The role of mangroves in disaster mitigation: a review

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Abstract: The aim of this paper is to study the role played by mangrove ecosystems in minimising the impact of disasters like tsunami, floods and cyclones. A comparison of the studies concerning effective mitigation of tsunami and natural disasters by mangrove ecosystems was carried out for countries with special focus on India. A study about the role of mangroves across various states in India is also presented. The main findings, based on the literature review, are that mangroves occurring near the coast play an important role in the protection of the coast from the natural disasters like tsunami, floods, cyclones, sea level rise, etc. It is concluded that it is necessary to realise the dangers and consequences of undermining the services provided by the mangrove ecosystems in coastal protection and to conserve mangroves in every part of the world.

The value of this paper lies in presenting an exhaustive review of the role played by mangroves in mitigating disasters.

Keywords: mangrove; tsunami; cyclones; floods; disaster mitigation.

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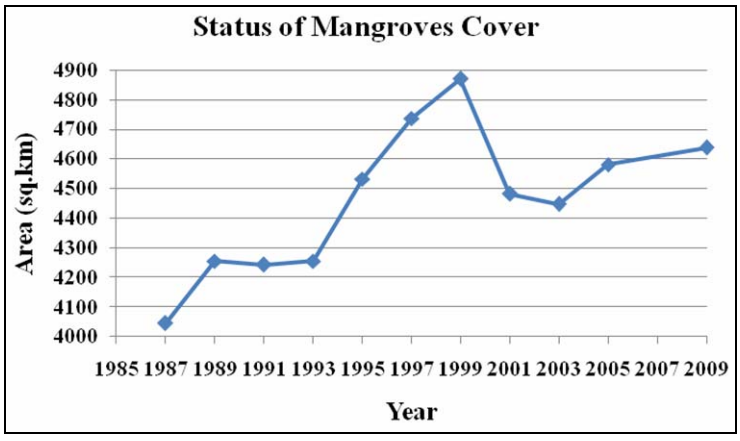
1 Introduction

Mangroves are salt-tolerant forest ecosystems found mainly in 124 tropical and subtropical (FAO, 2007) inter-tidal regions of the world. These are trees or shrubs that have the common characteristic of growing in shallow and muddy salt water or brackish water, especially along quiet shoreline and in estuary (FSI, 2003). These unique coastal tropical forests are among the most threatened habitats in the world (FSI, 2009). The term 'mangrove' describes both the ecosystem and the plant families that have developed specialised adaptations to live in tidal environment which are inundated twice daily by the tides (Tomlinson, 1986). There is growing evidence that mangroves and other coastal forests serve as a natural barriers against tsunami (Hamzah and Safwan, 2007), cyclones (Kabir et al., 2006) and flood (Das and Vincent, 2009).

1.1 Current status of mangrove cover in India and in the world

The five countries with the largest net loss of mangrove area during the period 2000–2010 were Indonesia, Australia, Myanmar, Madagascar and Mozambique (FRA, 2010). An alarming 17%, or 3.2 million hectares of mangroves, have been lost since 1980 (18.8 million ha) (FAO, 2007). The positive trend during 2005–2010 periods reflects an increased awareness of the value of mangrove ecosystem.

Figure 1 Trend of mangrove cover in India (see online version for colours)

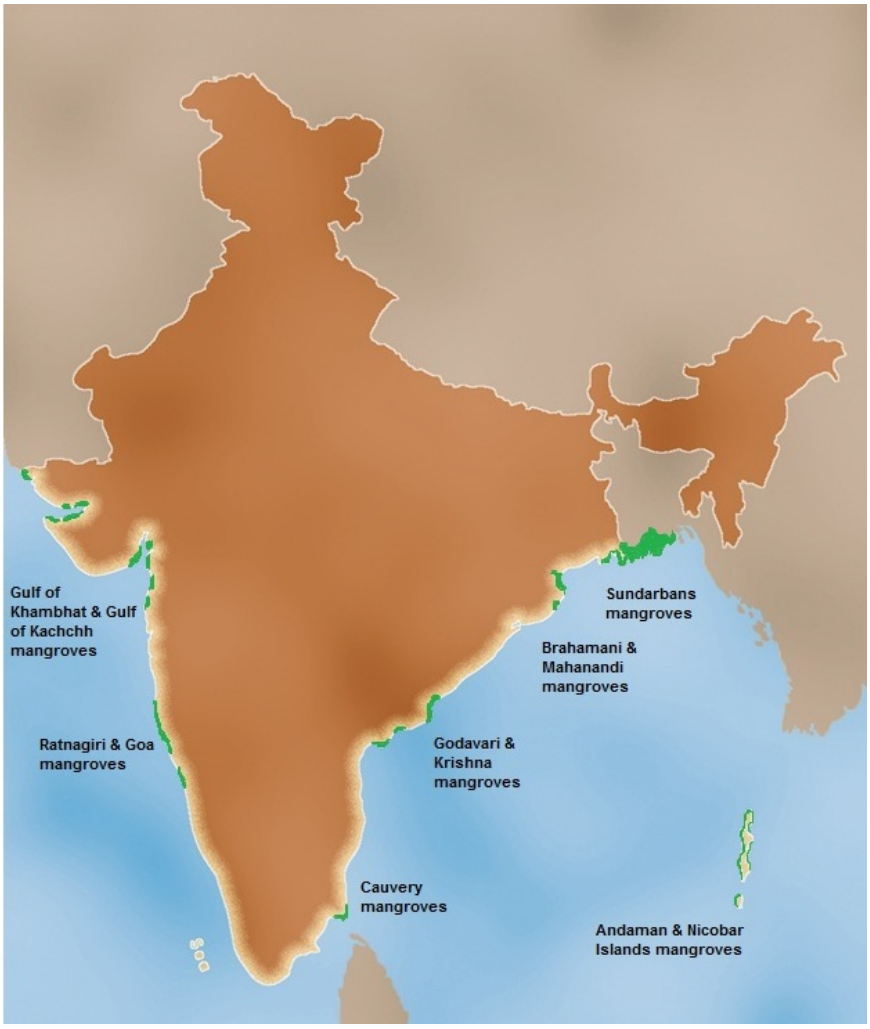


Source: FSI (2009)

Mangrove forests are scattered along the 12,700 km Indian coastline, 80% of India's mangroves are located along the East coast favoured by its gentler slope and the rich

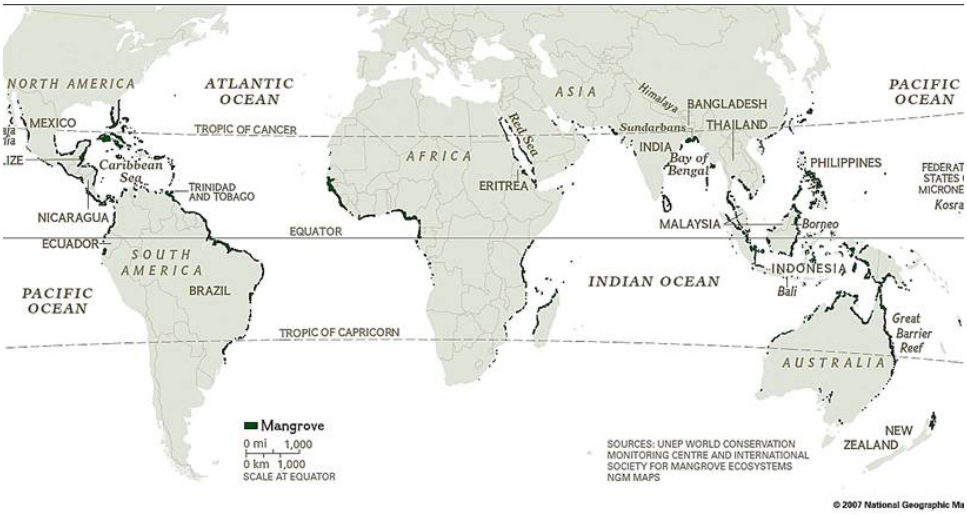
estuary (FAO, 2007). Sundarban in West Bengal accounts for a little less than 50% of the total area under mangroves in India (FSI, 2009). The change in area of mangrove from 1987–2009 is shown in Figure 1. Figures 2 and 3 show the distribution of mangroves in India and in the world.

Figure 2 Mangrove distribution in India (see online version for colours)



Source: http://www.google.co.in/imgres?q=mangrove+distribution+map+of+india&hl=en&newwindow=1&safe=off&rls=com.microsoft:en-US&biw=1280&bih=907&tbm=isch&tbnid=qO_57CgMkcXpyM:&imgrefurl=http://fishtalesindia.org/%3Fpage_id%3D95&docid=-LXvMzgLcDZeuM&imgurl=http://fishtalesindia.org/wp-content/uploads/India-Map-Mangroves-.jpg&w=625&h=737&ei=INXlT9WZGYHUrQeAmbz0CA&zoom=1&iact=hc&vpx=399&vpy=320&dur=222&hovh=244&hovw=207&tx=103&ty=171&sig=116611960031372940014&page=1&tbnh=176&tbnw=166&start=0&ndsp=20&ved=1t:429,r:6,s:0,i:89

Figure 3 Mangrove distribution in the world (see online version for colours)



Source: National Geographical Magazine (2007); Wikipedia (2010)

2 Role in carbon sequestration and disaster mitigation

Mangroves are important carbon sinks, and sequester approximately 25.5 million tonnes of carbon every year. They also provide more than 10% of essential dissolved organic carbon that is supplied to the global ocean from land (Spalding et al., 1997).

Carbon sequestration can be defined as the capture and secured storage of carbon that would otherwise be emitted to or remain in the atmosphere, or to prevent, carbon emission produced by human activities from reaching the atmosphere, by capturing and diverting it to secure storage. It is through this process that agriculture and forestry practices remove CO_2 from the atmosphere (Melkania et al., 2007). Carbon sequestration also provides associated ecosystem co benefits such as increased soil water holding capacity, better soil structure, improved soil quality, nutrient cycling and reduced soil erosion (Derner and Schuman, 2007).

2.1 Role of mangroves in protection against tsunami

Tsunamis are described as a chain of fast moving waves that are generated when water in the ocean or even a lake is rapidly displaced due to earthquake, volcanic eruption, landslide or the impact of the meteorite (Tibballs, 2005). Large tsunamis have been known to rise over 100 feet, while tsunamis 10 to 20 feet high can be very destructive and cause many deaths and injuries (NOAA, 2010). Tsunami waves have a small height offshore, and a very long wavelength ranging to hundreds of kilometres, because of which they are not easily detected in sea (Kowalik, 2004; Mojfeld et al., 2000). They can also be reflected off obstacles and travel in different directions (Yeh et al., 1994).

Majority of the human population in the world is concentrated in coastal areas which are more vulnerable to natural disasters such as floods, wind generated waves, tsunami

and storm surges (Ramesh and Ramachandran, 1999). Although mangrove ecosystems provide various services, the most important service provided by mangroves is the protection against coastal disasters and tsunamis (Osti. et al., 2009).

Mangroves prevent coastal erosion, and act as a barrier against typhoons, cyclones, hurricanes, and tsunamis, helping to minimise damage done to property and life (Upadhyay et al., 2002; Dahdouh-Guebas, 2006; Pearce, 1996; Mazda et al., 1997). Mangrove tree species that inhabit lower tidal zones can block or buffer wave action with their stems, which can measure 30 m high and several metres in circumference (Dahdouh-Guebas, 2006). Mangroves defend the land from wind and trap sediment in their roots, maintaining a shallow slope on the seabed that absorbs the energy of tidal surges (Pearce, 1999).

Mangroves protect the coast against waves, currents and storms and from coastal erosion. Mangroves are like live sea walls, and more effective than concrete wall structures (Kathiresan, 2000). Some of the mangrove species like Rhizophora acts as a physical barrier against tidal and ocean influences and shields the coast by means of its large above-ground aerial root system and standing crop (Dahdouh-Guebas et al., 2005). It is also found that these mangrove species seem to act as a protective force towards this natural calamity (McCoy et al., 1996).

In India and the Philippines, villagers tell how they have been protected from tsunamis, cyclones and other natural disasters in locations where mangroves were intact, but suffered where mangroves were converted to shrimp farms or were lost due to human activities (Dahdouh-Guebas et al., 2005; Walters, 2004). In Vietnam, mangroves have been observed to limit damage from tsunamis and cyclone waves and have led to large savings on the cost of maintaining sea dykes (Asian Wetland Symposium, 2005). In Chidambaram district in Tamil Nadu, India, the shore protection role of mangroves is recognised by local people. A 113 km^2 forest is used as a sacred grove and is traditionally known in Tamil as Alaithi Kadukal, meaning 'the forest that controls the waves' (WWF, 2005). Remains of rows of mangroves planted by Maoris can still be seen in New Zealand to stabilise the coast, indicating that mangroves helped in coastal protection (Vannucci, 1997).

Wave energy of tsunamis may be reduced by 75% in the wave's passage through 200 metres of mangrove (Massel et al., 1999). It has also been found that 1.5 km belt of mangrove may be able to reduce entirely a wave one metre high (Mazda et al., 1997).

Many observations suggest that mangroves also help to reduce damage of a tsunami by dissipating the force of the tsunami and preventing the debris washed up by it (IUCN, 2005a). In India, bathymetry and coastal profile were most important in determining the impact, but less erosion was observed in the Andaman Islands behind mangroves than where there were no mangroves (Department of Ocean Development, 2005).

Indian Ocean area experienced 63 tsunami events between 1,750 and 2,004 and more than three wind generated waves struck per year (Dahdouh-Guebas et al., 2005). A satellite and field data study done by Selvam (2005) showed that mangrove forest plays important role in mitigating the outcomes of the tsunami disaster, especially in 2004. He showed that 30 trees per 100 square metres might reduce the maximum flow of a tsunami by more than 90%. Similar results were obtained by Hiraishi (2005) which showed that tsunami flow pressure can be reduced by increasing the density of the planted zone, reproduced by considering drag forces exerted by the individual trunk and leaf parts of trees.

Studies have shown that mangrove forests and certain other types of coastal vegetation can effectively reduce the impact of tsunamis on coastlines (Hiraishi, 2003; Dinar et al., 2002; Hiraishi and Koike, 2001).

Studies in Vietnam also demonstrate the usefulness of mangrove forests in coastal protection and their role in reducing the impact of coastal disasters like tsunamis (Mazda et al., 1997).

It is reported that the tsunami did less damage to lives and property in Tamil Nadu in the regions of Pichavaram and Muthupet, which are both shielded with dense mangroves, than in areas where mangroves had been cleared or were absent (MSSRF, 2005). Some researchers argue that mangroves do protect shorelines, but the scientific evidence of the study performed is not sufficient to provide certainty about the role of mangroves in coastal protection (Cochard et al., 2008; Alongi, 2008; Vermaat and Thampanya, 2006; Kerr et al., 2007).

According to Chetenoux and Peduzzi (2007), mangrove forests are mainly located in sheltered areas and in estuaries and in protected bay area and hence they suspect that they were less impacted by tsunami waves and so the destruction was less behind mangroves forest. Bhalla (2007) has stated that mangroves do provide protection against tsunami but to lesser extent than other biological features. His paper pointed out the evidence of sand dunes as a defense against tsunami inundation is persuasive. Dunes act as windbreaks, protect against storm surges and tsunami inundation. According to Mohanty (2002) and Selvam et al. (2003), many coastal settlements built behind or on coastal dune formations were protected from the tsunami. Unfortunately, dunes are not considered a worthy ecosystem,

2.2 Role of mangrove forest in flood control and flood protection

It has been reported that mangroves protected villages and reduced death toll during floods and cyclones (Das and Vincent, 2009).

A public policy instrument has to be adopted which considers options for mitigation of coastal hazards, and adoption of measures for restoration of coastal sand dunes with sufficient forested shelter belts (Mascarenhas and Jayakumar, 2008).

The benefits of mangroves for shoreline protection and storm damage control have been estimated to run into tens of thousands of dollars per km^2 in Sri Lanka and Malaysia. Studies carried out in Vietnam show that the value over time of mangroves in protecting against extreme weather events lies around US$5,000 per km^2 (IUCN – The World Conservation Union, 2006).

2.3 Role of mangroves in reducing the impact of cyclones

Sundarban mangrove forests to the west of the Ganges River Delta are the largest in the world extending up to 80 kilometres into the Bay of Bengal; they reduce cyclone impacts significantly (Hermann et al., 2007). The role of mangroves forests could be important in reducing the impact from tropical cyclone (one of the most devastating natural hazard in India and Bangladesh) (Kairo et al., 2001)

It has been reported that mangroves reduce cyclone impact by dissipating wave energy and decreasing the impact caused due to cyclone (Badola and Hussain, 2005;

Fosberg, 1971). Das and Bellamy (2007) also concluded that mangroves played an effective role in providing protection against cyclones.

In one of the studies done by Narayan et al. (2010), it was concluded that the mangroves have a definite positive effect on the port in terms of wave attenuation. From the studies done world wide it has been concluded that the cyclone could have been greatly lessened and much loss in life and property damage avoided if healthy mangrove forests had been conserved along the coastlines of the delta (ASEAN, 2009).

Role of mangroves in saving coastal lives and property has been well established during the last Orissa super cyclone in Bhitar Kanika and during Tsunami, at Nagapattinam and Car Nicober (Panigrahi et al., 2008).

In Orissa, India, a powerful cyclone in 1999 and associated waves caused extensive economic damage and human mortality, but communities living near the mangrove ecosystems were protected by mangrove belts and were less affected (Mangrove Action Project, 2005).

3 Comparative review of studies in various states in India and in various countries

A brief comparative study of the role of mangroves in different countries is given in Table 1. The role of mangroves in minimising the impact of cyclones has been done mostly in countries like India, USA and Sri Lanka which are most prone to cyclonic storms.

Table 1 Studies done by authors of different countries worldwide showing protection by mangroves from various disasters

Country	*Author*	*Work done and analysis used*
Thailand	Sathirathai (1998)	Highlighted the role and importance of mangrove forest in protection from coastal disasters and their economic importance.
Thailand	Aksornkoae and Hawanon (2005)	Mangroves effectively provide protection against the action of waves, the width of the forest should not be less than 100 m from coastal shores.
Thailand	Harakunarak and Aksornkoae (2005)	Assessment of mangroves forest value in protection against tsunami and their other benefits, as well as conservation of mangrove ecosystem and threats to them.
Thailand	Vermaat and Thampanya (2006)	Using analysis of variance method, showed the protective role of mangroves from coastal hazards.
Sri Lanka	Gunawardena and Rowan (2005)	Indicated the protective role of mangroves and threat of loss of their protective role due to human activities.
Sri Lanka	Batagoda (2003)	Benefits from mangrove forest and their role in storm and coastal protection.
Sri Lanka	Jayatissa et al. (2005)	Studies showed that mangrove forest can be used as green barriers for protection against tsunami and tidal waves.

Table 1 Studies done by authors of different countries worldwide showing protection by mangroves from various disasters (continued)

Country	*Author*	*Work done and analysis used*
Sri Lanka	Withanage (2005)	Emphasised the role of mangroves in reducing the impact of tsunami waves and providing protection.
Sri Lanka	UNEP and Ministry of Environment and Nature Sri Lanka (2005)	Showed the effectiveness of mangroves in providing protection against coastal hazards.
USA	McCoy et al. (1996)	Discussed damage caused to mangroves and their role in reducing the impact of hurricane and cyclones.
USA	Dahdouh-Guebas (2006)	Used multivariate statistics and clustering and showed the positive role of mangroves in Tsunami protection
Vietnam	Mazda et al. (1997)	Effectiveness of mangroves in reducing waves and their intensity, age of mangroves and correlation with vegetation density
Japan	Danielsen et al. (2005)	Studied tsunami protection, and the protective role played by coastal vegetation.
Japan	Osti et al. (2008)	Showed the vital role of mangroves in reducing the impact of tsunami waves and providing coastal protection.
India	Kathiresan and Rajendran (2007)	Found that coastal mangrove forests mitigated tsunami. Method used- linear regression on individual variables.
India	Chaddha et al. (2005)	Comparative study of destruction caused by tsunami in area with mangroves cover and in areas with no mangroves.
Finland	Tynkkyen (2000)	Indicated the loss of green barriers such as mangrove ecosystem and its consequences on coastal protection from coastal hazards.
UK	EJF (2004)	Studied on the Protection of coasts against cyclones, typhoons and tidal waves.
--	IUCN (2005b)	Role played by mangroves in providing protection against tsunami disaster.
Indonesia	Parish and Lee (2005)	Assessment of tsunami affected area and role of mangrove forest in tsunami protection and consequences of loss of mangrove ecosystem on coastal protection.
Indonesia	Parish (2005)	Loss of mangroves and consequences of it on coastal protection.
Indonesia	Suwarni (2005)	It is necessary to replant mangroves and maintain them for protection from coastal hazards.
London, UK	Environmental Justice Foundation (2006)	A report on the impact of mangrove loss due to shrimp farm development on coastal land.
Malaysia	Abdullah et al. (2005)	Indicated that the loss of mangrove ecosystem can prove dangerous as the protective benefits provided by it can be lost.
Malaysia	Blasco et al. (2005)	Studied and recognised the importance of mangroves in reducing the impact of tsunamis.
Malaysia	Eong (2005)	Mangroves are necessary for protecting against tsunami and other coastal hazards.

Table 2 Studies done by different authors in India on how mangroves protected and reduced the impact of disasters

Author	*Title*	*Major findings*
Upadhyay et al. (2002)	'Human-mangrove conflicts: the way out', *Current Science*	Loss of mangrove species will have devastating economic and environmental consequences for coastal communities and may increase the risk, especially in those areas with low mangrove diversity and high mangrove area or species loss due to human activities. Studies indicated that mangroves minimises damage due to tsunami, cyclones and provide protection
Satapathy (1999)	'The times of India news service'	Areas having dense belt of mangroves were protected from tsunami and other natural coastal hazards.
Chaddha et al. (2005)	'The tsunami of the great Sumatra earthquake of M 9.0 on 26th December 2004 – impact on the East Coast of India'	Studied the impact of tsunami waves in regions having mangroves and in regions with no mangroves and found that the damage in regions with dense mangroves was less compared to regions with no mangroves.
Padma (2004)	'Mangrove forests can reduce impact of tsunamis'	Mangrove forest can help to reduce the devastating impact of tsunamis and coastal storms by absorbing some of the wave energy.
Vidal (2005)	'How the mangrove shield was lost'	Impact of tsunami was increased by tourist, shrimp farm, human activities and other industrial developments which have destroyed or degraded mangrove forests and other natural sea defences.
MSSRF (2005)	'Tsunami & Pichavaram mangroves'	The impact of tsunami waves was mitigated and the lives and property damage of the communities inhabiting the region behind mangroves were saved, where mangroves stood like a wall. It was found that wherever the mangroves had been regenerated, the damage due to the tsunami was minimal. Showed that how mangroves played important role in saving lives in Pichavaram and Muthupet region of Tamilnadu from tsunami.
Ganesan (2004)	'Point Calimere escapes tsunami fury'	Found that mangroves saved lives by reducing the impact of waves as well as by preventing people from being carried away by the waves into the sea. Showed how mangroves protected people and animals from Tsunami in Nagapattinam district, Tamil Nadu.

Table 2 Studies done by different authors in India on how mangroves protected and reduced the impact of disasters (continued)

Author	*Title*	*Major findings*
WWF (2005)	'WWF tsunami update 2'	WWF reported that mangroves along with other coastal ecosystem are very important for coastal protection against various natural coastal disasters. Reported that mangroves and coastal vegetation helped protect the coast and saved lives Andhra Pradesh District of India.
Ravishankar (2005)	'Ecological rehabilitation of post tsunami Andaman and Nicobar Islands'	Found that even the regions near the epicenter having dense mangroves forest were protected from the devastating tsunami waves and the damage was less. Mangroves played a vital role in reducing the impact of tsunami.
Kathiresan and Narayanasamy (2005)	'Coastal mangrove forests mitigated tsunami'	Suggested that fishermen's' hamlets should not be permitted within 1 km from the shoreline and that they should be encouraged to live behind dense mangrove or other coastal vegetation in elevated places.
Kathiresan and Rajendran (2007)	'Mangrove forests and tsunami'	Found that mangroves ecosystem reduces the energy and velocity of tsunami waves and helps in reducing their impact. Mangrove forests and Tsunami highlighted the importance of mangroves in reducing tsunami impact and saving lives.
Vermaat and Thampanya (2006)	'Mangroves mitigate tsunami damage: a further response'	Re-analysed the original data of Kathiresan and Rajendran (2006) with an ANOVA-model with covariates and found that mortality and property loss were less behind mangroves and also that mortality was strongly and significantly reduced with increasing elevation above mean sea level. Mangroves reduced tsunami impact and provided protection.
Das and Vincent (2009)	'Mangroves protected villages and reduced death toll during Indian super cyclone'	Used statistical model including wide range of variables and data based on more than 100 villages. They found that villages with wider mangroves between them and the coast experienced significantly fewer deaths than ones with narrower or no mangroves.
Roy and Krishnan (2005)	'Mangrove stands of Andaman vis-à-vis tsunami'	It was observed that most of the plants faced the impact of tsunami but were affected and died due to continuous inundation and continuous submergence.

As shown in Table 2, most of the studies in India have been carried out in the southern states like Tamilnadu and Andhra Pradesh, and in the Islands of Andaman and Nicobar.

4 Findings and conclusions

From the literature review done, it is found that mangroves play an important role in coastal protection against various coastal disasters, so coastal ecosystem restoration and protection of mangroves forests worldwide is an important thing. Many studies done in various countries across the world as shown in Table 1 has focused on the protective role of mangroves and threat of loss of their protective role due to human activities. The vital role of mangroves in reducing the impact of tsunami waves has been studied by various authors. It is interesting to note that some studies have shown a reduction of wave energy as much as 75% due to mangroves. Some studies have found that wherever the mangroves had been regenerated, the damage due to the tsunami was minimal. This is an important finding as governments of countries where vast stretches of mangroves have been destroyed should work towards regenerating these areas by planting fresh mangroves. The only study which differed a little was the one by Bhalla (2007) as his finding was that mangroves do provide protection against tsunami but to lesser extent than other biological features.

Loss of mangrove habitat would have adverse impacts on water quality, coastal protection from waves and storms, and related effects to fisheries production and tourism associated with fishing and healthy estuaries. Population awareness is an important thing in this case. Governments should continue monitoring at local level, research, conservation and restoration programmes should be undertaken. It is concluded that it is necessary to realise the dangers and consequences of undermining the services provided by the coastal ecosystems like mangroves in coastal protection. The review has brought out that mangroves play a very positive role during various disasters like tsunamis, floods and cyclones. Every effort should be taken by the government and private sector of the countries with large coastal areas to conserve and restore mangrove ecosystems. The review clearly brings out the valuable role played by mangroves in reducing the impact of various disasters. Participative management of mangrove ecosystems with the active support of local communities can be tried out in various parts of the world.

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