Can Mangroves Minimize Property Loss during Big Storms? An Analysis of House Damage due to the Super Cyclone in Orissa

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Abstract

Storm protection is an important regulating service provided by mangrove forests because they can shield inland property and lives during tropical cyclones. Theoretical as well as empirical research shows that mangroves provide protection from storm surge. But whether mangroves protect inland static property during storms is less explored. This paper estimates the storm protection benefits due to mangroves during the super cyclone of 1999 in Orissa. By combining GIS data with census information, the paper examines the mangrove mediated effects on residential property in the Kendrapada district of Orissa. The analyses suggest that the percentage of fully collapsed houses in the study area would have increased by 23% without the benefit of mangrove protection. On the other hand, if the mangrove cover had remained at the level that it had been in the 1950s, the area would not have suffered any fully collapsed houses at all. The total protection benefits of mangroves in terms of averted damages to residential property in Kendrapada are estimated to be INR 592,647,800 (USD14, 110, 662). This suggests that mangrove forests provided protection benefits to houses to the extent of INR 975, 800 (USD 23,233) per km width of forests or INR 51,168 (USD 1218) per hectare of forests. Thus, policy makers need to take mangrove conservation and re-planting into account in planning for tropical storms, which are expected to increase with global warming.

Key Words: Averted damages, Mangroves, Storm Protection, Wind damages, Property loss, Orissa

Can Mangroves Minimize Property Loss during Big Storms? An Analysis of House Damage due to the Super Cyclone in Orissa

Saudamini Das

1. Introduction

Mangrove forests provide a range of ecosystem services to humans (Dixon, *et al.,* 1994; MEA, 2003). Among these services, storm protection remains one of the most important regulating services provided by mangroves. During storms, mangroves provide protection to inland properties and lives by reducing wind and storm surge velocity. Given recent increases in the frequency of cyclones and the fear of further increases in frequency and intensity due to climate change (Steffen, 2006), research into and quantification of the storm protection function of mangroves becomes important.

Since the Indian Ocean Tsunami of December 2004, the protection services of coastal forests have been in the limelight. Though some anecdotal reports and studies have concluded that the presence of mangroves reduced the extent of tsunami damage (UNEP, 2005; Danielson *et al.,* 2005; Kathiresan and Rajendran, 2005; Dahdouh-Guebas *et al.,* 2006), critics have questioned their validity citing limited sample size and inappropriate statistical analysis (Kerr *et al.,* 2006; Baird, 2006). Some researchers, on the other hand, have seen the coastal forests as playing either a marginal or no role in containing tsunami damages and have underscored the need for clearer answers (Kerr and Baird, 2007; Chatenou and Peduzzi, 2007; Cochard, R. *et al.,* 2008). Theoretically, it is well established that mangroves can reduce cyclone impact by dissipating wave energy (Mazda *et al.,* 1997, 2006; Brinkman *et al.,* 1997; Massel *et al.,* 1999; Hamza *et al.,* 1999; Harada and Imamura, 2005; Quartel *et al.,* 2007). But there is little in the way of detailed empirical work (Khazai *et al.,* 2007). Moreover, few studies examine whether mangroves provide protection from wind velocity. Our paper attempts a detailed empirical analysis of the storm surge and wind protection services of mangrove forests of Orissa State in India during the October 1999 Super Cyclone by analyzing the damage to residential houses.

In October 1999, Orissa was battered by a super cyclone with a landfall wind velocity of 256 km per hour, heavy torrential rain ranging from 400 mm to 867mm, and a storm surge height of approximately 7 metres. It devastated 12 of the 30 districts of the state and damaged nearly 19,58,351 residential houses in addition to causing numerous other damages (Gupta and Sharma, 2000).

The state government reported house damages after the Super Cyclone under three different categories, namely, fully collapsed houses (FC), partially collapsed houses (PC) and swept away houses (SA). FC and PC reflected the number of houses damaged by surge and wind whereas SA houses were the result of flooding or storm surge related damages. While the number of damaged houses in the state came to 23,620 swept away, 7,46,322 fully collapsed, and 11,87,591 partially collapsed houses, the corresponding figures for Kendrapada district came to 2761, 45,834 and 1,32,981 respectively. Our study focuses on the fully collapsed and partially collapsed house damages avoided or reduced in areas of Kendrapada that mangroves were able to protect against wind and surge.

Cyclone-related damages are mediated by many factors including cyclone intensity. Cyclone intensity is reflected by wind velocity, velocity of storm surge and the quantum and duration of torrential rain. Factors like elevation, topography, bathymetry, coastal distance, coastal forests, economic and social relations, government efficiency, etc., also influence damage occurrences. Thus, the coastal mangrove forest is one factor among many that play a decisive role in the damage that occurs. Consequently, data availability, control for other factors, and an interdisciplinary approach are critical in understanding the specific role of coastal forests.

In this study, we use an interdisciplinary model and village level data on house damages suffered in the Kendrapara district of the State of Orissa in order to evaluate the storm protection services of mangroves. We offer an analysis of the protection offered to human life elsewhere (Das, 2007b). We attempt a spatial analysis of the damages by using detailed GIS and socio-economic data of the affected areas and examine the roles of multiple factors simultaneously. We first estimate a cyclone damage function and then calculate avoided damages.

2. Studies on Valuing the Storm Protection Role of Coastal Forests

Studies have seen the storm protection value of mangroves as equivalent to the construction of a sea wall at the coastline (Chan *et al.,* 1993). But rigorous economic analyses of this feature are rather limited. In recent years, a few studies have evaluated the protective services of mangroves using three different approaches: avoided damages (value of damages avoided due to mangrove presence); avoided expenditures (difference in expenditures when it comes to the maintenance and repair of infrastructure in a mangrove protected area as opposed to an unprotected area); or replacement costs (the cost of installing infrastructure that can provide the same protective services as mangroves) (Badola and Hussain, 2005; Tri *et al.,* 1996; Sathirathai, 1998). In a recent study, Barbier (2007) has suggested the use of the Expected Damage Function (EDF) to measure the storm protection value of coastal wetlands. Though each of these methods has different advantages, more studies have used the avoided damage approach comparatively speaking. The use of the avoided damages approach to value storm protection began with Farber (1987), who modeled wind velocity and valued the protection value of wetlands against wind damages from hurricanes.

One well conceptualized study using the avoided damage method to evaluate the cyclone protection services of mangroves is by Badola and Hussain (2005). Conducting a primary survey for damages in the aftermath of the Super Cyclone of October 1999, in Orissa, they showed the damages per household to be less in a village sheltered by mangroves as compared to the damages per household in a village with a dike nearby but without mangroves and a village without either mangroves or dikes. Although the authors deserve credit for their attempt to select villages that were similar except for the presence or absence of mangroves and dikes, the attribution of the entire reduced damages to the presence of mangroves seems to be an overestimate given the economic and geographic heterogeneity of the villages (Das, 2007b). In a more recent publication, Costanza *et al.* (2008) have also used this approach to measure the value of coastal wetlands for hurricane protection in the USA.

Researchers have also used the avoided damage approach to evaluate the protective role of coastal forests during the Indian Ocean Tsunami of 2004 (Kathiresan and Rajendran, 2005) although others have questioned the accuracy of the statistical analyses and findings (Kerr *et al.*, 2006; Baird, 2006; Vermaat and Thampanya, 2006, 2007).

The present paper also adopts the avoided damages method. This method takes into account the actual damages suffered in mangrove protected areas compared to damages in areas not protected by mangroves and helps in estimating the volume of damages that are averted due to mangrove presence or could have occurred if there had been no mangroves. The method involves two steps where step 1 estimates a storm damage function linking damages to possible explanatory variables and step 2 calculates the avoided damages with the help of the marginal effects. The value of avoided damages being the value of storm protection, the reliability of this measure is dependant on how accurately we account for all the potential factors that might have an impact on the occurrence of storm damages in the storm damage function. Inflated storm protection values due to the omission of potential variables in the damage function could be a serious limitation of this methodology.

Mangroves or other coastal barriers should never be considered the main decisive players when analyzing the damages due to extreme events. Some of the other recognized important factors are elevation, coastal distance and inundation distances (Bretschneider and Wybro, 1977; FAO, 2006; Baird, 2006; Chatenoux and Peduzzi, 2006, 2007; Dahdouh-Guebas *et al.*, 2006; Cochard *et al.*, 2008). But scholars are yet to examine the role of economic, sociological or hydrological variables in damage occurrence. Since every unit of analysis (whether hamlet or household) that responds to storms is socio-economically heterogeneous, ignoring this aspect will give biased estimates of the role of the coastal forests.

Our study, which evaluates the protective role of mangrove forests in reducing house damage, takes into consideration the roles played by socio-economic, geo-physical, and meteorological factors such as village level wind velocity and sea elevation (i.e., storm surge height) at different coastal points in impacting cyclonic damage.

3. Study Area

The study area for this research is the Kendrapada district of the State of Orissa in India. The district has eight *tahasils* which are demographically not very different from each other. Kendrapada is the most cyclone prone area in the Indian peninsula and experiences, on average, one cyclone per year (Das, 2007a; IMD, 2000). Figure 1 (a) shows the position of Kendrapada district in the super cyclone structure while Figure 1(b) shows the location of the Kendrapada district in cyclone affected Orissa.

The landfall point of the Super Cyclone 1999 was at a place called Ersama lying 20 km southwest of the Kendrapada district and the entire district was severely battered by both cyclonic wind and rain. Four of the eight *tahasils* of the district were affected by storm surge (Gupta and Sharma, 2000). The position of the district was to the north of the cyclone eye track throughout the cyclone period. Thus, the wind direction was from sea to land throughout the study area because cyclonic wind moves anti-clockwise in the northern hemisphere. This provided a good opportunity to test the wind buffering capacity of the mangroves.

In 1999, before the Super Cyclone hit the state, the Kendrapada district had 192 sq. km of mangrove forests spread in two different blocks of the district: one in Mahakalpada *tahasil* and the other in Rajnagar *tahasil*. At both locations, mangroves spread continuously for more than 20 km parallel to the coast but the width of the forest, spreading vertically to the coast, varied from 0.5 km to 10 km at different places. More than 93 per cent of the mangroves were densely stocked (FSI, 2001) and well-protected. 80% of the total mangrove forests were in Rajnagar *tahasil*. Figure 2 (a) shows the extent of mangrove presence in the Kendrapada district and adjoining areas in October 1999 before the Super Cyclone. Kendrapada district also has a few patches of casuarina plantation (of 0.2 to 0.4 km width) which were planted in 1974 under the coastal shelterbelt plantation scheme of the state government. The entire coastline of the study area was planted with casuarina 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 areas where mangroves grow and do not get inundated during high tide. But since the coastline of the study area was mostly swampy and low lying, casuarinas could survive only in limited pockets (Mohanty, 1992) and, where they have survived, the width of the forest is nearly uniform (0.2 to 0.4 km). The width being uniform, we represent the casuarinas by a dummy variable in our model and expect the casurinadummy, to capture the effect of the casuarina vegetation as well as the special topography of the casuarina area.

Figure 2 (b) presents a picture of the district and adjoining areas in 1950. This map shows that 80% of the district's 60 km long coastline was covered with mangrove forests of nearly 10 km width in the past. Different factors have led to the destruction of these forests over time, but maximum destruction seems to have occurred between 1952 and 1980 (Orissa District Gazetteer, 1996). 1952 was the year when ownership of these forests came to be transferred from the z*amindars* (the feudal land owners) to the state government while in 1980 the Wild Life Division Department was created by the state government and the management of the mangrove forests came to be transferred to this division. Most of the forest was destroyed in the Mahakalpada *tahasil* where only a thin strand of mangroves was left by 1999 when the Super Cyclone hit the area (see Fig. 2 (a) below). In contrast, the destruction of mangroves in Rajnagar *tahasil* was marginal. It may be that the presence of ferocious animals (crocodiles, for instance) in these forest areas made the conversion of forest to other land uses difficult initially when state protection was inadequate. But the declaration of the forest area as the Bhitarkanika Wild Life Sanctuary in 1975 and as a national park in 1988 ensured continued protection.

The study area has a high level of poverty. More than 50 percent of the population lives below the poverty line. According to the report of the Census of India (2001), 94 percent of the households in Kendrapada district live in rural areas. With regard to the quality of houses in rural Kendrapada, the census figures show that only 10 percent of the households have concrete roofs while only 17 percent have cemented walls. Of the 17 percent, only 2 percent have walls with concrete while the material used in the remaining 15 percent are either raw brick or mud. Thus their capacity to withstand the Super Cyclone is doubtful. Intuitively, we expected at least 98 percent of the rural households to suffer some form of house damage depending on the impact of the cyclone on their location.

4. Methodology

In order to evaluate the storm protection services of mangroves, we first estimate a cyclone damage function using the damage data in physical units, then calculate the volume of avoided damages due to mangrove presence in step 2 and finally estimate the storm protection value by valuing the avoided damages. During cyclones, the extent of damage in a particular area depends on the intensity of the cyclone (reflected in wind velocity and storm surge) as well as on the physical and socio-economic features of the area. Physical features like the location of the village vis-à-vis the coastline, the cyclone eye, the presence of mangroves or other cyclone barriers etc., can help reduce the cyclone impact. Similarly, economic well being and the strength of the community in terms of helping each other also influence the extent of damage. Thus, we expect cyclone damages, including human casualties in any location, to 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.[1] We present this in the following equation as

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

where i represents the location (villages),

D_i is the damage suffered,
V_i is velocity of wind,
W_i is velocity of storm surge or the severity of flooding due to surge,
P_i is population or property at risk and,
S_i is the group of socio-economic factors at the location

In order to estimate equation 1, we need data on damages suffered as well as all the other independent variables. However, we had no direct measures of either V_i and W_i at the different locations. We discuss below how these variables are approximated by taking into account their determinants. We also discuss the socio-economic variables used.

4.1 Wind Velocity

The wind velocity (V_i) at a place depends on the approximate radial wind (*RWi*) at the location and other factors such as the minimum distance of the location from the coast line ($dcoast_i$) and the type and the width of wind barriers near the village ($barrier_i$).

$$V_i = v(RW_i, dcoast_i, barrier_i) \quad (2)$$

[1] The study ignores flooding due to torrential rain as a cause of damage since it rained almost the same amount everywhere in the study area and there were no spatial differences in rainfall over the locations. Moreover, village-specific rainfall data was unavailable. 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.

However, in order to measure radial wind at a place, we need to understand its various determinants. Radial wind over a location during a tropical cyclone depends a) on the position of the location vis-à-vis the horizontal structure of the cyclone that consist of the eye, the eye wall, the wall cloud, and the outer storm structure and b) the minimum distance of the location from the centre of the eye of the cyclone (*dcypath*$_i$). Areas under the cyclone eye and the eye wall face maximum wind (*Vmax*) while wind velocity over other areas declines with distance away from the center of the eye or as *dcypath*$_i$ increases. Since meteorologists estimated the radius of the super cyclone eye to be approximately 15 kilometres (IMD, 2000), we assumed the radial wind to be at its maximum in areas lying within a 15 km radius (*dcypath*$_i$ <=15) from the center of the cyclone eye in our analyses. With the help of meteorologists, we approximated the radial wind for areas lying beyond a 15 km radius (*dcypath*$_i$ >15) by a power function (*velocitypow*) (Roy Abraham *et al.*, 1995).

$$Velocitypow_i = V_{\max}(dcypath_i / R)^{-\alpha} \qquad (3)$$

where *R* is the radius of the cyclone eye (15 km in the present case) and α was taken as 0.6 at the suggestion of meteorologists.

The study area is agricultural land with an average elevation less than 10 meters everywhere (District Planning Map for Cuttack, Jajpur, Kendrapada and Jagatsinghpur of Orissa, 2000). The only wind barriers are the coastal forests, i.e., the mangrove and casuarina plantations. We represent mangroves as the width of the forests in km between the village and the coast. Some coastal tracts also have casuarina forests. Because the width of these planted casuarinas is nearly uniform, we represent casuarinas by a dummy variable, the *casuarinadummy*.

Thus, the actual wind velocity at the i[th] location is given by equation (4) below:

$$V_i = v\,[V_{max} \text{ if } dcypath_i \le 15,\ velocitypow_i \text{ if } dcypath_i > 15,\ dcoast_i,\ mangrove_i,\ casuarinadumy_i) \qquad (4)$$

As the model includes variables *dcoast*$_i$ and *mangrove*$_i$, it also implicitly controls for the distance of a village from the mangrove forest boundary that equals $dcoast_i – mangrove_i$.

4.2 Velocity of Storm Surge *(W$_i$)*

Storm surge is the abnormal rise of the sea level in excess of the predicted astronomical tide. It is mainly due to the atmospheric pressure variation and the strong surface wind of a cyclone. We note that sea elevation also depends on other features of the cyclone as well as the physical features of the coastline. Due to these features, a coastal point facing high wind may face low sea elevation or vice versa. We expect the velocity or severity of surge at an interior location to depend on the level of sea elevation (*surge*$_i$) facing that location and physical features of the place such as the minimum distance from the coast (*dcoast*$_i$), the elevation of the place (*topodumy*$_i$), the distance of the place from river channels (*dmajriver*$_i$ *and dminriver*$_i$), the presence of natural barriers (*mangroves*$_i$, *casuarindadummy*$_i$ sand dunes, etc.) between the village and the coast line, the presence of man-made barriers (*roadumy*$_i$ - dikes) near the village, etc. Taking all these factors into account, we defined the following function for the severity of flooding due to storm surge:

$$W_i = w(surge_i, dcoast_i, dmajriver_i, d\min river_i, topodumy_i, mhabitat_i, mangrove_i, casaurinadumy_i, roadumy_i) \quad (5)$$

Surge$_i$, is the elevation of the sea at the nearest coastline facing the location. For our study, we measured the sea elevation during the Super Cyclone along the coast line of our study area with the help of a surge envelop curve (Kalsi *et al.*, 2004). This curve identifies the surge at all the locations along the coast affected by the Super Cyclone.

The study area is full of major and minor river channels and their roles during a storm surge are different. The major rivers carry the high velocity surge water to interior areas. As a result, the surge effect on coastal villages near the big river is reduced to a flooding effect. But the opposite happens in the case of minor rivers. Hence, we divided the minimum distance from river channels into two, i.e., minimum distance from a major river (*dmajriver*$_i$) and minimum distance from a minor river (*dminriver*$_i$).

Topodumy$_i$ is a dummy variable for low elevation and equals 1 if the village is located within a mangrove habitat area and 0 otherwise. Elevation data for the study area was unavailable. However, we know that mangrove forests grow mainly in low lying vulnerable areas that get inundated regularly during high tides. Hence, we demarcated low and high areas using the present and historical (1950) mangrove forest maps. Villages with *topodumy*$_i$ = 1 are likely to be low lying areas and ones with t*opodumy*$_i$ = 0 are likely to be situated at a higher elevation.

Mhabitat$_i$ is the width of the historical mangrove forests (or the width of the mangrove habitat) that lay between the village and the coast as seen in the 1950 forest map of the area. The study area has had a vast stretch of mangrove forests historically, some of which have been destroyed over the years. The width of the mangrove habitat in a particular location depends on the topographical, hydrological and bathymetric features of the area. Thus, this variable is taken as a proxy to capture the effects of these factors on storm surge velocity or storm damage occurrences. Researchers have also argued that since mangroves come up in sheltered bays, the physical features of the mangrove habitat could be reducing damage occurrences or that the physical features could be providing the protection which is wrongly ascribed to the vegetation (Chatenoux and Peduzzi, 2007). Hence, there is a need to separate the effect of physical features from the effects of vegetation on storm damages. We separate these two effects by (i) having both *mhabitat*$_i$ and the *mangrove*$_i$ variable in the damage equation and (ii) by excluding non-mangrove habitat areas (areas with *mhabitat*$_i$ = 0) from our analysis (see description of sample areas below).[2] Thus *mhabitat* is used as a proxy only for the physical features of the mangrove habitat areas, and not for all the physical features of the coastline.

[2] There could also be un-vegetated sheltered bays, mud flats, etc., in coastal areas having a significant impact on storm damages. Hence we restrict our sample to areas with *mhabitat*$_i$*>0* to exclude the un-vegetated areas from analysis and then keep both *mhabitat*$_i$ (width of mangrove habitat) and *mangrove*$_i$ (width of mangrove vegetation) as explanatory variables so that the former captures the effect of the physical features of mangrove habitat and the latter the effect of vegetation. Exclusion of areas with *mhabitat*$_i$ = 0 is also justified on the ground that we are evaluating the storm protection services of mangroves and these areas can never be protected by them.

$Mangrove_i$ is the width of the mangrove forest (vegetation) that existed on October 11, 1999, between the i[th] village and the coast.   *Casurinadumy***,** as previously explained, is the dummy variable for the presence of casuarina forests between the village and the coast. Lastly, *roadummy* is the dummy variable for the presence of village road or dikes as dikes are also used as village roads in coastal areas.

4.3 Socio-Economic Factors *(S_i)*

The cyclone, like any other natural calamity, is presumed to have a differential impact on people depending on their socio-economic status (FAO, 2000) and the coastal poor are likely to be more vulnerable than their wealthier counterparts. There are perceptible differences between a rich and a poor household when it comes to cyclone preparedness. A wealthy household owns a good quality house, a vehicle to escape in, a transistor radio or television set to listen to cyclone warnings and some educated members of the family who would be quick to react to cyclone warning.   In contrast, a poor household is more likely to live in an inferior quality house, which could be located in low-lying vulnerable areas, and may not have access to the same kinds of coping strategies as a rich household. In the case of our study, we unfortunately had no village level data to capture differences between the economically better off and worse off villages in the study area. We therefore tried to account for these differences by using the following village level factors: percentage of literates (since responsiveness of people to cyclone warning depends on their level of education (FAO, 2000); percentage of different types of main incoming earning members (we included five different types of earning members); percentage of scheduled caste population (the economically and socially most deprived); the minimum distance to a metallic road (better scope for economic prosperity); and presence of village road (connectivity to metallic road).[3] In addition, we used a *tahasildar* dummy variable to capture differences in the efficiency of local administration (*tahasildars* are responsible for cyclone warning, evacuation, relief, etc.) and other locational differences among *tahasils*.

Thus, we conceive each village as defined by a socio-economic index, which is influenced by the factors described above.

(6)

where S_i is the socio-economic well-being index of the i[th] village;

$Tahasildar_i$ is the dummy for both the local administration and other locational omitted variables. It equals 1 for all villages falling under one *tahasil* and zero for other villages. Since we are interested in property damage and not issues such as evacuation or lives lost, we include these dummy variables because we feel they are likely to be more important in capturing locational rather than institutional differences.

[3] In the absence of data on the availability of mass media (TV, radio) at the village level, we take the percentage of other workers (otworkers) that include people with high education, high mobility and in occupations other than agriculture and household industries (that is, doctors, teachers, engineers, barbers, washermen, priests, etc.) as proxies for the availability of this commodity.

Literate$_i$ is the percentage of literate people; *scheduled caste$_i$* is the percentage of scheduled caste people; *cultivator$_i$*, *aglabour$_i$*, *hhworker$_i$*, *otworker$_i$*, and *margworker$_i$* are the percentage of cultivators, agricultural labourers, percentage of workers in own household industries (located either at home or within the village), percentage of other workers (doctors, teachers, engineers, barbers, washermen, priests, etc.), and the percentage of marginal workers respectively in the i^{th} village; *droad$_i$* is the minimum distance of the village from the metallic road; and R*oadummy$_i$* is a dummy variable for the presence of the village road that equals 1 for a village if village road exists and 0 otherwise.

To sum up, equations 4, 5 and 6 above define the three sets of variables determining wind velocity, storm surge velocity and the socio-economic conditions of a village. Since these equations cannot be estimated as the dependant variables are unobserved, we combine the determinants of equations 4, 5 and 6 in equation1 and define the estimable cyclone damage function for a village as the following

$$D_i = d\ (\ mangrove_i, mhabitat_i,\ topodumy_i,\ casurinadumy_i,\ velocitypow_i,\ surge_i,\ dcoast_i\ dmajriver_i,\ dminriver_i,\ droad_i,\ roadumy_i,\ pop99_{i,}\ literate_i,\ scheduledcaste_i,\ cultivators_i,\ aglabours_i,\ hhworkers_i,\ otworkers_i,\ margworkers_,\ tahasildar_i,\ ) \qquad (7)$$

where D_i is the house damage suffered in the i^{th} village. The right hand side variables are already defined above and are also explained in Table 1.[4] The damage function (7) was estimated for both fully collapsed (FC) and partially collapsed (PC) houses separately in order to get a correct picture of the sheltering capacity of the mangrove forest.

Description of Sample areas

We estimated the damage equation over different sample areas in order to correctly assess the storm protection benefits from mangroves in terms of providing protection from wind and surge velocity. First, we restricted our sample to areas that historically had mangroves between those areas and the coast (or for which *mhabitat$_i$* >0). We did this because including villages that never had mangroves between them and the coast, i.e., the non-mangrove areas, is meaningless as these areas can never be protected by mangroves. Moreover, as explained above, by excluding these areas, we indirectly control for the topographical and bathymetric features of the study area.

In step 2, we further restricted the sample by excluding the areas that came under the cyclone eye where wind velocity was greater than or equal to 190 km per hour.[5] We did this because wind direction for areas coming under the cyclone eye is circular (anti-clockwise before the cyclone eye passes and clock-wise afterwards) and no forest can provide any sheltering service, particularly from the wind effects.

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4 Factors like time and season of occurrence of the cyclone, the number of hours between landfall and the broadcast of the cyclone warning, etc., have been ignored as the analysis is for the damage data of a single cyclone. Moreover, since the present analysis is for damages to static properties, these factors are not likely to have any impact.

5 V_{max} is the wind velocity in the eye wall region of a cyclone and areas coming under the cyclone eye face this wind velocity. We estimated V_{max} to be 190.1622 km h^{-1} for the Super Cyclone after landfall using the parameters from meteorologists (Das, 2007b).

In step 3, we further subdivided the sample into areas within 10 km of the coast and beyond 10 km from the coast in order to evaluate the effectiveness of mangrove protection for areas lying within different bandwidths from the coastline. In this case, we were interested in identifying the coastal distance up to which mangrove protection remains effective. Thus, regressions were estimated for four different samples as described below.

Sample 1: Areas with $Mhabitat_i > 0$.

Sample 2: Areas with $Mhabitat_i > 0$ and wind velocity < 190 kmh^{-1}.

Sample 3: Areas with $Mhabitat_i > 0$, wind velocity < 190 kmh^{-1} and $Dcoast_i <= 10$.

Sample 4: Areas with $Mhabitat_i > 0$, wind velocity < 190 kmh^{-1} and $Dcoast_i > 10$.

An explanation is necessary at this point for the use of the *tahasildars* dummies in the damage equation. We know that the *tahasildars* cannot impact damage to immovable properties. However, we included these dummies to capture the effect of locational variables (any omitted factors) impacting house damages. The *tahasils* are small administrative units under a district and we did not expect significant locational differences between them. Thus we estimated the damage equations both with and without these dummies.

4.4 Valuing Residential Damages

After estimating the cyclone damage equations for fully collapsed and partially collapsed houses, we quantify the role of mangroves in mitigating house losses. We do this by estimating the volume of house damages (both for FC and PC) averted by mangroves and then valuing the averted damages at different prices. We define the total averted damages (DA) in Kendrapada by mangroves as

$$DA = \sum_i \hat{y}_i - \sum_i \hat{y}'_i = \mathrm{Y} -, \sum_i \hat{y}' \qquad (8)$$

where   is the predicted or the fitted value of the model for the ith unit (village or *gram panchayat*). Thus, its sum equals the actual Y and $\hat{y}'_i$ is the predicted or the fitted value for the same unit with a restriction (like $mangrove_i = 0$).

We estimate the averted damages under two restrictions: a) if there were no mangroves present before the cyclone ($mangrove_i = 0$), and b) if the presence of mangroves were as they existed in 1950 ($mangrove_i = mhabitat_i$). We then compare these averted damages to damages actually witnessed. Again, as explained before, the protection services of mangroves are better captured in Sample 2. Sample 1 is the total area that receives storm protection from mangroves. Thus, we calculate the averted damages and the average values for Sample 2 and multiply this average value by the number of villages of Sample 1 in order to estimate the total storm protection value for the study area[6].

[6] This hypothesis has been found valid in our earlier analysis where the average value per unit of mangroves was found higher for Sample 2 area than the same value for Sample 1 area for different types of damages analyzed (Das, 2009).

Once we have estimated the physical volume of house damage avoided, the next step is to value these damages. We do this by using local construction costs to estimate the value of rebuilding damaged housing.

5. Data

The study required four different types of information: information on house damages due to the Cyclone, meteorological information on cyclone intensities, geo-physical or locational information, and socio-economic information. This information and their respective sources are described in Table 2.

We obtained house damages due to the Cyclone from three different offices of the Government of Orissa: the Emergency Department of Kendrapada and Jagatsinghpur district and the *tahsildar* office of Kendrapada district. The Orissa State Government categorized damaged houses into three categories: Fully Collapsed (FC) houses (with more than 80 percent damage), Partially Collapsed (PC) houses (which includes all damages that come to less than 80 percent) and Swept Away (SA) houses (where both the wall as well as the roof were completely washed away by water). Both FC and PC reflected mainly the wind and partially surge related damages to residential houses while SA houses were mainly due to flooding by the storm surge. SA houses were limited to the near coast areas while beyond that house damages were either FC or PC. This paper, as mentioned before, focuses only on FC and PC houses. Since we expect 98 % of the houses to have suffered damage in the district and damages were either FC or PC in a major part of the study area, we assume each additional house with partial damage to be one less house that is fully collapsed.

House damage figures were maintained at the *tahsildar* office. However, some *tahasils* had village level information while others had information only at the *gram panchayat* level, i.e., at a higher unit of administration between the village and *tahasil*. Accordingly, the study data includes a mix of 365 villages and 138 *gram panchayats* covering the Kendrapada district and 86 coastal villages of the Kujang-Paradeep *tahasil* of the adjoining Jagatsinghpur district. We included Kujang-Paradeep *tahasil*, situated southeast of Kendrapada, in the study area as some house damage data was available for this area[7].

We used two meteorological variables, i.e., $velocitypow_i$ (a measure of approximate wind velocity at different villages) and $surge_i$ (the height of sea elevation at the nearest coastline for each village) in our damage equation. To calculate $velocitypow_i$, we needed detailed information on the cyclone including the landfall point, the landfall wind velocity, the movement of the cyclone eye, the radius of the eye, the formula for calculating radial wind at different radial distances and the rate of decline of the maximum wind. We obtained this information from the Cyclone Warning

7 To have a data set with uniform units, we tried to group the villages according to the gram panchayats they belonged to, but this reduced the number of observations to 132 for Sample 1 and 89 for Sample 2. Many villages had to be dropped because we did not have data for other villages belonging to that particular gram panchayat. Regression results with only 132 and 89 observations did give similar results as the larger data set but the level of significance was comparatively lower. The coefficient of mangrove variable was significant for both the samples but we could not try the results for Sample 3 and 4 due to the very few observations. Hence, in spite of the heteroskedasticity problem, we decided to use the larger data set.

Division of the Meteorology Department (*Mausam Bhawan*), Government of India, New Delhi; the Department of Atmospheric Sciences, Indian Institute of Technology, New Delhi; and the publications of the National Center for Disaster Management (NCDM), Indian Institute of Public Administration, New Delhi. The NCDM Report (Gupta and Sharma, 2000) describes the positions of the cyclone eye at different locations. Using these details, we demarcated the cyclone eye path at the level of villages. We calculated the minimum distances of villages from this path (the variable, $dcypath_i$) with the help of Arc View GIS 3.2 and we used this distance and other parameters described above to calculate $velocitypow_i$ for all the locations (villages and *gram panchayats*) of the study area. We calculated it with the help of the formula described by meteorologists (see equation 3).

We calculated the $surge_i$ variable, i.e., the approximate height of the sea elevation at different coastal points, from a surge envelope curve (see Fig. 3). The Cyclone Warning Division of the Meteorology Department of the Government of India provided the surge envelope curve of the eastern India coast line for the Super Cyclone.

In order to generate the geo-physical and locational variables ($mangrove_i$, $mhabitat_i$, $casuarinadumy_i$, $roadumy_i$ and different distances), we used GIS files on village boundary, rivers, roads, coastline and forest cover, which were purchased from a private source, Digital Cartography and Services, Bhubaneswar, Orissa. We used the Indian Remote Sensing Satellite IRS-1D, LISS III Pan censor images of October 11, 1999, with 23.9 metre resolution, to measure the coastal forest cover (both mangroves and casuarinas) before the Cyclone. In order to demarcate the historical (1950) spread of the mangroves in the study area, we used jpg images (1: 250000 scale) from the archives of the US Army Corps (NF 45-14 Series U502, "Cuttack" sheet). We used the year 1950 as the reference year because mangrove destruction reportedly began after the abolition of the feudal system in 1952 (Orissa District Gazetteer of Cuttack, 1996). We then combined the different available digitized data with the help of Arc View GIS Software 3.2 in order to develop a village-level coastal Orissa digitized physical map. We did the geo-referencing of all the images at the 1:50000 scale.

With the help of the software, we then calculated the different distances as required for the analysis. We measured the distances (distance from cyclone path, from coastline, from a major river, from a minor river, from metallic road, etc.) as the minimum distances from the centre of the village (or *gram panchayat*) to the cyclone track, coastline, river, road, etc. We calculated the widths of the 1999 mangrove and the 1950 mangrove for each village as the width (distance between the coast and the interior boundary of the forest) of these forests along the minimum distance between the village and the coast.

We defined the mangrove variable as the width of the forest in km between the village and the coast (not the area of the forest) because the spread of the forest along the coast is continuous in the study area while the breadth is different at different places and our analysis focused on capturing the impact of the spatial features of the villages on damages witnessed.

We obtained the socio-economic variables (population, share of literates, scheduled castes and different categories of workers) for each village (or *gram panchayat*) from the Primary Census Abstract of Orissa for 1991 and 2001. The Super Cyclone hit Orissa in 1999 while we had census data for only 1991 and 2001. Therefore we decided to estimate the average annual compound rates of growth for the decade 1991-2001 for different variables and then extrapolated the 1991 figures for the year 1999 by making use of these growth rates.

We used Male 99 in place of the total population of 1999 as proxy for the number of households, which in turn was a proxy for the number of properties at risk in the damage equation. Male99 was the total number of males in a village (or *gram panchayat*) in the year 1999. We used this variable because we did not have an accurate measure of the total number of houses at risk in each village or *gram panchayat*. We felt that the total number of males was a more accurate measure of the number of households/properties than the total population as house ownership is usually with the male member of the house.

6. Results and Discussions

We show the summary statistics for the entire study area and Sample 1 areas in Table 3. As evident from the Table, the study area lies between 0.22 to 72.83 km from the cyclone path and within 0.65 to 51.23 km from the coastline. The width of the mangrove forest varies from 0 to 10 km at different places. Agriculture is the main occupation but nearly 70 percent of the population are non-workers. Owner farmers (cultivators) constitute 11 percent of the population while agricultural labourers total 5 percent of the population. The number of houses damaged range from 0 to 1885 for FC houses and 0 to 2365 for PC houses.

Of the different explanatory variables, we found three sets of variables to be significantly correlated with each other in the different sample areas: $Velocitypow_i$ and $surge_i$ (r » 0.65, P<0.01); $mangrove_i$ *and* $velocitypow_i$ (r » -0.50, P<0.01), $mangrove_i$ *and* $surge_i$ (r » -0.30, P<0.01). Both $velocitypow_i$ and $surge_i$ are dependant on cyclone intensity and thus it makes sense that they are correlated. However, there is no theoretical justification for the cyclone variables to be correlated with the mangrove variable. We take it as a coincidence that there are more mangroves with distances away to the north from the cyclone landfall point. Both $velocitypow_i$ and $surge_i$ are important variables in examining the impact of mangroves on houses and therefore, we chose to retain both the variables in the estimated model. In order to ensure that the significance of the mangroves is not due to the variables it is correlated with, we compared the results by dropping the variables correlated with mangroves one by one from the estimation and saw no change in the significance of mangrove.

We did expect a high and significant correlation between $mangrove_i$ and $mhabitat_i$, but this was not the case (r < 0.10, P>0.05) for all the sample areas. This was probably due to the fact that mangrove destruction has been random without a systematic pattern.

6.1 Fully Collapsed Houses (FC)

The estimated equation for this model is

$$FC_i = \alpha_0 + \alpha_1 mangrove_i + \alpha_2 mhabitat_i + \alpha_3 topodumy_i + --- + \alpha_{19} margworkers_i$$
$$+ \alpha_{20} tahasildar_i + \nu_i$$

where ν_i is the error term and other variables have been previously defined. We estimated Equation 8 for all four sample areas. The error term was heteroskedastic for all sample areas and we expected the presence of heterogeneous units (villages and *gram panchayats*) in the data set to be the main reason. Assuming error variances to be proportional to the size of the units, we tried weighted least squares estimates using both area as well as the total population as weights. We also tried OLS with robust standard errors and got very similar results from all the three types of estimates. We retained OLS with robust standard errors since the WLS estimates are based on some assumption about the error variances.

Expected Signs

We expect the $mangrove_i$ variable to reduce the degree of damage to houses and therefore to have a negative coefficient with FC; the same is true for the coefficient of $casurinadumy_i$. We also expect negative coefficients for the variables $dcoast_i$ (that is, distance from coast implying less intensity of cyclone), $dmajriver_i$ and $dminriver_i$ (since villages nearer rivers are likely to suffer more damage). Among other variables for which we expect a negative coefficient are $cultivators_i$, $hhworkers_i$ and $otworkers_i$ (they are the better-off people in the study area) and for $roadumy_i$ (villages with village road tend to be usually better off and to have better quality houses). We expect the variables, $velocitypow_i$ and $surge_i$, to have a positive coefficient (with high values indicating the higher intensity of the cyclone). The same goes for the following variables: $droad_i$ (proximity to metallic road means economic well-being), $male99_i$ (property at risk), $topodumy_i$ (because low lying areas are more vulnerable and poor), $schedulecaste_i$, $aglabour_i$ and $margworker_i$ (who tend to be very poor people). We use a question mark for both $tahsildar_i$ and $mhabitat_i$ as these variables are likely to capture the effects of unobserved omitted variables among *tahasils* and coastal topographic factors, respectively, with regard to house damage.

Discussions

We estimated equation 8 with and without *tahasildhar* dummies. We present the expected signs and the estimated regressions without the *tahasildar* dummies in Table 4 but show the results with the *tahasildar* dummies in appendix Table 8. After comparing the results, we have come to have more faith in the regressions without *tahsildar* dummies both under economic and econometric logic as discussed below.

The coefficients shown in Table 4, wherever significant, have the appropriate signs. As expected, wind velocity is the main cause of fully collapsed houses. The mangrove variable is significant with a negative sign for Samples 1, 2 and 4 as seen in Table 4. Thus, mangroves seem to have reduced the number of fully collapsed houses. But its effect is not visible in areas within10 km from the coast. It may be that these areas witnessed the maximum number of swept away houses and, consequently, the number of fully collapsed houses was limited. Interestingly enough, mangrove protection is seen to be effective for areas as far as 50 km away from the coast[8]. However, in most equations, the socio-economic variables are insignificant supporting the arguments on similarity in terms of house quality and demographics in the entire district.

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[8] We also tried interaction between mangrove and wind velocity by including terms like mangrove*velocitypow and velocitypow*exp (mangrove) etc., along with mangrove and mangrove remained significant in both cases. We do not report these results since we do not have scientific evidence on the nature of interaction between mangrove and wind velocity.

It is interesting to note that mangrove protection from wind damage is visible only when we capture the cyclone effects in a more disaggregated manner by dropping the *tahasildar* dummies. Appendix Table 8 shows results with the *tahasildar* dummies. All the dummies are significant either with a positive or negative sign depending on the sample area and the *tahasil*'s proximity to cyclone track. At the same time, meteorological and geophysical variables that were expected to capture the cyclone impacts are insignificant. Thus, we conclude that the *tahasildar* dummies, being locational variables, are only capturing the cyclonic effects in an aggregate manner. No omitted variables seem to be present among the *tahasils* as the significance of these dummies is completely in accordance with the cyclone impact on the respective *tahasils*. Furthermore, the results with *tahasildar* dummies are less reliable due to high multicollinearity among explanatory variables as reflected by the values of variance inflation factors (VIF).[9] The VIF of some of the tahasils is as high as 60 and the prediction of averted damage due to mangrove presence with these coefficients may not be very reliable. Hence, we use the results of Table 4 to calculate averted damages.

6.2 Partially Collapsed Houses (PC)

We used the same set of regressors as used for fully collapsed houses for partially collapsed houses. Table 5 and Appendix Table 9 present the two sets of results, one without the *tahasildar* dummies, and the other with these dummies, respectively, along with the expected signs. The heteroskedasticity test was significant for all samples for this data set and OLS with robust standard errors resulted in most of the variables being insignificant. The use of Weighted Least Squares estimates with both area and total population as weights produced better results and also gave expected signs of the coefficients. We retained the estimates with area as weight for the final analysis and for calculating averted damages because of higher $\overline{R}^2$ and F value[10].

In the case of partially collapsed houses, we expect the coefficients to show signs opposite to what we expected them to have in the case of fully collapsed houses. As mentioned earlier, the state government has grouped damaged houses into only two categories, i.e., either fully collapsed or partially collapsed, in the major part of the district (SA houses were limited to the near-coast areas) and the partially collapsed category included houses with a range of house damage varying from 10 percent to 80 per cent. Mangrove may have reduced the degree of partial damage to houses but there being no data on the severity of partial damage to houses in different areas, we cannot test this hypothesis. Considering that almost every house in the study area experienced some amount of damage during the Super Cyclone (only two percent of the houses had both concrete walls and roof), we expect the number of partially collapsed houses to be more in mangrove protected areas because this reflects a reduction in fully collapsed houses. On a cautious note, the correct dependant variable to test this hypothesis would have been the ratio of

9 The variance inflation factor is defined as $VIF = 1/(1-r^2_{ij})$, where r^2_{ij} is the coefficient of correlation between the i^{th} and the j^{th} regressor and $var(\hat{\beta}_i) = \sigma^2/\Sigma x_i^2 (1- r^2_{ij}) = \sigma^2/\Sigma x_i^2 * VIF$. Thus, VIF shows the extent to which the variance of an estimator gets inflated by the presence of multicollinearity.

10 Since the OLS results were insignificant and WLS estimates are based on the a priori assumption that error variances are proportional to the variable used as weight, we also calculated the Feasible Generalized Least Squares (FGLS) estimates (Wooldrige, 2003) for PC houses. FGLS estimates compared to WLS estimates had higher coefficients as well as t values, but because the variance inflation factors of these estimates were very high, we did not use them for the final analysis.

fully collapsed to partially collapsed houses in each location since we presume each additional partially collapsed house to be one less fully collapsed house. To substantiate our argument that mangroves reduce the degree of house damage, we did estimate models with ratio of FC to PC houses as dependant variable for different sample areas and found $mangrove_i$ significant with negative sign (see Appendix Table 10). However, we were more interested in regressions with FC and PC separately as dependant variables since our aim in the study was the valuation of storm protection and we wanted the number of averted house damages, the price being available for them. With the ratio of FC to PC as dependant variable, we had difficulty in interpreting and valuing the averted damage. Thus, for the present analysis and the type of data available, we expect the $mangrove_i$ variable to be positively associated with partially collapsed houses as mangrove protected areas are likely to see more of these houses.

The effect of mangroves on partially collapsed houses appears to be strong and robust. $Mangrove_i$ is significant with a positive coefficient in all the tables (with or without *tahasildar* dummies) for all sample areas and this proves either that mangrove-protected areas have witnessed more partially collapsed houses, or that mangroves have reduced the degree of wind damages to houses[11] by converting full damages to partial damages in respect of houses.

6.3 Damages Averted due to Mangrove Vegetation

As mentioned earlier, we defined house damages avoided due to the presence of mangrove forests as

$$= \text{Y} - \sum_i \hat{y}',$$

where $\hat{y}_i$ is the predicted value of the model for the i[th] unit and $\hat{y}'_i$ is the predicted value assuming that mangroves are currently non-existent *($mangrove_i = 0$).*

In this case the mangrove protection is defined as, $DA = -\sum_i (\hat{y}_i - \hat{y}'_i)$, where $\hat{y}'_i$ is the predicted value by replacing mangrove variable by 0. We calculate these values for FC and PC houses and present these averted damages for Sample 2 areas only (see Table 6) as this sample reflects the wind protection of the forests more accurately (Das, 2009). These figures are the extra damages that would have occurred if the district had no mangrove forest before the Cyclone. The averted partially collapsed houses are negative since mangrove protected areas witnessed more partially collapsed houses and less fully collapsed houses. This implies that in the absence of mangroves, the presently mangrove protected areas would have witnessed less partially collapsed houses as more houses would have collapsed fully.

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11 The mangrove variable remains significant even if we use robust option with the WLS estimates.

In the absence of mangrove forests, the villages lying in Sample 2 area would have witnessed 13,681 more fully collapsed houses and 14,339 less partially collapsed houses (see Table 6). The number of fully collapsed houses in these areas was 59,276 during the Super Cyclone. In the absence of mangroves, this number would have risen to 72,957. Thus, without mangroves, the people in these areas would have seen 23% more fully collapsed houses than they actually witnessed. These areas saw 58,867 PC houses. In the absence of mangroves, this number would have been 44,528, implying that the number of PC house would have been lower by 24%[12].

Another way to think about this is in terms of what the reduction in fully collapsed houses might have been if the 1950 level of mangroves had still remained intact. We analyze this by estimating the averted damages by historical mangroves (assumption 2). The answer to this is that the area would have witnessed only partially collapsed houses and no fully collapsed houses as the number of FC houses with the presence of the 1950 mangroves is negative while the number of PC houses increase by 78%.

6.4 Storm Protection Value of Mangroves

The next step is to value the residence protection services of mangroves. In order to do this, we assume that a 150 sq meter house has a construction cost of Rs.53, 800/- in rural Orissa based on estimations by HUDCO (Housing and Urban Development Corporation of India), the largest public sector undertaking engaged in house construction in India. We use this number for valuing avoided FC houses. We also use a negative value of Rs.10, 000/- for each averted (in fact, increased) PC house based on a personal communication from B. K. Mishra, the Emergency Officer of Kendrapada in 2006-07.

Multiplying the number of averted FC houses by Rs.53,800/- and the number of averted PC houses by –Rs.10,000/-, we estimate that the total value of house damages averted by mangroves in Sample 2 is Rs.59,26,47,800.[13] However, this is an aggregative measure which is related to the sample size and the sum of the mangrove variable over the sample.[14] We estimate the values per unit of mangroves in the next step where we calculate the values for both km widths and per hectare of mangroves.

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12 The percentage of averted FC houses is not exactly equal to averted (or rather increased) PC houses as our study area also includes areas that have swept away houses though we did not analyze them here.

13 The averted damage calculation for Sample 1 area shows the averted FC houses to be 17% more and PC houses to be 18% less in the absence of mangroves.

14 The total averted damages ($\sum_i AD_i$) due to mangroves are equal to $\hat{\beta}_M * \sum_i M_i$ in a linear model where $\sum_i M_i$ is the sum of the mangrove variable over all the observations in the model.

Value per km width of mangroves

First, we estimate the average value per km width of mangrove forest per village of Sample 2. As mentioned before, the average per village value of Sample 2 will be multiplied by the number of villages of Sample 1 in order to estimate the total storm protection value. The average value per km of mangroves per village for averting FC and PC damages in Sample 2 is defined as:

$$\bar{\beta} = \left[\sum_{i=1}^{N_2} AD_i \Big/ \sum_{i=1}^{N_2} M_i \right] / N_2 \,, \qquad (9)$$

where $\bar{\beta}$ is the benefit per village from 1 km width of mangrove, AD_i is the value of the averted damages in village i, M_i is the width of mangroves in km for village i, and N_2 is the number of villages in Sample 2.

Next, we estimate the benefits to all villages in Sample 1 as $\bar{\beta} * N_1$ where N_1 is the total number of villages in the bigger sample, i.e., Sample 1 (Sample 2 is a subset of Sample 1 or $N_2 \subset N_1$).

We had heterogeneous units (both villages and *gram panchayats*) in the Sample; hence we calculated both $\sum_{i=1}^{N_2} M_i$ and N_2 by the following formulas for the Sample 2 area.

(i) $$N_2 = R + \sum_j a_j v_j \qquad (10)$$

where *R* is the number of villages in Sample 2 for which village level data is available and the second term represents the total number of villages falling under the *gram panchayats* covered in Sample 2. In the second term, a_j is the average number of villages in a *gram panchayat* in the j^{th} *tahasil* and v_j is the number of *gram panchayats* of j^{th} *tahasil* falling in Sample area 2. Here the summation is over all *tahasils* in Sample 2.

(ii) $$M = \sum_{i=1}^{R} M_i + \sum_j \left(\sum_k M_{kj} \right) a_j v_j \,, \qquad (11)$$

where *M* is the total km width of mangrove in Sample 2, M_i is the km width of mangrove for village i and M_{kj} is the km width of mangrove for the k^{th} *gram panchayat* of the j^{th} *tahasil* and a_j and v_j are the same as above.

These average values / km of forest / village were Rs 1428/- for FC houses and (-) Rs 280/- for PC houses. Taking their difference, we get the average storm protection value / km of forest / village to be Rs 1148/- (see Table 7). To obtain the value of aggregate damages averted, we need to multiply this number by the total number of villages that can be protected by the mangroves. As all the villages of Sample 1 area can be protected by mangroves, we multiply the unit value calculated from Sample 2 by the total number of villages that fall within Sample 1. Thus, we estimate the total storm protection provided by one km width of mangroves in the study area to be Rs 9,75,800/- (USD 23,233). If the area has a two km wide forest, then this value would be doubled and so on.

Value per hectare of mangroves

It is also useful to think about the storm protection benefits in terms of hectares of mangroves. The study area had 30,766 hectares of mangrove forest in 1950 but this had been reduced to 17,900 hectares by October 11, 1999.[15] We consider only the dense mangroves which are 93% of the total mangrove cover (192 sq km) of the district.

We estimated the total value of damages averted by mangroves in Sample 2 as Rs. 59,26,47,800. This is the difference in terms of the values of averted FC houses and PC houses. We divide this value by the area of present mangroves and calculate the storm protection value per hectare of the forest as Rs. 33,109/- for the Sample 2 area. Dividing this by the number of villages of Sample 2 and multiplying by the number of villages of Sample 1, we get the protection value of hectare of forest as Rs. 51,168/- for the study area. Thus, the mangroves of Kendrapada provided storm protection worth Rs. 59,26,47,800/- by averting house damages to the district. In other words, the study area community benefited by Rs 51,168/- per hectare of the forests extant before the cyclone. We would like to note that these values only represent the benefits of mangroves in terms of providing protection to residential houses during the Super Cyclone of October 1999. These values are reported in Table 7.

7. Conclusions and Policy Recommendations

This paper assesses the wind and surge protection services afforded by the mangrove forests of the Kendrapada district of Orissa to the residential houses during the Super Cyclone of October 1999. We did so by analyzing the number of fully collapsed and partially collapsed residential houses in the study area. We calculated the mangrove effect on these houses by taking into account simultaneously the role of meteorological, locational, physical and socio-economic factors.

Mangrove protected areas witnessed fewer fully collapsed houses and more partially collapsed houses. We valued the house damage averted by mangroves by taking into account the market cost of repairing these damages. We find that the protection value of every km width of the mangrove for reducing residential house damages is about Rs.1148/- per village and Rs.9,75,800/- for the entire study area. The protection value per hectare of forest for the study area is Rs.51,168/-.

The next inevitable question is whether mangrove forests should be conserved to avoid these damages. In order to answer this question, we need to look at the alternate uses to which mangrove land in the area can be put and their value. We find that the value of a hectare of coastal land in the Kendrapada region is about Rs. 172,970/- (personal communication with

15 We consider only the dense mangroves which are 93% of the total mangrove cover (192sq km) of the district.

Jatindra Das, IANS correspondent, Bhubaneswar, Orissa). Thus, the value of coastal land in alternate uses far exceeds the value provided by mangroves through protecting residential property. If we base our decision on this information alone, we will not be able to justify mangrove conservation or rehabilitation. However, the argument for mangrove conservation or reservation rests on more complex grounds. Mangroves provide a lot more services than wind and storm surge protection. Furthermore, we have shown elsewhere that mangroves significantly reduce human and livestock casualties resulting from storm surge (Das, 2007b). Thus, the case for formulating policy to protect mangroves remains strong as long as we are careful to include the multiple services and benefits that mangroves provide. In this paper, we undertake a partial analysis mainly to outline the methodological issues that need to be considered in a careful evaluation of the benefits of mangrove conservation.

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LIST OF TABLES

Table 1: List of Variables (Alphabetically)

Variables	Definition of variables (all distances in km)
Aglabour	Percentage of agricultural laborers in a village
Casurindmy	Dummy variable for the presence of casuarina 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
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 between a village and the coast
Nonworker	Percentage of non-workers (aged dependants, housewives, students, children, etc.) in a village
Otworker	Percentage of other workers (doctor, teacher, engineer, barber, washerman, priest, etc.) in a village
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)
Schdulcaste	Percentage of scheduled caste people in a village
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)
Velocitypow	Approximate radial wind velocity (kmh^{-1}) in a village due to cyclone as given by a power function

Table 2: Description and Sources of Data

Data Head	Description	Source
Damages due to super cyclone	Number of houses swept away (SA), fully collapsed (FC) and partially collapsed (PC) in each village or in each *gram panchayat*	Emergency office and *Tahasildar* Office of Kendrapada and only Emergency Office of the District Jagatsinghpur, 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,Department of Atmospheric Sciences, Indian Institute of Technology, 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 *or gram panchayat* from coastline, cyclone track, river channels, metallic roads and width of present and historical mangrove forests	GIS data from Digital Cartography and Services, Bhubaneswar and GIS ARC VIEW Software.
Socio-economic Information	Total population, percentage of literates, scheduled caste, different types of workers and non-workers in different villages or in *gram panchayats* before cyclone	Primary Census Abstract of the State of Orissa for the year 1991 and 2001

Table 3: Descriptive Statistics of House Damage Model

	Entire Study Area (n = 589)		Sample 1 (n = 516)	
Variables	Mean (std. dev)	Mini (max)	Mean (std. dev)	Min (Max)
Fully collapsed (FC)	233.25 (295.2)	0 (1885)	229.31 (297.81)	0 (1885)
Partially collapsed (PC)	206.07 (335.85)	0 (2365)	119.87 (214.67)	0 (2119)
mangrove	0.44 (0.92)	0 (10)	0.46 (0.91)	0 (10)
mhabitat	4.01 (2.30)	0 (13.7)	4.58 (1.85)	0.5 (13.7)
topodmy	0.12 (0.33)	0 (1)	0.13 (0.33)	0 (1)
casurindmy	0.33 (0.47)	0 (1)	0.37 (0.48)	0 (1)
dcypath	21.64 (12.55)	0.22 (72.83)	19.20 (10.98)	0.22 (72.83)
velocitypow	156.73 (32.62)	73.69 (190.16)	163.19 (23.80)	73.64 (190.16)
surge	2.89 (2.03)	0.7 (5.9)	3.14 (2.04)	0.7 (5.9)
dcoast	26.00 (14.18)	0.65 (51.23)	26.65 (14.67)	0.65 (51.23)
dmajriver	3.83 (3.22)	0.06 (16.66)	4.01 (3.32)	0.06 (16.66)
dminriver	3.15 (3.10)	0.08 (15.23)	3.21 (3.21)	0.08 (15.23)
droad	2.44 (2.85)	0.02 (17.55)	2.21 (2.57)	0.02 (15.68)
roadumy	0.80 (0.40)	0 (1)	0.80 (0.39)	0 (1)
Male-99	943.37 (995.1)	3 (5340)	768.27 (863.8)	3 (5340)
literate	0.66 (0.09)	0.20 (1)	0.66 (0. 09)	0.19 (1)
schdulcaste	0.21 (0.17)	0 (1)	0.21 (0.17)	0 (1)
cultivator	0.11 (0.06)	0 (0.43)	0.12 (0.05)	0 (0.42)
aglabour	0.05 (0.04)	0 (0.25)	0.04 (0.08)	0 (0.25)
hhworker	0.004 (0.006)	0 (0.07)	0.004 (0.007)	0 (0.07)
otworker	0.06 (0.04)	0 (0.36)	0.06 (0.04)	0 (0.36)
Margworker	0.08 (0.08)	0 (0.57)	0.08 (0.08)	0 (0.57)
nonworker	0.69 (0.09)	0 (0.83)	0.68 (0.09)	0 (0.83)

Table 4: Ordinary Least Squares Estimates with Robust Std. Errors for Fully Collapsed Houses

Equation/ variable	Exp. signs	**Sample-1** Areas with mhabitat>0	**Sample-2** Part of sample-2 beyond cyclone eye	**Sample-3** Part of sample-3 within 10km from coast	**4** Part of sample-3 beyond 10km from coast
Mangrove	(-)	**-84.27 *** (3.83)**	**-60.11*** (3.12)**	-40.39 (1.19)	**-56.11 *** (3.48)**
Mhabitat	(?)	**20.83 *** (3.17)**	**11.14 * (1.87)**	-16.21 (0.73)	**21.00*** (3.15)**
Topodumy	(+)	-27.86 (0.70)	2.70 (0.10)	-33.50 (0.75)	-13.42 (0.36)
Casurinadumy	(-)	-45.22 (1.19)	-9.77 (0.27)	-37.96 (0.87)	-61.09 (1.22)
Velocitypow	(+)	**1.70** (2.55)**	**2.78*** (3.55)**	**14.30 *** (4.58)**	**3.04 *** (3.62)**
Surge	(+)	13.17 (1.34)	1.09 (0.11)	**-29.97 * (1.97)**	7.59 (0.52)
Dcoast	(-)	0.54 (0.59)	**-1.28 * (1.69)**	**-31.69 ** (2.06)**	0.64 (0.72)
Dmajriver	(-)	**-6.32 ** (2.41)**	**-8.09 ** (2.71)**	-15.12 (0.87)	**-8.17 *** (3.10)**
Dminriver	(-)	**-8.46 *** (2.73)**	**-5.92 * (1.68)**	**-29.50 * (1.84)**	-3.14 (0.85)
Droad	(+)	-7.37 (1.23)	-0.20 (0.04)	7.40 (0.92)	-0.95 (0.15)
Roadumy	(-)	28.43 (1.41)	9.20 (0.41)	**96.87 * (1.68)**	-12.65 (0.59)
Male99	(+)	**0.26 *** (10.38)**	**0.21 *** (6.87)**	**0.22 *** (6.55)**	**0.25*** (7.38)**
Literate	(-)	-49.35 (0.53)	-63.7 (0.89)	-27.28 (0.17)	65.07 (0.73)
Schdulcaste	(+)	59.77 (1.22)	17.05 (0.41)	42.94 (0.20)	47.06 (1.08)
Cultivator	(-)	35.47 (0.21)	**-260.90 * (1.88)**	-20.21 (0.07)	-161.66 (0.89)
Aglabour	(+)	-127.96 (0.62)	-1.29 (0.01)	-388.85 (0.80)	2.01 (0.01)
Hhworker	(-)	-622.63 (0.56)	-583.11 (0.76)	6923.27 (1.27)	-441.69 (0.59)
Otworker	(-)	**-495.70** (2.13)**	**-497.08**(2.40)**	**-1564.66*** (3.65)**	**-699.03 ** (2.53)**
Margworker	(+)	64.59 (0.58)	9.61 (0.08)	**-232.05 * (1.66)**	84.82 (0.52)
Constant	(?)	**-245.98 * (1.79)**	**-218.92 * (1.68)**	**-1256.18*** (3.52)**	**-507.93*** (2.80)**
		N=516, R^2=0.55,	N=338, R^2=0.54,	N=61, R^2=0.77,	N=277, R^2=0.58,
		F(19,496)=12.56	F(19,318)=7.61,	F(19,41)=4.93	F(19,257)=7.14,
		Pro=0.00	Pro = 0.00	Pro=0.00	Pro=0.00

*Notes: ***, **, and * imply 1%, 5%, and 10% level of significance respectively. Figures in parenthesis are the absolute t-values.*

Table 5: Weighted Least Squares Estimates (weight = area) for Partially Collapsed Houses

Equation/ variable	Exp. signs	Sample-1	Sample-2	Sample-3	Sample-4
Mangrove	(+)	**61.69 *** (6.81)**	**63.44*** (4.75)**	1.20 (0.03)	**29.83 *** (2.68)**
Mhabitat	(?)	5.07 (0.81)	**23.36** (2.08)**	**-55.23 ** (2.52)**	**27.57 *** (3.00)**
Topodumy	(-)	-2.31 (0.06)	36.03 (0.64)	**92.14** (2.10)**	**-132.95 * (1.96)**
Casurinadumy	(+)	-56.09 (1.60)	**-126.26** (2.21)**	-25.82 (0.44)	-86.10 (1.56)
velocitypow	(-)	**-3.18*** (4.75)**	**-3.21 *** (2.72)**	-1.53 (0.59)	**-2.07 ** (2.46)**
Surge	(-)	**24.84 ** (2.10)**	24.19 (1.29)	10.02 (0.44)	2.21 (0.15)
Dcoast	(+)	1.26 (0.88)	-2.45 (1.02)	18.97 (1.18)	**-5.55 *** (2.96)**
Dmajriver	(+)	**13.14 *** (3.25)**	**22.32 *** (3.86)**	**41.31 * (1.89)**	**16.27*** (4.19)**
Dminriver	(+)	**2.60 (0.45)**	**8.77 (1.00)**	**-35.91 * (1.93)**	**22.39 *** (3.76)**
Droad	(-)	-7.42 (1.03)	-2.57 (0.32)	**-11.31 (1.15)**	5.42 (0.87)
Roadumy	(+)	**-89.11*** (2.81)**	**-99.16 ** (2.35)**	52.93 (0.82)	**-158.49***(4.79)**
Male99	(+)	**0.11 *** (10.03)**	**0.12 *** (6.66)**	**0.06 *** (2.74)**	**0.24 *** (15.57)**
Literate	(+)	278.32 (1.53)	**393.84 * (1.61)**	**-448.14* (1.77)**	64.05 (0.29)
Schdulcaste	(-)	**307.97*** (3.42)**	**463.10***(3.67)**	**569.49**(2.49)**	-7.49 (0.08)
Cultivator	(+)	-159.54 (0.59)	-610.66 (1.58)	-203.29 (0.47)	**-1123.81*** (2.77)**
Aglabour	(-)	**-1546.75 *** (3.81)**	**-2032.36 *** (3.63)**	**-2599.18 *** (3.67)**	-253.73 (0.60)
Hhworker	(+)	3274.30 (1.44)	3396.18 (0.86)	-6707.80 (0.83)	-1995.19 (0.74)
Otworker	(+)	**-792.83 ** (2.21)**	**-979.39 **(1.94)**	**-1152.71** (2.04)**	-69.60 (0.11)
Margworker	(-)	**-291.94 * (1.73)**	**-347.51 * (1.60)**	**-600.64 ** (2.37)**	265.05 (1.54)
Constant	(?)	**-378.56 *** (2.48)**	310.45 (1.36)	**800.75 ** (2.11)**	**385.10 * (1.80)**
		N=515, F(19,495)=35.52, Pro = 0.00, $\bar{R}^2$ =0.56	N=337, F(19,317) =22.72, Pro =0.00, $\bar{R}^2$ =0.55	N=61, F(19,41) =9.31, Pro = 0.00, $\bar{R}^2$ =0.72	N=276, F(19,256) Pro=70.01, $\bar{R}^2$ =0.72

Notes: ****, **, and * imply 1%, 5%, and 10% level of significance respectively. Figures in parenthesis are the absolute t-values.*

Table 6: Averted House Damages and Values

Type of House Damage	Averted Damages (no of houses)	Value per km width of Mangrove per Village
	Sample 2	Sample 2
Fully collapsed houses	13,687 (72957-59276)	Rs.1428.15
Partially collapsed houses	-14,339 (44,528-58,867)	-Rs.280.18

Table 7: Storm Protection Values of Mangroves

Average storm protection value /km width of forest / village	Rs.1148 (Rs.1428 – Rs.280)
Total storm protection value / km width of forest for the study area	Rs.9,75,800
Total storm protection value / hectare of forest for study area	Rs.51,168/

Appendix Table 8: Ordinary Least Squares Estimates with Robust Std. Errors for Fully Collapsed Houses with Tahasildar Dummies

Equation/ variable	Exp. signs	Sample-1	Sample-2	Sample-3	Sample-4
Kujangparadep	(?)	**909.85*** (7.49)**	**556.26*** (4.24)**	686.47 *** (2.38)	99.52 (0.72)
Mahakalpada	(?)	**874.58*** (7.07)**	**460.83*** (5.97)**	948.17 *** (4.99)	-132.11 (1.32)
Rajnagar	(?)	Dropped	**-523.572*** (3.67)**	**Dropped**	**-830.38*** (5.26)**
Rajkanika	(?)	**315.66*** (3.10)**	**-139.24 (1.22)**	Dropped	**-694.83*** (5.73)**
Patamundai	(?)	**755.16*** (5.71)**	**268.69*** (2.87)**	Dropped	**-298.16** (2.41)**
Aul	(?)	**510.56*** (4.32)**	Dropped	Dropped	**-598.56*** (5.39)**
Garadpur	(?)	**1263.88*** (8.11)**	Dropped	Dropped	Dropped
Marsaghai	(?)	**1162.41*** (7.62)**	**570.23*** (6.38)**	Dropped	Dropped
Kend-derabis	(?)	**869.89*** (7.09)**	**431.25*** (5.91)**	Dropped	-147.91 (1.41)
Mangrove	(-)	-16.73 (1.02)	-10.05 (0.58)	**-38.16* (1.80)**	-13.62 (0.85)
Mhabitat	(?)	6.87 (1.21)	-0.20 (0.05)	**-36.76*** (3.19)**	3.69 (0.66)
Topodumy	(+)	-17.95 (0.53)	-7.54 (0.35)	45.02 * (1.81)	-49.32 (1.48)
Casurinadumy	(-)	-7.32 (0.23)	19.22 (0.62)	21.27 (0.63)	-11.60 (0.22)
Velocitypow	(+)	**-1.31 ** (2.15)**	-0.43 (0.64)	**4.80* (1.84)**	-0.56 (0.59)
Surge	(+)	9.87 (1.19)	-0.79 (0.09)	-10.59 (1.07)	5.59 (0.45)
Dcoast	(-)	-0.73 (0.61)	-0.07 (0.08)	9.03 (0.92)	-0.30 (0.30)
Dmajriver	(-)	1.02 (0.47)	-1.11 (0.40)	-1.66 (0.17)	-0.94 (0.34)
Dminriver	(-)	-0.68 (0.31)	-2.40 (0.90)	-1.37 (0.14)	-2.42 (0.78)
Droad	(+)	**-14.24 *** (2.89)**	-3.55 (0.86)	-2.49 (0.46)	-0.28 (0.05)
Roadumy	(-)	12.64 (0.74)	-7.20 (0.38)	36.49 (1.01)	-9.30 (0.45)
Male99	(+)	**0.26*** (10.34)**	**0.28*** (10.24)**	**030*** (9..79)**	**0.28*** (7.14)**
Literate	(-)	7.70 (0.11)	38.88 (0.68)	-123.41 (1.11)	57.44 (0.80)
Schdulcaste	(+)	**86.13** (1.98)**	28.80 (0.85)	-25.62 (0.23)	12.52 (0.36)
Cultivator	(-)	-78.74 (0.54)	-266.58 ** (2.37)	-141.38 (0.67)	**-234.89 * (1.74)**
Aglabour	(+)	**-331.12 * (1.87)**	-172.52 (1.36)	-527.43 (1.49)	-71.94 (0.48)
Hhworker	(-)	-1415.72 (1.14)	-512.98 (0.79)	2010.21 (0.65)	-694.77 (1.08)
Otworker	(-)	**-504.96 ** (2.77)**	**-635.22 *** (2.91)**	-445.53 (0.79)	**-539.58 ** (2.11)**
Margworker	(+)	-61.78 (0.69)	-69..90 (0.71)	-.113.86 (1.01)	-31.04 (0.22)
Constant	(?)	**-588.69 *** (3.70)**	**-262..08 * (1.87)**	**-1222.48*** (4.65)**	303.56 (1.18)
		N=516, R^2=0.66, F(27,488)=12.45, Pro=0.00	N=338, R^2=0.71, F(25,311) =missing,	N=61, R^2=0.91, F(21,39)=19.35 Pro=0.00	N=277, R^2=0.68, F(26,249) =missing,

*Notes: ***, **, and * imply 1%, 5%, and 10% level of significance respectively. Figures in parenthesis are the absolute t-values.*

Appendix Table 9: Weighted Least Squares Estimates (weight=area) for Partially Collapsed Houses with *Tahasildar* Dummies

Equation/ variable	Exp. signs	Sample-1	Sample-2	Sample-3	Sample-4
Rajkanika	(?)	**315.66*** (3.10)**	**-139.24 (1.22)**	Dropped	**-694.83*** (5.73)**
Patamundai	(?)	**755.16*** (5.71)**	**268.69*** (2.87)**	Dropped	**-298.16** (2.41)**
Aul	(?)	**510.56*** (4.32)**	Dropped	Dropped	**-598.56*** (5.39)**
Kujangparadep	(?)	**Dropped**	**-397.24 * (1.75)**	Dropped	**-503.74** 2.37**
Mahakalpada	(?)	**145.45 ** (2.26)**	-178.43 (1.04)	**349.40 * (1.85)**	**-432.76 *** 3.61**
Rajnagar	(?)	**433.79*** (3.64)**	36.99 (0.18)	**1112.86 *** (3.90)**	**499.46*** 3.72**
Rajkanika	(?)	**492.46*** (4.36)**	78.52 (0.39)	Dropped	28.35 0.24
Patamundai	(?)	**726.58 *** (8.82)**	**367.31 ** (2.10)**	Dropped	95.18 0.89
Aul	(?)	**655.26 *** (3.83)**	234.66 (0.93)	Dropped	**Dropped**
Garadpur	(?)	**251.07 *** (3.40)**	Dropped	Dropped	Dropped
Marsaghai	(?)	**205.14 *** (2.95)**	Dropped	Dropped	**-281.08* (1.84)**
Kend-derabis	(?)	35.56 (0.47)	**-349.99 ** (2.00)**	Dropped	**-510.61*** (4.39)**
Mangrove	(+)	**72.17*** (7.63)**	**66.25 *** (5.35)**	**33.38 ** (2.00)**	**21.85** (2.13)**
Mhabitat	(?)	-2.70 (0.40)	**19.90 * (1.87)**	**-37.82 ** (2.03)**	**41.73 *** (4.41)**
Topodumy	(-)	45.73 (1.30)	69.55 (1.39)	12.92 (0.32)	-25.77 (0.46)
Casurinadumy	(+)	**-64.33 ** (2.10)**	**-158.33 *** (3.13)**	**-140.57 ** (2.64)**	**-163.71 *** (3.54)**
Velocitypow	(-)	1.24 (1.23)	-0.70 (0.47)	**14.00 *** (3.70)**	0.80 (0.77)
Surge	(-)	10.91 (0.89)	-0.09 (0.00)	-26.03 (0.32)	6.27 (0.47)
Dcoast	(+)	0.23 (0.11)	2.02 (0.71)	-14.88 (0.99)	0.04 (0.02)
Dmajriver	(+)	9.27 (2.43)	**16.30 *** (2.93)**	25.23 (1.41)	**13.95 *** (4.06)**
Dminriver	(+)	**11.73 ** (2.12)**	**21.59 *** (2.64)**	**-54.55*** (3.49)**	**19.93 *** (3.90)**
Droad	(-)	**-12.61 *** (3.06)**	**-14.32 * (1.95)**	**15.94 * (1.66)**	-2.78 (0.52)
Roadumy	(+)	-20.14 (0.69)	-5.22 (0.13)	**91.22 * (1.75)**	-43.97 (1.53)
Male99	(+)	**0.04 ** (2.41)**	**0.04* (1.78)**	0.03 (1.40)	**0.12 *** (6.80)**
Literate	(+)	-192.43 (1.14)	-294.51 (1.29)	-327.11 (1.59)	**352.13 * (1.81)**
Schdulcaste	(-)	114.43 (1.40)	142.18 (1.24)	234.96 (1.17)	110.6 (1.29)
Cultivator	(+)	39.38 (0.16)	43.93 (0.13)	99.02 (0.28)	-310.48 (0.90)
Aglabour	(-)	**-718.90 * (1.95)**	**-908.86 * (1.81)**	**-1796.35*** (3.03)**	-60.86 (0.17)
Hhworker	(+)	2645.87 (1.34)	2567.03 (0.74)	1306.76 (0.20)	-1596.56 (0.73)
Otworker	(+)	-171.08 (0.54)	390.82 (0.71)	-483.83 (0.82)	615.84 (1.15)
Margworker	(-)	185.70 (1.22)	149.75 (0.76)	**-426.79** (2.07)**	**670.23 *** (4.68)**
Constant	(?)	-144.27 (0.70)	352.50 (1.11)	**-1519.72 ** (2.46)**	-234.10 (1.00)
		N=515, F (27,487) =40.35, Pro=0.00, $\bar{R}^2$ =0.67	N=337, F(26,310) =26.82, Pro = 0.00, =0.67 $\bar{R}^2$ =0.67	N=61, F(21,39) = 14.38, Pro = 0.00,=0.82 $\bar{R}^2$ =0.67	N=276, F(26,249) =90.00, =0.89 $\bar{R}^2$ =0.67

Notes: ***, **, and * imply 1%, 5%, and 10% level of significance respectively. Figures in parenthesis are the absolute t-values.

Appendix Table 10: Ordinary Least Squares Estimates with Robust Std. Errors for the Ratio of Fully Collapsed to Partially Collapsed Houses

Equation/ variable	Exp. signs	Sample-1	Sample-2	Sample-3	Sample-4
Mangrove	(-)	**-0.70** (2.19)**	**-0.66** (2.30)**	-1.22 (0.73)	**-0.39* (1.84)**
Mhabitat	(?)	0.53 (1.38)	-0.11 (0.45)	-1.94 (1.37)	**0.28 * (1.85)**
Topodumy	(+)	4.07 (1.27)	4.02 (1.56)	7.28 (1.48)	0.95 (0.66)
Casurinadumy	(-)	**3.82* (1.63)**	2.36 (1.45)	**15.31 * (1.76)**	0.81 (0.66)
Velocitypow	(+)	0.02 (0.81)	-0.002 (0.12)	-0.13 (0.48)	0.02 (1.09)
Surge	(+)	0.44 (0.91)	0.04 (0.10)	-0.49 (0.32)	0.37 (1.05)
Dcoast	(-)	**-0.18***(2.78)**	0.05 (1.41)	1.94 (1.57)	**0.08 ** (1.97)**
Dmajriver	(-)	**0.55** (2.14)**	**-0.21** (2.23)**	0.75 (0.36)	**-0.21***(2.65)**
Dminriver	(-)	-0.12 (0.65)	-0.04 (0.27)	0.34 (0.16)	-0.06 (0.46)
Droad	(+)	**-0.84***(2.61)**	**-0.63 ** (2.06)**	-2.22 (1.59)	**-0.25 ** (2.09)**
Roadumy	(-)	0.42 (0.27)	-1.56 (1.17)	-10.16 (1.11)	-0.57 (0.80)
Male99	(+)	**-0.001* (1.76)**	-0.001 (1.31)	**-0.005 * (1.69)**	0.0003 (0.77)
Literate	(-)	-8.65 (0.78)	-18.36 (1.33)	-74.96 (1.49)	1.18 (0.28)
Schdulcaste	(+)	-0.55 (0.15)	**-7.09 * (1.78)**	-20.32 (1.03)	-1.51 (1.03)
Cultivator	(-)	-5.31 (0.53)	-0.22 (0.03)	-68.64 (0.87)	-0.50 (0.10)
Aglabour	(+)	-5.17 (0.28)	6.55 (0.80)	-161.58 (1.17)	7.83 (1.25)
Hhworker	(-)	-48.53 (1.28)	-15.02 (0.40)	193.35 (0.39)	-40.80 (1.20)
Otworker	(-)	-20.51 (0.84)	19.01 (1.25)	-58.61 (0.45)	12.19 (1.12)
Margworker	(+)	-3.05 (0.44)	3.23 (0.97)	5.82 (0.42)	3.80 (1.01)
Constant	(?)	10.84 (1.04)	19.16 (1.36)	102.40 (1.22)	-3.85 (0.86)
		N=486, R^2=0.11, F(19,466)=3.91, Pro=0.00	N=318, R^2=0.15, F(19,298)=2.88, Pro=0.00	N=48, R^2=0.46, F(19,28)=1.02, Pro=0.47	N=270, R^2=0.15, F(19,250)=5.09, Pro=0.00

*Notes: ***, **, and * imply 1%, 5%, and 10% level of significance respectively. Figures in parenthesis are the absolute t-values.*

FIGURES

Figure - 1: (a) Super Cyclone Making Landfall near Kendrapada District

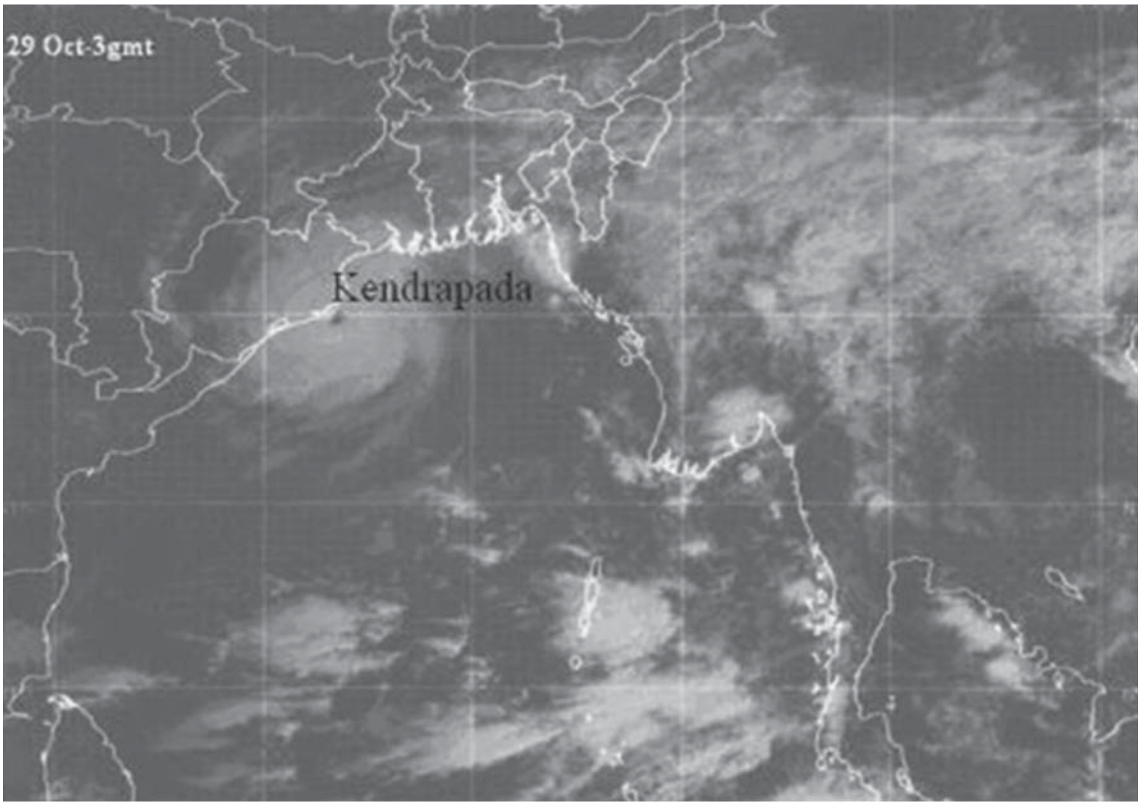


Figure 1: (b) Location of Kendrapada District in Cyclone Affected Orissa

Figure 2: (a) Mangroves of Kendrapada District as existed in 1999 and the Track of 1999 Super Cyclone

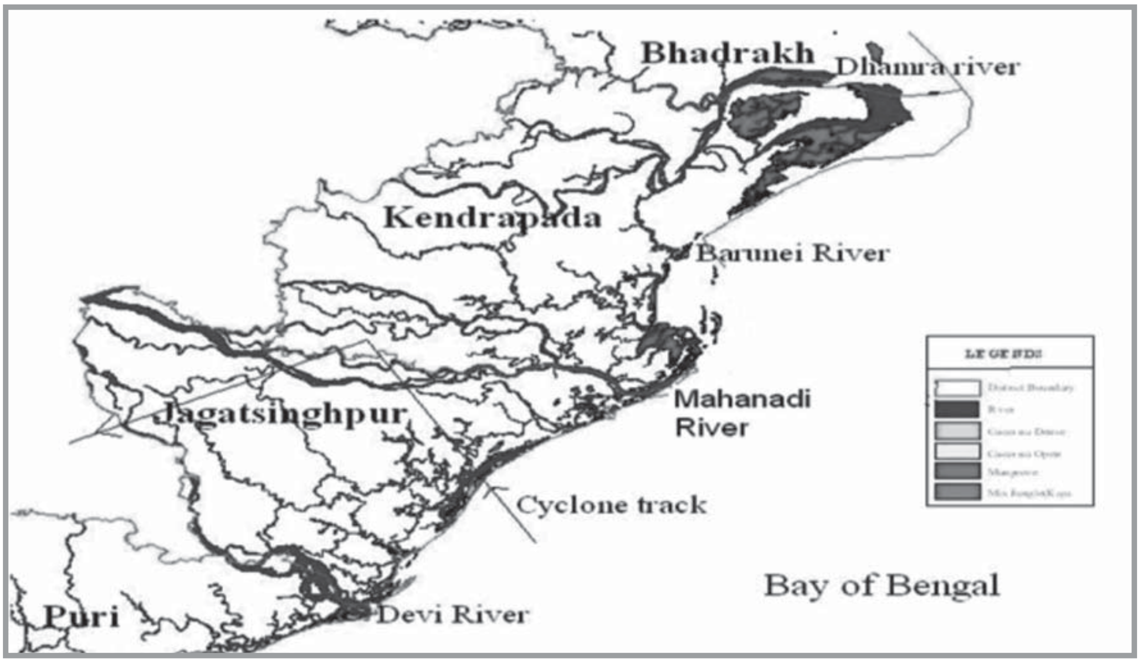
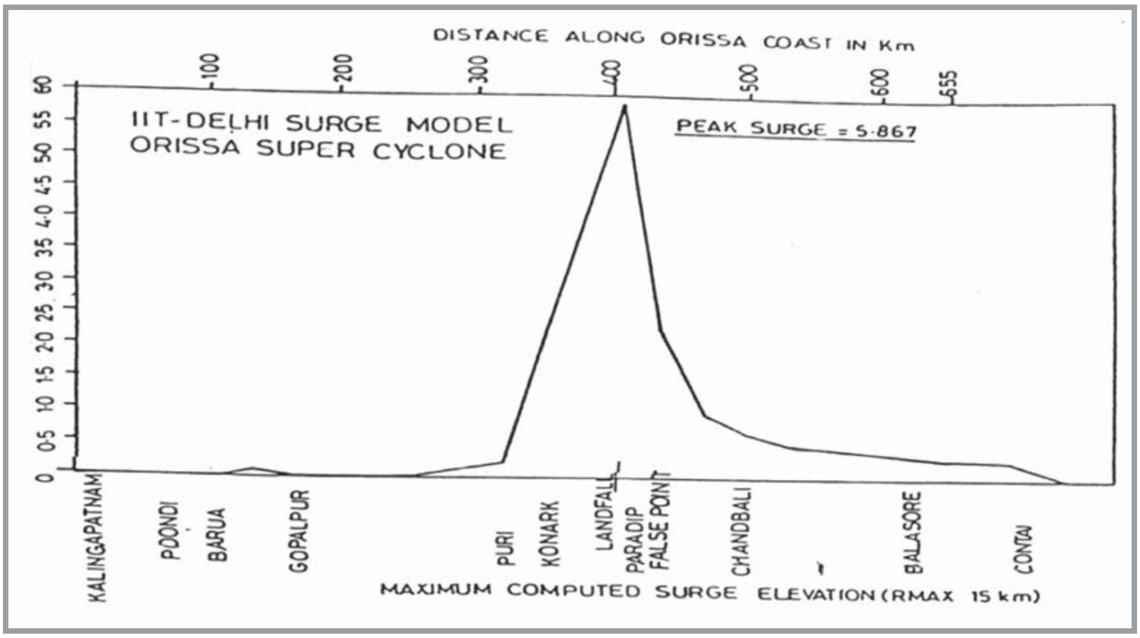


Figure 2: (b) Mangroves of Kendrapada District as existed in 1950 and the Track of 1999 Super Cyclone

Figure 3: Sea Elevations at Orissa Coast during 1999 Super Cyclone Landfall



Source: Meteorology Department, Government of India