Chapter 17
Valuing the Role of Mangroves in Storm Damage Reduction in Coastal Areas of Odisha

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Key Messages

- Storm protection service of mangroves is very high for cyclone prone regions.
- During 1999 super cyclone in Odisha, every hectare of mangroves provided storm protection in the range of USD 4335 to USD 43,352 to the Kendrapada district, which is 25–249 times the 1999 per capita income of the district (USD 174).
- The annualized storm protection value of a mangrove hectare is more than two times the land price of cleared forests and more than twenty times the annual return from alternative land uses clearly justifying mangrove conservation to receive storm protection.

17.1 Introduction

In disaster management, resilience has been defined as the "*ability of an entity (individuals, communities, organizations, states) to recover from the effects of exogenous shocks, such as natural hazards, without compromising the long-term prospects of growth*" (Kousky & Shabnam, 2015). This is possible if damage from natural disasters is low (static resilience) or people recover quickly (dynamic resilience).

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With climate change and increased threats from tropical storms to coastal dwellers, resilience building is an urgent need and the conservation of coastal vegetation provides both static and dynamic resilience from storms to people (Das & D' Souza, 2019). This chapter examines whether mangroves should be conserved for building coastal resilience.

Mangrove wetlands are one of the most important tropical and sub-tropical coastal wetlands and provide a range of provisioning, supporting, regulating, and cultural services to humans (MA, 2003). However, mangroves are threatened by change of land use to settlement, agriculture, aquaculture, or industrial uses (Field et al., 1998). This is because most of the important services of mangroves are indirect, invisible and occur off-site, whereas when these wetlands are converted to other land use like aquaculture or coastal development, the returns are visible, instantaneous, direct, and commercially very significant. Population pressure has resulted in high demand for land for different economic activities. Unless the benefits of the ecosystem services are explicitly measured, these benefits would be ignored in decisions on land use and result in underconservation of the mangroves. Ecosystem service valuation is therefore essential for sustainable land-use planning.

This research examines and quantifies the storm protection services of mangroves based on the October 1999 super cyclone damage data related to human lives, residential houses, and livestock loss in Kendrapada district of the eastern Indian state of Odisha.[1] Mangroves are seen to provide static resilience to coastal people by reducing loss of lives and damage to property during this storm and the storm protection value of mangroves is used to examine whether mangrove conservation is economically viable or not. In the coastal zones of Bangladesh which is also affected by frequent cyclones, Mahmud et al., (2021, Chap. 20 of this volume) describe local level learning effects by those affected. While in Indian Sunderbans, Ghosh and Roy (2022, Chap. 26 of this volume) find that younger educated residents and migrating as an adaptation strategy.

17.2 Why Use Averted Damage Approach to Measure Storm Protection Services

The measurement of storm protection value of mangroves, which was earlier equated to only that of constructing a sea wall at the coastline (Chan et al., 1993), has undergone tremendous methodological innovations in course of time. Both stated and revealed preference methods have been used to measure storm protection, the former being less advised due to the fear that people usually overestimate risks (Spanink & Beukering, 1997). Use of surrogate market-based methods like defensive expenditure and hedonic prices are also discouraged as they either overestimate or underestimate the storm protection value of mangroves because of high maintenance cost of substitutable structures or imperfect property markets (Bann, 1997). Researchers have also

[1] Called Orissa before the 113th amendment to the Indian Constitution on 24 March 2011.

used avoided expenditures and replacement costs methods to value this service (Sathirathai, 1998; Tri et al., 1996). However, all such methods measure storm protection indirectly and produce a proxy value. In comparison, the avoided damage approach takes into account the actual damage suffered in mangrove protected areas compared to damage in areas not protected by mangroves and provides a more realistic measure. It follows the production function approach where the storm damage as a function of storm features, location, and socio-economic factors including mangroves is estimated in step 1 and in step 2; the damage averted due to mangrove presence is quantified. It was pioneered by Farber (1987) and has been used to measure the protection provided by mangroves from storm (Costanza et al., 2008) as well as tsunami damage (Kathiresan & Rajendran, 2005). The expected damage function (EDF) has been suggested as an alternative method to measure the protection services of mangroves (Barbier, 2007). Presence of wetlands in some areas will reduce damage, and thus, the amount of compensation to be paid to the household and this change can measure the storm protection value of the wetland. However, the estimation technique as developed by Barbier (2007) is a variant of avoided damage (Costanza et al., 2008, pp 246).

Though the averted damage approach has the advantage of being based on the actual damage, it can estimate the protective service of mangroves accurately provided one controls for the impact of other factors that influence the occurrence of storm damage (Das, 2007). Otherwise, it can generate either a spurious or a highly inflated protection value due to omitted variable biases. The present paper follows this methodology and takes into account a wide range of socio-economic, geo-physical, and meteorological variables as controls to separate the impact of mangroves from those of other factors on storm damage. I arrive at a comparatively lower but possibly more accurate estimate of the storm protection value of the mangroves.

17.3 Study Area and the Mangroves

This study is based on village and gram panchayat level damage data from the *Kendrapada district* in Odisha (Fig. 17.1). This district is one of the most vulnerable districts in India having a high annual probability (nearly equal to one) of being hit by cyclones (Das, 2009) and was severely impacted by a super cyclone in Oct 1999. The cyclone had its landfall at a place called *Ersama*, 20 km southwest of Kendrapada. The district was the ideal choice to measure the storm protection services of mangroves as (1) it was situated north of the eye of the cyclone and path of the cyclone throughout,[2]

[2] In northern hemisphere, the direction of the cyclonic wind is anticlockwise and thus the wind direction in Kendrapada was from sea to land through the mangrove forest.

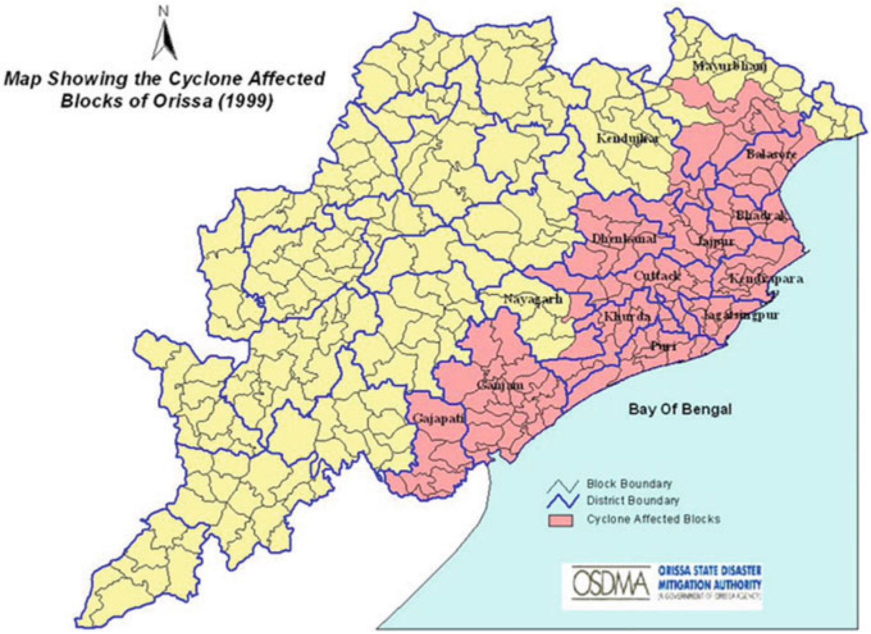

Fig. 17.1 Kendrapada district in cyclone hit Orissa. *Source* Orissa State Disaster Management Authority, Government of Odisha

(2) has mainly mangrove forest[3] and barren areas on the coast line, and (3) is devoid of highlands, the average elevation being less than 10 m everywhere (NATMO, 2000).

Kendrapada was an economically backward district with nearly 50% of the population living below the poverty line, 94% living in rural areas and around 2% of the rural houses having concrete structures when the storm struck in 1999.

17.3.1 The Mangroves of Kendrapada

The State of Orissa has 480 km of coastline covering seven coastal districts and 5133.60 km^2 of coastal wetlands. The state was endowed with rich mangrove cover historically; with nearly 500 km^2 in 1944, which was destroyed over time leaving it with 227 km^2 of mangrove forests, most of which (88%) is located in the Kendrapada district.

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[3] The main forests were the mangroves though a few patches of Casuarina plantations were also to be found in the coastal areas before the cyclone. But the width of these plantations everywhere was between 200 and 400 m.

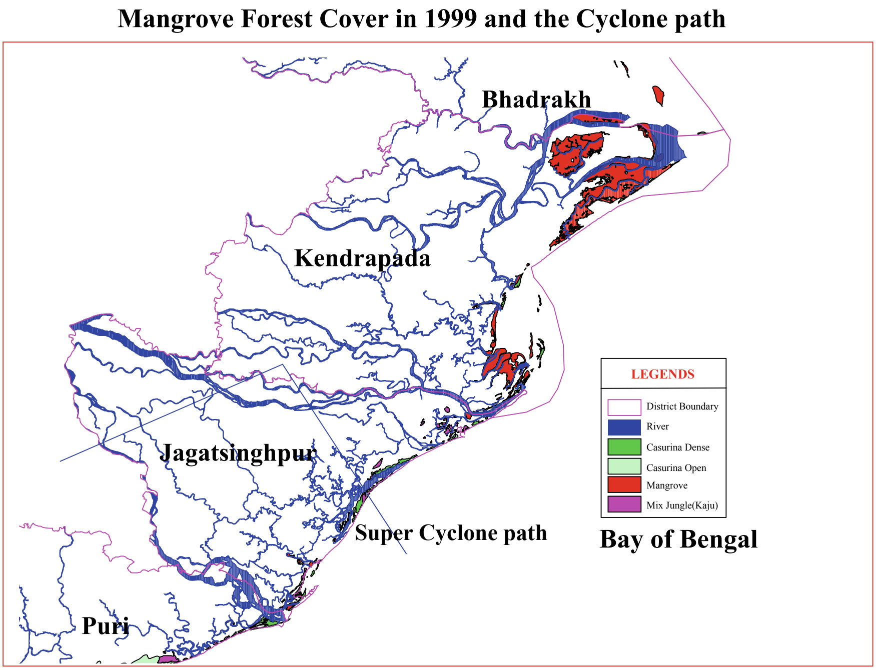

Fig. 17.2 Mangrove and other coastal forests of Kendrapada and Jagatsinghpur districts in October 1999. *Source* Das (2011)

Though both Jagatsinghpur and Kendrapada were the major mangrove districts of the state and witnessed mangrove loss, the loss was nearly 100% for Jagatsinghpur district (from 177.27 km^2 in 1944 to 5 km in 2001), whereas it was around 37% for Kendrapada (from 306.7 in 1944 to 192 km in 2001). In Kendrapada district, the mangroves are found in two patches as seen from Fig. 17.2 that shows the mangrove cover in Jagatsinghpur and Kendrapada districts as it existed on 11 Oct. 1999. In Kendrapada, 89 villages have been established after cutting down the mangroves, which are labelled as mangrove *habitat villages* and have been accounted for separately in the analysis.

17.3.2 *Drivers of Mangroves Loss in Orissa*

Figure 17.3 shows the mangrove forest map of the districts Jagatsinghpur and Kendrapada as it existed in the year 1944. As evident from the figure, more than 80% of the coastline from the mouth of the river Devi to the mouth of the river Dhamra was covered by mangrove forests of more than 10 km width as these areas are criss-crossed by river channels and their tributaries and rivulets (seen from the figure also). The mangrove forest of Jagatsinghpur district and the Mahanadi delta mangroves of

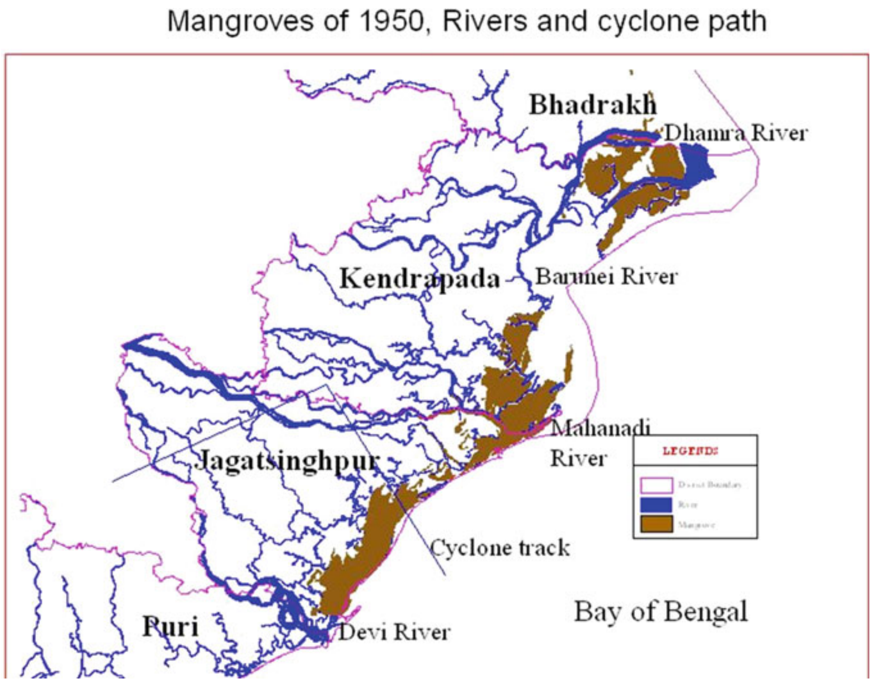

Fig. 17.3 Mangroves of Kendrapada and Jagatsinghpur districts as in 1944. *Source* Das (2011)

Kendrapada district were known historically as the Kujang Forest, and the mangroves of Bhitarkanika region, Bhadrakh, and Balasore districts were known as the Kanika forest after the name of the princely states that used to rule over these areas. Though there is less research on the drivers of mangrove loss in the State of Orissa, local vernacular publications and independent studies done by researchers and NGOs overwhelmingly link the loss of mangrove forests to the political economy of the state. The maximum mangrove destruction occurred during the 1960s and 1970s for various reasons including the lack of proper jurisdiction during the period following the abolition of Zamindari in 1957 till the formation of the Wild Life Division in 1980. The creation of the Paradeep port, rehabilitation of refugees from then East Pakistan (present-day Bangladesh), lack of knowledge of mangrove values, and conversion of mangrove land for betel vine, agriculture, and aquaculture farms, etc. are some of the main reasons for the destruction of the mangroves (Choudhaury, 1990; Das, 2009; Mohanty, 1992). The Ministry of Environment and Forest, Government of India, had listed the existence of 15 different types of threats to mangroves of the region (Das, 2009), the maximum being anthropogenic in nature, with the clearing of the forest due to the subsistence requirements of the people being the most prominent one. Another interesting observation was that the local people were not keen on preserving the mangrove. Though people have realized the importance of mangroves in their day to day life, there are still threats to mangroves from local inhabitants, which is reflected in their unhappiness and anger after the Bhitarkanika area was declared a national park by the government in 1998 (Badula, 2002). The mangroves of Bhitarkanika region probably survived when state protection was missing because of the presence of ferocious animals and interior location of the area. After the announcement of sanctuary and national park, government protection and strict implementation of laws have been able to protect the mangroves there.

17.4 Data

The paper analyses three types of asset damage due to the super cyclone, i.e. human lives, residential houses and livestock, which are collected from various sources (see Das, 2007 for detail). The data set for the human casualty model is at the village level and it consists of 1180 villages. The house damage analysis is based on heterogeneous units covering 451 villages and 138 *Gram Panchayats* and the analysis for livestock is based on data at a *Gram Panchayat* level analysis covering 216 *Gram Panchayats.* These differences in units and coverage area are due to the limitations of data which was only available in that format and for those specific areas.

Estimated cyclone damage models from Das (2011), which were based on Das (2007), are used in this paper to estimate the storm protection value of mangroves. Das (2007) did extensive testing for determinants of human death, three types of house damage (fully collapsed, partially collapsed, and swept away houses), and five types of livestock loss (cattle, buffaloes, sheep, goat, and poultry) suffered during the October 1999 super cyclone. Results for different sample areas were compared to infer the effectiveness of mangrove protection. Sample 1 was the entire study area excluding villages that never ever had mangroves in their coastal distance (called the mangrove non-habitat villages). Mangrove non-habitat areas were excluded as they can never be protected by mangroves or storm protection value of mangroves is meaningless for them. Secondly, by leaving them, I control for the topographic and bathymetric features of the study area[4] as my treatment villages (the ones protected by mangroves) and the control villages (the ones not having mangroves in their coastal distance during the 1999 cyclone, but which used to have mangroves that were destroyed over time) have similar bathymetry and topography. Sample 2 is sample 1 minus the areas falling under the cyclone eye. The wind direction inside the cyclone eye area being circular (anticlockwise before the eye passes and clockwise afterwards), the forest can provide little protection. Hence, the expectation is that the storm protection value per unit of mangroves is accurately captured in sample 2 and sample 1 is the entire area protected by mangroves.[5] Storm damage models based on sample 1 and 2, not others, are used in the paper. For estimating the storm

[4] Mangroves come up in areas with similar topographic and bathymetric features.

[5] In Das (2007), samples 3, 4, and 5 were parts of sample 2 that were within 10 km distance from coast, beyond 10 km distance from coast and suffered storm surge inundation during the cyclone, respectively. These samples 3, 4, and 5 are not discussed in the present paper.

protection value, I consider only those damage models of Das (2007) for the above two areas where the mangrove was found to have a statistically significant effect, i.e. human death, fully collapsed houses, partially collapsed houses, and losses of both cattle and buffaloes. See Das (2007, Tables 1, 2, 3, 4, 7, 8, and 10) for description of variables and regression results used.

17.5 Methods

First the physical estimates of damage avoided due to mangrove presence have been calculated, and then in step 2, this averted damage is valued to estimate the storm protection value. Averted damage is defined as the difference between the actual damage witnessed and the predicted damage in absence of mangroves. These are measured for different sample areas described above and for three different scenarios, i.e. no mangroves, if historical mangroves were present and if historical mangroves were present and mangrove habitat villages were not there. After measuring the averted damage for the three assets, i.e. human life, houses, and livestock, these damages are valued and summed to measure per unit storm protection value. In the valuation process, the differences in units and coverage of study areas are carefully taken into account to arrive at a realistic and representative value void of ambiguities and biases. Local prices prevailing in the study area and value of statistical life generated for India are used in valuation.

17.6 Results

17.6.1 Averted Damage

In total, 392 persons lost their lives during the 1999 cyclone in sample 1 area but the toll may have been 603 in the absence of the mangrove (Table 17.1). Thus, 211 deaths (54% of the lives lost in that area) were possibly averted due to the presence of the mangroves. The mangroves provided greater protection to areas of sample 2, where 217 deaths (82% of lives lost in sample 2) were estimated to have been averted by mangroves.

If the historical mangrove forest (as existed in 1944) had not been cleared by 1999, only 31 persons would have probably died instead of 392 in sample 1 area, even if the 89 forest villages would have been where they are. However, if the 89 coastal villages had not been permitted in the mangrove area, there would probably have been only 17 casualties.

In the absence of the mangroves, the number of fully collapsed houses may have been higher by 19,936; partially collapsed houses lower by 14,049 indicating that some of the partially collapsed houses would have been completely damaged (see

Table 17.1 Averted human death due to mangrove forests

	Actual deaths 1	Predicted death if mangrove = 0 (Assump-1) 2	Predicted death if mangrove = mhabitat (Assump-2) 3	Predicted death if mangrove = mhabitat and mangrove habitat villages = 0 (Assump-3) 4	Averted deaths (1–2) 5	Averted deaths (1–3) 6	Averted deaths (1–4) 7
Sample-1 (*N* = 840)	392	603	31	17	211 (54%)	361 (92%)	375 (96%)
Sample-2 (*N* = 711)	266	483	25	11	217 (82%)	241 (91%)	255 (96%)

Table 17.2 Volume of house damage and livestock[a] loss averted due to the mangrove forests (figures are numbers)

Damage type	Assumption-1		Assumption-2		Assumption-3	
	Sample-1	Sample-2	Sample-1	Sample-2	Sample-1	Sample-2
Fully collapsed houses	19,936	13,110	178,660	82,225	165,975	74,675
Partially collapsed houses	−14,049	−12,657	−125,900	−79,376	−119,702	−72,087
Buffaloes	704	683	1320	994	1399	1100
Cattle	3844	4668	17,946	12,993	17,385	12,312

[a]Swept away houses, goat, sheep, and poultry have been left out as mangrove was insignificant for them in all models

Table 17.2). Similarly, buffalo and cattle loss would have been higher by 704 and 3844, respectively, in sample-1 area. These figures would have been 13,110, −12,657, 683, and 4668 in sample 2 area. If the 1944 forest had been there, not a single house would have fully collapsed in both the sample areas.[6] We would probably have witnessed only partially collapsed houses.

17.6.2 Storm Protection Value of the Mangroves

The valuation of damage is done with the aim of understanding: (a) the saving in government compensation disbursed to victims and (b) the social benefit of

[6] This is inferred from the derivation that the number of averted fully collapsed houses (due to historical mangroves) is higher than the actual number of fully collapsed houses in those areas.

mangroves when valued at market price. Accordingly, the damages are valued @compensation paid, @revised compensation rates, and @prevailing market prices of damaged assets in 1999. What prices are used and how the value of statistical lives is adjusted to value human deaths are described in Das (2009).

17.6.2.1 Average Storm Protection Value

The mangrove variable was measured as kilometre width of the forest, and thus, the average storm protection value (ASPV) of every kilometre width of the existing and historical mangrove forest to a village are measured for sample 1 and sample 2 areas under the three assumptions. First these are measured for each of the damages separately and then added across the damages to measure weighted average storm protection (WASP) value to a village. These are shown in Tables 17.3 and 17.4. The ASPV to a village in sample 1 is Rs. 2239 for protecting human lives and Rs. 1157 for reducing house damage[7] (see Table 17.3, situation 1). If the 1944 forest were still there along with the villages subsequently established (Situation 2), these values would be Rs. 1207 and Rs. 2315, respectively. In situation 3, the corresponding values would be Rs. 1496 and Rs. 2488, respectively. These values are higher for sample 2 areas compared to the sample 1 area for every type of damage and situation. This suggests that the protective services of mangroves are more effective in the cyclone outer eye areas. The areas falling under the cyclone eye receive the strongest winds which are also circular and mangroves can provide little protection there. Thus, our hypothesis of using sample 2 as a more accurate valuation scheme for storm protection services by mangroves is supported by these findings. Another observation is that the average value of present mangroves is much higher than historical mangroves for every sample area but only for averting deaths (both human lives and livestock), whereas the reverse is the case for house damages. The average width of present mangrove is much smaller (approximately 1 km) compared to historical mangrove (approximately 4 km). This suggests that the relation between mangrove width and protection from different types of damages may not be linear. Having more mangroves may not help in averting more deaths but seems to avert more house damages. This allows for calibrating mangrove size depending on the social objective, and an optimum width of the forest can be defined to act as buffer during cyclones.

The WASP value provided by a kilometre of present mangrove in a village is Rs. 3928.43 when valued at market prices (see Table 17.4). However, if government compensation rates were used to determine these values (in terms reduced compensation to be paid), it varies between Rs. 46.55 (@actual amounts paid) and Rs. 183.63 (@revised house damage compensation rates). The average storm protection values of kilometre width of historical mangroves, shown in columns 3 and 4, varies between

[7] This is computed as value for reduced FC houses (Rs 1331)—value for increased PC houses (Rs 174).

Table 17.3 Average storm protection value per village provided by every km width of present mangrove and historical mangrove (in Rs.)

Type of damage	Value/km of present mangrove/village		Value/km of hist. mangrove/village (coastal villages remaining)		Value/km of hist. mangrove/village (coastal villages removed)	
	Sample-1	Sample-2	Sample-1	Sample-2	Sample-1	Sample-2
Human death	2239.35	2743.95	1207.87	1132.44	1495.68	1478.28
Fully collapsed houses	1331.53	1368.55	2663.52	3143.39	2873.11	3235.85
Partially collapsed houses	−174.42	−245.59	−348.88	−564.03	−385.15	−580.85
Buffaloes	5.91	8.77	2.32	3.97	2.62	4.83
Cattle	26.87	49.94	26.32	43.20	27.17	45.07

Notes Rates (market prices) used are: Value of Statistical life @ Rs. 10,918,132/; Price of FC house @ Rs. 53,800/; Price of PC house @ Rs. 10,000/; Price of Buffalo @ Rs. 6000/; Price of Cow @Rs. 5000/ and) Price of Sheep @ Rs. 1200/

Table 17.4 Weighted average storm protection value for a village by every km width of present mangroves and historical mangroves (in Rs.)

Value @ different valuation rates	Value/km of present mangrove	Value/km of hist. mangrove (coastal villages remaining)	Value/km of hist. mangrove (coastal villages removed)
Value @ government compensation paid	46.55	68.69	72.9
Value @ revised government compensation for house damage	183.63	385.42	399.06
Value @ market price and VSL with $\varepsilon = 0.35$	3928.43	3761.4	4185.68

Note: ε represents the income elasticity of marginal willingness to pay

Rs. 69/ and Rs. 4186/, and the values are the highest if the coastal villages established in mangrove habitat areas are relocated (situation 3).[8]

17.6.2.2 Total Storm Protection (TSP) Value

There are around 1250 villages in Kendrapada district and of which 850 villages had mangrove historically between them and the coast (sample-1) and 580 of these villages were outside the cyclone eye (sample-2). Sample 1 being the entire area that receives storm protection from mangroves, we multiply the unit values of present mangroves shown in Table 17.2 by 850 to get the TSP value (for protecting human lives, residential houses and livestock) of every kilometre width of the forest to the state exchequer and the society.

Dividing the value of total avoided damages of sample 1 area by the mangrove area (17,900 ha), total savings to the state exchequer and to the society by every hectare of the present forest were also calculated (see Table 17.5). [9]

A 1 km width of the forest saved Rs. 3,339,166 for the economy and Rs 3968 to the state government in the form of reduced compensation liability (Table 17.3).[10] In comparison, the savings by every hectare of mangroves forests are Rs.182, 080/

[8] The volume of damages averted due to mangrove presence being low for the mangrove habitat area villages, the unit values increase as these villages are removed from the analysis.

[9] As mentioned before, the per hectare values are the simple averages. To get the value at market price, we simply added the market values of different averted damages of sample 1 area and then divided it by the area of the present mangroves. Only sample 1 area was considered as that is the entire area benefited by mangroves. We did similarly to get values at other valuation rates.

[10] The savings to the state government by the present mangroves would have been Rs 156,083/ if the revised compensation rate was used.

Table 17.5 Total storm protection value (for Kendrapada) by every km width and by every hectare of present mangroves

	Value of damage averted per km (width) of mangrove	Value of damage averted per ha (area) of mangrove
Saving to state government in compensation paid in 1999	Rs. 39,568/(USD 943)	Rs. 2339/(USD 56)
Saving to state government if revised compensation for house damage would have been applicable in 1999	Rs. 156,083/(USD 3716)	Rs. 8550/(USD 204)
Saving to district economy (value of damages at market prices)	Rs. 3,339,166/(USD 79,504)	Rs. 182,080/(USD 4335)

Notes The exchange rate used is IUSD = 42 INR as prevalent in 1999

to the district economy for reducing human death, damage to residential houses, and loss of livestock.[11]

On the basis of these values, we try to analyse one important policy question, i.e. should the remaining mangroves be preserved to receive storm protection given high demand for land for alternate uses?

17.6.3 Is Mangrove Preservation Economically Justified?

This question is analysed by comparing the land price of agricultural land in cleared forest area (opportunity cost of preserving forest) to the storm protection value per ha of the forest. The average land price in Mahakalpada tehsil of Kendrapada, where maximum of the mangrove forests were converted to other uses, was Rs. 172, 970 per hectare during [12] 1999–2000. The partial storm protection value of a hectare of mangroves at market prices being Rs. 18,208 (Table 17.5) to the district for protecting only three assests (human lives, livestock and houses), prima facie, there is a strong case for the preservation of the forest. However, we also compare the annualized returns of these two values.

We assume the three types of averted damages discussed in this paper to constitute one-tenth of the total averted damages of mangroves by a conservative estimate.[13]

[11] Every hectare of mangrove saved the state exchequer Rs. 2339 (actual compensation paid) or Rs.8550 (revised rates) in the form of reduced compensation.

[12] The land price as reported by the land registration office varied between Rs. 70,000/ to Rs. 100,000/ per acre around 1999 (Personal communication with Jatindra Dash, IANS), and the land price in mangrove adjacent area being on lower side, we use the lower limit, i.e. Rs 70,000 per acre and this calculates the price per hectare as Rs. 172,970.

[13] Badola (2002) estimated the total storm protection value of Bhitarkanika Mangroves of Orissa during the same super cyclone of Oct 1999 by considering the protection of mangroves from multiple damages and found the value to be equivalent of USD 116.28 per household. As the average number

By this assumption, the storm protection value of a hectare of mangrove during super cyclone of October 1999 works out to be Rs. 1,820,800 which is much higher than the land price.

17.6.3.1 Probability of Extreme Events and Annualized Benefits

The study area is highly cyclone prone and records of the past 200 years reveal that the frequency of very severe cyclonic storms has gone up significantly in the last 3–4 decades. In between 1903 and 1999, Orissa witnessed 52 cyclones of which eight were Very Severe Cyclonic Storms and one was a Super Cyclone (Chittibabu et al, 2004). Moreover, six of the nine devastating cyclones occurred in the last 30 years so the annual probability of occurrence of a devastating cyclone is 0.2. Thus, the probability adjusted annual storm protection value of a hectare of mangrove (Rs. 364,160) is more than twice the market price of land cleared of forest. If we assume an interest rate at 8% per annum,[14] the annual opportunity cost of preserving mangrove forest at 1999 prices works out to be Rs. 13,837 or Rs. 20,756 if we assume a very high return @12% per annum. The annual benefit from protecting forest is therefore 18–26 times higher than the annual opportunity cost of preserving the forest. These findings support protection of mangrove forest to get storm protection benefit as a socially desirable strategy. Even if we use a lower annual probability of any cyclone (0.09 per annum), the mangrove preservation will still be justified. Under these rates and with the lower cyclone probability (0.09 per annum), the net present benefit to society or welfare gain to society from preserving mangrove forest is Rs. 143,393 and Rs. 215,089 per ha with 12 and 8% discount rates, respectively. These numbers indicate a very high benefit from preservation of the remaining mangroves.

17.6.4 Land-Use Change

Was the destruction of mangrove forest in the past economically justifiable? As mentioned earlier, 12,866 ha of mangroves were converted between 1950 and 1999 mainly for agriculture. We now estimate the net loss in protective cover that could have been averted if the mangrove of 1944 level was not destroyed. We calculate this as the difference between the market values of avoided damages ($\sum$VAD) with historical mangroves and the present mangroves ($\sum \text{VAD}_{1944} - \sum \text{VAD}_{1999}$).

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of household in her study villages is 37, this gives the total storm protection value as USD 4302 per village which is 45 times higher than the highest storm protection value per village obtained in the present study. So a 10 times escalation of benefits to estimate total benefits is still on the conservative side.

[14] In the absence of information on rate of return from agriculture in coastal Kendrapada, we calculated annual return @8% which is the average of the estimated range of real discount rates (7.6–9.7%) from the Indian labor market studies and also comparable to financial market rates in 1990s (Shanmugam, 2006).

Dividing the above value by the area of the lost mangrove forest (12,866 ha), the extra burden for destroying every hectare of forest comes out to be Rs 706,882 for only three damages. The benefit of forest destruction, which is captured by per hectare land price, is much lower than this. Under the assumption that these three averted damages are one-tenth of the total averted damages of the mangroves, the extra burden for destroying every hectare is Rs 7,068,820. If we multiply this value by the annual probability of devastating cyclones (0.2), the probability adjusted annual burden due to loss of storm protection cover comes out to be nearly seven times higher than the benefit from forest destruction (i.e. the land price of cleared forest land).

We may infer that the social benefit of retaining the forest cover is much higher than the current land value (Rs1, 72,970 per ha). As noted earlier, the benefits estimated are lower bound values, and therefore, actual benefits are likely to be much higher than indicated here.

17.7 Conclusion and Policy Implications

The study quantifies the storm protection services of mangroves of Odisha and the storm protection value of every km width of present mangrove to have been Rs 39,568 to the state exchequer in the form of reduced compensation and Rs 3,339,166 to society for saving human life, livestock, and preventing house damage. The per hectare benefits (for just averting the three damages) were estimated to be Rs 182,080. These three damages are a small proportion of the total damages averted by the mangroves. Making some conservative assumptions, we find the cyclone probability adjusted annual storm protection value per hectare of mangroves to be more than twice the market price of cleared mangrove forest land and 18–26 (or nearly 20) times higher than the annual return from land. All these suggest the preservation of remaining mangroves as a socially and economically viable strategy to receive storm protection services.

Mangroves save lives and properties in the vulnerable coastline areas and thus provide static resilience to society during natural disasters like storms. This is also found by Mahmud et al., (2021, Chap. 20 of this volume) in the context of Bangladesh. Climate change makes it imperative to conserve the mangroves and policy makers need to make arrangements for their protection. Usually, people living in areas around the mangrove do not realize the importance of mangroves as most of the ecosystem services are invisible and indirect. Awareness generation can go a long way in ensuring mangrove conservation, especially in vulnerable coastal areas like the state of Odisha.

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SANDEE working papers to measure the averted damage by mangroves, values them and finally examines the question of mangrove conservation to build resilience. An earlier version of this paper titled "The Case for Mangrove Conservation: Valuing Damage Averted in Orissa's 1999 Super Cyclone" was presented at the 4th World Congress of Environmental and Resource Economists (WCERE) held in Montreal, Canada, during 28th June to 2nd July 2010. The paper has been enriched after addressing the comments received from reviewers, discussant, and from the floor.

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