# Examining the Storm Protection Services of Mangroves of Orissa during the 1999 Cyclone

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The paper examines whether the mangrove forests in Kendrapada district of Orissa played any protective role during the severe cyclone that hit the state in October 1999. Using data on human casualties and damages suffered by the houses as dependent variables, and different meteorological, geophysical and socio-economic factors as independent variables, this study estimates a cyclone damage function to bring out the mitigating effects of the mangrove vegetation. The results show that mangroves did significantly reduce the occurrence of human deaths and the extent of damage to residential houses. Areas with mangrove protection are seen as having fewer fully collapsed houses and more partially collapsed houses. They are also found to have been more effective in reducing deaths than in reducing the damages to static properties.

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Mangroves are tropical and subtropical coastal forests that grow in inter-tidal saline areas and estuary mouths between the land and the sea. These ecosystems provide a bunch of direct and indirect services to humankind (Dixon and Lal 1997; Gilbert and Janssen 1998). Some of the indirect uses of these forests are both unexplored and unquantified as yet. Storm protection services form an important ecological service afforded by mangroves (Barbier et al 2008), whereby they protect inland areas from the fury of tropical cyclones. The increase in frequency of cyclones in recent years and the fear of further increased frequency and intensity due to climate change (Steffen 2006) make the storm protection function of mangroves especially important for research and quantification.

Protective services of coastal forests and trees, particularly, those provided by mangrove forests against natural hazards, are a subject of debate. Some recent studies and anecdotal reports have highlighted the effectiveness of mangrove forests in reducing damages from natural hazards like cyclones and tsunamis (Badola and Hussain 2005; Barbier 2007; Danielson et al 2005; Fosberg 1971; Kathiresan and Rajendran 2005; Tynkkonen 2000; UNEP 2005). The evidence as well as methods used in some of these studies (particularly in the context of tsunami and coastal protection) have been questioned (Kerr et al 2006). Though it has been established theoretically and in field experiments that mangroves dissipate normal wind wave energy (Massel et al 1999; Mazda et al 1997 and 2006), empirical analysis evaluating the protective service of mangrove forests during a tropical storm is limited.

This paper addresses this issue for the mangrove forests of Kendrapada district of Orissa, by analysing damages suffered during the cyclone of October 1999 that had a landfall wind velocity of 256 km per hour. It devastated 12 of the 30 districts of the state causing massive damages including nearly 10,000 human casualties (Gupta and Sharma 2000). We examine the storm protection of mangroves in terms of its protection to human life and residential houses by taking into account the role of multiple factors likely to have some impact on cyclone damage occurrences. We briefly review the related studies in Section 1 followed by some description of the study area, the methodology used, the data, and an estimation of the models and the results in the subsequent sections.

## 1 Previous Studies on Storm Protection

Mangrove forests have been compared to a seawall during tropical cyclones (Chan et al 1993) and there have been attempts to value this protective service. Farber (1987) pioneered the effort of examining the storm protection services of coastal wetlands. He used a scientific model of wind velocity and demonstrated that wetland areas provided significant protection from the wind damages of hurricanes sweeping the Louisiana coast in the United States (US). Badola and Hussain (2005) surveyed the cyclone damages in three different kinds of villages in Orissa, namely, those: (a) sheltered by mangroves; (b) protected by dikes but no mangroves; and (c) with neither dikes nor mangroves. They showed the damages per household in the village sheltered by mangroves to be relatively less compared to others. Barbier (2007) argued that the presence of mangroves decreases the incidence of damaging coastal disasters and thus measured the storm protection value of mangroves for Thailand. Costanza et al (2008) estimated the storm protection value of coastal wetlands for providing protection from hurricanes in the coastal areas of the US.

Damage occurrences during storms depend on the intensity of storms and also on other characteristics of the affected location like socio-economic conditions, physical features (elevation, coastal distance, topography, bathymetry, hydrology), and the nature of the terrain between the location and the coast (whether hilly area, forest land, plain agricultural land, etc). Hence, coastal forests or the coastal wetland area are just one among the many other factors affecting the occurrences of cyclone-related damages and an empirical work evaluating the protective roles of coastal forests should consider the role of all possible factors simultaneously to arrive at a conclusive result. Studies have so far used a very few control variables to bring out the mangrove impact on storm damages. Factors like elevation, coastal distance, etc, are now being recognised as critical factors (Baird 2006; Bretschneider and Wybro 1977; Chatenoux and Peduzzi 2006, 2007; Dahdouh-Guebas et al 2006; FAO 2006), but the role of economic, sociological or even hydrological factors in causing damages, particularly in the context of developing countries, is not talked about.

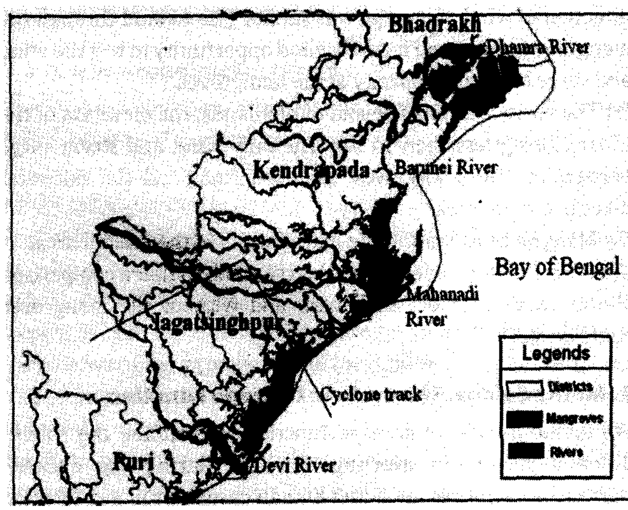
This paper addresses these gaps and examines the protective role of mangrove forests by including socio-economic, geophysical and meteorological variables in the analysis. We use a large sample and also do a village-level analysis compared to the aggregative analysis of many of the earlier works.

## 2 Study Area: Kendrapada District of Orissa

The study analyses cyclone damages mainly in the Kendrapada district of Orissa, though the study area is extended marginally in the northern and southern directions for some of the analysis depending on the availability of damage data. At the time of the cyclone, nearly 78% of the population of Kendrapada was dependent on the primary sector, just 5% on the secondary sector, while almost 94% lived in rural areas (HDR 2004). More than 50% of the population subsisted below the poverty line (*District Statistical Handbook* 2001). The quality of the residential houses was poor with only 2% of the rural houses having both a concrete wall and roof, though 15% of the houses had cemented walls (Census of India 2001).

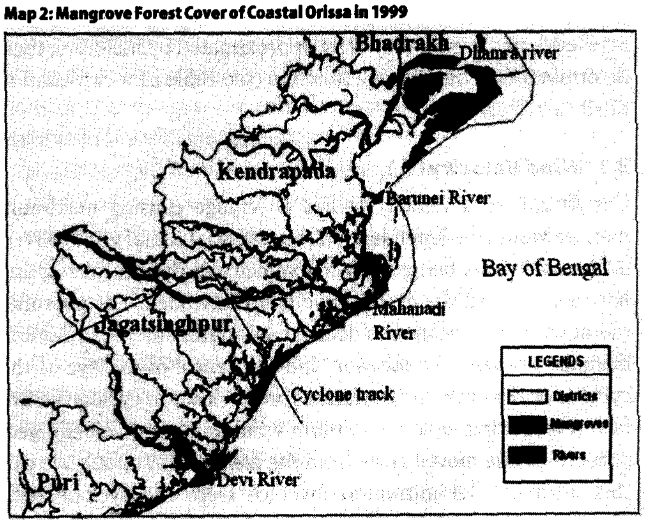
Kendrapada has mangrove forests in the Mahakalpada and Rajnagar tahasils and they are the main forests in the district.[1] The district has a nearly 60 km long coastline with 80% of it being covered by mangrove forests of nearly 10 km width in the past as per the historical forest map of the area[2] (Map 1). In 1952, the ownership of these forests was transferred from the zamindars (feudal system) to the state government and thereafter in 1980, the wildlife division was created by the state government and the management of the mangrove forests was entrusted to the division (Orissa District Gazetteer, Cuttack 1996):

**Map 1: Mangrove Forest Cover of Coastal Orissa in the 1940s**




By 1999, the Mahakalpada tahasil had witnessed a maximum destruction of the mangroves where only a thin strand of forest was left when the cyclone struck. In contrast, the mangroves in Rajnagar tahasil have been well-preserved probably due to the presence of ferocious animals (crocodiles) and the declaration of the forest area as Bhitarkanika Wildlife Sanctuary in 1975 and then a national park in 1988 (Map 2). The Mahakalpada forests, though declared a reserve forest in 1978, were brought under the Gahirmatha Marine Wildlife Sanctuary as late as in 1997. The district had 192 sq km of mangrove forests as reported in 2001, more than 93% of it being densely stocked with more than 40% canopy cover (Forest Survey of India 2001).

**Map 2: Mangrove Forest Cover of Coastal Orissa in 1999**




### 2.1 Reasons for Choosing Kendrapada as Study Area

The cyclone of October 1999 had its landfall at a place called Ersama lying nearly 20 km south-west to Kendrapada district and the entire district was severely battered by both cyclonic wind and rain and four of its tahasils were reported to be affected by saline inundation (Gupta and Sharma 2000). Broadly, the reasons for choosing Kendrapada district as the study area are as follows:

(1) The wind direction in Kendrapada district was mainly from sea to land during the 1999 cyclone period as the district lay to the north of the cyclone landfall[3] and cyclone eye. Thus, the direction of wind and surge was similar (sea to land through the mangrove forests) and it gave a good opportunity to test the wind and surge buffering capacity of the mangroves.

(2) The entire district is devoid of highlands: the elevation of the district being less than 10 m.[4] The only wind and storm surge barriers are the mangroves, the casuarinas and the saltwater dikes in coastal areas.

(3) Mangroves constitute the main forests in the coastal areas of the district interspersed by barren coastline so that a comparison of the cyclone impact both with and without the mangroves could be made.

## 3 Methodology: The Cyclone Damage Function

We define a cyclone damage function to examine the role of different factors in averting damages during the cyclone. Damage occurrences including human casualties in any location during cyclones are expected to depend primarily on the velocity of wind, the severity of flooding due to storm surges, the population or property at risk and other socio-economic factors of the location.[5]

$$\therefore D_i = d(V_i, W_i, P_i, S_i) \quad ...(1)$$

where $D_i$ is the damage suffered (loss of human life and damaged residential structures),

$V_i$ is velocity of wind at the $i^{th}$ location,

$W_i$ is the severity of flooding due to surge at the $i^{th}$ location,

$P_i$ is population or property at risk at the location,

$S_i$ is the group of socio-economic and institutional factors at the location influencing the volume and extent of damages. Except $D_i$ and $P_i$, we had no direct measure of either $V_i$, $W_i$ or $S_i$ at the village level, and hence, they were approximated by including their determinants in the damage function (see Table 1 for explanation of all variables).

### 3.1 Wind Velocity ($V_i$)

The actual wind velocity at any $i^{th}$ village causing maximum damage would be dependent on the potential radial wind (*RWi*)[6] at the place, this being the wind velocity in the absence of any barriers between the cyclone eye and the village. The potential radial wind at a location is determined mainly by the minimum distance between the location and the centre of the eye of the cyclone or the cyclone eye track as areas closer to cyclone centre face severe wind called maximum wind and wind velocity gets reduced as one moves away from the centre (IMD 2002). We call this distance, the minimum distance from the cyclone path (*dcypath$_i$*), and use it as the proxy for the radial wind. Thus, the actual wind velocity at a place would depend on *dcypath$_i$* and different wind barriers (*Barriers$_i$*) present nearby.

$$\therefore V_i = v(\text{dcypath}_i, \text{Barriers}_i) \quad ...(2)$$

The study area, as mentioned before, is predominantly agricultural with an elevation of less than 10 m and the only wind barriers present are the mangrove forests (width ranging from 0.1 km to 10 km), the casuarinas plantations (width ranging from 0.2 km to 0.4 km) on the coastline and of course, the distance of the village from the coast (*dcoast$_i$*). Hence, we represent the barriers by *dcoast$_i$*, *mangrove$_i$* (the width of the mangrove forest between the village and the coast or along the minimum coastal distance of the village) and *casuarinadumy$_i$*. The casuarinas being in near uniform width wherever present in the study area are represented by a dummy variable. It takes the value 1 if there is casuarinas plantation between the village and the coast.

Substituting these factors into equation 2, the actual wind velocity at the ith village is defined as:

$$V_i = v(\text{dcypath}_i, \text{dcoast}_i, \text{mangrove}_i, \text{casuarinadumy}_i) \quad ...(3)$$

The actual estimates of wind velocity over different locations not being available, it is approximated by including the variables of equation 3 in the main model.

### 3.2 Flooding Due to Storm Surge ($W_i$)

In addition to the wind velocity, storm surge also needs to be considered to explain the cyclone damages, especially the cross-section damages of a single cyclone. Storm surge is the abnormal rise of sea level in excess of the predicted astronomical tide and is caused by the cyclone. Along with the atmospheric pressure variation and the strong surface wind, other factors that also play a decisive role in the generation of the storm surge are the direction (inclination) of the cyclone at landfall, radius of maximum wind, local offshore bathymetry, inland topography, density of sea water, speed of the cyclone, the height of astronomical tide, etc (Kalsi et al 2004). This explains why there may not exist a perfect correlation between the wind velocity at a coastal point and the sea elevation over there. In the case of cyclone of October 1999, very high surge (surge height more than 4.5 m) was witnessed only over a coastal stretch of nearly 30-40 km (ibid), whereas nearly 250 km of the coastline was battered by very high surface wind.

The severity of flooding at a village due to surge depends on the level of sea elevation (surge) at the nearest coastline and other physical features of the village like the minimum distance from the coast, the elevation and the hydrology (the distance from river channels) of the place, presence of natural barriers like mangroves, sand dunes or man-made barriers like dikes near the village, etc. Taking all these factors into account, the following function was defined to explain the severity of flooding due to storm surge in a place.

$$W_i = w(\text{surge}_i, \text{dcoast}_i, \text{dmajriver}_i, \text{dminriver}_i, \text{topodumy}_i, \text{mhabitat}_i, \text{mangrove}_i, \text{casurinadumy}, \text{roadumy}) \quad ...(4)$$

$W_i$ is the severity of flooding due to storm surge at the ith village inland, *surge$_i$* is the height of sea elevation at the coast (land sea interface) nearest to the village. *dcoast$_i$* is the minimum distance of the village from coast (or from the point at which *surge$_i$* is measured), *dmajriver$_i$* is the minimum distance of village from a major river (directly connected to sea) and *dminriver$_i$* is the minimum distance from a minor river (either a tributary of a major river or a drain connected to the tributary). The study area is full of major and minor river channels and their roles during storm surge are different. The major rivers carry away the high velocity surge water to interior areas, and as a result, the surge effects on nearby villages get reduced. But the opposite happens in case of minor rivers. Hence the minimum distance from river channels was divided into two, i e, $dmajriver_i$ and $dminriver_i$.

$Topodumy_i$ is the dummy variable for low elevation. It equals 1 if the village is located within a mangrove habitat area and equals 0 otherwise. The village level elevation data for the study area was unavailable and we demarcated the low lying areas by using the present and historical mangrove forests maps.[7] As mangrove forests come up in low lying areas that get inundated regularly during high tide, villages with $topodumy_i = 1$ are likely to be low lying and the ones with $topodumy_i = 0$, to be situated at a higher elevation.

$Mhabitat_i$ is the width of the mangrove habitat between the village and the coast as seen from the historical forest map of the area. It is included as an explanatory variable for a few reasons, namely, to separate the effect of mangrove vegetation from that of the mangrove habitat, to control for any unobserved feature of the habitat, etc. Moreover, the width of the mangrove habitat in an area depends on the bathymetric and topographical features of the area and by including *mhabitat*, we could have a control for the aggregative effects of these features on the storm surge velocity.[8]

$Mangrove_i$ and $casurinadumy_i$ are explained before and $roadumy_i$ is the dummy variable for the presence of village road or the dikes as dikes are also used as village roads in the coastal areas. It equals 1 if village road exists.

**Table 1: List of Variables**

| Name of Variables | Definition of Variables (All Distances in Kilometre) |
|---|---|
| Aglabour | Percentage of agricultural labourers in total population of a village. |
| Barrier | Wind barriers present along the wind direction |
| Casurinadumy | Dummy variable for the presence of casuarinas forest in coastal distance of a village. |
| Cultivator | Percentage of people working as cultivators in a village |
| Dcoast | Minimum distance of a village from the coast. |
| Dcypath | Minimum distance of a village from the path of cyclone. |
| $D_i$ | Damage suffered (loss of human life, damage to residential structures) in the ith village. |
| Dmajriver | Minimum distance of a village from a major river (directly connected to sea). |
| Dminriver | Minimum distance of a village from a minor river (a tributary of major river). |
| Droad | Minimum distance of a village from a metallic road. |
| Hhworker | Percentage of people working in (own) household industries in a village. |
| Literate | Percentage of literate people in a village |
| Mangrove | Width of existing mangrove forest in coastal distance of a village. |
| Margworker | Percentage of people working as marginal workers in a village. |
| Mhabitat | Width of the historical mangrove forest in coastal distance of a village. |
| Otworker | Percentage of other workers (doctor, teacher, engineer, barber, washer man, priest etc.) in a village. |
| $P_i$ | Population or property at risk at the location. |
| Pop99 | Total population of a village in 1999. |
| Radial wind | The expected wind velocity at different radial distances (dcypath) from the cyclone eye. |
| Roadumy | Dummy variable for the presence of village road (=1, if village road exists, =0, otherwise). |
| $RW_i$ | Radial wind at the ith location. |
| Schdulcaste | Percentage of scheduled caste people in a village. |
| $S_i$ | The group of socio-economic factors at the location influencing the volume and extent of damages. |
| Surge | Level of sea elevation (in metres) at different coastal points. |
| Topodmy | Low elevation dummy (1 for villages that are situated in mangrove habitat areas, and 0 for others). |
| $W_i$ | Velocity or the severity of flooding due to storm surge at the $i^{th}$ location. |

### 3.3 Socio-economic Factors ($S_i$)

The cyclone like any other natural calamity is presumed to have differential impacts on people depending on their socio-economic status (FAO 2000) and the coastal poor are expected to be the more vulnerable during cyclones.[9]

Along with economic well-being, institutional, infrastructural as well as social factors also play decisive roles in averting human death and other movable damages during cyclones. Efficiency of the meteorology department in providing accurate cyclone warning, promptness of local administration in proper dissemination of the cyclone warning or evacuating people from vulnerable areas, presence of cyclone shelters or some other concrete structures in neighbourhoods, community behaviour of people in helping each other during crisis, etc, also play important roles.

In the absence of a proper economic well-being index for different villages, the differences in the socio-economic conditions of different villages are captured by using factors like percentage of literates (ibid), percentage of different types of workers,[10] percentage of scheduled caste population (economically and socially most deprived), the proximity of villages to metallic road (better scope for economic prosperity), presence of village road (connectivity to metallic road), etc.[11] Thus, the socio-economic well-being index as affecting cyclone damages is defined as:

$$S_i = S\,(\,literate_i, scheduledcaste_i, cultivators_i, aglabours_i, hhworkers_i, otworkers_i, margworkers_i, droad_i, roadumy_i) \quad ...(4)$$

Combining population (or property) at risk, the factors affecting wind velocity, surge velocity and the socio-economic conditions of the villages, the following cyclone damage function is obtained for a village.

$$D_i = d\,(\,population99_i, dcypath_i, surge_i, dcoast_i\, mangrove_i, mhabitat_i, topodumy_i, casurinadumy_i, dmajriver_i, dminriver_i, droad_i, roadumy_i, literate_i, scheduledcaste_i, cultivator_i, aglabour_i, otworkers_i, margworkers_i) \quad ...(5)$$

where $D_i$ is the damage suffered in the ith village and the right hand side variables are explained in Table 1.[12]

This study attempts to evaluate the sheltering capacity of the mangrove forest and to infer mangrove protection accurately, we estimated the above equation for the sample villages with $mhabitat_i > 0$. We imposed this restriction on the sample as villages that never had mangroves in between them and the coast (or for which $mhabitat_i = 0$) can never be protected by mangroves, and second, these villages have a different coastal topography than the villages behind mangrove habitat areas. Thus, by considering only villages for which $mhabitat_i > 0$ in the sample, we analysed the damages for villages with a similar coastal topography, and thereby included villages both with and without mangroves as quite a bit of the mangrove habitat area in Kendrapada has been cleared of mangroves.

## 4 Data Used

Four different categories of secondary data like damages due to cyclone, meteorological information, geophysical information and socio-economic information are used for the analysis. They were either generated or collected from different sources (Table 2).

We collected cyclone damage information in the form of human deaths and three types of house damages, namely, fully collapsed houses (FC); partially collapsed houses (PC); and swept away houses (SA) caused during the cyclone. Though, we could get village-level data on human death (total observations = 1,180), the number of observations was limited to 558 for house damages as much of this data was available at the gram panchayat level.

**Table 2: Description and Sources of Data**

| Data Head | Description | Source |
|---|---|---|
| Damages due to cyclone | Details of human casualties in each village. | Emergency office, Kendrapada and Bhadrakh districts. |
| | Number of houses swept away, fully collapsed and partially collapsed in each village or in each gram panchayats. | Emergency and tahasildar offices of Kendrapada and Jagatsinghpur districts. |
| Meteorological information | Landfall wind velocity, radius of cyclone eye and sea elevation at different coastal points. | Cyclone Warning Division, Mausam Bhawan, Government of India, New Delhi. |
| | Track of the cyclone. | National Centre for Disaster Management (NCDM), Indian Institute of Public Administration, New Delhi. |
| Geophysical information | Distances of different villages or gram panchayats from coastline, cyclone track, river channels, metallic roads and width of present and historical mangrove forests. | Geographic Information System (GIS) files purchased from private source: Digital Cartography and Services, Bhubaneswar. |
| Socio-economic information | Total population, percentage of literates, scheduled caste and different types of workers in different villages or in gram panchayats before cyclone. | Primary Census Abstract of Orissa for 1991 and 2001. |

The geophysical variables were generated from the village-level physical map of coastal Orissa that was developed by GIS Arc View Software by using the GIS files on village boundaries, rivers, drains, roads and coastal forests of Orissa (as existed on 11 October 1999 and before 1950).[13] Then the different location-specific positions of the cyclone eye as described in the NCDM Report (Gupta and Sharma 2000) were superimposed on the village map and the cyclone eye track was demarcated at the village scale. Different distances as required for the analysis were then calculated with the help of the software. The approximate sea elevation at different coastal points was calculated from the surge envelope curve as described in the Indian Meteorology Department of the Government of India report on storm surge height of Orissa cyclone (Kalsi et al 2004).

The socio-economic variables were generated from the primary census abstract of Orissa for 1991 and 2001. The annual rate of growth for the period 1991 to 2001 was obtained for different variables (population, scheduled castes, different types of workers, etc) and then the 1991 figures were extrapolated for the year 1999 by making use of the respective growth rates.

## 5 Estimation and Results

The cyclone damage function derived in equation 5 was estimated separately for human death and three types of house damages using the appropriate estimates depending on the data. The same explanatory variables were used for each type of damage equation with the exception of population or property at risk for comparison of the results. Separate estimation of these equations was also necessary as different damage data were available over different units and the nature of data was also different. We discuss here the sample areas and the type of estimates used for different types of damages.

### 5.1 Human Casualties

The cyclone damage function (equation 5) with human deaths as the dependent variable was estimated using village-level data consisting of 1095 revenue villages of Kendrapada district and 85 coastal villages of the Chandbali tahasil of Bhadrakh district situated next to the mangrove forest of Kendrapada in the north-eastern direction.[14] The dependent variable, $sucydeath_i$ (the number of deaths witnessed in a village due to cyclone) is a non-negative count with most of the observations either zero, one or small integers, and hence a Poisson distribution is used for this model. Rearranging the variables of equation 5 and writing the mangrove-related variables first, the estimating equation is written as follows:

$$E\,(\text{sucydeath}_i) = \lambda_i = \exp\begin{pmatrix} \beta_0+\beta_1\text{mangrove}_i+\beta_2\text{mhabitat}_i+\beta_3\text{topodumy}_i \\ +\beta_4\text{casuarinadumy}_i+\beta_5\text{dcypath}_i \\ +\beta_6\text{surge}_i + --- + \beta_{19}\, margworkers+\varepsilon_i \end{pmatrix} \quad ...(6)$$

where $\varepsilon_i$ is the error term and other variables have been explained in Table 1. We present both the Poisson and negative binomial estimates[15] for this model in Table 3 (p 65) for the villages of the sub-sample of the study area with restriction $mhabitat_i$>0 (840 villages), as this sample, as explained before, has control for more variables affecting damage occurrences and is likely to give more accurate results.

### 5.2 House Damage

House damages were described under three different categories by the state government, namely, FC, PC, and SA houses and we estimated regressions for these damages separately. The study area for these models is a heterogeneous mixture of 365 villages and 138 gram panchayats covering the entire Kendrapada district and 86 coastal villages of the Kujang-Paradeep tahasil of the adjoining Jagatsinghpur district situated south-east to Kendrapada.[16]

The explanatory variables used in these regressions are the same as used in the previous model. *Male 99* (total male population of the village or the gram panchayat in 1999) has been used as proxy for properties at risk (in place of *population99*) as no accurate measure of total number of houses at risk was available.

**Table 3: Coefficient Estimates for Human Death Model Using Both Poisson and Negative Binomial Regressions for the 840 Villages of Study Area with Restriction mhabitat>0**

| Equation/Variable | Estimated Coefficients under Poisson Regression | | Estimated Coefficients under Negative Binomial Regression | |
|---|---|---|---|---|
| Mangrove | -0.838*** | (5.66) | -0.829*** | (4.75) |
| Mhabitat | 0.079*** | (3.72) | 0.135*** | (3.96) |
| Topodumy | 1.092*** | (5.18) | 1.078*** | (3.31) |
| Casurinadumy | 0.149 | (0.363) | 0.297 | (1.32) |
| Dcypath | -0.01 | (1.42) | -0.003 | (0.35) |
| Surge | 0.057 | (1.16) | 0.0372 | (0.55) |
| Dcoast | 0.002 | (0.27) | 0.0124 | (1.28) |
| Dmajriver | 0.021 | (1.08) | 0.0211 | (0.86) |
| Dminriver | -0.058** | (2.19) | -0.0419 | (1.22) |
| Droad | -0.009 | (0.34) | -0.008 | (0.21) |
| Roadumy | -0.56 | (0.39) | -0.007 | (0.04) |
| Male99 | 0.0004*** | (10.45) | 0.0005*** | (6.96) |
| Literate | -1.518** | (2.29) | -1.841** | (1.93) |
| Schdulcaste | -0.99** | (2.36) | -1.082* | (1.83) |
| Cultivator | -1.042* | (1.73) | -0.5603 | (0.63) |
| Aglabour | 1.149 | (1.06) | 1.226 | (0.76) |
| Hhworker | 1.659 | (0.20) | 3.210 | (0.27) |
| Otworker | -1.593 | (1.06) | -2.597 | (1.11) |
| Margworker | 1.695*** | (2.63) | 1.583* | (1.85) |
| Constant | -0.149 | (0.25) | -0.881 | (1.00) |
| Log likelihood | -618.225 | | -562.489 | |
| Number of observations | 840 | | 840 | |
| Pseudo R square | 0.35 | | 0.20 | |
| LR Chi2 (19) | 668.13, Prob > Chi2 = 0.00 | | 285.02, Prob > chi2 = 0.00 | |
| Lnalpha | | | 0.0131 (standard error=0.19297) | |
| Alpha | | | 1.0131 (standard error=0.19551) | |
| Likelihood-ratio test of alpha = 0: | | | Chibar2 (01) = 111.47, Prob >= chibar2 = 0.00 | |

(1) Values in parenthesis next to the coefficient estimates in both the columns are the z values. But the values in parenthesis for lnalpha and alpha in the last but one row of the table are the standard errors.
(2) ***, **, and * imply level of significance to be 1%, 5% and 10%, respectively.

**Fully Collapsed Houses:** The estimating equation for fully collapsed houses is similar to equation 6 for human deaths except that we use a linear regression model rather than an exponential model with the same set of explanatory variables,

$$FC_i = \alpha_o + \alpha_1 mangrove_i + \alpha_2 mhabitat_i + \alpha_3 topodumy_i + \alpha_4 casuarinadumy_i + \alpha_5 dcypath_i + \alpha_6 surge_i + --- + \alpha_{19} margworkers_i + v_i \quad ...(7)$$

The error was heteroskedastic (Breusch-Pagan Chi2 (1) = 498.14, P = 0.00), the range of FC houses in the sample was wide (0 to 1885), and thus, we tried both ordinary least squares estimates (OLS) with robust standard errors and weighted least squares (WLS) estimates with area as well as total population as weights. Though we got similar results, OLS estimates with robust standard errors were retained. Table 4 shows the estimated coefficients for the sub sample areas of the study area with the restriction $mhabitat_i > 0$ (516 observations).

**Partially Collapsed Houses:** The same set of regressors as used for human casualty and FC house models were used for PC. The range of PC houses was also wide (0 to 2364), the heteroskedasticity test was significant (Breusch-Pagan Chi2 (1) = 1794.49, P = 0.00) and we tried OLS with robust standard errors, WLS estimates with area as well as total population as weights and also the feasible generalised least squares (FGLS) estimates (Wooldrige 2003). OLS resulted in most of the variables being insignificant with wrong signs, but both WLS and FGLS estimates gave similar results on expected lines. We retained the WLS estimates (weight = area) on the basis of low values of the variance inflation factors compared to other estimates. The WLS estimates for the sub-sample areas with the restriction $mhabitat_i > 0$ (516 observations) are shown in Table 4.

**Swept Away Houses:** Five different tahasils in the study area (Kujang-Pardeep, Mahakalapada, Rajnagar, Patamundai and Marshaghai) were reported to have been affected by storm surge but only the first three tahasils (adjoining the coast) witnessed swept away houses (Gupta and Sharma 2000). We assumed a Tobit distribution for this model as the dependent variable, $SA_i$ (the number of houses getting swept away in ith village or gram

**Table 4: Coefficient Estimates for Fully Collapsed Houses, Partially Collapsed Houses and Swept Away Houses Models Using Ordinary Least Squares, Weighted Least Squares and Tobit Estimates Respectively#**

| Equation/Variable | Results for Fully Collapsed Houses | Results for Partially Collapsed Houses | Results for Swept Away Houses |
|---|---|---|---|
| Type of Estimates Used | Ordinary Least Squares Estimates with Robust Standard Errors | Weighted Least Squares Estimates using Area under Villages or Gram Panchayats as Weights | Tobit Estimates with Robust Standard Errors (Interval Regression) |
| Mangrove | -58.67*** (2.73) | 70.62 *** (6.94) | 23.19** (2.01) |
| Mhabitat | 17.28*** (2.81) | 1.26 (0.19) | 17.19** (2.02) |
| Topodumy | -34.82 (0.87) | -25.22 (0.63) | 124.07*** (2.80) |
| Casurinadumy | -54.42 (1.41) | -53.94 (1.50) | 11.16 (0.25) |
| Dcypath | -8.52*** (4.36) | 2.27 (1.38) | -3.16 (0.94) |
| Surge | 4.85 (0.50) | -1.21 (0.11) | 42.19*** (2.51) |
| Dcoast | 0.31 (0.35) | 0.13 (0.09) | -17.08*** (3.96) |
| Dmajriver | -5.61 ** (2.41) | 11.42*** (2.78) | 11.80 *** (2.51) |
| Dminriver | -4.13 (1.46) | 4.27 (0.72) | 16.87 (1.59) |
| Droad | -4.40 (0.75) | -6.24 (1.34) | 31.72*** (4.68) |
| Roadumy | 33.94* (1.73) | -83.23** (2.56) | 27.04 (0.68) |
| Male99 | 0.26*** (11.66) | 0.12*** (10.23) | 0.08*** (3.48) |
| Literate | -130.79 (1.40) | 184.88 (0.99) | -163.59 (0.75) |
| Schdulcaste | 37.42 (0.80) | 286.78*** (3.10) | 76.41 (0.69) |
| Cultivator | 90.63 (0.54) | -59.41 (0.21) | -525.47* (1.64) |
| Aglabour | -107.72 (0.53) | -1591.95*** (3.84) | -1078.69* (1.79) |
| Hhworker | -914.10 (0.76) | 3674.89 (1.59) | -1753.87 (0.46) |
| Otworker | -434.41** (1.94) | -791.45 ** (2.15) | -996.33** (2.21) |
| Margworker | 85.19 (0.81) | -256.49 (1.48) | -73.48 (0.39) |
| Constant | 251.48 ** (2.23) | -14.41 (0.09) | -173.60 (0.96) |
| Number of observations | 516 | 515 | 516 (449 zero and 67 non-zero) |
| R square | 0.57 | 0.56 | Pseudo R square = 0.19 |
| F value | F(19,496) = 13.58, P = 0.00, Root MSE = 198.61 | F (19,495) = 33.06, P = 0.00, Root MSE = 254.08 | Wald chi2 (19) = 66.32, P=0.00 |

(1) Figures in parenthesis next to the coefficient estimates are the student t values in the columns for fully collapsed and partially collapsed houses. These values are the z values in swept away houses column.
(2) ***, **, and * imply level of significance to be 1%, 5% and 10%, respectively.
# The results are for the 516 units (450 villages and 66 gram panchayats) with restriction mhabitat>0.

panchayat) is a censored series, equating 0 for a significant part of the observations (86%) and the range of the non-zero observations was also very high (1-1005).[17] We used the same set of regressors as used for the previous models and after getting the tobit estimates calculated the robust standard errors by using the interval regression procedure. The results for areas with $mhabitat_i > 0$ (516 observations) are shown in Table 4 along with the results for FC and PC houses.

**Discussion:** Two sets of data, one for human mortality and the other for house damages, are analysed in the paper. Our regression results are expected to have low omitted variable biases as we control for 18 other variables in addition to our variable of interest, the width of mangrove forest, but we did expect a multicollinearity problem. The coefficient of correlation between different explanatory variables except for a few was less than 0.4 for both sets of data. High correlation was found between $dcypath_i$ and $surge_i$ (r = -0.65, P = 0.00), $dcypath_i$ and $mangrove_i$ (r = 0. 62, P = 0.00), $surge_i$ and $casuarinadumy_i$ (r = 0. 76, P = 0.00) and $casuarinadumy_i$ and $dcypath_i$ (r = -0.43, P = 0.00). The correlation coefficients between the socio-economic variables were found as less than 0.3, though in some cases significant, in both the data sets. Both $dcypath_i$ and $surge_i$ are cyclone-related variables and are expected to be correlated, but the high correlation between cyclone-related variables and $mangrove_i$ is coincidental as we have more mangroves as one moves away from the cyclone path (Figure 2). To ensure that the significance of $mangrove_i$ is not due to its correlation with other variables, we estimated the models by dropping each variable correlated with mangrove from the estimating equation, but found no change in significance or sign (even little change in the magnitude) of $mangrove_i$ coefficient. Both $dcypath_i$ and $surge_i$ being important, we have retained both in the regressions.

We expect $mangrove_i$ to have a negative coefficient for deaths, fully collapsed houses and swept away houses, but to have a positive coefficient for partially collapsed houses. As per the socio-economic standard of rural Kendrapada before the cyclone, almost 98% of the houses were expected to witness some damage during the cyclone depending on the exposure to and intensity of the cyclone.[18] The damaged houses were put into only three categories, i e, either FC, or PC or SA, where PC was a broad category including a wide range of lower damage to houses. We expected mangroves to provide protection, and thus, expect areas in leeward side of mangrove forest to have less fully collapsed and swept away houses, but more partially collapsed houses.

Both the Poisson and negative binomial estimates for human mortality during cyclone give similar results (Table 4). Mangrove is significant with a negative coefficient in both the models and this supports the argument that mangroves have played a significant protective role in saving human lives during the cyclone of October 1999. We have three variables capturing different aspects of the mangrove habitat areas on human death. $Topodumy_i$ identifies villages that are located in areas where mangroves were historically present and hence, captures the vulnerability of these areas due to low elevation. The $Mhabitat_i$ (the width of mangrove habitat in between the village and coast) captures the effect of the topographic, hydrologic and bathymetric or any other unobserved confounding factors present there and $mangrove_i$ captures the effect of the mangrove vegetation present before the cyclone. Of these three factors, both $topodumy_i$ and $mhabitat_i$ seem to have increased human casualty. Only mangrove vegetation seems to be playing a protective role in saving lives.

Of the other significant variables, the results on scheduled caste and marginal workers are surprising. The scheduled caste people are socially and economically most deprived, have very low quality houses and are treated as untouchables. The marginal workers are also poor and we expected both to have positive coefficients. In contrast, the former is significant with a negative coefficient in both the equations,[19] though, the latter's coefficient is positive and significant. This negates the hypothesis that the impact of natural calamities is similar on all economically backward people. Scheduled caste people pursued a set job pattern to earn their livelihood and were probably not taking a risk during the cyclone by doing some work outside. Their future income, though low, was not uncertain. Their household non-removable asset holdings being very low, they were probably quick to leave their houses and moved to safer places after hearing the cyclone warning and hence could avoid death. The marginal workers, though poor and have a low asset holding, did not have a secure or set pattern of job to earn their livelihood. Probably they took risks and were exposed during the cyclone while doing some job to earn extra income!

## House Damages

On house damages, mangroves seem to have reduced the damage to houses, but not along expected lines with respect to the swept away houses (Table 5). It has a significant and negative coefficient for fully collapsed houses and as expected, a significant positive coefficient for partially collapsed houses implying that mangrove protected areas witnessed less fully collapsed houses and more partially collapsed houses. This means probably that the presence of mangroves turned the full damage of houses to partial damage by reducing the wind velocity. Fully collapsed houses seem to have been caused by wind as evident from the significance of $dcypath_i$ with a negative sign in the results for these houses (Table 4, col 2). In contrast, the swept away houses are a consequence of storm surge as evident from the significance of variable $surge_i$ in the results for swept away houses (Table 4, col 4) and $mangrove_i$ is significant with a positive coefficient implying that the presence of mangrove did not protect the static properties from water-related damages. Mangroves are expected to reduce the velocity of storm surge, but not the flow of water and the houses being predominantly kuchha houses, they must have collapsed after coming in

**Table 5: Elasticity Measures of Mangrove on Different Types of Cyclone Damages**

| Type of Damages (Name of Dependant Variable) | Elasticity Measure |
|---|---|
| Human death (sucydeath) | Poisson: -1.221*** (5.66) |
| | Negative binomial: -1.209*** (4.75) |
| Fully collapsed houses | -0.118*** (2.72) |
| Partially collapsed houses | 0.235*** (6.72) |
| Swept away houses | 0.189* (1.88) |

***, ** and * imply significant at 1%, 5% and 10%, respectively.
Figures in parenthesis are the z values.

contact with water. Villages established in mangrove habitat areas seem to have seen more houses swept away as observed from the significance of *topodumy*$_i$, the control for the low lying mangrove habitat villages.

We compare the elasticity[20] of mangrove width for different types of damages to obtain some approximation of the degree of protection by mangroves to movable and immovable assets. As shown in Table 5, mangrove protection seems to be much higher for human death compared to static properties. A 1% increase in mangrove width seems to decrease human death by 1.22%, whereas the decrease for fully collapsed houses is only by 0.12%. Though, it seems to increase partially collapsed houses and swept away houses by 0.235% and 0.189%, respectively, the effect on swept away houses is less significant, the level of significance being only 10%.

## 6 Conclusion and Policy Implications

The protective role of coastal forests, particularly mangroves, has remained under-researched and this paper addresses this shortfall by looking at the role of the mangrove forest of Orissa. Our work analyses human casualties and the damage to static properties like residential houses witnessed in Kendrapada district during the cyclone of October 1999. The impact of mangroves on the above damages caused by both cyclonic wind and storm surge are analysed, and by controlling for the socio-economic and geophysical features a disaggregated picture of the storm protection services of mangroves is obtained. The existence of mangrove forests was found to have reduced human casualties significantly during this cyclone and this result was robust.

In contrast to popular belief, all poor people were not found equally vulnerable during the cyclone and we expect the security and certainty of sources of livelihood to have influenced their exposure to the cyclone. Mangroves also seem to have reduced house damages, at least, by converting a likely full collapse of houses to only partial collapse. In general, the protective role of mangrove forests was found to be more effective in reducing deaths than in reducing the damages to static properties like houses as observed from the elasticity.

Kendrapada district is one of the most cyclone-prone areas of peninsular India, and is highly vulnerable to disaster due to high population density and sallow bathymetry. Thus protection of the existing mangroves should be a priority, given their protective services and an expected increase in high intensity cyclones due to climate change.

NOTES

1 The main forests consisted of mangroves though a few patches of casuarinas plantation were also present in the coastal areas before the cyclone, but the width of these plantations everywhere was between 200 and 400 metres.

2 The earliest forest map available for these areas is one online 1:250,000 scale US Army map (NF 45-14 Series U502, "Cuttack" sheet). The map was based on 1929-31 ground surveys, updated by 1944 aerial photographs and gives a correct assessment of coastal forests before 1950 which were mainly mangroves as casuarinas plantation started in 1974 in coastal Orissa under the coastal shelterbelt plantation.

3 In the northern hemisphere, the direction of the cyclonic wind is anti-clockwise and over areas south of cyclone eye, the wind blows from land to sea.

4 District Planning Map for Cuttack, Jajpur, Kendrapada and Jagatsinghpur of Orissa (2000 ed), Reg No 112 - NA/DP-1000-1000, National Atlas and Thematic Mapping Organisation, Calcutta.

5 Flooding due to torrential rain as a cause of damage has been ignored here as the paper analyses the cross section damages of a single cyclone and in the study area, it rained almost the same amount everywhere without much spatial differences. Moreover, the variation in rainfall is expected to be correlated with distance from coast and distance from cyclone path and we have implicitly controlled for it by including these variables in the model.

6 Radial wind is wind velocity at different horizontal distances from the centre of the eye of the storm (cyclone path in present case) and is dependant on the maximum wind at the cyclone eye wall.

7 The earliest forest map available for these areas, as mentioned before, is the online 1:250,000 scale US Army map (NF 45-14 Series U502, "Cuttack" sheet). This map gives a correct assessment of mangrove habitat areas as mangrove destruction seems to have started after 1952 with the change in land ownership due to the abolition of feudal system in India and population pressure after 1961 (Mohanty 1992; Orissa District Gazetteer, Cuttack 1996; Chadha and Kar 1999). We georeferenced this toposheet at 1:50000 scale and demarcated the mangrove habitat areas for the study.

8 Both *mangrove*$_i$ and *mhabitat*$_i$ were likely to be correlated, one being the width of the habitat and the other, the width of the vegetation present in the same habitat. But fortunately this was not the case for the study area probably because of the random pattern of mangrove clearing. Some localities had witnessed a 100% clearing of the mangroves, some marginal clearing and in some places there has been marginal increase in mangrove cover compared to what existed historically. Thus *mhabitat*$_i$ and *mangrove*$_i$ were not found to be strongly correlated and were included in the same regression.

9 A wealthy household has a good quality house, has a transistor or television set to listen to cyclone warnings and some members being educated, they are quick to react to a cyclone warning, etc. In contrast, a poor household has bad quality houses, likely to be in low lying vulnerable areas, members are uneducated and less informed, have low quality health, etc, because of which they are more likely to die and suffer more loss than the rich people.

10 We use different types of workers as defined in Census of India (cultivators, agricultural labourers, workers in own household industries, other workers and marginal workers) and calculate their percentages with respect to the total population of the village.

11 In the absence of data on access to mass media (TV, Radio) at the village level, the percentage of other workers (*otworkers*) that include people with high education, high mobility and in occupation other than agriculture and household industries (doctors, teachers, engineers, barbers, washermen, priests, etc.) are taken as proxies for availability of this commodity.

12 Factors like time and season of occurrence of the cyclone, number of hours of advanced warnings to cyclone, efficiency of governmental institutions, etc. have been ignored as the analysis is for the damage data of a single cyclone and for a single district.

13 We use IRS-ID LISS-III pan image of 11 October 1999 to demarcate the coastal forest of Orissa before the cyclone (both mangrove and casuarinas) and the historical forest map described before to demarcate the 1950 forest.

14 Though Chandbali tahasil was included in the human death model, it could not be included in the house damage analysis as data on house damages could not be arranged.

15 In practice, the Poisson regression model is found to be restrictive in many ways because of its assumption that events occur independently over time and space and the conditional mean and variances of the dependent variable are equal to each other or there is no over- or under-dispersion (variance > or < mean) in the model. As the presence of over-dispersion results in small estimated standard errors and inflated z-values of the estimated β coefficients, the test of significance proves to be unreliable. Hence, the negative binomial results are presented along with Poisson as negative binomial regression corrects for over-dispersion.

16 Kujang-Paradeep tahasil of Jagatsinghpur could not be included in the human death analysis as the emergency office of Jagatsinghpur could provide some information on house damage for this tahasil, but information on human death was difficult to compile at the village level. This tahasil witnessed high cyclone impact and the human death was in thousands (nearly 8,000 people had died in Kujang block). The information was kept either at the individual level or at household level and it was difficult to compile the data at the village level both in terms of time and resources. Hence Kujang-paradeep tahasil could be included in the house damage analysis, but not in human death analysis.

17 Though Tobit distribution is assumed for continuous data, it can also be used over discrete observations if the range of non-zero observations is high (Woolridge 2003).

18 Ninety-four per cent of the households in the district lived in the rural areas and only 2% of the rural households had both concrete roof as well as concrete wall before the cyclone. Though 15% of the households had cemented walls (83% had mud walls), the material inside being either raw brick or mud, its capacity to withstand the super-cyclone impact was doubtful. Thus, it is expected that at least 98% of the rural households must have suffered some form of house damage depending on the cyclone impact on their location.

19 As most of the scheduled caste people work as agricultural labourers, the significance of scheduled caste may be presumed to be due to the high correlation between the two. However, the correlation coefficient between $aglabour_i$ and $schedulcaste_i$ is 0.17 in the human casualty model.

20 Elasticity is calculated by the formulae ∂logy/∂log$x_i$, where y is the dependent variable and $x_i$ is the ith independent variable. The elasticity of a variable in a Poisson model equals the estimated coefficient times the average value of the independent variable whereas for linear models, it equals the estimated coefficient times the ratio of the average values of the independent variable to the dependent variable.

## REFERENCES


Badola, Ruchi and S A Hussain (2005): "Valuing Ecosystem Functions: An Empirical Study on the Storm Protection Function of Bhitarkanika Mangrove Ecosystem, India", *Environmental Conservation*, 32, 85-92.

Baird, Andrew H (2006): "Tsunamis: Myth of Green Belts", SAMUDRA Report No 44: 14-19 July.

Barbier, E B et al (2008): "Coastal Ecosystem-based Management with Nonlinear Ecological Functions and Values", *Science*, 319 (5861): 321-23.

Barbier, E B (2007): "Valuing Ecosystem Services as Productive Inputs", *Economic Policy*, 22 (49): 177-229.

Bretschneider, C L and P G Wybro (1977): "Tsunami Inundation Prediction" in C L Bretschbeider (ed.), *Proceedings of the 15th Coastal Engineering Conference*, American Society of Civil Engineers, New York, 1006-24.

Census of India 2001, Orissa: *Tables on Houses, Household Amenities and Assets*, Series-22, Vol 1, Registrar General and Census Commissioner, India, New Delhi.

Chadha, S and C S Kar (1999): *Bhitarkanika, Myth and Reality* (Dehradun: Natraj Publisher), 388.

Chan, H T, J E Ong, W K Gong and A Sasekumar (1993): "The Socio-Economic, Ecological and Environmental Values of Mangrove Ecosystems in Malaysia and Their Present State of Conservation" in B F Clough (ed.), *The Economic and Environmental Values of Mangrove Forests and Their Present State of Conservation in South-East Asia/Pacific Region*, 1, Okinawa, Japan: International Society for Mangrove Ecosystems, International Tropical Timber Organisation and Japan International Association for Mangroves, 41-81

Chatenoux, B and P Peduzzi (2006): "Analysis of the Role of Bathymetry and Other Environmental Parameters in the Impacts from the 2004 Indian Ocean Tsunami", UNEP/DEWA/GRID-Europe, Switzerland: Accessed on November 2007 (http://www.grid.unep.ch/product/publication/download/environment_ impacts_tsunami.pdf)

– (2007): "Impacts from the 2004 Indian Ocean Tsunami: Analysing the Potential Protecting Role of Environmental Features", *Natural Hazards*, 40: 289-304.

Costanza, R, O Perez-Maqueo, M L Martinez, P Sutton, S J Anderson and K Mulder (2008): "The Value of Coastal Wetlands for Hurricane Protection", *Ambio*, 37(4 June): 241-48.

Dahdouh-Guebas, F and Nico Koedam (2006): "Coastal Vegetation and Asian Tsunami", *Science*, 311 (January): 37.

Dahdouh-Guebas, F, L P Jayatisa, D Di Nitto, J O Bosire, D Lo Seen and N Koedam (2005): "How Effective Were Mangroves as a Defense Against the Recent Tsunami?" *Current Biology*, 15: R443-R447.

Danielson, F et al. (2005): "The Asian Tsunami: A Protective Role for Coastal Vegetation", *Science*, 310: 643.

*District Statistical Handbook* (2001): "Directorate of Economics and Statistics", Kendrapada, Government of Orissa, Bhubaneswar.

Dixon, J A and P N Lal (1997): "The Management of Coastal Wetlands: Economic Analysis of Combined Ecological Economic Systems" in P Dasgupta and K G Maler (ed.), *The Environment and Emerging Development Issues, Vol 2* (Oxford: Clarendon Press).

FAO (2000): "Reducing Agricultural Vulnerability to Storm Related Disasters", COAG 01/6, FAO Corporate Document Repository, Annexure, XI, APDC/01/7.

– (2006): "Coastal Protection in the Aftermath of the Indian Ocean Tsunami: What Role for Forests and Trees?" Concept note, conclusion and policy recommendation for the Regional Technical Workshop, Khao Lak, Thailand, 28-31 August.

Farber, S (1987): "The Value of Coastal Wetlands for Protection of Property against Hurricane Wind Damage", *Journal of Environmental Economics and Management*, 14: 143-51.

Forest Survey of India (2001): *The State of Forest eport*, Ministry of Environment and Forests, Government of India, Dehradun.

Fosberg, F R (1971): "Mangroves Verses Tidal Waves", *Biological Conservation*, 4: 38-39.

Greene, W H (2000): *Econometric Analysis*, 4th Edition (Delhi: Pearson Education Asia).

Gilbert, Alison and R Janssen (1998): "Use of Environmental Functions to Communicate the Values of a Mangrove Ecosystem under Different Management Regimes", *Ecological Economics*, 25 (3): 323-46.

Gupta, M C and V K Sharma (2000): *Orissa Super Cyclone, 99*, National Centre for Disaster Management, Indian Institute of Public Administration, New Delhi (New Delhi: New United Press).

HDR (2004): *Human Development Report* (prepared by Nabakrushna Choudhury Centre for Development Studies), Planning and Coordination Department, Government of Orissa, Bhubaneswar.

IMD (2002): *Damage Potential of Tropical Cyclones*, Indian Meteorological Department, Government of India, New Delhi.

– (2000): *Tracks of Cyclones in Bay of Bengal and Arabian Sea, 1890-1990*, Indian Meteorological Department, Government of India, New Delhi.

Kalsi, S R, N Jayanthi and S K Roy Bhowmik (2004): *A Review of Different Storm Surge Models and Estimated Storm Surge Height in Respect of Orissa Supercyclonic Storm of 29 October, 1999*, Indian Meteorological Department, Government of India, New Delhi, January.

Kathiseran, K and N Rajendran (2005): "Coastal Mangrove Forest Mitigate Tsunami", *Estuarine, Coastal and Shelf Sciences*, 65: 601-06.

Kerr, A M, A H Baird and S J Camphell (2006): "Comments on 'Coastal Mangrove Forest Mitigate Tsunami'" by K Kathiresan and N Rajendran, *Estuarine, Coastal and Shelf Sciences*, 67: 539-41.

Massel, S R, K Furukawa and R M Brinkman (1999): "Surface Wave Propagation in Mangrove Forests", *Fluid Dynamics Research*, 24: 219-49.

Mazda,Y, M Magi, M Kogo and P N Hong (1997): "Mangroves as a Coastal Protection from Waves in the Tong King Delta, Vietnam", *Mangroves and Salt Marshes*, 1: 127-35.

Mazda, Y, M Magi, Y Ikeda, T Kurokawa and T Asano (2006): "Wave Reduction in a Mangrove Forest Dominated by Sonneratia sp", *Wetlands Ecology and Management*, 14: 365-78.

Mohanty, N C (1992): *Odisara Luna Jangal abauon Banyapranni (Mangroves of Orissa)*, Project Swarajya Publication, Nayapalli, Bhubaneswar (In Oriya language).

Orissa District Gazetteers Cuttack (1996): The Gazetteers Unit, The Department of Revenue, Bhubaneswar, Government of Orissa.

Steffen, W (2006): "Stronger Evidences but New Challenges: Climate Change Science 2001-2005", Department of Environment and Heritage, Australian Green House Office, Australian Government.

Tynkkonen, O (2000): "Orissa Cyclone: A Natural Phenomenon or a Sign of Things to Come," *Report of Friends of Earth*, Finland.

UNEP (2005): "After the Tsunami: Rapid Environmental Assessment", Report of UNEP Asian Tsunami Task Force, February (see http://www.unep.org/tsunami/tsunami rpt.asp)

Wooldridge, J M (2003): *Introductory Econometrics: A Modern Approach* (Ohio: Thomson Learning).