALL

Sr. No.	Soil chemical parameter	WSSM	AALL
1	Soil Organic matter	20.96	16.20
2	Total Carbon Percent	12.18	9.38
3	Total nitrogen percent	0.22	0.15
4	Total phosphorous percent	25.27	12.32

sites, due to this the farmers near Bhitarakanika were made aware nutrient status of mangrove forests, due to which they are willing to pay a higher price for the land adjoining mangrove forests.

[18] studied soil chemical properties and compared forest soil health of two mangrove sites i.e. Wildlife Sanctuary Sibuti Mangrove Forest, Miri (WSSM) and Awat-Awat Lawas Mangrove Forest, Limbang (AALL) in the State of Sarawak, Malaysia (Table 4). They observed that status of nutrient status of mangrove forest varied within similar agro climatic conditions. Similarly, [19] evaluated the spatial variation in mangrove soil characteristics within the larger Zambezi River Deltaic structure. They found the mean soil C content for the Zambezi river sediments was 1.38 to 2.38% C. In contrast some other studies report mangrove soil C concentrations ranging from 9 to 26% [20]; [21]; [22].

[23] quantified the soil texture and organic carbon content of the mangrove wetland located in Hooker bay at Colombia. The studied site characterizes with 53.17% sand 27.8% Clay and 18.98% silt, whereas it contains an average of 17396 kg C/m^3 in the top 100 cm depth. They revealed that mangrove soils are textured as sandy clay loam with high potential of carbon reservoir in the form of organic matter. In another study conducted by Mendes and Tsai in 2017 [24] at south-eastern Brazil, soil physical and chemical properties of the mangrove site showed higher differences when compared to other sites (Forest and restinga). Soil pH ranged from 6.33 to 3.23, with highest values in mangrove and lower values in forest and restinga. Mangrove soil is found to be the most distinct site with functional soil microbial diversity in comparison with forest and restinga soils.

[25] worked on the Physico-chemical properties of mangroves of Kachchh-Gujarat. According to them the pH of sediment ranged 6.29 and 8.45, Total organic carbon varied from 0.29% to 2.56% and the total inorganic phosphorus ranged between 0.12 mg g^{-1} and 1.97 mg g^{-1}, Total nitrogen varied from 0.02 mg g^{-1} to 1.95 mg g^{-1}. Sediment textures ranges 0.26-19.2 sand; 7.6-47 clay and 47-87.4 so the soil texture characterized by the abundance of silty loam, silty clay and silty clay loam. [26] recorded sediment nutrients of Arasalar estuary, Karaikkal, south-east coast of India. They found that sediment temperature, pH and nutrients (N, P, K and organic carbon) were higher during summer season and lower during monsoon season. Higher value during summer was due to a course of the redox changes in the sediments, settling of decayed plant and animal wastes adjacent agricultural field, oxidation of dead plant organic matter.

Many studies have been carried out so far on sediment nutrients from various estuaries and mangrove sites. Such studies would form a useful tool for further ecological assessment and monitoring of the coastal mangrove ecosystems.

3. MANGROVE FOR PROTECTION FROM COASTAL EROSION

Coastal erosion are a kind of natural degradation, they have become widespread in the coastal zone of Asia and other countries in the Indian Ocean. Population growth, unmanaged economic development along the coast, within river catchments and offshore are the reasons or such type of erosion.

Studies conducted have proven that forests and trees provide some coastal protection and that the clearing of coastal forests and trees increase the vulnerability of coasts to erosion experienced in Vietnam [27] and Sri Lanka [28]. Fig. 1 show the how mangrove retreat and stop coastal damage due to the waves.

On the basis of multidate satellite data of 1989–1991 and 2004–2006 [29] estimated the length of coastal erosion (Table 5). The longest length of erosion was observed in Andaman Islands (740.34 km) and shortest in Goa (27.03 km).

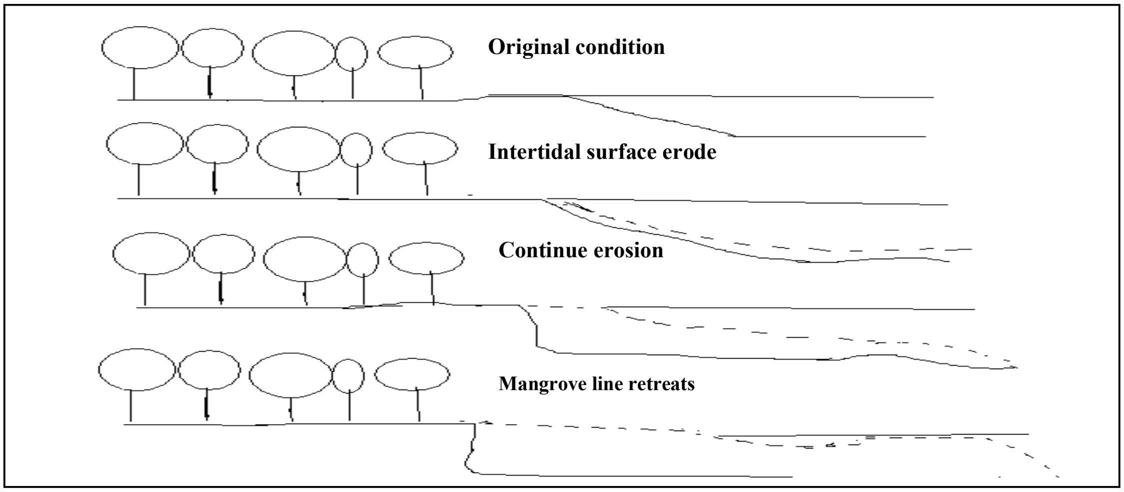

Fig. 1. Mangrove retreat to the erosion

Table 5. Coastal length under erosion in different Maritime states / Union Territories of India [29]

Maritime states and union territories	Erosion length (km)	Area under erosion (sq km)
Gujarat, Daman and Diu	486.4	27.3
Maharashtra	449.5	7.8
Goa	27.03	0.8
Karnataka	106.1	5.2
Kerala	218	5.3
Tamil Nadu and Pondicherry	281.6	17.2
Andhra Pradesh	443.9	46.9
Odisha	199	13.8
West Bengal	115.1	11.6
Lakshadweep Islands	72	1.7
Andaman Islands	740.4	17.9
Nicobar Islands	690.1	94.7
Total	**3829.1**	**250.2**

Table 6. Temporal variations in eroded and deposited area along the 160 km stretch of the Godavari delta [30]

Sr. No.	Period	Erosion (Ha)	Deposition (Ha)	Net loss (Ha)
1	1976-92	3014	1950	1064
2	1992-97	982	495	487
3	1997-1999	378	242	136
4	1999-2001	429	280	149
5	Total	4803	2967	1836

Table 7. Coastal change in the East and West coast of Southern Thailand

Sr. no.	Coast	Length of coastline (km)	Mangrove area in 2000 (km^2)	Eroded coastal length (km)	Accretion coastal length (km)
1.	East	880	296	258 (29%)	82 (9%)
2.	West	983	1766	113 (11%)	35 (3%)

In the Godavari delta there was a net loss of 1800 ha of land in 25 years period of study. However, when the entire 160 km long deltaic coast is considered, erosion is found to be dominant along as much as 102 km, while deposition is limited to the rest of 48 km coastal section only, this 48 km area was sheltered by mangroves. Coastal erosion decreased due to sea level rise and sand supply reduced from the rivers due to different anthropogenic activities on the river catchment like dams and port construction. Global coastal erosion rates may increase in coming decades [31]. Similarly, [32] assessed the relationship between mangrove presence and changes in coastal area of West coast and East coast Thailand (Table 6). Overall, eroded distances for the east and the west coasts accounted for 29% and 11% of their total length, percent accretion had a similar pattern, ranging from 9% for the west and from 3% for the east coast.

Mangroves produce organic matter, so soils are rich in organic matter, including living roots, dead leaves and wood. Fine roots network helps reduce the erosive forces and bind sediments together. Mangrove soils are often in anaerobic conditions, due to this, organic matter accumulates; creating peat and thickness of peat layer increase with the time.

4. MANGROVE AGAINST T SUNAMI AND CYCLONES

Mangroves are resistance to long waves of Tsunamis, it helps in decreasing the flow velocity, significantly [33]. Mangrove interactions to reduce waves and hydraulic forces have been studied thoroughly by many authors. After the 2004 Asia tsunami lining the Indian Ocean, IUCN (International Union for Conservation of Nature) highlighted how in-tact mangrove forests provided protection to coastal communities. It reported that only two people were killed in a Sri Lankan village, where there were dense mangrove and scrub forest, whereas, 6,000 people lost their lives in settlements, where Mangroves or similar vegetation was not there [34].

[35] reported the number of human consequences due the tropical cyclones between the 1980-2009 (Table-8).

[36] Studied mangrove forest as a coastal protection measure from wind-generated waves and found effectiveness of mangroves in reducing waves thrust on the age of mangroves and that it correlates with vegetation density. Similar observations were found by [37]. [38] Mazda with his co-workers in 2005 on the basis of tidal hydrodynamics found that drag force and the horizontal eddy viscosity play a dominant role in the tidal-scale in mangrove wetlands. They stated that tidal flow within mangrove areas depends to a large degree upon the submerged vegetation density that varies with the tidal stage. *Rhizophora apiculata* and *Rhizophora mucronata* are two species commonly used in mangrove restoration and afforestation. The presence of stilt roots of *Rhizophora spp*. helps to withstand the fury of cyclones and tsunamis and thereby helps in mitigating the impact of such natural calamities [39]. Analysis of satellite images of the west coast of Aceh by Bayas [40] and co-researchers of the University of Hohenheim, Germany, in 2010 reported that forests in front of settlements reduced 5 per cent casualties during the tsunami. On the basis of field survey and continues experimental studies by Hiraishi and Harada in 2003 [11] at south pacific region concluded that 30 trees per 100 m^2 in a 100-m wide belt may reduce the maximum tsunami flow pressure. [42] on the basis of field survey observed differences in drag coefficient and in vegetation thickness with tsunami height, and found that species differed in their drag force in relation to tsunami height. The palm, *Pandanus odoratissimus*, and *Rhizophora apiculata*, being more effective than other common vegetation, including the mangrove *Avicennia alba*. In a study conducted in the Bay of Bengal, by [43], it was reported that the mangrove areas in India and Bangladesh, especially at Sunderbans were able to heal cyclonic wounds and maintain the extent of their total area through natural succession without human interference. Das and Vincet in 2008 on the basis of their field survey plotted the relation between the width of mangrove and number of deaths during the 1999 Odisha cyclone. Fig. 2 depicted that the number of deaths were higher at narrowest belt of mangroves, whereas wider mangrove belt reduced number of deaths.

Table 8. Cumulative impact of tropical cyclones, 1980-2009 [35]

Human consequence	Best estimate
Deaths	4,12,644
Injuries	2,90,654
Homeless	2,01,60,878
Total Affected	46,60,98,192

**The figures are based on the highest reported number of deaths or injuries in an event from either EM-DAT or NHC (National Hurricane Center).*

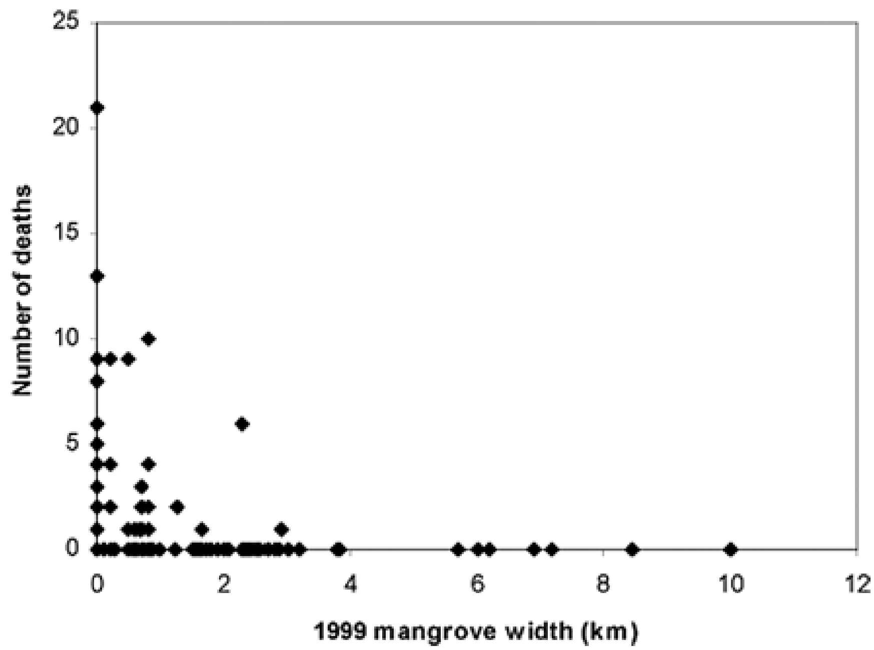

Fig. 2. Number of Deaths during cyclone of 1999 plotted against width of mangroves [44]. Whereas, Shuto 1987 [45], based on his study stated how mangroves reduce the impact of tsunami: 1) Stops driftwood and wreckage 2) Reduces water flow velocity and inundation depth; 3) Provides a life-saving net for people from swept off land by a tsunami and 4) Assemble wind-blown sand and create dunes, which serve as a natural barriers against tsunamis

5. MANGROVE INCREASES SEDIMENTATION

Sediment retention is one of the important ecological services provided by the mangroves. Thus mangroves are not just colonising mud banks but actively contribute to the creation of mud banks [46]. The mangrove trees catches sediment by their complex aerial root structure, thus functioning as land builders. In numerous cases, there has been proof of annual sedimentation rate in mangrove areas, ranging between 1 and 8 mm [47]. Sediment mechanisms in mangrove waters are mostly based on the hydrodynamic process rather than biological process [48]. Suspension of the sediment particles carried into the forest during tidal inundation and forms large flocks. These flocks remain in suspension as a result of the turbulence created by the flow around the mangrove [49]. It is observed that areas covered with mangroves are flooded. particular during the south west monsoon, the flood brings in sediment-laden water. As most of the suspended sediments settle in between the roots of the mangrove trees and around slack water [50].

According to [29] Coastal length that has sedimentation is maximum for Andaman Islands (944.84 km) and minimum for West Bengal (19.46 km). From the Table 5 and 9, it could be concluded that in the state of Tamilnadu the rate of sedimentation is more than the erosion, there net gain area is maximum (25.5 sq km) compared to other states and UTs, whereas in the Nicobar Island net loss area (-94 sq km) means total erosion is higher than the accretion.

[46] said that about 80% of the suspended sediment brought in from coastal waters at spring flood tide was trapped in the mangroves, resulting in a rise of the substrate by about 1 cm year^{-1}. A study conducted by [51], in 2009 on sedimentation within and among mangrove forests at Queensland, showed that mean average sedimentation was about 0.64 mg cm^{-2} spring tide^{-1}, which was variable within sites. Sedimentation is more intense in the complex matrix of roots in mangrove trees *Rhizophora sp.* and *Ceriops sp* [49] Conceptual graph of of sedimentation rate and mangrove belt width (Fig. 3), shows that for narrow mangrove belts, there is no sedimentation [52], whereas,

Table 9. Coastal length under erosion accretion and as stable in different Maritime states/Union Territories of India [29]

Maritime states and union territories	Erosion length (km)	Accretion length (km)	Stable length (km)	Total length (km)	Area under accretion (sq km)	Area under erosion (sq km)	Net gain/loss (sq km)
Gujarat, Daman and Diu	486.4	298	697.7	1482.1	43.5	27.3	16.2
Maharashtra	449.5	244.5	48.3	742.3	5.1	7.8	-2.8
Goa	27	47	81.4	155.4	1.5	0.8	0.8
Karnataka	106.1	118.7	73.3	298.1	6.3	5.2	1.1
Kerala	218	294	73.6	585.6	9.5	5.3	4.2
Tamil Nadu and Puducherry	281.6	514.1	29.3	824.9	42.6	17.2	25.5
Andhra Pradesh	443.9	186.9	340.5	971.3	25.1	46.9	-21.8
Odisha	199	205	32.1	436.1	13.3	13.8	-0.5
West Bengal	115.1	19.5	147.7	282.2	1.5	11.6	-10.1
Lakshadweep Islands	72	63.2	1	136.3	0.8	1.7	-0.9
Andaman Islands	740.4	944.8	36.8	1722	27.1	17.9	9.2
Nicobar Islands	690.1	68.3	19.2	777.6	0.8	94.7	-94
Total	**3829.1**	**3004**	**1580.8**	**8413.9**	**177.2**	**250.2**	**-73.1**

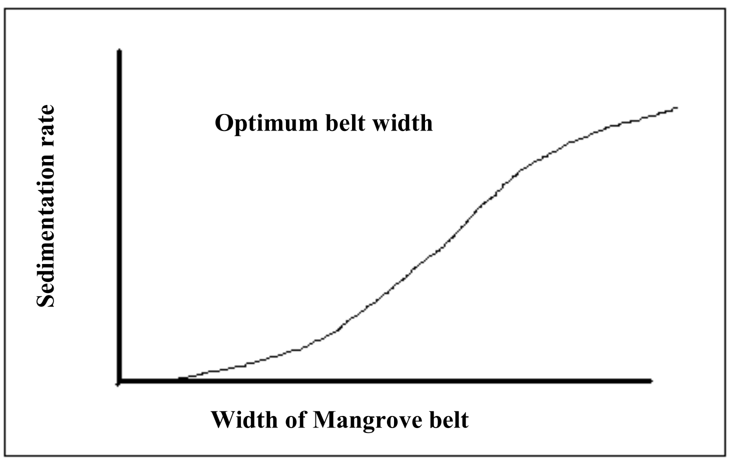

Fig. 3. Conceptual sketch of sedimentation rate as a function of mangrove belt width

for wider belts, the sedimentation rate increased rapidly. [53] revealed that the roots of *Rhizophora mangle* can significantly reduce the velocity of tidal water, and provide a better sediment binding capacity compared with a variety of sea-grasses and algal mats. Therefore, it is proved fact that the existence of mangroves and a continued sedimentation are crucial to maintain coastal stability.

6. CONCLUSION

The objectives of this study are to provide information about the constructive role of mangrove forest to protect coastal zones. The rapid erosion observed is the result of destruction in intertidal area by the human intervention *viz.* land subsidence, sand mining, dam construction etc. Mangroves are able to keep pace with rising sea levels and are acting as a barrier to the sea coast and are acting as a barrier to the sea coast. They do this by capturing sediments and organic matter, thus building up soils and store carbon. This highlights the need to maintain and restore healthy mangroves and their sediment supplies. There is need to initiating appropriate action for protecting the Indian coast by afforestation, restoration, establishment and management of mangrove forests, promotion of joint mangrove management systems within the coastal communities and raise mangrove shelterbelts along the coastal zone.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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