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Climate risk sensitivity livelihood matrix in Bay of Bengal coast of India

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ABSTRACT

In this study climatic risk sensitivity livelihood matrix was prepared for Bay of Bengal coast of India to appraise the exposure of extreme events on ecosystem and livelihoods of the region based on exposure and impact scores. The frequency of different extreme events of the study area *viz.*, drought, flood, cyclone, heat waves etc. was computed from historical meteorological data and prevalence of major livelihoods was surveyed through structured questionnaire. A computer based dynamic tool 'CLIMM' was developed which will be useful for preparing climate risk sensitivity livelihood matrix in any parts of the world. The exposure and impact scores were determined after performing climate risk sensitivity analysis. The drought frequency was analyzed with the Standardized Precipitation Index (SPI) and the study revealed that three types of agriculture droughts *viz.*, initial drought/delayed monsoon, midseason drought/dry spells and late season drought occurred in the study area with their frequency of 7 %, 16% and 9%, respectively. The other two extreme events were cyclone (September to December) and flood (June to September), which occurred with the frequency of 16 % and 33 %, respectively. Six major livelihood groups *viz.*, wage earner, crop farmers, services, rural artisans, livestock rearers and fishing were prevalent in the study area. The sum of the weighted exposure scores for the livelihoods was computed as 23.0 and sum of the weighted impact scores for the climatic hazards was 59.5. These aggregate values will be useful in comparing different regions or scenarios with respect to climate induced natural disaster (CIND) in any parts of the world.

Key words: Climate change, livelihood matrix, exposure index, extreme events, Bay of Bengal.

Climate change is very likely to increase the frequency and magnitude of extreme weather events like drought, flood, heat waves, cyclones etc. and affect developmental activities in many countries (Hay *et al.*, 2003). Survey says that present basic livelihood services to the poor in developing countries are not able to cope even with today's' climate variability and stresses and over 96 % of disaster related deaths in recent years have taken place in developing countries. Keeping these aspects in view, studies of frequency and intensity of extreme weather events and adaptation to those are a priority for reducing vulnerability, eradicating poverty and sustainable agricultural development (Burton 1992).

The areas adjacent to the Bay of Bengal like Kendrapara district, Orissa are the most vulnerable to elevated climate induced natural disaster or extreme weather events because of its geographical position. The district is placed at the head of the Bay of Bengal and even a slight change in the sea's behaviour can have an immediate impact on the coast. The Bay becomes the center of low pressures causing heavy rains and cyclones. The costal Orissa has tropical climate characterized by high temperature, high humidity, high monsoon rainfall, short and mild winters. The agriculture in the state provides direct or indirect employment to 64% of the total workforce but extreme weather events, like flood, drought, cyclones occurring alone or in combination cause untold misery to the farmers by creating instability in agricultural production.

Many studies were conducted in India on drought, dry spells, cyclone (Mooley and Parthasarathy, 1984, Smith and Sikka, 1987, Chowdhury *et al.*, 1988, Singh *et al.*, 1992, Sastri, 1993, Kar 2003, Kar 2004). Bhalme and Mooley (1981) prepared a time series of the drought area index. Sen and Sinha Ray (1997) have shown a decreasing trend in the area affected by drought in India. Sinha Ray and Shewale (2000) have determined the probability of occurrence of drought on the basis of summer monsoon rainfall for the period 1875-1909. But no climate risk sensitivity analysis was done in relation to prevalent livelihoods of the affected areas or a particular region. Hence, there is a need of climate risk sensivity livelihood matrix through which the prevalent climate risks and ecosystem services, livelihood activities or livelihoods can be linked up. In this study a software 'CLIMM' was developed for preparing livehood matrix to appraise the impact of extreme weather events on existing natural resources, livelihoods and ecosystem services.

MATERIAL AND METHODS

The study area:

The Kenderapara district of Orissa (Lat. 20°30′ N and Long. 86° 25′) was taken as study area to characterize climate and extreme weather events on micro-scale. Owing to the geographical proximity of Kendrapara district to the Bay of Bengal and 67 % of the rainfed cultivated area, the district suffers from multiple climatic hazards mainly drought, flood, cyclone, heat waves, salinization or sea water intrusion etc. Out of nine blocks of the district, 2 blocks (Derabishi and Kendrapara) are fully irrigated, 4 blocks (Garadpur, Mahakalpara, Marsaghai and Pattamundie) are partially irrigated and remaining 3 blocks (Aul, Rajkanika and Rajnagar) are completely rainfed (District disaster management plan, Kendrapara, Orissa).

For extreme weather frequency analysis different weather data like rainfall, cyclone, extreme temperature as well as river discharge of past 20 – 40 years were collected from different sources like Board of Revenue, Cuttack, India Meteorological department, Pune, Regional Meteorological Center, Bhubaneswar.

Drought frequency analysis through Standardized Precipitation Index (SPI)

Drought is a period of abnormally dry weather sufficiently prolonged for the lack of precipitation to cause a serious hydrological imbalance and carries connotations of a moisture deficiency with respect to man's usage of water (Mc Mahan and Arenas, 1982). The chief characteristic of a drought is a decrease of water availability in a particular period and over a particular area (Beran and Redier, 1985). Based on the probability distribution of precipitation in this study standardized precipitation index (SPI) was used for drought frequency analysis. McKee *et al.*, (1993) developed the SPI for the purpose of defining and monitoring drought which requires less input data and calculation. In a SPI long-term precipitation record at the desired station was fitted to a probability distribution, which was then transformed into a normal distribution for computing mean SPI with different time steps (*eg.* 1 month, 3 months, ...48 months). Positive SPI values indicated greater than median precipitation and negative value indicated less than median precipitation. The 'drought' part of the SPI range is arbitrary split into 'normal' conditions (0.99 $<$SPI $<$ -0.99), 'moderately dry' (-1.0$<$SPI$<$ -1.49), 'severely dry' (-1.5$<$SPI$<$ -1.99) and 'extremely dry' (SPI$<$-2.0). A drought event starts when SPI value reaches -1.0 and ends when SPI value becomes positive again. Therefore, each drought event has a well-defined duration.

The long term precipitation record is found to fit with gamma distribution, which is defined by its frequency of probability density function:

$$g(x) = \frac{1}{\beta^{\alpha}\tau(\alpha)} x^{\alpha-1} e^{-x/\beta} \qquad \text{For } x>0$$

and where, a > 0, b > 0 ... . (1)

a and b are the shape and scale factors, respectively.

This distribution is skewed to the right with a lower bound of zero much like a precipitation frequency distribution.

The alpha and beta parameters of the gamma probability density function was estimated for each station, for each time scale of interest (1 month, 2 months, 3 months, etc), and for each month of the year.

The maximum likelihood solutions were used to optimally estimate a and b:

$$\hat{\alpha} = \frac{1}{4A}\left(1+\sqrt{1+\frac{4A}{3}}\right);\ \hat{\beta} = \frac{\bar{x}}{\hat{\alpha}} \ \ldots\ldots (2)$$

Where:

$$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n},$$ n=number of precipitation observations

The resulting parameters are then used to find the cumulative probability of an observed precipitation event for the given month and time scale for the station in question. The cumulative probability G(x) corresponding to an observed precipitation is

$$G(x) = \int_0^x g(x)dx = \frac{1}{\hat{\beta}^{\hat{\alpha}}\tau(\hat{\alpha})}\int_0^x x^{\hat{\alpha}-1}e^{-x/\hat{\beta}}dx \quad ...(3)$$

The incomplete gamma function of above equation is undefined for x=0 but month with zero precipitation is possible. Then the actual probability of non exceedance P (x) should given by;

$$P(x)= q + (1-q)\, G(x) \quad ......(4)$$

Where q is the probability of x=0. If m is the number of zeros in a precipitation time series n, then q can be estimated by m/n.

The cumulative probability, P (x), was then transformed to the standard normal random variable Z with mean zero and variance of one, which was the value of the SPI.

Monthly rainfall of different probability levels

Extreme Value Distribution Type-1 was found best for estimating monthly probabilistic rainfall (Kar 2002), the probability density function f (x) and distribution function F (x) are given as,

$$f(x)=[\exp-(x-u)/\alpha-\exp\{-(x-u)/\alpha\}]/ \quad ....(5)$$

and $$F(x)=\exp[-\exp\{-(x-u)/\alpha\}] \quad ....(6)$$

$$-\alpha<x<\alpha;\ -\alpha<u<\alpha;\ \alpha>0$$

Where, α and u are the shape and location parameters of the distribution, respectively.

In term of the reduced variate

$$Y= [(x-u)/\alpha] \quad ....(7)$$

$$F(x) =\exp[-\exp(-Y)] \quad .... (8)$$

The method of moment estimation of the parameters have been used for this study to fit extreme value distribution as follows.

$$\alpha= (\sqrt{6}/\pi)\ [\Sigma(x-x)^2/ (N-1)]^{1/2};$$

$$u=x-0.577216\alpha \quad .... (9)$$

Drainage system and flood analysis

The Mahanadi river and its tributaries form the major drainage system in the study area. The Mahanadi Basin is an inter state basin comprising of four States *viz.*, Orissa, Chhatisgarh, Jharkhand and Maharashtra and total basin area constitutes 141589 sq km. For flood frequency analysis, the peak river discharge data of the Mahanadi river was collected and probability of occurrence of flood level discharge was determined using Weibull's method and Log Pearson probability distribution method.

Frequency of occurrence of cyclone

The major cyclones in Bay of Bengal coast in last three decades were collected from India Meteorological Department, Pune and frequency (%) was analyzed for preparing climate risks sensitivity livelihood matrix.

Frequency of heat waves

The major heat waves across Bay of Bengal coast in last two decades were collected from India Meteorological Department and frequency (%) was analyzed for preparing climate risks sensitivity livelihood matrix.

The probability of occurrence of any extreme event $P(E) = \frac{F(E)}{N}$ ...... (10)

Where, F (E) = frequency of extreme events, N= Numbers of years of data used.

Development of software

The software 'Climate risks Livelihood Matrix Models' (CLIMM) was developed using Visual Basics 6.0 programming language for preparing climate risk sensitivity livelihood matrix. Based on the frequency of extreme weather and their impact on ecosystem services, livelihood activities and livelihoods in the region, exposure and impact score were computed.

Module 1: Module 1 of the software consists of the list of some default climate risks and the possible ecosystem/ livelihood services, livelihood activities and livelihoods. For an user of particular study area if the list is exhaustive, then next module is to be operated. If it is not, then additional risks and livelihoods can be added by clicking 'add' button. The undesired item can also be deleted by clicking the 'delete' button in the module.

Module 2: Module 2 consists of different climate risks in the region with their corresponding frequencies of occurrence. Based on the level of exposure of different climate risks on different livelihoods/ ecosystem services, their corresponding weightage (minimum 1 and maximum 5) has to be given to compute exposure score and weighted exposure index for each ecosystem/ livelihood service as per the following formula.

Exposure score = $(\Sigma s_i / n \times s) * 100$ .... (11)

Weighted exposure score

$= (\Sigma f_i s_i / \Sigma f_i) * 100$ .... (12)

Where, f_i = frequency of individual climate risk in the study area, n= number of climate or related risks identified, s_i= weightage assigned to the particular climatic risk (1 to 5), s= Maximum score (5) assigned for individual climate risk based on exposure to livelihoods, i = 1...n.

Module 3: Module 3 of the software develops relationship between climate risks and livelihood activity (Form-3). In this step each element of exposure to each climatic risk is sensitized and also the exposure score and weighted exposure index were computed for each of the livelihood activities by using the previous formula.

Module 4: Module 4 consists of the climate risks, their corresponding frequencies and the existing livelihoods with their corresponding weightages and percentage

Table 1: Predicted and observed monthly rainfall (mm) with different probability

Months	Normal			Lognormal			Log Pearson			Extreme Value			Weibulls		
	30%	50%	70%	30%	50%	70%	30%	50%	70%	30%	50%	70%	30%	50%	70%
Jan	16.3	8.1	-	-	-	-	-	-	-	13.7	5.6	-	7.6	0.5	0.0
Feb	28.3	17.1	5.6	-	-	-	-	-	-	24.7	13.5	4.2	20.3	5.2	0.5
Mar	42.3	24.8	6.9	-	-	-	-	-	-	36.7	19.3	4.7	26.9	14.1	4.2
April	42.0	28.4	14.4	30.9	16.0	8.5	33.5	18.5	9.4	37.7	24.1	12.7	35.4	19.5	8.2
May	131.2	86.3	40.6	95.5	56.8	33.5	101.4	62.4	36.1	116.8	72.2	35.0	97.2	62.9	33.9
Jun	233.2	191.6	149.1	219.5	175.6	139.9	221.2	177.6	141.1	219.9	178.4	144.0	224.6	178.0	139.1
July	374.5	310.5	245.3	351.8	289.9	238.0	349.9	287.8	236.7	354.0	290.3	237.4	358.6	285.6	225.8
Aug	401.1	347.4	292.7	288.1	333.1	285.1	388.0	333.0	285.0	384.0	330.5	286.0	392.7	322.2	271.5
Sept	269.1	225.8	181.7	268.8	203.9	153.8	284.8	240.7	183.7	255.3	212.1	176.3	266.6	230.8	206.4
Oct	200.6	139.0	76.2	157.4	96.0	58.0	166.7	105.2	62.5	180.9	119.5	68.5	144.1	109.1	72.9
Nov	64.9	35.0	4.5	-	-	-	-	-	-	55.3	25.5	0.8	29.5	8.7	1.4
Dec	6.6	2.8	-	-	-	-	-	-	-	5.4	1.6	-	0.0	0.0	0.0

of prevalence. From these data the exposure score, weighted exposure index for each livelihood, impact score, weighted impact index are to be computed for deriving aggregate weighted exposure index and weighted impact index.

Impacts score = $(\Sigma l_i /n' l) *100$ ....(13)

Weighted impact index

$= (\Sigma p_i l_i / \Sigma p_i) *100$ ...... (14)

Where, p= Percentage of prevalence of livelihood, n= number of livelihood prevailed in the study area.

l_i= weightage (1 to 5) assigned to the particular livelihood based on magnitude of exposer, l= Maximum score (5), i = 1 ....n.

RESULTS AND DISCUSSION

Monthly rainfall at different probability levels

The probable date of onset of southwest monsoon in the region is 23[rd] standard meteorological week (10[th] June) and thus growing period (LGP) also generally starts from 23[rd] standard week. Hence sowing operation can be initiated from that week but prediction of amount of southwest monsoon rainfall in different seasons is of paramount importance for assessing rainfall at highly assured level to raise crops successfully. Hence, monthly southwest monsoon (June-September) rainfall was predicted at 30, 50 and 70 percent probability levels using probability distribution (Table 1). In the first southwest monsoon month i.e., in June, 139 mm rainfall

Table 2: Predicted probability of occurrence of flood in the Mahanadi

Log Pearson Type-III		
Value (Cusec)	**Return Period (years)**	**Probability**
165464.8	1.01	99
525717.8	1.25	80
626759.8	1.42	70
711837.7	1.66	60
809066.3	2	50
871720	2.32	43
988129.8	2.33	30
1092690	5	20
1148333	6.66	15
1223661	10	10
1282093	14.28	7
1317708	20	5

was observed at 70 % (most dependable limit) probability level. (based on Weibull's method). Therefore, in the rainy season direct seeded crops namely groundnut (*Arachis hypogea* L.), pigeonpea [*Cajanas cajan* (L.) Millsp.], cowpea [*Vigna unguiculata* (L.) Walp], maize (*Zea mays* L.) and blackgram (*Phaseolus mungo* L.) can be sown and rice nurseries can be prepared in 23rd to 24th standard week with the commencement of southwest monsoon in the region. The rainfall at dependable level during June can be utilized for upland direct seeded crop planning. In the month of July at 70 % probability level, 225 mm rainfall was projected, which could be utilized for rice transplanting starting from first fortnight of July in medium and low land rice ecosystems. The transplanting of rainy season rice in the first week of July will have additional advantage of assured rain during August and September.

To increase the rainwater use efficiency and productivity of light textured rainfed upland, rice can be substituted with other low water requiring crops through sole or intercropping. If in any case maize, groundnut, pigeonpea and direct seeded rice based intercrops could not be sown by the end of June or fail to establish in June due to dry spell or aberrant weather, late sowing of these crops results in crop failure or very low productivity. The crops like blackgram, cowpea, and sesamum can be sown successfully up to last week of July. Since the rainfall after October is uncertain and erratic, sowing of high value winter crops without supplemental irrigation is not possible in the region.

Frequency of extreme weather

Based on SPI values three types of drought were recognized. The drought part of the SPI2 of June –July, SPI2 of August-

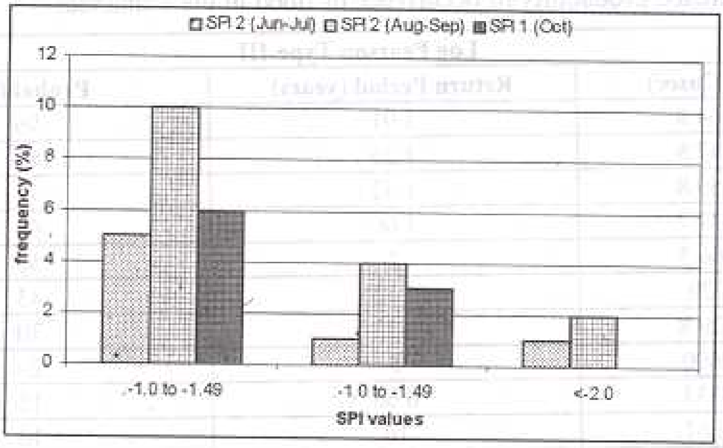

Fig.1: Frequency of early, mid and late season drought based on SPI 2 and SPI 1

September, SPI1 of October were designated as early season, mid season and late season, respectively. Based on SPI values initial drought/ delayed monsoon, mid season drought/ dry spells and late season drought occurred with frequency of 7, 16 and 9%, respectively. Frequency of flood was estimated based on probability of exceeding the Mahanadi river discharge of more than 9.0 lakh cusec. Based on Log Pearson Type III distribution, probability of exceeding that level of discharge was computed as 33%. The other two extreme events were cyclone (September to December) and heat waves, occurred with the frequency of 16 and 5 percent, respectively (Fig.1).

Prevalence of major livelihood groups in the study area

Six major livelihood groups *viz.*, wage earners, crop farmers, services, rural artisans, livestock's rearers and fisheries were practiced in the study area with their percentage of prevalence are 40, 32, 12, 10, 4 and 2%, respectively.

A brief description of these different livelihood groups is given below.

a. Labour households- Labour households constitute 40% of the major livelihood groups in the study area who are mainly agricultural labourers, factory workers and trolley puller.

b. Crop-farmers-This livelihood group is the second dominant group which represents 32% of total livelihoods. The area is mainly mono-cropped dominated by rice (about 90% of total area) during rainy season (*kharif*) only. Groundnut, greengram and vegetables are the main crops during *rabi* where irrigation facilities or shallow water table are available.

c. Services- The 12% of major livelihoods are engaged in shops, offices and trading.

d. Rural artisans- The 10% of major livelihoods are engaged in palm leaf weaving, rope making, bamboo crafts, mat weaving etc. After super cyclone, 1999, a project called '*Aparajitha*' has been implemented in the study area by the Voluntary Health Association of India to help and impart training to rural women artisans. Some self help groups (SHGs) like Binapani, Galeswari, Jagannatha and Ramchandi are associated with different activities like bamboo knitting, dry fishing, weaving etc.

e. Livestock rearing; (dairy and poultry): Only 4% of livelihoods are dependant on livestock rearing.

f. Fishermen- Only 2% of total major livelihoods are engaged in fishing activities in rivers, estuaries and sea. Some are also engaged in fish seed collection and rearing, fish drying etc.

3.4 Climate risks sensitivity analysis

Following the procedures mentioned in the methodology, climate risks sensitivity analysis was performed and livelihood matrix was prepared (Table3). The weighted exposure index of ecosystem/ livelihood services, livelihood activities and major livelihoods were computed as per methodologies discussed in materials and methods. Study revealed that among ecosystem services, agriculture and food security was mostly affected by climatic vulnerability with the weighted exposure index of 3.66 (Table 3). Among livelihood activities rice productivity in medium and lowland were the most affected, with the weighted index of 3.94 followed by livestock rearing (2.83) and craft sale (2.68). Among livelihoods, the highest weighted score was obtained for crop farmers (3.97) followed by livestock rearers (3.65) and wage earners (3.14). The sum of the weighted exposure score for the livelihoods was computed as 23.0 and the sum of the weighted impact scores for the climate hazards was 54.5. These aggregate values will be useful for policy makers in comparing different scenarios or regions for identifying hotspots.

CONCLUSION

The software for preparing climate risk sensitivity livelihood matrix will be useful for linking different ecosystem services, livelihood activities and livelihoods, based on weighted exposure and impact index in any parts of the world. The exposure and impact index are determining factors for comparing different scenarios and identifying hot spots with respect to climate induced natural disasters. The computed weighted impact scores for the climate hazard was 54.5, which was quite high and indicates the study area is highly vulnerable to climate risks or climate induced natural disaster.

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Table 3: Output of the risks sensitivity analysis and livelihood matrix model

Events	Prevalence	CLIMATE RISKS								EXPOSURE INDEX	
		Initial drought/ delay in Southwest monsoon	Mid season drought/ dryspell	Terminal drought	Cyclone (Sept-Dec)	Flood (Jun-Sept)	Land degradation	Pest-diseases	Heat waves	Exposure score	Weighted exposure score
Frequency (%)		7	16	9	16	33	5	5	5	96	
(A) NATURAL RESOURCES, LIVELIHOOD AND ECOSYSTEM SERVICES											54.55
(i) Shortage of seeds and agril. Inputs		3	4	5	4	4	1	1	1	58	3.55
(ii) Soil water deficit		4	5	4	1	1	1	1	1	45	2.17
(iii) Agriculture and food security		3	4	5	4	4	1	5	1	63	3.06
(iv) Soil and water quality (salinization, erosion)		1	1	1	5	3	3	1	1	40	2.45
(v) Grazing and fodder availability		2	4	4	2	3	1	1	1	45	2.70
(vi) Shortage of raw materials for crafts		2	3	1	5	4	1	1	1	45	3.10
(vii) Deforestation shortage of fossil fuel		2	4	4	3	3	3	1	1	53	2.97
(viii) Shortage of livestock		5	4	2	4	3	1	1	1	53	3.17
(ix) Migration of livestock		4	3	2	4	3	1	1	1	48	2.83
(B) LIVELIHOOD ACTIVITIES											
(i) Rice (upland)		4	5	2	1	1	1	1	1	40	1.97
(ii) Rice (mid and lowland)		2	5	4	4	5	2	1	1	60	3.94
(iii) Vgetables and groundnut (winter)		1	1	5	4	1	1	1	1	38	1.87
(iv) Livestock rearing		4	4	2	3	3	1	1	1	48	2.83
(v) Fishing		2	2	3	4	1	1	1	1	38	1.92
(vi) Craft sale		2	3	2	4	3	1	1	1	43	2.68
(C) LIVELIHOODS	**Prevalence**										
(i) Wage earners/ casual labourers	40	4	4	3	4	3	2	1	1	33	3.14
(ii) Crop farmers	32	4	5	3	5	4	2	4	1	70	3.97
(iii) Services	12	2	2	2	4	3	1	1	1	40	2.52
(iv) Rural artisans	10	3	3	3	5	3	1	1	1	50	3.02
(v) Livestock rearers	4	4	4	3	5	4	1	2	1	60	3.65
(vi) Fishing	2	2	3	2	5	2	1	1	1	48	2.51
IMPACT INDEX	100	63.33	70	53.33	93.33	63.33	26.67	33.33	20		
WEIGHTED IMPACT INDEX	23.02	3.66	3.96	5.86	4.48	3.34	1.72	2.00	1.00		

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