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Vulnerability to Climate Change: Review of Conceptual Framework

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ABSTRACT

The paper presents a conceptual framework on vulnerability to climate change. Vulnerability is a multi-dimensional process and is calculated by identifying the indicators of exposure, sensitivity and adaptive capacity. Among the components of vulnerability, exposure followed by sensitivity has the highest contribution but they cannot be controlled directly as the climatic factors that influence vulnerability like temperature, rainfall and natural disasters were beyond the immediate control of policy makers. The only option to reduce vulnerability is to increase adaptive capacity. Hence, policy makers should make arrangement for increasing adaptive capacity so as to reduce vulnerability.

Keywords: Vulnerability, exposure, sensitivity, adaptive capacity

Climate change refers to "a change in the state of climate that can be identified by changes in mean and/ or variability of its properties, and that persists for an extended period, typically decades or longer" (IPCC, 2007a). In recent years, it has become one of the major environmental threads faced by the world today (Ojwang *et al*. 2010). The global temperature has increased by 0.74 °C in 100 years during 1906-2005 wherein the trend is faster in the last 50 years which is at the rate of 0.13°C (almost twice the per decade rise in temperature in the last 100 years. Rainfall has been erratic; there was significant increase in the amount of rainfall in eastern part of North and South America, northern Europe and northern and central Asia. While, the area around the Mediterranean, the Sahel, southern Africa and southern Asia experienced a decrease in rainfall (IPCC, 2007a; IPCC, 2007b). In India, over the period from 1901-2009, the annual mean temperature has been increased by 0.56°C and based on period 1961-1990, the annual mean temperature has been above normal since 1990 (IMD, 2009). While the temperature has increased, there was declining trend in *kharif* rainfall by 22 mm during 1969-2005 in India and in the past 100 years, the moderate rainfall and number of wet days has been declined. (Rupa *et al*. 2006).

The change in the climatic variability is a great challenge for the human livelihood. This adverse effect will be more towards poor and vulnerable section of the society because they mostly reside in areas of high exposure and also have low adaptive capacity to cope with the changing climate (World Bank, 2010). Hence, vulnerability is the key concern of climate change. Vulnerability is "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change including climate variability and extremes" (IPCC, 2001). The recent studies linked vulnerability with adaptive capacity as it is not only a characteristic of hazard but also a property of human-environment system (Vincent and Cull, 2010; Viscent, 2004; Adger and Kelly, 1999). There are different approaches of vulnerability *viz*biophysical and social vulnerability. Biophysical vulnerability is related with exposure and sensitivity of natural environment to climate change but this approach has less implication on policy making as it totally neglects the social system. While, the other approach *i.e*., social vulnerability relates vulnerability with the social

environment and has more implication on policy making as it focuses on socio-economic factors like poverty and access to resources (Vincent, 2004; Brooks, 2003). Although, the two approaches are completely different theoretically, social approach cannot be completed without analysing biophysical vulnerability since vulnerability is hazard specific. Hence, it is rational to integrate both the approach to give a complete picture of vulnerability. Many researchers have therefore integrated social and biophysical vulnerability to analyse the overall vulnerability (Nelson *et al.* 2010; Gbitibouo and Ringler, 2009; Cutter, 1996).

Exposure, sensitivity and adaptive capacity are the three main components of vulnerability. Exposure is the degree to which a system is exposed to climatic variability *viz.* rainfall, temperature, *etc.* Sensitivity can be defined as the degree to which a system is affected either negatively or favorably by the climate variability. Adaptive capacity is the ability of the system to cope up the negative effect of climatic variability (Brooks, 2003).

DATA BASE AND METHODOLOGY

Earlier literatures were review for identifying, assessing and interpreting the concepts on vulnerability assessment. For the present paper, reviewed articles studied globally as well as in India published during 1982-2016 were reviewed. The present paper follows the following steps *viz*., identification of literature, linking of earlier literatures using inclusion and exclusion criteria, analyzing the methodology and results of earlier literatures, framing authors' view.

Construction of Vulnerability Index

Vulnerability index is calculated by identifying the different indicators under sensitivity, exposure and adaptive capacity. Vulnerability is a multidimensional process and is affected by large number of indicators which were selected based on relevance of these indicators with the different components of vulnerability. The indicators are also selected based on availability of data, review of earlier literatures and personal judgement.

Indicators of vulnerability

Exposure

Exposure is "the nature and degree to which a system is exposed to significant climatic condition". There are several methods for development of vulnerability index but most of them have their own limitations. The limitation arises from the assumptions made about the indicators and assigning of weightage in the aggregate index. The climatic variables come under exposure and these variables are positively related to vulnerability. Any change in climatic variables like precipitation and temperature would have negative impact on food production and would induced vulnerability (Glantz and Wigley, 1986). Rao *et al.* (2016) assessed the district level vulnerability of Indian agriculture to climate change and use annual rainfall, maximum temperature, minimum temperature, frequency of heat wave, cold wave, occurrence of drought, frost, dry spells and occurrence of extreme rainfall events as indicators of exposure. Hiremath and Shiyani (2013) identified demography, climate, agriculture and occupation as component of vulnerability in assessing vulnerability of various agro-climatic zones of Gujarat. Variance in annual rainfall, South-West monsoon and mean maximum and minimum temperature were the indicators that come under climatic factor. Gosain (2014) studied vulnerability assessment of Madhya Pradesh towards climate change and classify the indicators into social, economic, agriculture, forest, water resource, health and climate. These indicators are further grouped into exposure, sensitivity and adaptive capacity.

The climatic factors like cool nights (days with minimum temperature less than 10th percentile), warm nights (days with minimum temperature more than 90th percentile), cool days-cool nights (days when maximum temperature less than 10th percentile), warm day-cool nights (days when maximum temperature more than 90th percentile), frost days (annual count when temperature minimum less than 0^{o}C), duration of warm spell (annual count of days with at least 6 consecutive days with maximum temperature more than 90th percentile), average annual rainfall, extreme wet days, consecutive dry days, frequency of drought and flood were under exposure. Piya *et al.* (2012) assessed vulnerability of rural household to climate change and extremes in Mid-hill of Nepal and use frequency of occurrence of climate related natural disaster like flood, drought, hailstorms over the last 10 years, change in annual precipitation,

and change in annual maximum and minimum temperature as indicators for exposure. A study on livelihood vulnerability index and livelihood effect index used socio-demographic, livelihood strategy, social network, health, food water, climatic variation, knowledge and skills and finance as the components for assessing vulnerability. Household data on climatic variation in the past 10 years like percentage of household reported as less rain, drought, flood, occurrence of unusual rain, increase in temperature, less rain this year than average rainy season were use as indicators for climatic variation Botero and Salinas (2013). In the recent studies, the indicators of exposure include the projected change in climate to understand the future vulnerability to climate (Rao *et al*. 2016; Eriyagama *et al*. 2012; Ravindranath *et al*. 2011).

Sensitivity

Sensitivity is 'the degree to which a system is affected, either adversely or beneficially by climate related stimuli'. Mainly environmental condition and demographic factors are related to sensitivity. Net shown area, percentage of degraded land, availability of water holding capacity, stages of ground water development, rural population density and area under small and marginal farmer were the major factors influencing sensitivity (Rao *et al*. 2016). Health related factors like illness, life expectancy, reduction in nutrition; food and water related factors like household dependent on family farm for food, crop diversity index, time for fetching drinking water, number of months household is difficult to provide food, insufficient water supply, depletion in natural water resource were also used as indicators for sensitivity (Botero and Salinas (2013). Sensitivity is directly related to vulnerability.

The more sensitive a system or environment is, more is the vulnerability. Density of population is positively related with vulnerability and is a function of sensitivity. It is assumed that with increase in number of persons per sq. km. global warming also increases, which may be due to increase in pollution and emission of greenhouse gases. Increase in population may lead to rapid destruction of natural ecosystem, deforestation, destruction in natural habitat and extinction of living beings. Moreover, the occurrence of impact of extreme climatic events like flood, drought are more in highly populated area (Rao *et al*. 2016; Hiremath and Shiyani, 2013; Patnaik and Narayanan, 2005).

Adaptive capacity

Adaptive capacity is 'the ability of the system to adjust to climate change, including climate variability and extremes to moderate potential damage, to take advantage of opportunities, or to cope with the consequences' (Rao *et al*. 2016). Adaptive capacity is inversely related with vulnerability; higher the adaptive capacity, lower is the vulnerability. Wealth, technology, education, information, skills, infrastructure, access to resources and management capabilities are the indicators that comes under adaptive capacity (McCarthy *et al*. 2001). Increase in net irrigated area increases crop productivity hence, it minimize vulnerability and is a function of adaptive capacity (Rao *et al.* 2016; Gosain, 2014; Ravindranath *et al.* 2011). Increase in literacy rate indicate that the people are more aware of the impact of different climatic shocks and its coping mechanism. Higher the literacy rate higher is the adaptive capacity and lesser is the vulnerability (Rao *et al*. 2016; Gosain, 2014; Hiremath and Shiyani, 2013; Palanisami *et al*. 2009). Productivity of crop, net sown area, crop diversity;cropping intensity, which is the ratio of net shown area and gross crop area is also a function of adaptive capacity and helps in mitigating climate change (Gosain, 2014; Hiremath and Shiyani, 2013). Area under forest and biological richness is also an indicator of adaptive capacity as it is a source of livelihood for the people (Gosain, 2014; Hiremath and Shiyani, 2013; Ravindranath *et al.* 2011). Access to banks and agriculture credit society helps in meeting the financial need of the farmer by providing loan with low interest which they repay by selling agricultural products. It increases the productivity of the crop and in turn improves the income level of the farmer. Farm households which are more linked to banks and credit societies have more adaptive capacity and are less vulnerable (Gosain, 2014; Piya *et al*. 2012).

Normalization of indicators

The indicators have different units and have different functional relationship with vulnerability. Hence, they are normalised so that all the indicators lie between 0 and 1 and are unit free(UNDP, 2006).

Normalization for positively related indicators

$$Z_i = (X_{ij} - \text{Min } X_{ij}) \div (\text{Max } X_{ij} - \text{Min } X_{ij})$$

Normalization for negatively related indicators

$$Z_i = (\text{Max } X_{ij} - X_{ij}) \div (\text{Max } X_{ij} - \text{Min } X_{ij})$$

After normalization, the indicators are constructed by giving equal weightage to all the indicators or by giving unequal weights. Simple average method and Patnaik and Narain method (Patnaikand Narayanan, 2005) are the methods of computing vulnerability index using equal weightage. Earlier, some researchers follow the method of equal weightage (Nelson *et al*. 2005; Vincent, 2004)but this method may lead to overweighting of less important indicators and under-weighting of important indicators. Expert judgement, Iyengar and Sudarshan's method (Iyengar and Sudarshan, 1982), Principal Component Analysis (PCA) method and Cluster method are the vulnerability indexing method using unequal weight. The method of weighting by expert judgement (Rao *et al*. 2016; Ravindranath *et al*. 2011; Vincent, 2007; Adger and Vincent, 2005) has some drawback as it is too subjective. There may be disagreement among the subject matter specialist and may often lead to bias. Among all the methods, assigning weight through PCA is the most appropriate and preferred method (Nelson *et al*. 2010b; Gbetibouo and Ringler, 2009; Cutter *et al*. 2003).

Household and Regional Vulnerability

Many researchers analysed household as well as regional vulnerability, first by identifying the indicators of exposure, sensitivity and adaptability. Among the indicators of exposure minimum temperature trend, rainfall and number of natural disasters contribute positively to exposure index while maximum temperature contributes negatively in an analysis of Chepang households in mid-hills of Nepal. Among the sensitivity indicators, share of remunerative income decreases the overall household sensitivity while on the other hand households with higher share of income from natural resource were more sensitive to climate change and extremes. Among the physical assets that contribute to adaptability, household type and information devices were the most important indicators that have positive relation with adaptability; followed by distance to road and percentage of irrigation. Among human assets, higher qualification and training increases adaptability while dependency ratio decreases adaptability. The quality of land owned which was under natural assets has the highest impact and contributes positively to adaptability. Among the financial assets, household annual income contribute highest weightage followed by small livestock, saving and diversification index while, among the social assets members of CBOs and access to credit have equal weight. Overall, financial and human assets were the two most important assets followed by social and physical assets that contribute to overall adaptability. The region with highest exposure and lowest adaptive capacity was the most vulnerable region. The second most vulnerable region was identified to have high exposure index despite having highest adaptive capacity (Piya, 2012).

The indicators that contribute to exposure, sensitivity and adaptability were different from place to place. But irrespective of location, household with low adaptive capacity were faced with higher exposure and sensitivity to climate change and poor household were more vulnerable, irrespective of locations (Piya, 2012; Abate, 2009). A study on household vulnerability to climate change in Swaziland showed that livestock index, number of employed members, household size, number of dependents and number of sick members significantly influence households to shift from low vulnerable category to other moderate or high vulnerable category. Livestock index and number of employed members (Nkondze, 2013; Inayatullah *et al*. 2012) negatively influence vulnerability while number of sick members, household size (Nkondze, 2013; Abate, 2009) and number of dependents positively influence vulnerability implying that households with higher livestock index and number of employed members have low probability of shifting from low vulnerable category to moderate or high vulnerability. While, households with higher numbers of sick members, larger household size and number of dependents have high probability of sifting from low to moderate or high vulnerability (Nkondze, 2013). The livelihood indicators like education level of household head, age, job

experience, number of employed members and per capita income also contribute to household vulnerability (Inayatullah *et al*. 2012).

The household vulnerability can also be accessed through livelihood vulnerability index (LVI). A study in Karnataka showed that the major components that affect the LVI were finance, socio-demographic, livelihood strategies, social network, health, food, water, natural vulnerability and climate variation, knowledge and skills (Botero and Salinas, 2013). The financial component contribute the highest to vulnerability with an index value of 0.772 followed by, climatic variability (0.696), health (0.621), water (0.617), knowledge and skill (0.414), food (0.409) and socio-demographic (0.333). Among the three factors that contribute to vulnerability *viz.* exposure, adaptive capacity and sensitivity, exposure with an index value of 0.696 contribute the highest to LVI followed by, sensitivity (0.535) and adaptive capacity (0.498).

Policy Implication

Literatures shows exposure, followed by sensitivity contributes the highest to household vulnerability but adaptive capacity played an important role to reduce vulnerability (Botero and Salinas, 2013; Urothody and Larsen, 2010; Eakin and Bojórques-Tapias, 2008; Liu *et al*. 2008; Chambers, 2006; Ellis, 1998). Sensitivity can be reduced by improving adaptive capacity. For instance, development in irrigation facilities in a locality decreases crop loss due to drought thus, reducing crop sensitivity to drought. Improving non-farm income reduces the dependency of household farmers to agriculture and natural resources thereby, reducing sensitivity due to climatic factors. The climatic factors that influence vulnerability like temperature, rainfall and natural disasters were beyond the immediate control of policy makers but adaptive capacity has direct policy implications. In areas where there is low exposure, sudden onset of extreme events will have great impact if the households have low adaptive capacity. Hence, policy makers should focus on arrangement of post-disaster relief measures, buffer stocks to be used during lean period, establishment of early warning system and evacuation centers for areas having high exposure and low adaptive capacity (Piya, 2012).

CONCLUSION

Vulnerability is a multi-dimensional process which is affected by large number of indicators that comes under the broader category *viz.*, exposure, sensitivity and adaptive capacity. The indicators that come under vulnerability depend on relevance and availability of data. Bio-physical and social vulnerability are the two approaches of vulnerability. But in the recent times, integration of the two approaches *i.e*., bio-physical and social vulnerability are considered to be rational for analysing vulnerability. The climatic factors like change in rainfall and temperature comes under exposure. Recently, many researchers include the projected change in climate along with the other climatic factors to predict future vulnerability. The environmental and demographic factors like net sown area, percentage of degraded land and water holding capacity were the variables that come under sensitivity. Exposure and sensitivity have direct positive impact on vulnerability while, adaptive capacity has inverse relationship with vulnerability. In the analysis of vulnerability, adaptive capacity place an important role as, irrespective of location, households with low adaptive capacity were faced with higher exposure and sensitivity. Moreover, sensitivity can be reduced by improving adaptive capacity.

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