Mangroves provide protection during Cyclone: Evidences from the Super Cyclone of October 1999 in India

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Abstract
The paper analyzes the protective role of the mangrove forests of the State of Orissa iby using the data on human casualties suffered in the Kendrapada district of the state due to the super cyclone of Oct. 1999 and calculates the partial storm protection value of the mangroves. A methodology based on meteorological, geo-physical and socio-economic factors was used to analyze the data and the mangrove forest was found to have significantly reduced the human death. The study area witnessed 392 deaths due to the cyclone and in the absence of mangroves, the death toll would have been 54 percent more or another 211 persons would have lost their lives, other things remaining as they are. However, if the present mangroves were at the 1950 kevel, only 31 persons would have died or 92 percent of the deaths could have been avoided. Using value transfer, the value of statistical life was found to be Rs10, 918, 132/ for Orissa and valuing averted deaths at this rate, the partial storm protection value of every kilometer width of the forest was found to be Rs2239.35 per village and Rs18, 81, 054/ for the study area.

Key words: Storm Protection by mangroves, Wind Velocity, Storm Surge, Human Casualty, Averted Deaths, VSL for Orissa.

JEL Classification: Q01 and B41

1. Introduction

Coastal forests and trees, particularly, the mangroves forests are reported to be providing protection against natural hazards like cyclones and tsunamis. Local folklore in many coastal areas, traditional literature as well as some recent studies and anecdotal reports have highlighted the effectiveness of mangrove forests in reducing damages due to natural hazards (Fosberg, 1971; Mohanty, 1992; Tynkkonen, 2000; Badola & Hussain, 2005; UNEP, 2005; Kathiresen and Rajendran, 2005). The evidence as well as methods used in some of these studies (particularly the ones in the context of Tsunami and coastal protection) has been questioned (Kerr et al. 2005). Though, it has been established theoretically that mangroves dissipate wave energy (Massel et al., 1999; Mazda et al., 1997 and 2006), no satisfactory empirical analysis to evaluate this protective services of mangrove forests is available till date. The present paper tries to quantify the storm protection services of the mangrove forests. Two issues that needs to be comprehensively addressed in this type of research are that the cyclone related damages are dependant on various other factors along with cyclone intensity and hence, the role of every potential factor impacting cyclone damages should be analyzed simultaneously when evaluating the protection function of coastal forests. Secondly the diffusion of cyclone intensity or the diffusion of both wind velocity and storm surge velocity by mangroves during cyclone should be modeled properly in the methodology to correctly access the protection value of mangroves. The present paper addresses the first issue comprehensively and analyzes the protection of mangroves during a super cyclone representing the mangrove variable as the width of the forest before a hamlet[1]. The second issue is left out due to lack of scientific information on the diffusion of wind and water velocity by mangroves.

Tropical cyclones cause widespread damages including human casualties depending on their intensities. Besides cyclone intensities, other factors that play a decisive role in damage occurrences are socio-economic conditions and geo-physical features of the affected regions like elevation, topography, bathymetry, hydrology, the nature of the vegetation etc. Thus coastal forests are just one among the many other factors impacting the occurrences of cyclone related damages and any empirical work evaluating the protective services of coastal forests has to consider the role of every other factor simultaneously in order to arrive at a conclusive result. The present work tries to address this issue for the mangrove forests of Orissa State in India by using the data on damages suffered during the super cyclone of October 1999 in the state. The paper evaluates the protection of mangroves to human lives, calculates the number of casualties averted due to the presence of mangrove forest in coastal area and then calculates the partial storm protection value of mangroves for saving lives during cyclone. Section 2 briefly describes the super cyclone of October 1999; section 3 describes the mangrove forests of Orissa, section 4, the study area; section 5, the review of literature; section 6, the methodology; section 7, the data; section 8, the results; section 9, the storm protection value and section 10, the conclusion of the study.

[1] The mangrove forest in the study area was in uniform health.

2. Super Cyclone of October 1999 in Orissa

The Super Cyclone of Oct 1999 was a T-7 category[2] cyclone with landfall wind velocity of 256 kmh^{-1}accompanied by heavy torrential rain ranging from 400 mm to 867mm continuously for three days and a storm surge height of approximately 7 meters. This cyclone was described stationary by meteorologists, as it remained stationed at different locations for number of hours over the state for three days after which it lost its entire damage potential (Indian Meteorological Department (IMD), 2002; Gupta & Sharma, 2000). It made landfall near a place called Ersama in Jagatsinghpur District of Orissa, then moved slowly in the northwestern direction covering 30 kilometers and lay centered over a place called Garadpur for another 3 hours. Then the cyclone moved southwest covering around 50 kilometers and then remained stationary over a place near the state capital Bhubaneswar for more than 30 hours after which it was reduced to a depression. It devastated 12 of the 30 districts of Orissa and caused 9893 human casualties, 441,531 livestock deaths, 1,958,351 damaged houses and 1,843,047 hectares of damaged crops along with volumes of other damages (Gupta and Sharma, 2000).

3. Mangrove Forests of Orissa

The state of Orissa has five coastal districts, but mangroves are found mainly in Kendrapada district that lies in between $86^0 14^/$ to $87^0\ 3^/$ east longitudes and $20^0\ 21^/$ to $20^0\ 47^/$ north latitude. In Kendrapada, the only forests found are the coastal mangrove forests and they are present in the Mahakalpada and Rajnagar blocks (tahasils)[3] of the district. The district has 60 km long coastline and 80 percent of it was covered with mangrove forests of nearly 10 kilometers width in the past (as per the 1950 mangrove forest map of the area) totaling 30766.06 hectares (see panel (a) of figure-1). Different drivers destroyed these forests over time, particularly in between 1952, when the ownership of these forests were transferred from the Zamindars (the feudal land owners) to the state government and 1980, when the Wild Life Division Department was created by the state government and the management of the mangrove forests were transferred to this division (Orissa District Gazetteer, Cuttuck, 1996). Of the two tahasils having mangroves, maximum destruction of the forest was witnessed in case of Mahakalpada Tahasil where a thin strand of mangroves was left (width less than 1 kilometers every where) by 1999 when the super cyclone hit the state (see panel (b) of Figure-1). In contrast, the destruction of mangroves in Rajnagar tahasil has been marginal and it may be due to the presence of ferocious animals (crocodiles) in these forests when the state protection was inadequate and then the declaration of the forest area as Bhitarkanika Wild Life Sanctuary later vide notification No.69584F (W) – 34/75 – FAH/ dated 22.04.1975 and then a national park in 1988. The Mahakalpada mangrove forests were declared reserve forest in 1978 and were later brought under the Gahirmatha Marine Wildlife Sanctuary in

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[2] Cyclonic disturbances are categorized and given different T Nos depending on their damage potential and landfall wind velocities. Cyclone types like Deep Depression (T=2.0, wind speed= 50-61kmh^{-1}), Cyclonic Storm (T=2.5 to 3.0, wind speed=61-88 kmh^{-1}), Severe Cyclonic Storm (T= 3.5, wind speed=88-117 kmh^{-1}) bring minor to moderate damages where as cyclone types like Very Severe Cyclonic Storm (T=5.0 to 6.0, wind speed=117-220 kmh^{-1}) and Super Cyclone (T=6.5 and above, wind speed > 221 kmh^{-1}) bring catastrophic damages.

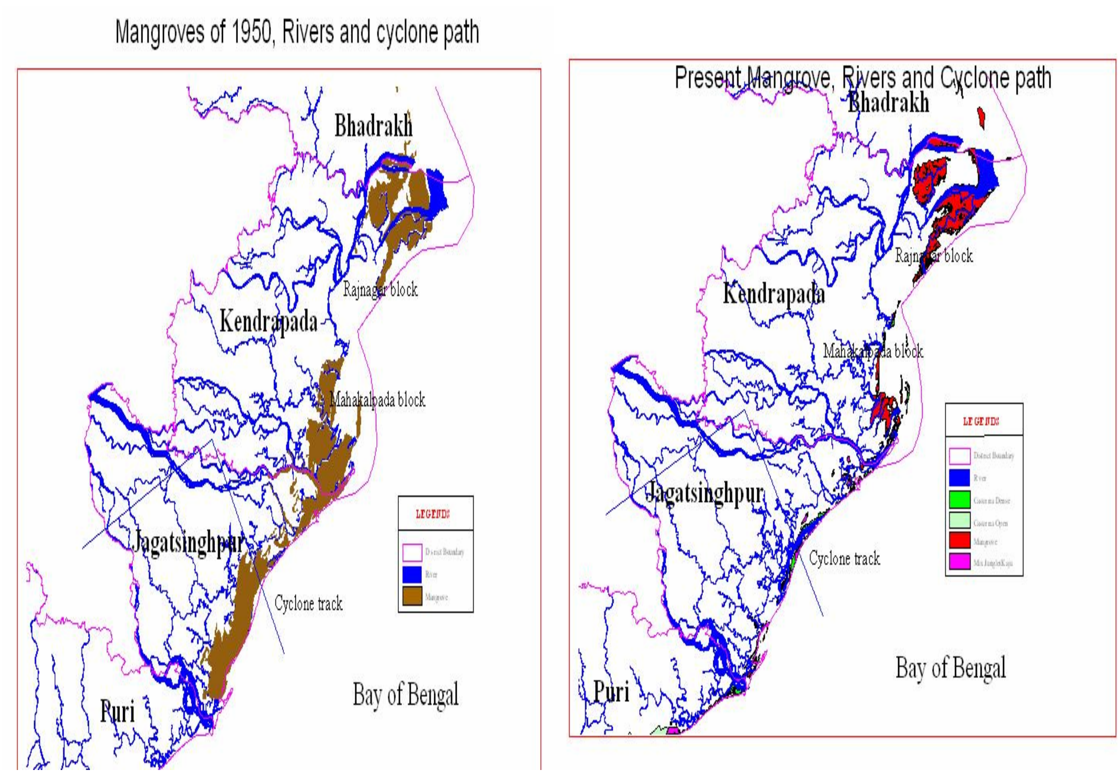
[3] Both blocks and Tahasils are local administrative units under a district and are headed by Block Development Officer and Tahasildar respectively. The BDO undertakes developmental works whereas the Tahasildar undertakes all revenue decisions for this area.

September1997. In 1999, before the super cyclone hit the state, the Kendrapada district had 192 sq. km of mangrove forests, more than 93 percent of it being dense[4] and well protected.

The figure below shows the extent of mangroves present in the year 1950 and their existence in October 1999 before the super cyclone.

Figure-1 Mangroves of Kendrapada District as existed in 1950 and in 1999

Mangroves of 1999, rivers and cyclone path



(a) (b)

Source- Purchased from Private Source (DCS, Bhubaneswar, Orissa, India)

4. Study Area

The paper analyzes the human casualties witnessed during the super cyclone and tries to isolate the role of mangroves in saving human lives. The study area for this analysis is the entire Kendrapada district and a part of the Bhadrakh district (only 85 coastal villages), which is adjacent to Kendrapada in the northeastern direction. The super cyclone had its landfall at a place lying 20km south west to Kendrapada and the entire district was severely battered by both cyclonic wind and rain and four of its eight tahasils were affected by storm surge. Broadly, there were four main reasons for choosing Kendrapada district as the study area.

(i) Kendrapada district was to the north of cyclone landfall and track throughout and thus the wind direction was uniform (sea to land) during cyclone period.[5]

[4] The State of Forest Report (2001), Forest Survey of India
[5] In northern hemisphere, the direction of the cyclonic wind is anti-clockwise.

As the wind was reaching the interior areas after passing through the mangrove forests, it gave a good opportunity to test the wind buffering capacity of the mangroves.

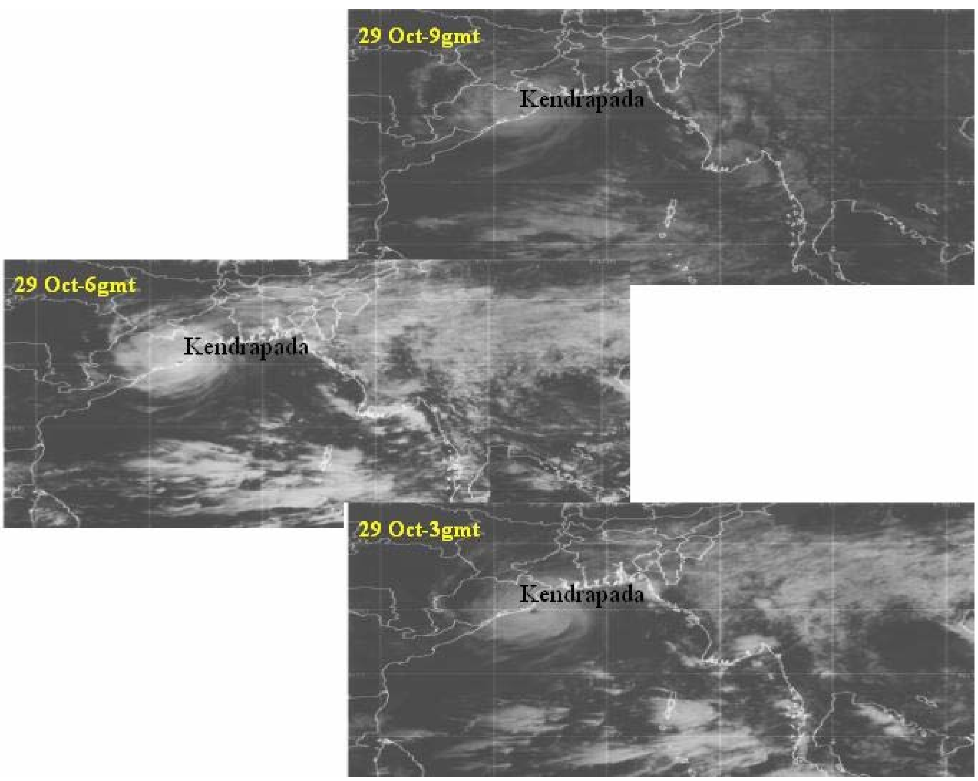
(ii) The entire district is devoid of highlands, the elevation of the district being less than 10 meters and that of the coastal blocks less than 4 meters (Public Works Department, Government of Orissa). The only wind and storm surge barriers are the forest, the sand dune and the saltwater dikes in coastal areas.

(iii) The only forests in the district are the mangrove forests in the coastal areas.[6]

(iv) The district has coastal areas with mangroves and also areas with barren coastlines and the width of the mangrove forests varied from 100 meters to 10 kilometers at different places (see Figure-1 (b) above). All these provided enough scope to compare the cyclone impact on interior areas both with and without the mangroves and also for different width of the mangroves.

85 coastal villages of Bhadrakh district which were next to the mangrove forest of Kendrapada were taken as they reflected cyclone impact in a more far off place from the cyclone eye (or cyclone track) than the mangrove protected areas. Figure-2 shows the position of Kendrapada in super cyclone structure.

Figure-2 Position of Kendrapada District in Super Cyclone Structure



Source- DCS, Bhubaneswar, Orissa, India

[6] Few patches of casuarinas plantation were also there in the coastal areas before the cyclone, but the width of these plantations everywhere was in between 200 to 400 meters and the main forests were the mangroves.

5. The Literature Review

Conventional literature has emphasized the role of mangrove forests as a seawall during tropical cyclones (Chan et.al.1993). In recent years, quite a few studies have come up in evaluating this protective service of mangroves using either avoided damages or avoided expenditures or replacement costs approach. Both avoided expenditure (Tri et al., 1996) and replacement cost (Sathirathai; 1998) have been used to value a single specific protection of mangroves whereas avoided damages approach is being widely used to quantify the protection of mangroves from different types of both cyclonic and Tsunami damages. The present methodology also falls under the avoided damages category. Barbier (2007) has advocated the use of Expected Damage Function (EDF) to measure the storm protection value of coastal wetlands. Of the different approaches, avoided damages is more widely used as it is based on actual damages suffered in protected and unprotected areas and is likely to give a more realistic picture of protection services.

The use of avoided damages approach for storm protection started with Farber's (1987) pioneering work in which he used a scientific model of wind velocity and valued the protection value of wetlands from only wind damages of hurricanes. Farber talked about the homogeneity of the population and this may justify the exclusion of socio-economic factors from damage analysis. But the limitation of his work was that he assumed wetlands to be reducing wind damages where as wetlands, unless have high vegetation, can provide little protection from wind. Of course, the wetlands do provide a distance buffer between the coast and human settlements, which may result in the wind speed being lower by the time the hurricane strikes the settlements, but if the wetlands are pure water bodies, then the weakening of the storm becomes less prominent due to moisture supply than it would have been with a more rough surface. Wetlands provide more protection from storm surges and he hadn't accounted for storm surges in his model.

The best analytical as well as very correctly conceptualized work till date on the protection of mangroves from cyclone damages has been by Badola and Hussain (2005). Conducting primary survey for damages in the aftermath of the super cyclone of October 1999, they showed the damages per household to be less in the village sheltered by mangroves compared to the damages per household in a village having a dyke nearby but no mangroves and a village without both mangroves and dikes. Though, the authors are given credit for selecting villages as similar as possible except for the presence or absence of mangroves and dikes in order to neutralize the impacts of socio-economic factors on storm damages, these impacts are still visible and the attribution of the entire reduced damages by the authors to mangrove presence looks to be an overestimate and biased due to the following reasons:

(1) The study villages are not socio-economically homogeneous as glances at the summary statistics of data on the villages show their economic heterogeneity. Hence a statistical analysis looking at the effect of all the factors simultaneously on damage occurrences will definitely give different results.

(2) The hydrology of the area in the form of distance from rivers, the position of dikes Vis-à-vis Rivers and the villages etc. have not been considered.

(3) The village claimed to be having only mangroves and no dykes nearby cannot be true. It is an agricultural village with 70 percent of people as farmers in the mangrove forest area and no agriculture is possible there without dikes. The dike could have reduced the damages if it is in-between the village and the main river nearby.

(4) The villages are differently situated with respect to their distance from the cyclone path and accordingly the wind impact would have been very different on them. This has not been taken into account in the analysis.

The avoided damage approach is also being used to evaluate the protective role of coastal forests in impacting damages during the Indian Oceans Tsunami of 2004. The three widely quoted studies are of Kathiresan and Rajendran (2005), Danielson et al. (2005) and Dahdouh-Guebas et al. (2005). The findings of these studies were criticized on the grounds of methodological and data base inadequacy (Kerr et al., 2006; Baird, 2006) and later on, the findings of Kathiresan and Rajendran were reconfirmed by Vermat and Thampanya (2006) after doing some statistical reanalysis of the original data.

The role of mangrove forest in impacting cyclonic and Tsunami damages are likely to be different as the generation and flow of energy in a storm wave is different form that of a Tsunami wave (Baird, 2006) and to that extent the degree of resistance provided by the mangroves to these waves and providing protection to inland properties would be different. However, in analyzing the damages due to these extreme events, the mangroves or other coastal barriers should never be considered as the main decisive players. Though, the role of elevation, coastal distance and inundation distances have started been recognized now (Bretschneider and Wybro, 1977; FAO, 2006; Baird, 2006; Chatenoux and Peduzzi, 2006; Dahdouh-Guebas et al. 2006) the role of other important players like economic, sociological and hydrological factors in causing damages, particularly in the context of developing countries, are not being talked about at all. Every unit of analysis (whether hamlet or household) are socio-economically heterogeneous and ignoring this aspect will give biased estimates of the role of the coastal forests, even if they play significant roles in averting damages. Side by side, the most essential point that every researcher seems to have missed out is the need to control for the unobserved characteristics of the mangrove habitat areas, in order to identify clearly the impact of the mangrove vegetation on cyclone damages.

The present work aims at addressing these issues and will evaluate the protective role of mangrove forests in the occurrences of cyclone related damages by looking at the roles of socio-economic, geo-physical and meteorological factors including the sea elevation (storm surge height) at different coastal points simultaneously. Secondly, the present study aims to control for the unobserved characteristics of the mangrove habitat areas to isolate the mangrove vegetation effect by (1) including a variable, Mhabitat, that measures the width of the mangrove habitat areas (using the historical mangrove forest map of 1950) between a village and the coast in the model for storm damages and (2) by limiting the sample to villages that historically had mangroves located between them and the coast by including only those villages in the sample for which Mhabitat>0. The second part of the control is more important as it is meaningless to talk about the protection value of mangroves in areas where they can't grow (villages with Mhabitat = 0) and secondly, limiting the sample to villages with Mhabitat > 0 will enable one to interpret the coefficient of the mangrove variable (the width of the mangrove vegetation at the time of the super cyclone as defined in the study) to be capturing the effect of only the mangrove vegetation, not the unobserved features of the mangrove habitat areas.

The mangrove variable, in the present paper, has been defined as the width of the forest in kilometer (not the area of the forest), in between the village and the coast as the spread of the forest along the coast, in the study area, is continuous and the breadth of the forest is different at different places. Thus, the average partial storm protection values calculated are for the km width of the forest, though, from these values, the approximate per hectare values also has been calculated.

6. The Methodology: The Cyclone Damage Function

Storm protection services are analyzed by estimating a cyclone damage function. Damages including human casualties in any location, i, during a cyclone will depend on the wind velocity, the velocity of storm surge water, the population or property at risk and other socio-economic factors of the location[7].

$$\therefore \mathbf{D_i = d\ (V_i,\ W_i,\ P_i\ S_i)} \qquad (1)$$

Where D_i is the damage suffered at the ith location,

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

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

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

S_i is the group of socio-economic factors at the location influencing the volume and extent of damages.

6.1 Wind Velocity

The actual wind velocity at any i^{th} village (V_i) causing maximum damage would be dependent on the potential wind velocity at the place, which is the wind velocity in absence of any barriers between the cyclone and the village and this potential wind velocity is approximated by the radial wind[8] of the cyclone at the place (RW_i). Thus the actual wind velocity at a place would be depending on the radial wind and other factors like the minimum distance of the place from the center of the village to the coast line ($dcoast_i$) and the type and width of wind barriers present in the wind path before the village ($barrier_i$) etc.

$$\therefore \mathbf{V_i = v\ (RW_i,\ dcoast_i,\ barrier_i)} \qquad (2)$$

The radial wind over a place during a tropical cyclone will depend on the position of the place vis-à-vis the horizontal structure of the cyclone that consists of four different parts i.e. the eye; the eye wall or the wall cloud region; the rain/spiral bands and the outer storm area (IMD, 2002). Areas coming under the eye and eye wall face the maximum

[7] Flooding due to torrential rain as a cause of damage has been ignored here as in the study area, it rained almost the same amount everywhere and there were not much spatial differences in rainfall over the locations. Moreover getting village specific rainfall data was also difficult. As the variation in rainfall is expected to be correlated with distance from coast and distance from cyclone path, we have implicitly controlled for it by including these variables in the model.

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

wind[9] where as wind velocity over the other two structures goes on declining with distance away from the cyclone path or from the center of the eye.

Wind profile of cyclone shows nonlinear movements. The maximum wind of cyclones decreases exponentially with distance inland after the land fall (Dube et all, 1981; Basu and Ghose, 1987; Kalpana and Demaria, 1995; Kalsi et al., 2003; Singh and Bandyopadhyay, 2005) due to reasons like inter action of cyclone with rough surface, reduced moisture supply being away from the sea, conversion of heat in the form of rain etc. In case of super cyclone of October 1999, the maximum wind was shown to have declined at an exponential rate of 0.0991 per hour on average (Kalsi et al, 2003).

However, for explaining the radial wind, both exponential (Holland, 1980; Dube et al. 1981; Basu and Ghosh, 1987) and power functions (Jalesnianski, 1965; Das et al 1974; Roy Abraham et al. 1995) have been used by people and accordingly two different values of radial wind, velocityexp and velocitypow, have been calculated for every location for the present work. We follow Dube et al. (1981) formula to calculate velocityexp and Roy Abraham et al. (1995) formula to calculate velocitypow.

(i) $$\mathbf{Velocityexp_i = V_{max}\ exp\ (-\ (dcypath_i - R)/\beta))\ and}$$

(ii) $$\mathbf{velocitypow_i = V_{max}\ (dcypath_i/R)^{-\alpha}} \quad (3)$$

where, V_{max} is maximum wind at the eye area, dcypath is the minimum radial distance of the ith village (or location) from the center of the eye or the cyclone path, R is the radius of the cyclone eye (15 km in the present case) and α and β are the parameters specific to the cyclone. In the present case, α was taken to be 0.6 and β to be 240 km. after consulting the meteorologists and experts. The maximum wind at the eye area was calculated as:

$$\mathbf{V_{max} = 256\ kmh^{-1}\ exp.\ (-\ 0.0991 * 3) = 190.1622\ kmh^{-1}} \quad (4)$$

Where 256 kmh^{-1} was the landfall wind velocity of the super cyclone, 0.0991 was the average rate of decline of the maximum wind per hour (Kalsi et al., 2003) and the cyclone had taken nearly three hours to reach Garadpur[10], the location over which, the cyclone was stationary and caused maximum damage to the Kendrapada district. Thus, the maximum wind in the entire eye region (areas for which dcypath was <=15) of the study area was taken to be 190.1622 kmh^{-1} and the radial winds for different villages were calculated with the help of this maximum wind and the minimum radical distances (dcypathi) of these locations from the cyclone track.

$$\therefore\ \mathbf{Radial\ Wind\ (RW_i) =} \begin{cases} \text{Vmax } (=190.1622\ \text{kmh}^{-1} \text{ if dcypath}_i \le 15 \\ \text{Velocitypow (or exp.) if dcypath}_i > 15 \end{cases} \quad ......(5)$$

The study area is a predominantly agricultural land with elevation less than 10 meters every where and the only wind barriers present are the mangrove forests (width ranging from 0.1 to 10 km) or the casuarinas forests (width ranging from 0.2 to 0.4 km) on the coast line.

[9] Maximum wind is the wind speed at the eye wall region of the cyclone.
[10] It took two hrs for the cyclone eye to cross the landfall point (Gupta & Sharma, 2000) and 1 hr to cover 25 km, the distance between landfall and Garadpur.

$$\therefore \textbf{Barriers}_i = \textbf{B (mangrove}_i\textbf{, casuarinadumy)} \quad (6)$$

where $mangrove_i$ is the width of the mangrove forests in between the coast and the ith village[11], and casurinadumy is a dummy variable equating 1 if casuarinas forest is present in the coastal distance of the village and equating 0 otherwise. As the casuarinas forest were nearly in uniform width wherever they were present in the study area, it was represented by a dummy variable.

Substituting equation (5) and (6) into equation (2), the actual wind velocity at the ith village is defined as:

$$\textbf{V}_i = \textbf{v [V}_{max} \textbf{ if dcypathi}_i \leq 15\textbf{, velocitypow (or exp) if dcypath}_i > 15\textbf{,}$$
$$\textbf{dcoast}_i\textbf{, mangrove}_i\textbf{, casuarinadumy)} \quad (7)$$

The actual estimates of wind velocity over different locations not being available, it is approximated by including the four variables of eq-7 in the main model. Moreover, as the model includes variables dcoast and mangrove, it also implicitly controls for the distance of a village from the mangrove forest boundary that equals dcoast – mangrove.

6.2 Velocity of Storm Surge

Storm surge is an abnormal rise of sea level in excess of the predicted astronomical tide and is caused mainly due to the atmospheric pressure variation and the strong surface wind of a cyclone. Along with the wind velocity and pressure variation, other factors that play decisive role in the generation of the storm surge are the direction (inclination) of the cyclone at landfall, radius of maximum wind, local off shore bathymetry, inland topography, density of sea water, speed of the cyclone, the height of astronomical tide, etc (Kalsi et.al, 2004). Because of these reasons, there exists no perfect correlation between the wind velocity at a coastal point and the sea elevation over there. In case of the super cyclone of October 1999, very high surge was witnessed only over a coastal stretch of nearly 30 km whereas nearly 250 km of the coastline was battered by very high surface wind. This explains the necessity of accounting for the sea elevation at different costal points along with the wind velocity to explain the cyclone damages, especially the cross-section damages of a single cyclone.[12]

The severity of flooding that depends both on level of water as well as on the velocity of water at a place due to storm surge will depend on the level of sea elevation (surge height) facing that location and other physical features of the location like the minimum distance from the coast, the elevation of the place, the topography and the hydrology of the place, the distance of the place from river channels, presence of natural barriers like mangroves, sand dunes etc. in between the location and the coast line, presence of man made barriers (dikes) near the village etc. Taking all these factors into account, the following function was defined for the level of flooding in a place.

$$\textbf{H}_i = \textbf{h (surge}_i\textbf{, dcoast}_i\textbf{, dmajriver}_i\textbf{, dminriver}_i\textbf{, topodumy}_i\textbf{, mhabitat}_i\textbf{, mangrove}_i\textbf{, casurinadumy, roadumy)} \quad (8)$$

[11] The present mangrove forests, as mentioned earlier, are nearly in uniform health.

[12] During cyclone, storm waves also play a critical role in bringing damage in the near shore area. However, there being a proportional relation between surge height and storm waves, the surge height is likely to capture the storm waves effect also.

The meaning of the different variables and what role they are likely to play during storm surge are explained below.

H_i is the severity of flooding due to storm surge at the ith location inland.

$Surge_i$ is the surge height or elevation of sea at the nearest coastal point facing the location (calculated from the surge envelop curve provided by the Indian Meteorological Department).

$Dcoast_i$ is the minimum distance of the place from coastline.
$Dmajriver_i$ is the minimum distance of the place from a major river (directly connected to sea) and **$dminriver_i$** is the minimum distance of the place 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 to flooding effect. But the opposite happens in case of minor rivers. Hence the minimum distance from river channels was divided into two i.e. minimum distances from a major river (dmajriver) and minimum distance from a minor river (dminriver).

Topodumy is the low elevation dummy that equals 1 if the village is located within an area that historically or in 1999 had mangrove vegetation within its boundary and equals 0 other wise. In the absence of complete elevation data for the study area, present and historical mangrove forests (as existed in 1950) maps were used to demarcate the low-lying areas. As mangrove forests come up in low lying vulnerable areas that get inundated regularly during high tides, villages with topodummy = 1 are likely to be low lying and the ones with topodumy = 0, to be situated at higher elevation level.

$Mhabitat_i$ is the width of the historical mangrove forests that lay between the village and the coast as seen in the 1950 forest map of the area (Figure-1 (a)). This variable is likely to capture the effect of the topographic, hydrological and bathymetric factors of the mangrove habitat areas in storm surge inundation. The study area had vast stretch of mangrove forests historically and different drivers have cleared them over the years. The physical features of mangrove areas being different from those of the non-mangrove areas, the width of the historical mangrove forest was taken to capture the effect of those special features on cyclone damages. Moreover this variable also was believed to control for any unobserved confounding factors that could cause spurious correlation between the present mangroves i.e. the mangrove vegetation present before the super cyclone and the damages.

$Mangrove_i$ in the width of the mangrove forest (vegetation) as existed on 11th October 1999 in between the ith village and the coast.

Casurinadumy, as previously explained, is the dummy variable for the presence of casuarinas forests in between the village and the coast[13]. Lastly, **roadumy** is the dummy

[13] The entire coastline of the study area was planted with casuarinas trees after a very severe cyclonic storm hit the area in the year 1972. Casuarinas grow on sandy beaches and on sand dunes that are more elevated (than the areas where mangroves grow) and don't get inundated during high tides. The study area being mostly swampy and low lying, casuarinas could survive only in some limited pockets and whenever they survived, the width of the forest is nearly uniform (0.2 to 0.4 km). Hence the casuarinas dummy was

variable for the presence of village road as dikes are also used as village road in the coastal areas.

6.3 Socio-Economic Factors

The cyclone, like any other natural calamity is presumed to have differential impacts on people depending on their socio-economic status (FAO, 2000) and coastal poor are likely to be the most vulnerable ones during cyclones[14]. Along with economic well being, institutional, infrastructural as well as behavioral factors also play decisive roles in averting human death and other damages during cyclones[15]. In the absence of proper economic well being index for different villages, the differences in socio-economic conditions of different villages are captured by using factors like percentage of literates (responsiveness of people to cyclone warning depend on their level of education (FAO, 2000)), percentage of different types of workers (earning members), percentage of scheduled caste population (economically and socially most deprived and posses very little assets), percentage of non workers (who are likely to remain indoor and less exposed during cyclones), the proximity of villages to metallic road (better scope to economic prosperity), presence of village road (connectivity to metallic road), dummies for local administration etc.[16] Thus the socio-economic well being index influencing the cyclone damages is defined as the following (ignoring the subscript i) :

S_i = S (Tahasildar, literate, scheduledcaste, cultivators, aglabours, hhworkers, otworkers, margworkers, nonworkers, droad, roadumy) (9)

where S_i is the socio-economic well being index of the ith village, Tahasildar is the dummy variable for the local administration in change of all revenue decisions including evacuation, relief and rehabilitation, literate is the percentage of literate people in the ith village, scheduledcaste is the percentage of scheduled caste people in the village, cultivators, aglabourns, hhworkers, otworkers, margworkers and non-workers are the percentage of cultivators, agricultural laborers, percentage of workers in own household industries (located either at home or within the village), percentage of other workers (doctors, teachers, engineers, barbers, washer men, priests etc.), percentage of marginal workers and percentage of non-workers (old dependants, housewives, students, children

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used to capture the effect of the casuarinas vegetation as well as the special topography of the casuarinas forest area.

[14] A wealthy household has good quality house, vehicle to escape, has a transistor or television set to listen to cyclone warning and some members being educated, they are quick to react to cyclone warning etc. In contrast, poor household has bad quality houses, their houses are likely to be in low lying vulnerable areas, members are uneducated and less informed, have no vehicle to escape, have low quality health etc. because of which they are more likely to die and suffer more loss than the rich people.

[15] Efficiency of meteorology department in providing accurate cyclone warning, promptness of local administration in proper dissemination of the cyclone warning (evacuating people from vulnerable areas), presence of cyclone shelters or some other concrete structures in neighborhoods, community behavior of people in helping each other during crisis etc. are some of the important factors that can influence human casualties as well as livestock losses.

[16] In the absence of data on availability of mass media mediums (TV, Radio) at the village level, the percentage of other workers (otworkers) that include people with high education, high mobility and in occupation other then agriculture and household industries (doctors, teachers, engineers, barbers, washer man, priests etc.) are taken as proxies for availability of this commodity.

etc.) respectively in the ith village, droad is minimum distance of the village from the metallic road and roadumy is a dummy variable for the presence of village road that equals 1 if village road exists and equals 0 otherwise.

Combining the factors affecting wind velocity, surge velocity and the socio-economic conditions, the following cyclone damage function is obtained for a village.

D_i = d (Tahasildar, velocitypow (or exp.), surge, dcoast, topodumy, Mhabitat, mangrove, casurinadumy, dmajriver, dminriver, droad, roadumy, population99, literate, scheduledcaste, cultivator, aglabour, hhworkers, otworkers, margworkers, nonworkers). (10)

where D_i is the damage suffered in the ith village and the right hand side variable, though defined above, are explained in table-1 below.[17] The dependant variable presently is **sucydeath**, the number of human casualties in a village due to super cyclone.

The averted damages by mangroves were defined as $DA = \sum \hat{y} - \sum \hat{y}' = Y - \sum \hat{y}'$, where $\hat{y}$ is the predicted value of the model and (thus, the sum of it equals the actual Y) and $\hat{y}'$ is the predicted value with some restriction (like mangrove = 0).

7. Data Required

Information was collected from different sources to estimate the cyclone damage function (eq.-10) described above. The details of data used and the respective sources are described in the table-2.

The geo-physical variables were generated from the village level coastal Orissa digitized physical map that was developed by GIS Arc View Software 3.1 by using the digitized village map, river map, road map and coastal forest map of Orissa (as existed on 11th October, 1999 and in 1950). Then the different location specific position of the cyclone eye as described in NCDM Report (Gupta & Sharma, 2000) was superimposed on the village map and cyclone eye track was demarcated at the village scale. The study area received maximum damage due to the cyclone when it was making landfall and was stationary over Garadpur and accordingly, this part of the cyclone eye track has been considered in the analysis to calculate the radial wind for different villages[18]. Different distances as required in the damage equation were then calculated with the help of the GIS software. The approximate sea elevation at different coastal points were calculated from the surge envelope curve provided by the cyclone warning division of the meteorology department of the Government of India.

The socio-economic variables were generated from the primary census abstract of Orissa for 1991 and 2001. First of all, the average compound 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.

[17] Factors like time and season of occurrence of the cyclone, number of hours before the landfall when cyclone warning was broadcasted etc. have been ignored as the analysis is for the damage data of a single cyclone.

[18] As described earlier, after Garadpur, the cyclone moved southwest and was away from Kendrapada district.

8. Results and Discussion

The purpose of the study was to get a correct picture of the sheltering capacity of mangroves and accordingly, the damage function was estimated for the entire study area, called sample-1 and one of its sub-sample, called sample-2. In sample-2, we excluded those villages that never had or are having mangrove between them and the coast or the villages, not having any mangrove habitat area between them and the coast (the variable Mhabitat = 0). As explained earlier, these areas can never be protected by mangroves and thus, have zero storm protection value. Sample-2 being the entire area that can be protected by mangroves, the storm protection value of mangroves is calculated for these areas only. Thus, the damage equation is estimated for both the samples, but averted deaths are calculated only for sample 2 and valued. The two samples are:

Sample-1: Entire study area,

Sample-2: Areas with Mhabitat>0,

The summary statistics of the variables of sample-1 and 2 are presented in table 3. The values of dcypath and dcoast show that the villages of the study area lie within 0.34 to 51.23 km from the coastline and within 0.62 and 83 km from the cyclone path. Villages of the study area are of different sizes with more than 65 per cent of the population as non-workers and cultivation is the most widely adopted occupation among workers. The dependant variable, **sucydeath** (number of human casualty in a village due to super cyclone), is a count with maximum observations either 0 or 1 (951 zeros and rest non-zeros) and the range of variation 0 to 21. Hence a Poisson distribution is assumed for this model.[19]

The Poisson regression model assumes each y_i to be drawn from a Poisson distribution with parameter λ_i (the conditional mean of the variable) which is assumed to be related to the regressors X_i. The primary equations of the model are:

$$P(y_i = y_i) = \frac{e^{-\lambda_i} \lambda_i^{y_i}}{y_i!}, \qquad y_i = 0,1,2, \tag{11}$$

and $$\lambda_i = exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + ---) \tag{12}$$

In the present case the estimating equation is E (sucydeath) =

$$\lambda_i = \exp(\beta_0 + \beta_1 Tahasildar_i + \beta_2 wind\ velocity_i + \beta_3 surge_i + --- + \beta_{29} nonworkers + \varepsilon_i) \tag{13}$$

where ε_i is the error term and other variables have been explained in Table-1.

[19] 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, we present the negative binomial estimates along with Poisson estimates. Negative binomial distribution can control for the over dispersion problem by scaling the standard errors. However both zero-inflated Poisson and zero-inflated negative binomial distributions were rejected for all the sample areas on the basis of Vuong test results.

The study area includes 9 tahasils and the tahasildar dummies have been represented by the respective tahasil names (Mahakalpada to Bhadrakh). Table-4 gives the expected signs and the estimated Poisson and negative binomial coefficients of the equations for the two different sample areas described above using velocitypow measure of wind velocity[20].

Expected Signs

The tahasil dummies are expected to proxy for the institutional arrangements of the local administration that plays very important roles during natural calamities in saving human lives as well as other movable properties. Accurate and timely forecasting of the cyclone, proper dissemination of cyclone warning, evacuating people from vulnerable areas, providing logistics (particularly in a poor and backward region) and basic facilities, making post cyclone arrangements for return and rehabilitation etc. are some of the crucial issues that affect human death and the tahasildars play an important role in this context. Simultaneously, these dummies being locational, they are also expected to capture the effects of any other omitted variables specific to the administrative unit. Since the efficiency of local administration is unknown, a question mark is used for the expected signs of these dummies. Similarly, a question mark is also used for Mhabitat (width of the historical mangrove forest) as the effects of the physical features of mangrove habitat areas on human death are also unknown.

We expect the coefficients of topodummy, wind velocity and surge to be positive as the high values of these variables indicate greater human casualty. Positive coefficients are also expected for dmajriver (less the distance, lower the death as major rivers carry away the surge water), droad (nearer the road, more the economic well being and less the damage), pop 99, scheduled caste (scheduled caste people are socially and economically more backward, more vulnerable and more presence should indicate more death), aglabour (poor like scheduled caste) and margworkers (poor as well as more exposed during cyclone). In contrast, negative coefficients are expected for dcoast (less the distance from coast, more human death expected), mangrove (greater vegetation is expected to provide protection), dminriver (areas nearer to small river experience more severe flooding as small rivers have low capacity to absorbs more water and hence, less the distance, the more the death), roadumy (high value indicate presence of village road, more prosperity and hence less death), literate (educated people respond quickly), cultivator, hhworker and otworkers (all three categories are economically well off compared to other groups in the study area) and also for non-workers (are likely to stay indoors and hence less exposed during cyclones).

Discussion

There were four categories of explanatory variables in the damage equation, like institutional (all tahasildar dummies), meteorological (velocitypow and surge), geo-physical (include variables from dcoast to dminriver) and socio-economic (include variables from droad to non-workers). We discuss only the results of those variables

[20] Both the means as well as the standard deviations of the two measures of wind velocity (velocitypow and velocityexp) were very different from each other but the coefficient of correlation between them was very high (0.97) and so the results with both the measures of wind were very similar. The variables significant in the model using velocitypow measure of wind were also significant if velocityexp measure was used.

found significant both in Poisson as well as in negative binomial models. Human casualties seem to have occurred due to both cyclone intensity as well as some of the physical features of the villages. The two meteorological variables, velocitypow and surge capture the cyclone intensity and both are significant in all the models. The storm surge has been the main cause of death and the negative coefficient of velocitypow is possibly due to the high correlation between this variable and surge (0.75).

We have three variables capturing different aspect of the mangrove habitat areas on human death. Topodumy identifies villages that are located in areas where mangroves are currently or were historically present and hence captures the vulnerability of these areas due to low elevation. The Mhabitat captures the effect of the topographic, hydrologic, and bathymetric or any other unobserved confounding factors present there and mangrove captures the effect of the current vegetation. Of these three factors, both topodumy and Mhabitat are significant with positive coefficient and thus have increased human casualty. Only mangrove vegetation seems to be playing a protective role in saving lives. Interestingly, the mangroves variable is significant with negative coefficient for all sample areas irrespective of the type of estimates used (it was also significant in ZIP as well as in ZINB models) and its negative marginal effect[21] (-0.0128) is higher than the combined positive marginal effects of both topodumy (0.0074) and Mhabitat (0.00013).[22] These results strongly suggest that mangroves acted as protectors of human lives during the super cyclone of Oct 1999 and this result is robust and conclusive as we control for every possible factors likely to have some impact on occurrences of human casualty in a village. Thus, the physical features of the mangrove habitat areas make them highly vulnerable for human habitation, but having mangrove vegetation in these areas can reduce the threats of these areas to human life during a natural calamity like cyclone.

The role of the other coastal forests, the casuarinas seem to have been the opposite as the casuarinas dummies are with a positive sign and insignificant. Casuarinas trees grow in sandy beaches that don't get inundated during high tides and hence the terrain of casuarinas habitat areas is comparatively more elevated than the mangrove habitat areas. As reported by local people, casuarinas trees broke down with the first few strokes of cyclonic wind during the super cyclone and could provide no protection. The econometric results confirm these views. Of the other geo-physical variables, the distance from a major river is significant with a positive sign (only over large samples) and this validates our hypothesis that major rivers play a protective role during cyclone. The distance from a small river is significant with negative sign and this suggests their destructive roles.

9. Storm Protection Value of Mangroves

To quantify the protective services of mangroves, we calculate the deaths averted due to the presence of mangrove forest and then value the averted deaths. We do

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[21]The marginal effect of a variable in a Poisson regression model is given by the estimated coefficient of the variable multiplied by the predicted value of the model ($\hat{\beta} \bullet \hat{\lambda}_i$). However in case of dummy variables, the marginal effects are given by $\hat{\lambda} * \{\exp(\hat{\beta}) - 1\} = \hat{\lambda} * g$, where g is approximately equal to the bracketed term only if $\hat{\beta}$ has a value less than 1 (Halversen and Palmquist, 1980).

[22] These marginal values are for the sample-2 area of the poisson model.

this for the sample-2 area as sample-1, as mentioned earlier, includes some areas that receive no storm protection service from mangroves. The Poisson model is used to predict the averted deaths.[23] Averted deaths are calculated under two different assumptions, i.e. (i) if there were no mangroves in study area before the cyclone and (ii) if the 1999 mangroves were at the 1950 level. The averted deaths for the sample-2 area are the followings.

Actual deaths during the 1999 super cyclone	392
Predicted deaths if there were no mangroves	603
Predicted deaths if the 1999 mangroves were at 1950 level	31
Averted deaths under assumption-1 (=603 - 392)	211 (54%)
Averted deaths under assumption-2 (=392 – 31)	361 (92%)

As evident from the above table, 392 persons died in sample-2 area during the super cyclone and the death toll would have been 603 if the mangroves had not been there. In other words, the mangroves present before the super cyclone were able to avert 211 deaths, which is 54% of the lives lost in that area. However, if the historical mangrove forests of 1950 were present before the super cyclone, only 31 persons in place of 392 would have died or the death of 361 persons or 92 percent of the deaths could have been avoided. Thus mangroves have played a very crucial role in protecting human beings during the cyclone.

The government of Orissa paid compensation @Rs75, 000/ per death of a person and using value transfer method, the Value of a Statistical Life (VSL) in Orissa is found to be Rs10, 918, 132/.[24] However, we use the VSL measure to estimate the partial storm protection value per unit of mangroves for the study area. This value is partial as it is based only on the protection of mangroves to human lives.

The mangrove variable is defined as width of forest in kilometer before a village and the values obtained are the following.

Value/km width of present mangrove /village	Rs2239.35
Value/km width of present mangrove/ entire sample-2 area	Rs18, 81, 054/

[23] The averted deaths by mangrove in the negative binomial model are higher than those of Poisson model and to that extent, the Poisson model under estimates the benefits of mangroves.

[24] In the absence of any study on the value of statistical life (VSL) in Orissa, we apply the benefit transfer principle to use Madheswaran's (2004) estimate of VSL for the workers of Chenai city (the capital of the state of Tamil Nadu in India) for Orissa. A non-linear transformation of VSL was done by using the value of income elasticity of willingness to pay (ε) as 0.35 (Mitchell and Carsen, 1986).

In money terms, every kilometer width of present forest has provided partial protection worth Rs2239.35 to every village or protection worth Rs18, 81, 054/ to entire sample-2 area by protecting human lives. As mangroves have high storm protection value, then the question comes whether the 1950 level of forest should be regenerated? If the 1950 forest had been present, then the value/km width of forest/ village would have been Rs1207.84, which is less than the value of present mangroves. The average width of present mangrove being much smaller (approximately 1 km) compared to the average width of historical mangrove (approximately 4 km), it seems having lots of mangrove may not lead to avert proportionately more deaths. This implies that the required width of forest to get optimum storm protection will be less than the width of forest present in 1950. The partial storm protection value of a hectare of forest comes out to be Rs1, 28, 700/ only for saving human lives and along with this mangroves do provide protection to other properties and other economic and ecological services. The land price in mangrove forest areas being Rs2, 10, 000/ per hectare, the economy will be benefited if land is acquired for forest regeneration. However, one needs to value the entire storm protection services of mangroves and other benefits to provide a clear monetary solution to this issue.

10. Conclusion

The paper analyzed the protection of mangroves to human lives during the super cyclone of October 1999 in the state of Orissa in India. The Kendrapada district of Orissa was taken as the study area and the human casualties witnessed in that part of the district lying behind the mangrove habitat areas were analyzed by using an interdisciplinary model. The impact of mangrove vegetation on human casualties was carefully separated by controlling for the elevation, the other physical features of mangrove habitat areas, the wind velocity, the storm surge velocity and the socio-economic features of the villages of the study area. Mangrove vegetation was found to have significantly reduced the human deaths, whereas the physical characteristics of mangrove habitat areas to be responsible for more death. The impact of casuarinas plantation was found insignificant.

The study area witnessed 392 deaths and the death toll would have been 603 if the mangrove forests were not there before the cyclone. However, if the present mangroves had been at the 1950 level, only 31 persons would have died instead of 392, other things remaining as it is. Valuing the averted deaths at the rate of value of statistical lives in Orissa, the partial storm protection value of a kilometer width of forest is found to be Rs2239.35 for every village of study area and Rs18, 81, 054/ for the entire study area. Interestingly, comparing the value per km of present mangroves with that of historical mangroves, we found the existence of the law of diminishing returns in protection of human lives by mangroves. Land being precious, the optimum width of the forest should be defined and maintained by the policy makers to get the optimum storm protection services.

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Table-1
List of Variables (alphabetically)

Variables	**Definition of variables (all distances in kilometers)**
Aglabour	Percentage of agricultural laborers in a village.
Barrier	Wind barriers present along the wind direction
Casurindmy	Dummy variable for the presence of casuarinas forest in coastal distance of a village.
Cultivator	Percentage of cultivators in a village
Dcoast	Minimum distance of a village from the coast.
Dcypath	Minimum (radial) distance of a village from the path of cyclone.
D_i	Damage suffered in the ith location (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 marginal workers in a village.
Mhabitat	Width of the historical mangrove forest (as existed in 1950) in coastal distance of a village or in between a village and the coast.
Nonworker	Percentage of non-workers (old dependants, housewives, students, children etc.) in 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.
R, α , β	R is the radius of the eye of the cyclone (15 km in the present case), α and β are parameters specific to different cyclones. $\alpha = 0.6$ and $\beta = 240$ for super cyclone of 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.
Sucydeath	Number of human death in a village during the super cyclone
Surge	Level of sea elevation (in meters) at different coastal points.
Tahasildar	Dummy variable for local administration
Topodmy	Low elevation dummy (=1 for villages that have or had mangrove earlier and = 0 for others)
Velocityexp	Approximate radial wind velocity **(kmh^{-1}**) in a village due to cyclone as given by an exponential function
Velocitypow	Approximate radial wind velocity (**kmh^{-1})** in a village due to cyclone as given by a power function
V_i	Vvelocity of wind at the i^{th} location
V_{max}	Maximum wind velocity at the eye wall region of a cyclone
W_i	Velocity or the severity of flooding due to storm surge at the i^{th} location,

Table – 2

Data Sources

Data Head	Description	Source
Damages due to supercyclone	Details of Human Casualties in each village	Emergency Offices, Kendrapada and Bhadrakh district of Orissa
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 Center for Disaster Management (NCDM), Indian Institute of Public Administration, New Delhi
Geo-physical Information	Distances of different villages from coastline, cyclone track, river channels, metallic roads and width of present and historical mangrove forests	Private Source: DCS, Bhubaneswar, Orissa.
Socio-economic Information:	Total population, percentage of literates, scheduled caste, different types of workers and non-workers in different villages before cyclone	Primary Census Abstract of the State of Orissa for the year 1991 and 2001

Table – 3

Summary Statistics

Variables	**Sample-1 (n=1180)**		**Sample-2 (n=840)**	
	Mean (std .dev)	Min (max)	Min (max)	Mean (std. dev)
Sucydeath	0.38 (1.22)	0 (21)	0 (21)	0.46 (1.39)
Dcypath	37.08 (18.75)	0.62 (83)	0.62 (83)	32.78 (18.83)
Velocitypow	124.10(38.72)	68.12 (190.16)	68.13 (190.16)	134.40 (40.21)
Velocityexp	173.61 (12.89)	143.24 (190.16)	143.24 (190.16)	176.61 (12.96)
Surge	1.70 (1.55)	0.6 (5.9)	0.6 (5.9)	2.01 (1.73)
Dcoast	20.62 (13.02)	0.3 (51.23)	0.34 (51.23)	22.99 (13.49)
Topodmy	0.08 (0.27)	0 (1)	0 (1)	0.11 (0.31)
Hmangrove	3.29 (3.08)	0 (14.1)	0.2 (14.1)	4.62 (2.67)
Mangrove	1.07 (2.11)	0 (10)	0 (10)	1.46 (2.38)
Casurindmy	0.17 (0.38)	0 (1)	0 (1)	0.24 (0.42)
Dmajriver	3.55 (3.58)	0.05 (26.48)	0.05 (22.21)	3.52 (3.41)
Dminriver	3.22 (2.98)	0.01(19.1)	0.08 (15.28)	2.98 (2.78)
Droad	3.08 (3.17)	0.02 (18.17)	0.02 (14.29)	2.66 (2.57)
Roadumy	0.73 (0.45)	0 (1)	0 (1)	0.75 (0.43)
Pop99	967.3 (1042.08)	2 (7545)	6 (7545)	991.74 (1090.27)
Literate	0.62 (0.12)	0 (1)	0 (0.9)	0.63 (0.11)
Schdulcaste	0.18 (0.19)	0 (1)	0 (1)	0.18 (0.18)
Cultivator	0.13 (0.10)	0. (1)	0 (1)	0.13 (0.09)
Aglabour	0.05 (0.06)	0 (1)	0 (1)	0.05 (0.06)
Hhworker	0.003 (0.007)	0 (0.08)	0 (0.07)	0.003 (0.007)
Otworker	0.05 (0.05)	0 (1)	0 (0.28)	0.06 (0.04)
margworker	0.08 (0.10)	0 (0.56)	0 (0.56)	0.09 (0.11)
Nonworker	0.67 (0.14)	0 (0.99)	0 (0.99)	0.66 (0.14)

Table-4

Poisson and Negative Binomial Estimates for Human Casualties Model
Dep. Variable = sucydeath (Wind measure = velocitypow)

		Poisson Estimates		Negative Binomial Estimates	
Equation/ variable	Exp sign	Sample-1	Sample-2	Sample-1	Sample-2,
Mahakalpada	(?)	0.52 (1.50)	0.34 (0.31)	0.78 (1.44)	-0.05 (0.04)
Rajnagar	(?)	**-0.98** (2.11)**	-1.49 (1.36)	-0.27 (0.40)	-1.59 (1.24)
Rajkanika	(?)	-15.38 (0.03)	-14.91 (0.03)	-15.43 (0.02)	-15.25 (0.03)
Patamundai	(?)	**-1.19*** (2.86)**	-1.35 (1.21)	-0.72 (1.21)	-1.60 (1.21)
Aul	(?)	**-1.84 *** (3.80)**	Dropped	**-1.23 * (1.85)**	Dropped
Garadpur	(?)	Dropped	0.04 (0.03)	Dropped	-0.50 (0.34)
Marsaghai	(?)	0.22 (0.87)	0.38 (0.32)	0.62 (1.29)	0.15 (0.11)
Kend-derabis	(?)	0.25 (0.78)	0.32 (0.27)	0.42 (0.84)	-0.13 (0.09)
Bhadrakh	(?)	**-1.29** (2.27)**	Dropped	-0.56 (0.71)	Dropped
Velocitypow	(+)	**-0.02*** 94.52)**	**-0.023*** (4.69)**	**-0.02*** (3.04)**	**-0.02*** (3.31)**
Surge	(+)	**0.18*** (3.26)**	**0.22*** (3.65)**	**0.17** (1.95)**	**0.22** (2.59)**
Dcoast	(-)	0.01 (0.93)	0.008 (0.54)	0.02 (1.20)	0.01 (0.78)
Topodumy	(+)	**0.36* (1.75)**	**0.40 * (1.85)**	0.38 (1.30)	0.48 (1.48)
Mhabitat	(?)	**0.07*** (3.00)**	**0.08*** (2.99)**	**0.10*** (2.77)**	**0.10 *** (2.60)**
Mangrove	(-)	**-0.83*** (4.74)**	**-0.81*** (4.30)**	**-0.74*** (4.16)**	**-0.72*** (3.80)**
Casurinadumy	(-)	0.23 (1.49)	0.12 (0.73)	0.35 (1.56)	0.17 (0.75)
Dmajriver	(+)	**0.05 *** (2.87)**	**0.05** (2.49)**	**0.05 ** (2.34)**	**0.06 ** (2.16)**
Dminriver	(-)	**-0.07*** (3.09)**	**-0.07** (2.56)**	**-0.06** (2.20)**	**-0.06 * (1.74)**
Droad	(+)	**-0.05 ** (2.21)**	**-0.05* (1.61)**	**-0.06** (1.99)**	-0.05 (1.19)
Roadumy	(-)	-0.07 (0.49)	-0.21 (1.41)	0.01 (0.07)	-0.17 (0.85)
Pop99	(+)	**0.0004*** (9.79)**	**0.0004*** (9.03)**	**0.0004*** (7.13)**	**0.0005*** (6.44)**
Literate	(-)	-0.93 (1.54)	**-1.28* (1.81)**	-1.06 (1.31)	-1.44 (1.51)
Schdulcaste	(+)	-0.52 (1.40)	**-0.92** (2.12)**	-0.42 (0.85)	-0.84 (1.46)
Cultivator	(-)	-0.64 (1.10)	-0.78 (1.21)	-0.20 (0.39)	-0.60 (0.70)
Aglabour	(+)	-0.18 (0.27)	-0.11 (0.17)	-0.32 (0.33)	0.14 (0.08)
Hhworker	(-)	6.55 (0.92)	8.59 (1.10)	5.13 (0.50)	6.68 (0.58)
Otworker	(-)	-1.41 (1.01)	-1.77 (1.11)	-0.67 (0.38)	-2.27 (1.00)
Margworker	(+)	0.80 (1.27)	0.86 (1.29)	0.72 (0.88)	1.26 (1.37)
Nonworker	(-)	-0.34 (1.26)	-0.34 (1.19)	-0.56 (1.56)	0.13 (0.20)
Constant	(?)	**2.31** (2.39)**	**2.96** (2.31)**	1.32 (0.99)	2.43 (1.50)
Likelihood Ratio Test for Alpha = 0 (Chi bar 2 (01))				**106.81, Pro=0.00**	**82.12, Pro = 0.00**
		N=1180, LR Chi2 (28)= 818.08, Pro = 0.00, Pseudo R^2=0.35	N=840, LR Chi2 (27)= 736.97, Pro = 0.00, Pseudo R^2=0.39	N=1180, LR Chi2 (28)= 358.39, P = 0.00, Pseudo R^2=0.20	N=840, LR Chi2 (27)= 319.66, P = 0.00, Pseudo R^2=0.23

Notes: - The figures in parenthesis are the absolute z-values and *** implies significant at 1%, ** implies significant at 5% and * implies significant at 10% level of significance.

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