Storm Protection Value of Mangroves from the Valuation of Expected Damage to Properties and Lives Due to Cyclones in Coastal Orissa*

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Abstract: *The paper describes a methodology that can be used to capture the storm protection value of mangrove forests and casurina forests. The storm protection value is conditional for the probability of cyclone hitting the coastline and this methodology uses the cyclone probability of the coastline to calculate the value of mangroves and casurina trees.*

Introduction

Mangroves are the salt tolerant tropical and sub-tropical forests that grow in the inter-tidal areas and estuary mouths of the coastal zone. These forests are habitat to a wide variety of marine and terrestrial flora and fauna and also provide a range of provisioning, supporting, regulating and cultural services to mankind (MA, 2003). Mangrove loss or conversion of mangrove areas into acquacultural, developmental or anthroprogentic uses is worldwide and the most prominent global drivers are acquaculture, agricultural practices and population growth of low and middle income countries (Barbier and Cox, 2003).

Mangroves forests act as safty net to coastal poors (Ruintenbeck, 1997; Barbier and Sathirathai, 2004) by providing both the sources of livelihood as well as protection to their lives and properties in face of natural calamities like cyclone. Mangrove loss increases the vulnerability of coastal people and more so, if the coastal areas are dominated by poor people living in mud houses. The glaring example is the colossal loss of human life, livestock and properties in the backward State of Orissa of India due to the supercyclone of 1999 that originated in the Indian ocean and had its landfall near the Pardeep port of Orissa coast. If the mangrove forests world have been there , that were bestowed with that area by nature initially, the loss, probably, would have been much less.

Storm Protection Function of Mangroves

Storm protect in function of mangroves is a well recognised protective service both in tropical and sub-tropical areas and there is reported evidence of areas protected by mangroves receiving less damage due to cyclone than the nonprotected areas. [**International Federation of Red Cross and Red Crescent News, 19th June, 2002; Badola, 2002; Tynkknen, 2000; Fosberg, 1971; Environmental Protection Agency, Queensland Parks & Wildlife Series**]. Mangroves trees provide wind break and the strong criss-crossed roots of mangrove trees break the wave energy and reduce the height as well as the speed of the storm surges. Research has shown that for every mile of vegetative wet land (not necessarily mangrove), storm surge height can be reduced by one foot.[1]

However, there has neighter been any attempt to evaluate this function of mangroves systematically nor to link up this value to the probability of cyclone hitting the coastal areas or to the storm surge vulnerability of the coast. The present paper describes a methodology that can be used to evaluate this function and calculate the probabilistic

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[1] Centre for Environmental Communication & M. Rockel (1991). Economic Valuation of Wetlands; Discussion Paper 065, Institute of Environmental Communication, Louisiana, US.

or expected value of mangroves.

Cyclones and Coastal Orissa

The climatically sensitive State of Orissa is a frequent witness to the ravages of cyclones and super cyclones and the additional calamities resulting from them. In Indian subcontinent, the annual frequency of cyclones crossing the east coast of the country is very high compared to west coast and along the east coast, it is again highest for the coast of Orissa as evident from Table 1 and 2.

Table 1: Monthly distribution of cyclonic storms for the period 1891-1990 for the east and west coast of India.

Month	BOB	**AS**	**Month**	BOB	**AS**
January	6	1	August	27	6
February	1	0	September	40	6
March	4	1	October	82	17
April	21	6	November	99	15
May	51	19	December	42	4
June	39	18	Total	**454**	**95**
July	42	2			

Source : Damage Potential of Tropical Cyclones, Indian Meterological Department, Govt. of India, 2002.

Note : BOB : Bay of Bengal; AS : Arabian Sea

Table 2: Total number of cyclonic storms (CS) and severe cyclonic storms (SCS) crossing different coast of India (1891-2000).

State	**No. of CS and SCS**
West Bengal	69
Orissa	98
Andhra Pradesh	79
Tamil Nadu	62
Karnataka	02
Maharashhtra and Goa	18
Gujarat	28
Kerala	03
Total	363

Source : G.S. Mandal, WMO 1991, "Tropical Cyclones and their forecasting and warning system in North Indian Ocean : WMO TD No.430, Tep No.28, WMO, Geneva.

Note : The frequencies don't include the occurrence of depressions or deep depressions or cyclones of less than 62 KMPH wind speed.

Compared to 445 cyclonic disturbances in east coast of the country, the west coast experienced only 95 disturbance in between 1891-1990 and the State of Orissa faced maximum severe cyclones compared to other coastal states of India.

Again of the 12 most devastating cyclonic storms that made landfall in east coast of India in the last 263 years, the state of Orissa was witness to five of them where as the State of Andhra Pradesh to four and West Bengal to three (Appendix table A-1).

The cyclone tracks published by the Metrological department of Govt. of India, and shown in Figure 1 and 2 shows a particular coastal stretch of Orissa (Coast of Jagatsinghpur, Kendrapara, Bhadrakh and Balasore districts) to be more vulnerable to cyclones as maximum cyclones originating in the months of June to September have their landfall in these areas.

Along with the high frequency of cyclones, these areas also have high vulnerability index due to high population density and high storm surge vulnerability. Mr. Kavi Kumar of Madras School of Economics, Chennai, India has done a detailed vulnerability indexing of coastal districts of Indian Union taking multiple of factors like demographic, coastal, topographical metrological and economic indicators. Various indexes calculated by him also corroborates the fact that districts along the eastern coast are more vulnerable than those on western coast of the 49 coastal districts of India; Baleswar and Cuttuck (these districts were further subdivided into Baleswar, Bhadrakh, Kendrapara and Jagatsinghpur by Government of Orissa in 1993) of Orissa and North and South 24 Parganas of West Bengal came out to be the most vulnerable districts with the only difference that Orissa districts have a slightly higher ability to bounce back after a disaster than the 24 parganas. In Orissa, though historically Balaswar was the most vulnerable district, with global climate change, Cuttuck (presently Kendrapara and Jagatsinghpur) is being predicted to be the most vulnerable one (Sukla et al., 2003).

These coastal region was bestowed with thick mangrove forest from nature[1] which were destroyed due to developmental factors like establishment of Paradeep port, roads, fishing ports etc., anthropogenic activities like human settlement, agriculture, bettlevine farms etc. and also due to establishment of acquacultural firms both by private and government sectors. Presently, this region has approximately 216 sq.km of mangrove forests (both dense and degraded) in different patches.[2] Because of their strategic location at a highly cyclone prone area and storm protection value of mangroves being conditional to the frequency of cyclones crossing the coast line, evaluation of the storm protection function of the mangroves of Orissa coast could give the most approximate value of this protective serviceof mangroves.

The Casurina Forest of Orissa

The entire coastline of Orissa has basically two types of forests, mangroves in the low lying swampy areas and casurina trees on the slightly higher sandy beaches. The casurina forest that dot the coast line of Orissa were planted under the special scheme of coastal shelter belt plantation to protect the coastal areas from the ravages of cyclonic storms. Like the super cyclone of 1999, the State of Orissa was ravaged by a severe cyclonic storm in October 1971 that had brought heavy human, cattle casuality as well as property loss. The then Govt. of India, Ministry of Irrigation and Power had appointed a cyclone distress mitigated committee headed by Dr. P. Koteswaram, DG of Observatories, Indian Metrological Department. The Committee gave 59 recommendations of which the 32nd measure was to built coastal bundhs along the tidal inundation vulnerable areas and afforestation to a depth of about 1(one) kilometer from coast line to act as wind breaker and prevent soil erosion. The afforestation programme was implemented with great sincerity under the coastal shelterbelt plantation scheme that started in 1974 and was abolished in 1984 after covering 7880.59 hectare of sandy coast under the plantation. Under this scheme, casurina, cashew and coconut plantation were raised along the sea, coast and on the estuaries of major rivers of the then Cuttuck and Balaswar districts and their branches. Though there is hardly any research on the contribution of these forests to micro or macro livelihood support base, the initial aims of these plantations were to protect coastal area from cyclone and sand casting, supply firewood and improve social environment. However, the wind break or cyclone buffer function of these forests will be evaluated by the present methodology and compared with that of mangroves. Mangrove trees and casurina trees are complementary to each other as areas where mangroves grow are not suitable for casurina and so is the case with casurina areas. Hence location having casurina will have no mangroves in their coast line.

Review of Literature

Most of the literature on mangrove forests have mostly focussed on three different issues :

1. Identifying the drivers of mangrove loss [Lahman et al., 1987; Parks et al., 1994; Dewalt et al., 1996; Primavera, 2000; Mirian et al., 2000; Barbier and Cox, 2004].

2. Comparing the economic value of mangrove preservation to mangrove conversion [Christensen, 1982; Dugan, 1990; Lal, 1990; Ruitenbeck, 1997; Naylor and Dew, 1998; Gilbert & Janssen, 1998; Janseen and

[1] District Gazetteers of Cuttuck districts, 1939 and 1996.

[2] Status of mangrove in Orissa : Wildlife organisation, Forest Department, Govt. of Orissa, 2004.

padilla, 1999; Nickerson, 1999].

3. Modelling and valuing the mangrove fishery linkage (Sathirathai, 1997; Barbier & Strand, 1998; Ronnback, 1999; Barbier and Sathirathai, 2004].

Evaluation of other critical functions of mangroves like storm protection, shore line stabilization, flood control etc. have received scanty attention so far. The storm protection value of mangroves is mostly being equated to the cost of erecting a protective structure in coastline [Chan et al., 1993; Govt. of Schuelles, 1994]. However, this measure is hypothetical and is not based an any survey or statistical data. Moreover, erecting a wall in coastline will segregate the interdependent coastal ecosystem that may have severe ecological impact in future. Badola (2002) equated the storm protection value of mangroves to the difference in average damage suffered per household due to cyclones in a mangrove protected village compared to a unprotected village. This study is on a very small scale and the villages of Badola's study area being not so homogeneous, the result has little use for policy making.

Sathirathai (1998) though mentioned the protection function of mangroves to be both wind break and shore like stabilization, she has actually equated the protection value of mangroves to the shore line stabilization function leaving, the wind break function unvalued. Peter Espeet (2000) wrote about the heavy payment by insurance companies and more expenditure of public works Department in mangroves cleared areas compared to a mangrove protected area after cyclones. The difference in insurance claims (or insurance premium) and expenditure of public works department (or tax rates) could be a way to capture the storm protection value of mangroves. But this is possible if all properties are insured and all areas are homogeneously developed and hence can't be applied to under-developed countries.

On the question of appropriate methodology to measure this value, Spanink and Beukering (1997) argued the inappropriateness of either WTP or WTA measures as suggested by James (1991) to measure the expected damages or increased risk due to the loss of mangrove protection to people. They suggested the hedonic price method and defensive expenditure to be the more appropriate approaches to value this protective services though their applicability to a particular area is conditional upon the presence of a developed house market or to the degree of substitutability between the defensive measures and the protection provided by the mangroves. In poor underdeveloped countries, the absence of the above mentioned requirements limits the applicability of hedonic price method or defensive expenditure approaches.

The present methodology is based on actual damages suffered due to cyclones in mangrove protected and mangrove cleared areas and hence doesn't suffer from any subjective bias or doesn't require the existence of any market or the substitutability or complementarily between any economic measures.

The Methodology

This methodology is based on the model used by Prof. Stephen Faber to estimate the value of coastal wetlands for protection and property against (of Louisiana) Hurricane wind damage.

Total Damage = Damage due to high wind and storm surge (damages due to flood are excluded).

Location i = Village Panchayats.

Damage at any location, i, due to cyclones depend on the wind velocity at the location and the property at risk :

$$\therefore D_i = f(V_i, P_i) \quad \ldots \quad (1)$$

where D_i is total damage at location i,

V_i is velocity of wind at location, i, and P_i is property at risk (can be represented by population or some measure of income) of location, i.

Wind velocity at a location is dependent on the distance of the location inland, do_i; the distance of the location from the path of the storm, d_{1i}; the intensity of the storm at landfall, g; and the nature of intervening terrain between landfall and the location, l_i or the bounded area of location and landfall.

$$\therefore Vi = F(d_{0i}, d_{1i}, g, l_i) \quad \ldots \quad (2)$$

F(.) is a non-linear function as wind velocity decreases with distance from the path of the storm and distance inland. Hence an exponential function is used for F(.).

$$V_i = g \exp.(\beta_1 d_{oi} + \beta_2 d_{1I}\, l_i) \quad \ldots \quad (3)$$

Wind damage is proportional to square of wind velocity form surge damage is also proportional to height of storm surge that depends on wind speed and total damage is again proportional to property at risk or P.

Hence $D_i = \alpha V^{\gamma}{}_i.\ \phi P_i = \alpha\ \phi\ V_i^{\gamma} P_i = \lambda V_i^{\gamma} P_i \quad \ldots \quad (4)$

where $\alpha \neq 0$, $o < \phi < 1$, $\gamma \approx 2$ and $\lambda = \alpha\ \phi$.

In the study area, the intervening area between the land fall and location has either mangrove forests or casurina forests. Hence l_i is defined as the km of mangrove(M) or casurina(C) forests on the inland distance of the location i or $l_i = d_{oi}\ M + d_{oi}C$. Casurina forests grow on the sandy beaches which are at a higher topography than the sea level and the mangroves grow on the swampy low lying areas of the sea coast.

Hence if $M > 0 \Rightarrow C = 0$

or $C > 0 \Rightarrow M = 0$

Now eq.(3) can be written as

$$V_i = g \exp.(\beta_1 d_{oi} + \beta_2 d_{1i} + \beta_3\ d_{0i} M + \beta_4\ d_{oi}\ C) \quad \ldots \quad (5)$$

where M is defined as width (km) of mangrove forest, W_m, multiplied by health index of the forest, h_m

or

$$M = h_m W_m$$

when $0 < h_m < 1$ and W_m is width of the forest patch in kilometers traversed by the storm.[1]

C is simply the width of casurina forest in kilometers on the inland distance traversed by the storm.[2]

Eq.(4) can be written as

$$D_i = \alpha\phi V_i^{\gamma}\ P_i = \lambda\ [g \exp(\beta_1 d_{0i} + \beta_2 d_{1i} + \beta_3\ d_{0i}\ M + \beta\ d_{0i} C]^{\gamma}\ P_i$$

or $(D/P)_i = \lambda\ g^{\gamma} \exp.(\beta_1\ \gamma d_{0i} + \beta_2 \gamma d_{1i} + \beta_3\ \gamma d_{0i} M + \beta_4 \gamma d_{oi} C)$.

or

$$(D/P)_i = \lambda g^{\gamma} \exp.(\beta_1'\ d_{oi} + \beta_2'\ d_{1i} + \beta_3'\ d_{0i} M + \beta_4'\ d_{oi} C) \quad \ldots \quad (6)$$

where $\beta_1^1 = \gamma\beta_1$, $\beta_2^1 = \gamma\beta_2$ … etc. and $\lambda = \alpha\phi$.

As per metrological calculation, the damages at the left of convergence zone being 1.5 times higher than the damages at the right of the convergence zone, eq.(6) will be divided by 1.5 for all areas lying to the left of cyclone path.

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[1] Typically as defined earlier, W_m should have been the sq.km of mangrove forests in the rectangular area between landfall, the location, distance inland and distance from path of the storm. But mangroves grow only in coastal zone and provide protection to areas lying inland.

[2] Casurina forests are being grown and maintained by the government and the forests are in uniform health in the entire coast line, whereas the mangroves don't here uniform health in the study area. In some areas they are in very good ecological health and in others, in highly degraded form.

$$\left(D/P\right)_i = \frac{1}{\sigma_i}\left[\lambda g^{\gamma} \exp.\left(\beta_1' d_{oi} + \beta_2' d_{1i} + \beta_3' d_{oi} M + \beta_4' d_{oi} C\right)\right] \tag{7}$$

where σ_i = 1.5 for left areas to the left of cyclone path and σ = 1 for areas lying to right of cyclone path.

Eq.(7) expresses the proportional damage at any location or in a particular village panchayat to be dependent on the wind intensity of the storm at landfall and other physical factors like distance in land, distance from the path of the storm, the mangrove or casurina forests on the coast line and whether it is at the left or right of convergence zone, etc.

This equation will be estimated using the cross-sectional data over different village panchayats for the super cyclone that crossed the Orissa coast in Oct.-Nov., 1999 by making a logarithmic transformation of the variables.

The particular coast line of Orissa in the study area is quite prone to cyclones and the probability of a cyclone having its landfall in this area is very high.

Let Π_i (d_{1i}, g) is the probability of a cyclone with land fall wind intensity, g, passing within d_1 km of location, i, hitting the coast line.

Hence the expected storm damage per unit of property at risk at i will be

$$E(D/P)_i = \frac{\lambda}{\sigma_i} \exp.\ (\beta_1' \ d_{0i} + \beta_3' \ d_{0i} M + \beta_4' \ d_{oi} C)$$

$$\int \int g^{\gamma} \exp.\left(\beta_2' d_{1i}\right) \Pi_i \ (d_{1i}, g) \ dg \ dd_{1i} \qquad \ldots \qquad (7)$$

If the mangroves are over exploited or are cleared, the expected damage or the risk to properties at any location due to cyclones will increase.

Hence the marginal expected per unit damage effect at any location, i, due to mangrove loss or over exploitation is

$$-\left[\frac{\partial E\left(D/P\right)_i}{\partial h_m} + \frac{\partial E\left(D/P\right)_i}{\partial W_m}\right]$$

$$= \frac{\lambda}{\sigma_i} \exp.\ (\beta_1' \ d_{0i} + \beta_3' \ d_{oi} \ M + \beta_4' \ d_{oi} C)$$

$$\left[\int \int g^{\gamma} \exp.\left(\beta_2' d_{1i}\right) \Pi_i\left(d_{1i}, g\right) dg, dd_{1i}\right] \left[\beta_3' d_{oi}\left(W_m + h_m\right)\right]$$

$$= \frac{\lambda}{\sigma_i} \exp.\left(\beta_1' d_{0i} + \beta_3' d_{0i} M + \beta_4' d_{oi} C\right) \beta_3' d_{0i}\left(W_m + h_m\right)$$

$$\int \int g^{\gamma} \exp.\left(\beta_2' d_{1i}\right) \Pi_i\left(d_{1i}, g\right) dg, dd_{1i} \qquad \ldots \qquad (8)$$

Eq.(8) shows the marginal damage effect of mangrove loss due to both over exploitation of forest and clearing of every km of the forest.

The marginal damage effect of casurina loss will be :

$$\frac{\partial E(D/P)_i}{\partial C} = (\beta_4' d_{0i}) \frac{\lambda}{\sigma_i} \exp.(\beta_1' d_{0i} + \beta_3' d_{0i} M + \beta_4' d_{oi} C)$$

$$\int \int g^{\gamma} \exp.(\beta_1' d_{1i}) \Pi_i (d_{1i}, g) dg, dd_{1i} \qquad \ldots \qquad (9)$$

Then eq.(8) and (9) will be valued by using the estimated parameters of equation (7) for every location i.e. village panchayats.

For storm protection value of mangrove, the marginal damage of every village Panchayat having mangrove protection will be multiplied by the property at risk of the respective panchayats and will be added together to get the marginal value of a km of mangroves.

Similarly the value of a km of casurina forest will be calculated by adding the marginal damages of panchayats having casurina protection.

Cyclone Probability of Orissa Coast

The Indian metrological department categorises the cyclonic disturbances into seven different categories as given below :

Types of Disturbances	**Meterological Name**	**Associated Wind Speed**
Low Pressure Area	L	< 17 knots
Depression	DD	17-27 knots
Deep Depression	DD	28-33 knots
Cyclonic Storm	CS	34-47 knots
Severe Cyclonic Storm	SCS	48-63 knots
Very severe cyclonic storm	VSCS	64-119 knots
Super cyclonic storms	SUCS	≥ 120 knots

Note : 1 knot = 1.86 km per hour (kmph)

The damage potential of the 1st two category of disturbances is very negligible where as it increases at an increasing rate with the later categories. The metrological department of Government of India has published the path of three types of cyclonic disturbances over the Indian ocean and Indian subcontinent for the period 1891-1990. The maps show the point of origin, the landfall point as well as the inland path of the different disturbances like depression, storm and severe storms.

The cyclone probability for the coast of Orissa has been calculated from these cyclone track records. Though DD and CS are very frequent on Orissa coast, the occurrences of catastrophic disturbances like VSCS and SUCS and rare. In between 1737 and 2000 (263 years), the State of Orissa witnessed only five catastrophic cyclones (Appendix Table-A).

The mangrove forests are found in Jagatsinghpur, Kendrapara and Bhadrakh district where as casurina forests are found in all coastal districts and the cyclone frequency of these districts are not uniform. Hence the cyclone probability to be used in the valuation of these forests is calculated separately. For mangroves it is the annual probability of cyclone per km of coastline of Bhadrakh, Jagatsinghpur and Kendrapara districts where as for casurina, it is per km of coast line of the above three and Puri district. The cyclone track records show an uniform cyclone vulnerability of the locations of Bhad, Jagat and Kend. districts where as the cyclone frequency is very low for Puri. Table 3 shows the frequencies of different cyclonic disturbances for the coast of Bhad, Jagat and Kend districts.

Table 3: Monthly frequency distribution of cyclonic disturbances in the coast of Jagat, Kend and Bhad districts of Orissa State for the period 1891-1990.

Cyclone Type	**January to April**	**May**	**June**	**July**	**August**
DD	0	0	10	10	15
CS	0	1	7	11	14
SCS	0	2	1	3	2
VSCS	0	1	0	0	0

Cyclone Type	**September**	**Oct.**	**Nov.**	**Dec.**	**Total**
DD	7	1	1	0	44
CS	7	1	1	0	42
SCS	0	5	1	0	14
VSCS	0	0	0	0	1

Source : Track Records of depressions and storms over Indian ocean, IMD, Govt. of India.

The combined coast line of the above three district being 185 km and that of Puri being 155 km the annual probability per km of coastline is calculated in Table 4.

Table 4: Annual probability of cyclone per km of selected coast line of Orissa coast.

	Wind Criteria in kmph	Mid print wind speed	Total frequency in 100 years	Annual frequency per km	
				a	b
DD	52-61	56.54	44	0.0023784	0.0018333
CS	62-88	75	42	0.0022703	0.00175
SCS	89-117	103	14	0.0007568	0.0005833
VSCS	119-221	170	1	0.0000541	0.0000417

Source : Table 3

Note : (a) For coast line of Bhad, Kend and Jagat (185 km); (b) For coastline of Bhad, Jagat, Kend and Puri (240 km)

The annual frequencies presented in column 5 and 6 and the associated mid point wind speed of different cyclone categories will be used to estimate the expected damage to properties due to mangrove or casurina loss.

Estimation of Expected Damage

The marginal expected damage to properties at any village panchayat, i, due to mangrove loss or over exploitation of mangrove has been shown to be equal to :

$$-\left[\frac{\partial E(D/P)_i}{\partial h_m}+\frac{\partial E(D/P)_i}{\partial W}\right]$$

$$=\frac{\lambda}{\sigma_i}\exp.(\beta_i' d_{oi}+\beta_3' d_{oi}M+\beta_4' do;C)$$

$$\left\lfloor\iint g^{\gamma}\exp(\beta_2' d_{0i})\Pi_2;\quad (d_{1i},g)dg\ dd_{1i}\right\rfloor\ [\beta_3' d_{0i}(W_m+h_m)]$$

The calculation of this value needs the estimated coefficients of damage function, the β_s; the distances inland and from the path of the cyclone to the panchayat, i, the existence of either mangrove or casurina on coast line; the cyclone probability function and the range of integration for the cyclone types and damage diameter area.

The cyclone probability function is the discrete probability distribution described in Table 4. Though the damage potential of DD is very less, due to non-availability of detailed data on landfall, wind speed of different cyclones, excluding them would have made the data points of discrete probability distribution very small. As the study area included four districts and the super cyclone of October 1999 had affected a vasttarea of more than 200 km radius, the range of integration for d_1 is taken to be 0-100 km. As the damage function has not been estimated for the study area, some approximate values of β coefficients are used to get some approximate result.

Suppose[1] :

β_1 = -0.1150

β_2 = -0.0486

β_3 = 0.0017

β_4 = 0.0006

λ = 5.687

If there is a village panchayat within 4 km on the right side of the path of the storm and 5 km from the sea coast and having 2 km of dense mangrove forest on the inland distance, the per capita marginal value of mangrove for that location will be as follows :

MV (do_i, M) = MV (5, 2)

$$= \frac{5.687}{T_i = 1} \exp.(-0.1150 \text{ x } 5 + 0.0017 \text{ x } 5 \text{ x } 1 + 0.0006 \text{ x } 0)$$

$$\int_0^{100} \exp.(-0.0486 d_1) dd_{1.} 2(\Sigma g^{\gamma} \Pi) \left[0.0017(5+1)\right]$$

$$= 5.687 \exp.(-0.5750 + 0.0085) \int_0^{100} \exp.(-0.0486 d_1) dd_1 \, 2 \Sigma g^{\gamma} \Pi (0.0102)$$

As the location is having mangroves in the coastline, C = 0 and the discrete storm probability is multiplied by 2 as any location will be affected if a cyclone passes through either its left or right side.

The mangrove being dense mangrove, $W_m = 5$ and $h_m = 1$.

Using the discrete probability distribution of Table 4 and $\gamma = 2$, $2\, \Sigma g^{\lambda} \Pi = 59.910532$

Putting the respective values, the MV (5, 2) = Rs.40.2664.

The loss of one km of mangrove increases the expected damage to properties by Rs.40.2664 per capita. If there are 5000 people living in that panchayat, the value of a km of mangrove to that panchayat comes out to be Rs.2,01,332. Thus the value of a km of mangrove to every panchayat getting the protection can be calculated and summed up.

Similarly the value of casurina forests will be calculated.

[1] These value are based on Prof. S. Farber's work.

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