Supporting Information

Das and Vincent 10.1073/pnas.0810440106

Table S1. Definitions and data sources for variables

Variable	Description	Source
Human deaths	Number of deaths per village during the cyclone	Emergency Office, Kendrapada, Government of Orissa
Village population	Estimated number of residents	Interpolated from estimates for 1991 and 2001 reported in the Primary Census Abstract of the State of Orissa
1999 mangrove width	Distance (in km) between the coast and the interior boundary of the forest along the shortest distance from a village to the coast	Forest boundary based on October 11, 1999, images from the LISS-III Pan sensor of Indian satellite IRS-1D
1944 mangrove width	Distance (in km) between the coast and the 1944 interior boundary of the forest along the shortest distance from a village to the coast	Forest boundary based on 1:250,000 U.S. Army map (NF 45–14 Series U502, "Cuttack" sheet)
Height of storm surge	Height of storm surge (in m) along the coast, at the shortest distance from a village	Surge envelope curve constructed by the Indian Meteorological Department (1)
Low elevation	0–1 dummy variable, equal to 1 if a village was located within the 1944 or 1999 mangrove boundary and 0 otherwise	Same as for 1944 and 1999 mangrove widths
Casuarina buffer	0–1 dummy variable, equal to 1 if there was a casuarina buffer between a village and the coast and 0 otherwise	Same as 1999 mangrove width
Seawater dike	0–1 dummy variable, equal to 1 if there was a seawater dike in a village and 0 otherwise	GIS files purchased from Digital Cartography and Services, Bhubaneswar, Orissa
Distance from coast	Minimum distance between a village and the coast	Same as seawater dike
Distance from major river	Minimum distance between a village and a river that flowed directly into the sea	Same as seawater dike
Distance from minor river	Minimum distance between a village and a tributary of a major river	Same as seawater dike
Distance from nearest road	Minimum distance between a village and a metallic road	Same as seawater dike
Literacy rate	Fraction of village residents who were literate	Same as for village population
Scheduled caste	Fraction of village residents who were members of a scheduled caste	Same as for village population
Cultivator	Fraction of village residents employed as cultivators (farmers)	Same as for village population
Agricultural laborer	Fraction of village residents employed as agricultural laborers	Same as for village population
Worker in home industry	Fraction of village residents self-employed in businesses operated out of their homes	Same as for village population
Marginal worker	Fraction of village residents employed as casual laborers	Same as for village population
Other worker	Fraction of village residents employed in all other occupations (teacher, doctor, etc.)	Same as for village population
Tahasil: Marshagai	0–1 dummy variable, equal to 1 if a village was located in Marshagai *tahasil* and 0 otherwise	Primary Census Abstract of the State of Orissa
Tahasil: Patamundai	0–1 dummy variable, equal to 1 if a village was located in Patamundai *tahasil* and 0 otherwise	Primary Census Abstract of the State of Orissa
Tahasil: Rajnagar	0–1 dummy variable, equal to 1 if a village was located in Rajnagar *tahasil* and 0 otherwise	Primary Census Abstract of the State of Orissa
Tahasil: Mahakalpada	0–1 dummy variable, equal to 1 if a village was located in Mahakalpada *tahasil* and 0 otherwise. Note: This variable was excluded from the regression models to avoid perfect colinearity between the *tahasil* variables and the regression constant.	Primary Census Abstract of the State of Orissa

Unless otherwise noted, all estimates are for 1999. Village and district boundaries and many other spatial variables were based on GIS files purchased from a private source (Digital Cartography and Services, Bhubaneswar, Orissa). Distances were calculated using ArcView 3.2.

1. Kalsi SR, Jayanthi N, Roy Bhowmik SK (2004) A Review of Different Storm Surge Models and Estimated Storm Surge Height in Respect of Orissa Supercyclonic Storm of 29 October, 1999 (Indian Meteorological Department, New Delhi).

Table S2. Number of deaths caused by October 1999 cyclone in state of Orissa, India: Villages in area affected by storm surge in Kendrapada District

Sample	No. villages	No. villages with no deaths	Village-level deaths			
			Mean	SD	Minimum	Maximum
All villages	409	307	0.63	1.81	0	21
Villages within 10 km of coast	154	116	0.77	2.04	0	13
Villages beyond 10 km of coast	255	191	0.54	1.66	0	21

Table S3. Coefficient and standard error estimates from multivariate regression models of deaths caused by October 1999 cyclone in state of Orissa, India: Sample includes all 409 villages in area affected by storm surge in Kendrapada District

				Model			
Variable	Only 1999 mangrove width and population	Add 1944 mangrove width	Add height of storm surge	Add topography variables	Add distance variables	Add socioeconomic characteristics	Add government administration
1999 mangrove width	−0.631 (0.187)***	−0.515 (0.174)***	−0.524 (0.183)***	−0.519 (0.141)***	−0.507 (0.148)***	−0.505 (0.149)***	−0.485 (0.163)***
Village population	0.000335 (0.0000904)***	0.000384 (0.0000916)***	0.000390 (0.0000982)***	0.000200 (0.0000919)**	0.000207 (0.0000931)**	0.000253 (0.0000982)***	0.000198 (0.000102)*
1944 mangrove width		0.0862 (0.0351)**	0.0886 (0.0377)**	0.104 (0.0374)***	0.0628 (0.0404)	0.0748 (0.0411)*	0.0880 (0.0564)
Height of storm surge			− 0.0143 (0.0824)	0.126 (0.0786)	0.140 (0.0890)	0.156 (0.0925)*	0.0502 (0.111)
Low elevation				1.54 (0.270)***	1.16 (0.349)***	1.12 (0.393)***	1.22 (0.405)***
Casuarina buffer				0.650 (0.271)**	0.576 (0.270)**	0.466 (0.284)*	0.286 (0.304)
Seawater dike				−0.130 (0.245)	−0.294 (0.248)	−0.309 (0.249)	−0.370 (0.257)
Distance from coast					−0.0171 (0.0196)	−0.0147 (0.0204)	−0.0145 (0.0240)
Distance from major river					−0.0199 (0.0364)	−0.0109 (0.0368)	0.0129 (0.0427)
Distance from minor river					−0.174 (0.0761)**	−0.183 (0.0814)**	−0.146 (0.0841)*
Distance from nearest road					0.0615 (0.0463)	0.0422 (0.0485)	0.0406 (0.0488)
Literacy rate						0.364 (1.33)	0.317 (1.33)
Scheduled caste						−1.14 (0.909)	−0.843 (0.913)
Cultivator						−0.271 (1.12)	−0.599 (1.13)
Agricultural laborer						3.22 (2.09)	3.14 (2.07)
Worker in home industry						9.90 (14.0)	9.21 (13.8)
Marginal worker						1.29 (1.26)	0.676 (1.31)
Other worker						−2.23 (3.22)	−1.54 (3.23)
Tahasil: Marshagai							0.635 (0.748)
Tahasil: Patamundai							−0.625 (0.511)
Tahasil: Rajnagar							−0.447 (0.465)
Constant	−0.356 (0.240)	−0.980 (0.346)***	−0.965 (0.358)***	−1.52 (0.401)***	−0.745 (0.608)	−1.05 (1.08)	−0.671 (1.09)

Dependent variable is village-level number of deaths. All models were estimated using zero-inflated negative binomial regression, with population used to adjust for the inflated number of villages with zero deaths. Standard errors are shown in parentheses beside or beneath coefficient estimates. Significance levels: ***1%, **5%, *10%.

Table S4. Coefficient and standard error estimates from multivariate regression model of deaths caused by October 1999 cyclone in state of Orissa, India: Coefficient on population and regression constant allowed to differ between villages within 10 km of coast and villages beyond 10 km of coast

Variable	Coefficient estimate (standard error)
1999 mangrove width	−0.587 (0.191)***
Population: villages within 10 km	0.000397 (0.000122)***
Population: villages beyond 10 km	−0.0000986 (0.000145)
1944 mangrove width	0.0330 (0.0542)
Height of storm surge	0.0271 (0.105)
Low elevation	1.29 (0.383)***
Casuarina buffer	0.115 (0.285)
Seawater dike	−0.394 (0.254)
Distance from coast	−0.0282 (0.0268)
Distance from major river	0.0180 (0.0428)
Distance from minor river	−0.135 (0.0806)*
Distance from nearest road	0.0708 (0.0476)
Literacy rate	−0.385 (1.25)
Scheduled caste	−0.828 (0.879)
Cultivator	−1.25 (1.01)
Agricultural laborer	4.75 (2.02)**
Worker in home industry	0.788 (12.8)
Marginal worker	1.61 (1.31)
Other worker	−1.90 (3.12)
Tahasil: Marshagai	1.19 (0.762)
Tahasil: Patamundai	−0.832 (0.526)
Tahasil: Rajnagar	−0.538 (0.460)
Constant	1.19 (1.14)
Village located within 10 km of coast	−1.98 (0.530)***

Dependent variable is village-level number of deaths. Sample includes all 409 villages in area affected by storm surge in Kendrapada District. All models were estimated using zero-inflated negative binomial regression, with population used to adjust for the inflated number of villages with zero deaths. Significance levels: ***1%, **5%, *10%.

Table S5. Estimated impact of government warning issued to villages within 10 km of coast in advance of October 1999 cyclone in state of Orissa, India

Step in calculation	Result
Predicted mean number of deaths per village within 10 km of the coast (= mean of fitted values from regression model in Table S4)	0.808
Coefficient on dummy variable for villages within 10 km of the coast (from regression model in Table S4)	−1.98
Ratio of number of deaths per village within 10 km of the coast to number of deaths per village beyond 10 km, controlling for all observable village characteristics	0.138 (= $e^{-1.98}$)
Predicted mean number of deaths per village within 10 km of the coast, in absence of government warning	5.84 (= 0.808/0.138)

Calculations are for subsample of 154 villages within 10 km of coast, in area affected by storm surge in Kendrapada District.

Table S6. Coefficient and standard error estimates from multivariate regression model of damage caused by October 1999 cyclone in state of Orissa, India: Dependent variable changed from village-level deaths to village-level number of damaged houses

Variable	Type of house damage	
	All damage	Most severe damage
1999 mangrove width	99.1 (77.9)	12.3 (30.8)
Population: villages within 10 km	0.148 (0.0399)***	0.146 (0.0208)***
Population: villages beyond 10 km	0.243 (0.0474)***	0.150 (0.0361)***
1944 mangrove width	4.35 (10.3)	0.0806 (7.03)
Height of storm surge	1.67 (15.3)	4.06 (13.8)
Low elevation	−6.49 (60.9)	0.754 (40.0)
Casuarina buffer	47.9 (87.6)	32.4 (67.6)
Seawater dike	−23.2 (49.9)	−23.0 (40.1)
Distance from coast	−12.5 (8.33)	−7.54 (5.67)
Distance from major river	−2.60 (12.5)	−4.93 (11.0)
Distance from minor river	−4.17 (14.8)	−6.83 (11.4)
Distance from nearest road	−4.82 (10.5)	−2.86 (5.85)
Literacy rate	−10.3 (183)	48.1 (129)
Scheduled caste	56.5 (132)	67.8 (104)
Cultivator	−1005 (503)**	−615 (379)*
Agricultural laborer	−1729 (893)*	−930 (644)
Worker in home industry	991 (6692)	−343 (5104)
Marginal worker	8.16 (224)	53.2 (194)
Other worker	−548 (964)	−711 (671)
Tahasil: Marshaghai	196 (287)	228 (208)
Tahasil: Patamundai	168 (222)	−176 (157)
Tahasil: Rajnagar	−873 (331)***	−1051 (180)***
Constant	432 (241)*	304 (160)*
Village located within 10 km of coast	−2.36 (89.5)	−38.4 (58.4)

"Most severe damage" refers to houses that were completely destroyed; "All damage" adds in the number of houses that were damaged but not destroyed. Sample includes 147 *gram panchayats* and villages in area affected by storm surge in Kendrapada District. (In some areas, house damage was reported at the *gram panchayat* level, not the village level.) The coefficient on population and the regression constant were allowed to differ between villages within 10 km of coast and villages beyond 10 km of coast. All models were estimated using ordinary least squares regression. Robust (Huber-White sandwich) standard errors are shown in parentheses beside coefficient estimates. Significance levels: ***1%, **5%, *10%.

Table S7. Coefficient and standard error estimates from multivariate regression models of deaths caused by October 1999 cyclone in state of Orissa, India: Interaction between mangrove and storm surge

	Model			
Variable	Base model (no interaction)	Add interaction with height of storm surge	Drop 1999 mangrove width	Split interaction term for smaller and larger storm surges
1999 mangrove width	−1.64(0.394)***	−0.347 (0.905)		
1999 mangrove width × Height of storm surge		−1.24 (0.839)	−1.54 (0.345)***	
1999 mangrove width × Below-mean height of storm surge				−1.85 (0.588)***
1999 mangrove width × Above-mean height of storm surge				−1.36 (0.429)***
Village population	0.000610 (0.0000898)***	0.000590 (0.0000881)***	0.000584 (0.0000864)***	0.000589 (0.0000870)***
1944 mangrove width	−0.552 (0.142)***	−0.545 (0.144)***	−0.535 (0.141)***	−0.559 (0.146)***
Height of storm surge	0.255 (0.149)*	0.620 (0.289)**	0.705 (0.196)***	0.628 (0.220)***
Low elevation	2.40 (0.598)***	2.49 (0.621)***	2.49 (0.624)***	2.50 (0.621)***
Casuarina buffer	−0.500 (0.415)	−1.04 (0.579)*	−1.18 (0.483)**	−0.974 (0.553)*
Seawater dike	−0.0472 (0.376)	−0.0616 (0.369)	−0.0542 (0.367)	−0.110 (0.382)
Distance from coast	0.531 (0.148)***	0.504 (0.150)***	0.490 (0.146)***	0.522 (0.153)***
Distance from major river	0.190 (0.115)*	0.208 (0.113)*	0.212 (0.112)*	0.208 (0.113)*
Distance from minor river	−0.120 (0.108)	−0.114 (0.108)	−0.109 (0.107)	−0.126 (0.110)
Distance from nearest road	0.0102 (0.0588)	−0.0386 (0.0672)	−0.0478 (0.0633)	−0.0273 (0.0696)
Literacy rate	−3.40 (1.20)***	−3.08 (1.23)**	−2.98 (1.20)**	−3.24 (1.25)**
Scheduled caste	−3.24 (1.73)*	−3.28 (1.70)*	−3.27 (1.69)*	−3.29 (1.70)*
Cultivator	0.196 (1.15)	0.178 (1.17)	0.195 (1.17)	0.161 (1.16)
Agricultural laborer	3.99 (1.65)**	5.09 (1.97)***	5.21 (1.99)***	5.01 (1.94)***
Worker in home industry	4.16 (31.6)	5.66 (31.3)	6.87 (31.1)	4.45 (31.4)
Marginal worker	3.68 (1.31)***	3.84 (1.35)***	3.86 (1.36)***	3.80 (1.34)***
Other worker	−2.61 (2.98)	−2.35 (2.98)	−2.22 (2.96)	−2.43 (2.97)
Tahasil: Patamundai	−3.20 (1.17)***	−3.51 (1.20)***	−3.56 (1.20)***	−3.50 (1.20)***
Tahasil: Rajnagar	−0.715 (0.502)	−1.14 (0.576)**	−1.25 (0.500)**	−0.996 (0.625)
Constant	−1.43 (1.24)	−1.51 (1.26)	−1.57 (1.26)	−1.53 (1.25)

Dependent variable is village-level number of deaths. Sample includes 154 villages within 10 km of coast, in area affected by storm surge in Kendrapada District. All models were estimated using poisson regression. Dummy variable for Marshagai was dropped because this *tahasil* is beyond 10 km of coast. Standard errors are shown in parentheses beside coefficient estimates. Significance levels: ***1%, **5%, *10%.

Table S8. Coefficient and standard error estimates from multivariate regression models of deaths caused by October 1999 cyclone in state of Orissa, India: Add distance from cyclone path

Variable	Full sample of 409 villages	Subsample of 154 villages
Distance from cyclone path	0.00817 (0.0272)	0.0441 (0.0517)
1999 mangrove width	−0.477 (0.163)***	
1999 mangrove width × below-mean height of storm surge		−1.73 (0.612)***
1999 mangrove width × above-mean height of storm surge		−1.26 (0.430)***
Village population	0.000204 (0.000104)**	0.000607 (0.0000916)***
1944 mangrove width	0.0860 (0.0568)	−0.543 (0.147)***
Height of storm surge	0.0717 (0.132)	0.626 (0.220)***
Low elevation	1.17 (0.434)***	2.28 (0.653)***
Casuarina buffer	0.303 (0.309)	−0.677 (0.643)
Seawater dike	−0.367 (0.257)	−0.109 (0.385)
Distance from coast	−0.0115 (0.0260)	0.536 (0.156)***
Distance from major river	0.0159 (0.0437)	0.189 (0.117)
Distance from minor river	−0.145 (0.0841)*	−0.132 (0.111)
Distance from nearest road	0.0386 (0.0491)	−0.0510 (0.0756)
Literacy rate	0.279 (1.34)	−3.35 (1.28)**
Scheduled caste	−0.828 (0.914)	−3.15 (1.75)*
Cultivator	−0.572 (1.13)	0.0182 (1.19)
Agricultural laborer	2.91 (2.21)	4.51 (2.02)**
Worker in home industry	9.96 (14.0)	3.04 (32.0)
Marginal worker	0.538 (1.39)	3.66 (1.35)***
Other worker	−1.70 (3.27)	−2.92 (3.04)
Tahasil: Marshagai	0.599 (0.758)	
Tahasil: Patamundai	−0.699 (0.567)	−3.68 (1.22)***
Tahasil: Rajnagar	−0.693 (0.941)	−2.47 (1.86)
Constant	−0.907 (1.35)	−2.75 (1.98)

Dependent variable is village-level number of deaths in all models. Subsample refers to villages within 10 km of coast. Model for full sample was estimated using zero-inflated negative binomial regression, with population used to adjust for the inflated number of villages with zero deaths. Model for subsample was estimated using poisson regression, with dummy variable for Marshagai dropped because this *tahasil* is beyond 10 km of coast. Standard errors are shown in parentheses beside coefficient estimates. Significance levels: ***1%, **5%, *10%.

Table S9. Estimated average cost of saving a life by retaining 1999 mangrove area in Kendrapada District, Orissa, India

Step in calculation	Result
Predicted mean number of deaths per village (= mean of fitted values from model in last column of Table S7)	0.77
Predicted mean number of deaths per village, if mangroves had been absent (= mean of fitted values from model in last column of Table S7, with 1999 mangrove width = 0)	2.49
Predicted increase in mean number of deaths per village, if mangroves had been absent	1.72 (= 2.49 − 0.77)
Predicted increase in total number of deaths, if mangroves had been absent	265 (= 1.72 × 154)
1999 mangrove area (hectares)	17,900
Predicted number of averted deaths per hectare of mangrove	0.0148 (= 265/17,900)
Average price of agricultural land near mangroves in Kendrapada District in 1999 (rupees per hectare)	172,970
Estimated average cost of saving a life by retaining 1999 mangrove area (rupees per life)	11,667,592 (=172,970/0.0148)

Calculations are for subsample of 154 villages within 10 km of coast, in area affected by storm surge.

Table S10. Alternative standard error estimates from multivariate regression model of deaths caused by October 1999 cyclone in state of Orissa, India

Variable	Full sample (409 villages)		Subsample (154 villages)	
	Robust standard errors	Clustered standard errors	Robust standard errors	Clustered standard errors
1999 mangrove width	−0.485 (0.124)***	−0.485 (0.112)***		
1999 mangrove width × below-mean height of storm surge			−1.85 (0.654)***	−1.85 (0.576)***
1999 mangrove width × above- mean height of storm surge			−1.36 (0.454)***	−1.36 (0.593)***
Village population	0.000198 (0.0000949)**	0.000198 (0.000101)*	0.000589 (0.0000713)***	0.000589 (0.0000700)***
1944 mangrove width	0.0880 (0.0587)	0.0880 (0.0634)	−0.559 (0.154)***	−0.559 (0.140)***
Height of storm surge	0.0502 (0.109)	0.0502 (0.108)	0.628 (0.211)***	0.628 (0.225)***
Low elevation	1.22 (0.418)***	1.22 (0.396)***	2.50 (0.602)***	2.50 (0.669)***
Casuarina buffer	0.286 (0.381)	0.286 (0.327)	−0.974 (0.486)**	−0.974 (0.395)**
Seawater dike	−0.370 (0.239)	−0.370 (0.278)	−0.110 (0.333)	−0.110 (0.312)
Distance from coast	−0.0145 (0.0247)	−0.0145 (0.0265)	0.522 (0.148)***	0.522 (0.119)***
Distance from major river	0.0129 (0.0558)	0.0129 (0.0579)	0.208 (0.122)*	0.208 (0.129)
Distance from minor river	−0.146 (0.0841)*	−0.146 (0.101)	−0.126 (0.115)	−0.126 (0.110)
Distance from nearest road	0.0406 (0.0529)	0.0406 (0.0510)	−0.0273 (0.0663)	−0.0273 (0.0645)
Literacy rate	0.317 (1.34)	0.317 (1.39)	−3.24 (1.08)***	−3.24 (0.945)***
Scheduled caste	−0.843 (0.688)	−0.843 (0.729)	−3.29 (1.85)*	−3.29 (2.18)
Cultivator	−0.599 (1.30)	−0.599 (1.38)	0.161 (0.834)	0.161 (0.706)
Agricultural laborer	3.14 (1.67)*	3.14 (1.69)*	5.01 (2.14)**	5.01 (2.90)*
Worker in home industry	9.21 (11.2)	9.21 (9.93)	4.45 (25.1)	4.45 (23.9)
Marginal worker	0.676 (1.13)	0.676 (1.39)	3.80 (1.50)**	3.80 (1.83)**
Other worker	−1.54 (3.21)	−1.54 (3.00)	−2.43 (3.14)	−2.43 (2.59)
Tahasil: Marshagai	0.635 (0.696)	0.635 (0.824)		
Tahasil: Patamundai	−0.625 (0.447)	−0.625 (0.545)	−3.50 (1.09)***	−3.50 (0.710)***
Tahasil: Rajnagar	−0.447 (0.482)	−0.447 (0.546)	−0.996 (0.595)*	−0.996 (0.677)
Constant	−0.671 (1.16)	−0.671 (1.17)	−1.53 (1.16)	−1.53 (1.12)

Robust estimates refer to Huber-White sandwich estimates; clustered estimates allow for nonindependence across villages within the same *gram panchayat* (number of clusters = 77 in full sample; 19 in subsample). Dependent variable is village-level number of deaths in all models. Subsample refers to villages within 10 km of coast. Models for full sample were estimated using zero-inflated negative binomial regression, with population used to adjust for the inflated number of villages with zero deaths. Models for subsample were estimated using poisson regression, with dummy variable for Marshagai dropped because this *tahasil* is beyond 10 km of coast. Standard errors are shown in parentheses beside coefficient estimates. Significance levels: ***1%, **5%, *10%.