Climate Variability and Agricultural Productivity
Case Study of Rice Yields in Northern India

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Abstract

Agriculture being a climate sensitive sector and a sector that provides livelihood for more than 60 percent of Indian population, there have been a large number of studies over the past decade that tried to assess the impacts due to the climate variability and climate change. This study attempts to characterize the vulnerability of a farmer to climate change and climate variability, and tries to identify the regions that are relatively more vulnerable to climate variability and change. Using two different methodologies (one borrowed from the poverty literature which defines vulnerability as expected poor yield, and another from the climate change literature that defines vulnerability as expected value of impact of shock on the yield, normalized with the region's position with respect to the threshold yield), the study assesses the vulnerability of rice yields to temperature and rainfall fluctuations for the Northern states of Punjab, Haryana, Uttar Pradesh and Uttaranchal in India. The study concludes that regions that are presently 'poor' need not become 'vulnerable' under climate change conditions. This has significant policy implications for the resource allocation.

Key Words: Climate Variability; Vulnerability; Agricultural Productivity
JEL Classification: Q10; Q54; R10

1.0 Introduction

The world is beautiful with its bountiful resources and endless opportunities. Unfortunately, for many people it is not so, for the risks are plenty – risks of poverty, ill-health, unemployment, accidents, food insecurity, market fluctuations, crimes, climatic variations and natural disasters. Nature is unfair for it did not give an equal standing to all the people. The genetic lottery decides who is born to a millionaire in a rich country under favorable economic and political circumstances and who is not. Given this natural inequality imposed by birth, different people and societies face different risks and differing magnitude and intensities of these risks. A person in Tibet runs the risk of political insecurity and a person in Florida has the risk of losing his house in a Tornado. There cannot be much that can be done about this 'natural inequality' in spite of all the efforts and debates. What is worse, re-enforcing the natural inequality by social and economic institutions is another layer of man-made inequality which makes the world an unequal playing field in which all people are not in a position to face these risks in the same manner. Climatic variations are there throughout the world but the impacts are worst felt in developing countries that have lesser resources to cope with the adverse affects. It is this part of the inequality that can be dealt with and that is where vulnerability assessments become important. With limited resources and too many problems, it becomes increasingly essential to identify the vulnerable groups and to the extent that they are vulnerable so as to effectively intervene and assist in formulating policies that reduce their vulnerability. In sum, risks are unavoidable but it is possible to reduce vulnerability to those risks.

Vulnerability basically refers to the degree to which, human and environmental systems are likely to experience harm due to a perturbation or stress (Kasperson *et al*., 2003). Vulnerability of climate sensitive sectors such as agriculture acquires significant importance in the context of global climate change. The Intergovernmental Panel on Climate Change (IPCC) in its fourth assessment report observed that, 'warming of climate system is now unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global sea level' (Solomon *et al.*, 2007). Agriculture being a climate sensitive sector and a sector that provides livelihood for more than 60 percent of Indian population, there have been a large number of studies over the past decade that tried to assess the impacts due to the climate variability and climate change. The relevant research questions in the context of climate change and Indian agriculture include:

a) Is Indian agriculture likely to get adversely affected by climate change? If so what is the extent of impact?

b) How to characterize the vulnerability of a farmer to climate change and climate variability? Which regions are relatively more vulnerable to climate variability and change?

c) How to assess effectiveness of adaptation options in ameliorating the present and future vulnerability?

In an attempt to answer the first set of questions, Kumar and Parikh (2001a, b), Kumar (2009), and Sanghi and Mendelsohnn (2008) have used a variety of techniques and broadly indicated that climate change would adversely affect Indian agriculture.

O’Brien *et al*. (2004) on the other hand attempts to identify agriculturally most vulnerable regions in India to multiple stresses including climate change and globalization. These two strands of literature are referred as impact assessment and vulnerability assessment studies (Fussel and Klein, 2006). Studies attempting to answer the third set of questions are referred as adaptation assessment studies, and there are not many studies that can be qualified as true adaptation assessment studies. Some recent studies on Indian agriculture and drought (World Bank, 2008; Mckinsey, 2009) comes closest in this regard.

The present analysis is an attempt to supplement the existing knowledge in the field of vulnerability assessment with focus on rice cultivation in the Northern Indian states. In particular the analysis attempts to go beyond the indicator based approaches that dominate the vulnerability assessment literature and has the following specific objectives: (a) comparison of vulnerability to climate variability assessed on the basis of different methodologies; (b) comparison of vulnerability to temperature and precipitation variability; and (c) comparison of vulnerability to present and future climate.

The discussion is structured as follows: first a brief survey of literature on vulnerability assessment is presented. This is followed by description of the methodology, study region and the data sources. The results are discussed along with a few concluding remarks in the end.

2.0 Vulnerability Assessment – Review of Literature

Vulnerability is a widely used concept in development economics, disaster management, and global climate change literature. To understand the difference in the conceptualization followed in different disciplines, Alwang *et al*. (2001) provide a framework wherein vulnerability is divided into three components of a risk chain: risk, risk response and outcome. There is a known or unknown probability distribution of events known as risk (say, price fluctuations) and individuals or societies have a mechanism to cope with this risk (like borrowing and saving or selling assets) known as risk response. The nature of risk and risk response intertwine leading to the outcome (could be poverty, under nutrition). The confusion arises in vulnerability conceptualization and assessment because different streams focus on different components of this risk-chain as well as on different risks and outcomes. Box 1 elaborates the vulnerability conceptualization across different disciplines using an illustrative example.

Box 1: Vulnerability to Poverty; Vulnerability to Climate Change

Focus on ‘outcome’ in development economics (in the context of poverty) stream and ‘shock’ in the disaster management and climate change literatures creates an impression that these fields are describing two entirely different concepts. That there is indeed close link between the two disciplines could be illustrated through an example. Here a hypothetical example introduced in Ionescu *et al*. (2009) is expanded to defend both the notions.

Consider a motorcyclist riding his motorcycle on a winding mountain road, with the mountain to his left and a deep valley to his right. Unbeknownst to the motorcyclist an oil spill covers part of the road ahead of him, just behind a left-hand curve. In natural language one would say that the oil spill represents a hazard and that the motorcyclist is at risk of falling down the cliff and being killed. One could say that the motorcyclist is vulnerable to the oil spill with respect to the prospect of an accident. This is the notion of vulnerability in the context of climate change introduced above. Alternatively one could also say that the motorcyclist is vulnerable to the threat of an accident, possibly caused among other things by the oil spill on the road. This captures the notion of vulnerability in the poverty literature.

One would normally say that a second motorcyclist who drives slowly and/or more carefully is less vulnerable to the oil spill and/or to the threat of accident. All disciplines are interested in capturing such comparative statements about vulnerability. One can also expand the time horizon and think of a third motorcyclist who is aware of the likelihood of shocks on mountain roads in general or oil spill in particular and gears up for it by improving her driving skills and buys a new set of tyres. Such actions constitute the adaptive capacity of the vulnerable entity. Of course a fourth motorcyclist who is aware of the actions needed but is unable to implement them due to variety of constraints (e.g., lack of money) represents an entity with lower adaptive capacity.

Vulnerability to climate change not only accounts for different time scales, but also introduces new aspects such as the ability of the vulnerable entity to act proactively to avoid future hazards. That is, the motorcyclist in collaboration with her fellow road users can influence the local administration to relay the road more frequently to reduce the probability of oil spill and hence her exposure and sensitivity to the same.

On the other hand, as in the context of vulnerability to poverty, the motorcyclist could worry about the prospect of an accident independent of a specific shock such as oil spill mentioned here. For instance, she could be confronted with a speeding truck or a brake system failure. Since a large set of her response strategies (e.g., wearing a helmet) primarily aim at reducing the damage, it may not be meaningful to focus on any single exogenous shock, but instead look at the distribution of outcomes, along with their probabilities. In this context it may not be inappropriate to refer the motorcyclist’s vulnerability to sustaining damage. In a similar vein, the economics literature focuses on vulnerability to poverty that could have been caused by a range of exogenous inputs.

In development economics literature, vulnerability is an ex-ante concept which is simply the expected value of the ex-post outcome (for e.g., what is the probability of a household falling below the poverty line in each of the next 60 months). The focus here is on the outcome. The literature on poverty dynamics, food security and sustainable livelihoods are similar in that they focus on the outcome but some of them like food security and sustainable livelihoods focuses on risks as well as risk response. As Adger (2006) notes, all of these traditions, stems from the analysis of vulnerability as a lack of entitlements. This stream of literature focuses on the social factors like institutions, social status, gender etc., as variables that lead to vulnerability, i.e., vulnerability is induced by human actions and initial entitlements, and can be prevented.

The disaster management literature again focuses on the vulnerability from the hazard/shock perspective rather than the outcome it leads to. There is confusion in terminology contributed by this stream. They call the shock as a hazard (in development stream, this is called the risk) and the outcome (as used by other streams) as risk. However, the disaster management literature has successfully bridged the physical and social sides of vulnerability. As against the entitlement approach which focuses on social factors as leading to vulnerability, natural hazards stream focused only on the physical side arguing that the exposure, probability and impact of hazards is what leads to vulnerability. In contrast, the human ecology approach emphasizes on the social factors which dictates how people adapt to the exogenous risk (Adger, 2006). The Pressure and Release model by Blaikie *et al*. (1994) successfully integrated these opposing views proposing that the physical hazard is one pressure and the social factors right from the root causes leading to the cumulative progression of vulnerability acts as a further pressure culminating to the disaster. Here, disaster is seen as interplay of the hazard and vulnerability, i.e., if one faces a hazard like tsunami AND if he/she is vulnerable by living in a hut along the coast, then he/she has a risk of a negative outcome like death which when realized becomes a disaster (Blaikie *et al*., 1994).

Several studies over the past two decades have analyzed the impacts of climate change and have used the word ‘vulnerability’[1] without necessarily providing careful definition to it. The Intergovernmental Panel on Climate Change (IPCC) described in its Third Assessment Report vulnerability as, ‘a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity’ (McCarthy *et al*., 2001, p. 995). While much confusion surrounds the operationalization of this definition, it is widely considered to capture the wide range of concerns that vulnerability to climate change poses.

The multiple conceptualizations of vulnerability notion are introduced here as in the next section the methodology adopted for vulnerability measurement in the context of climate variability is compared with prevalent methodologies of other disciplines.

3.0 Methodology and Data Sources

Food security literature introduced indicator based approaches and mapping as methods of measuring vulnerability which is widely used in the climate change literature as well. The idea of indicator based approaches is to develop a composite index of

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[1] Janssen *et al.* (2005) note that more than seven hundred articles in the global change literature have used the term ‘vulnerability’ as key word.

vulnerability by aggregating several proxy indicators with specified weights. For instance, Brenkert and Malone (2004) use the Vulnerability-Resilience Indicator Prototype (VRIP) model where they disaggregate vulnerability into two components: sensitivity and coping-adaptive capacity. They use 17 indicators grouped in sectors like food security, water resources, economic capacity, human health and so on which reflects either sensitivity or adaptive capacity. These 17 indicators are then aggregated into an overall index of vulnerability. This widely used method has some distinct disadvantages in terms of subjectivity of the selected variables and their corresponding weights and the method of aggregation.

No single variable or a combination of variables can characterize vulnerability. Moreover, as Leurs *et al*. (2003) argues, measures should focus on the vulnerability of selected variables to specific stressors rather than assess the vulnerability of a place (as the indicator-based approaches do) because even the simplest system is too complex. Recognizing the limitations of the indicator based approaches Leurs *et al* (2003) and Luers (2005) derive a generic vulnerability metric that translates vulnerability, as susceptibility to damage, into a mathematical expression.

Following the IPCC definition, they define vulnerability as a function of the sensitivity of the system, exposure to stressors, the state of the system and its adaptive capacity. To do this, one needs to first specify a threshold of damage (below which a system can be said to be damaged) and calculate vulnerability as susceptibility to damage in terms of sensitivity, exposure and state relative to this threshold.

Vulnerability to climate change (V^{CC}) is in its most general form can be represented as (Luers, 2005; Adger, 2006):

$$Vu\ln erability, V^{CC} = \sum_{i} \frac{\beta}{y_i / y_0} p_i \qquad (1)$$

where, numerator (β) represents the sensitivity, the denominator represents the outcome of interest relative to a threshold, and p_i is the probability of the i^th^ state.

For interpreting V^{CC} consider that one is interested in measuring vulnerability of representative farmer to a climatic shock. For the sake of illustration consider the farmer's vulnerability with regard to poor rice yield caused by potential changes in temperature. The representative farmer's vulnerability can be meaningfully expressed by either of the two statements: (i) vulnerability to poor wheat yield due to temperature change, or (ii) vulnerability to temperature change with reference to poor wheat yield. While in poverty literature non-consideration of external stimulus causing vulnerability enables simple projection of the outcome of concern in several states of the future, the vulnerability metrics in climate change should first establish link between the outcome of concern and the stimulus in question. That is, in the present example the analyst must identify how yield of wheat changes due to temperature changes. In other words, the sensitivity of the entity must be assessed. This is represented in the numerator of equation 1. The denominator captures the relative position of the yield with reference to the threshold. Finally using the probability of the future states the vulnerability is calculated as expected value as in (1). Note that in this formulation as expected, with increase in outcome (y) the vulnerability decreases. However, vulnerability also increases with sensitivity, irrespective of the direction of change of the stimulus.

Alternatively, vulnerability to climate change can be interpreted as follows: Continuing with the above example of farmer, for each future state, the shock (or stimulus) is assessed in terms of the change in temperature with respect to present (or some normal value). With the help of sensitivity the change in temperature can be translated into corresponding change in the yield and from which state specific yield can then be generated. Once state probabilities and the associated outcome (y) values are known vulnerability can be measured in similar manner as it is done in the case of vulnerability to poverty as in equation (2) (Dercon, 2005; Calvo and Dercon, 2005):

$$V^* = \sum_{i=1}^{n} p_i v(x_i) \ , \quad x_i = \frac{\hat{y}_i}{z} \ , \quad \hat{y}_i = \min(y_i, z) \tag{2}$$

where V^* is the vulnerability measure

$v(x_i)$ is monotonically decreasing and convex

y_i is the outcome of interest (*e.g.*, yield) in state i

z is the corresponding poverty line (equivalent to y_0 in equation 1)

p_i is the probability of occurrence of state i

n represents the number of states of the world

This metric means that vulnerability is the probability-weighted average of some (convex) function of outcomes. More specific measures that correspond with the FGT measures (Foster *et al.*, 1984), used by Suryahadi and Sumartho (2003), Kamanou and Morduch (2004) and Chaudhuri *et al.* (2002), can be represented as:

$$V^{EP} = \sum_{i \forall y_i < z} p_i \left(\frac{z - y_i}{z} \right)^a \tag{3}$$

Since most studies see vulnerability as some form of expected poverty[2], the vulnerability is referred to as V^{EP} in the above formula. For a=0 and a=1, the above measure captures vulnerability as either the probability of being poor and as the expected shortfall from the poverty line, respectively.

Similar to vulnerability to poverty only adverse shocks could be considered for vulnerability assessment. In this interpretation all the axioms that Calvo and Dercon (2005) introduced in the context of vulnerability to poverty will be equally applicable for the vulnerability to climate change metric.

Thus, the present analysis attempts to assess vulnerability of rice yields to climate variability, (a) first as given in equation (1), and (b) then as given in equation (3) with a=0. While these measures of vulnerability are related, they capture different aspects of vulnerability. Most striking difference between the two measures being: V^{CC} as given in (1) captures impact of all perturbations, whereas V^{EP} as given in (3) focuses only on perturbations that lead to ‘bad’ states.

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[2] In the present example, vulnerability is expected poor yield, or yield falling below a threshold.

Study Region

Rice is the most important cereal food crop of India occupying about 24% of gross cropped area of the country and contributing 43% of the total food grain production of the country. It plays vital role in the national food grain supply. Rice is the staple food of more than 60% of the world's population. Among the rice growing countries in the world, India has the largest area under rice crop and ranks second in production next to China. Within India, the Northern region comprising the states of Punjab, Haryana, Uttar Pradesh and Uttarchal contribute significantly to India's rice production due to higher productivity. The four states together contribute to about 27 percent of the total rice production in the country and 22 percent of the total area under rice. The climatic conditions are quite diverse across these regions and the productivity ranges from a very low of 800 kilograms per hectare to a high of 3700 kilograms per hectare which makes it ideal to study the different districts for the vulnerability of rice yields to the climate stressors. Figure 1 compares rice yield in the study area with that in India and as could be seen the productivity in the study area is consistently higher that in India over the past twenty years.

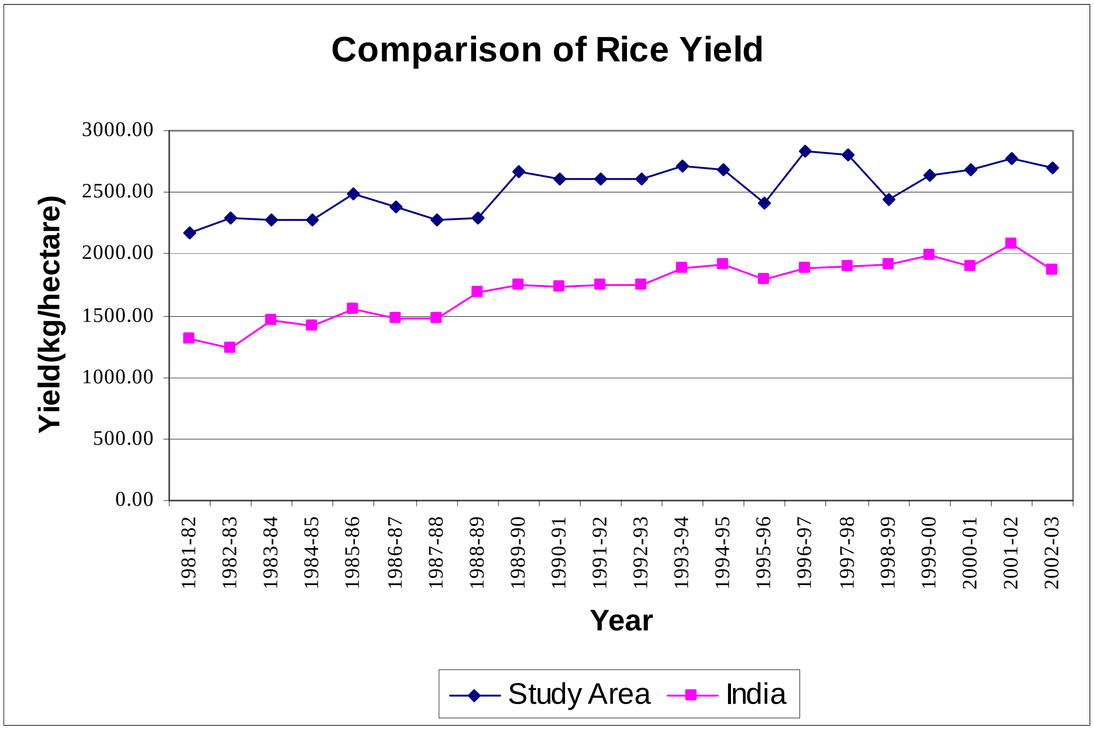
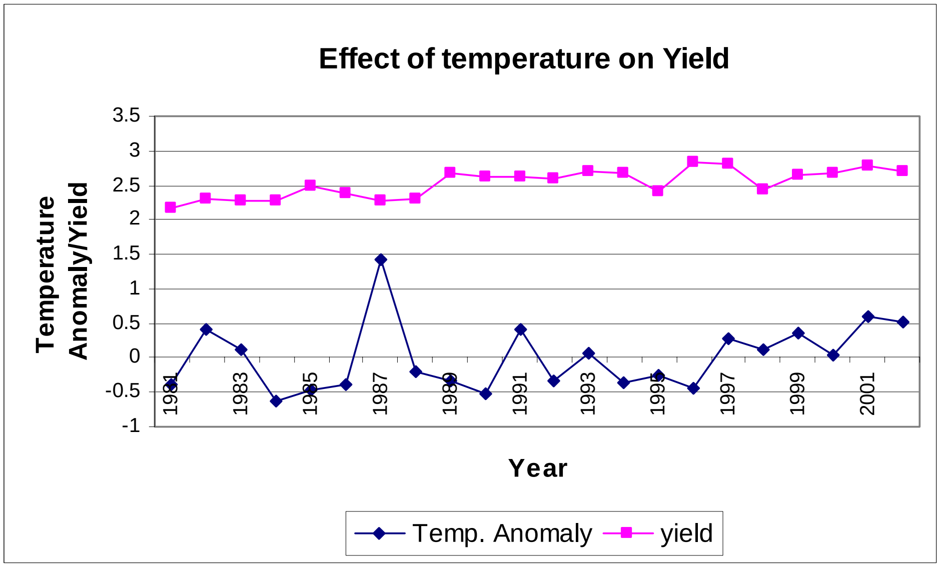


Figure 1. Productivity Comparison

The vulnerability analysis is carried out using districts as units of analysis. Out of a total of 119 districts in the four states, six districts could not be included in the analysis due to data limitations. Both temperature and rainfall variability are considered as stressors causing vulnerability to rice production. Temperature through its influence on the rate of plant phenological development, the length of growing period and rates of evaporation and transpiration can have significant impact on crop yields. Lack of precipitation through its influence on moisture stress and variability of rainfall leading to droughts or floods with additional implications for irrigation can lead to reduced crop yields. Figures 2 shows the temperature and precipitation anomalies along with the rice yields in the study region over the past two decades. The anomalies are assessed as deviation of a particular year temperature/precipitation from its long-run average (or, 'normal'). Temperature anomalies appear to have little greater influence on the yield compared to the precipitation anomalies.



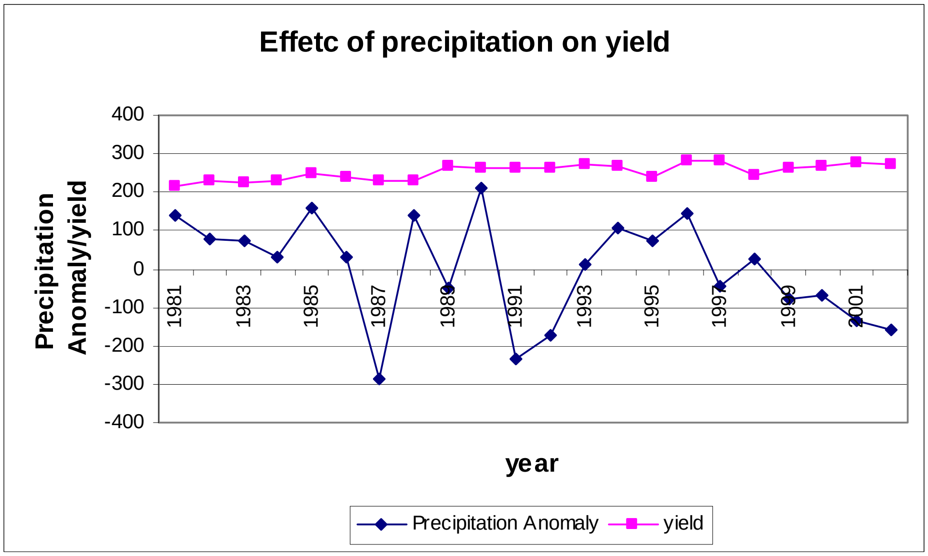


Figure 2. Temperature and Precipitation Anomalies – Rice Yield

Data Sources

The data for rice yields is from Centre for Monitoring Indian Economy (CMIE). The years that are taken for analysis are 1985-2000. Rice is primarily a Kharif crop (about 84% of paddy production is from Kharif rice) in India and in the northern belt the same season is considered for the analysis. In view of the change in the boundaries that the districts have undergone time and again, the yield data had to be adjusted for most of the 'old' districts, which have now been divided into newer districts and interpolated for the 'new' districts from the information that is available from the old districts.

The temperature and precipitation data is from Indiawaterportal for the same years[3]. The sowing season for the Kharif rice is roughly around June to October. So, the temperature considered is the average of the daily average temperature of the quarter July-September and is measured in degree Celsius. Kharif rice depends on the southwest monsoon and hence for precipitation, the total rainfall of the months June to September measured in millimeters is used. For the purpose of simulation of the variables, temperature and precipitation, mean and standard deviation of these variables over a long period of time is needed and for this, data from the years 1960-2002 is used.

To calculate the threshold level of yield, the break-even yield for the year 2002-03 is used. This yield helps the rice-farmer to just recover his costs. The cost of cultivation for each of the states is given in rupees per hectare. The farm harvest price for each of the states is given in Rupees/quintal. These numbers were converted to relevant units to arrive at the final break-even levels for all the districts in kilograms per hectare. Due to lack of data, the threshold yield of Uttarkhand is taken to be the same as that of Uttar Pradesh. Table 1 shows the state-level threshold yields estimated.

Table 1: State-level Threshold Yield

States	**Cost (Rs/hectare)**	**Price (Rs /quintal)**	**Yield (kg/hectare)**
Punjab	21035	701	3001
Haryana	21534	847	2542
Uttar Pradesh	13315	434	3068

Source: Authors own calculations

Vulnerability Estimation

The steps involved in vulnerability estimation outlined below:

a) Using the historic data on yield and climate variables (temperature and precipitation), sensitivity for each of the districts is estimated separately using the regression equation (non-linear specification is :

$$y_t = \alpha + \beta T_t + \delta T_t^2 + \gamma P_t + \lambda P_t^2 + u \qquad (4)$$

where y_t is the annual yield of paddy

T_t is the average temperature of the months July to September

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[3] http://www.indiawaterportal.org/data/metdata - last accessed on 15.5.2009)

P_t is the total rainfall during June to September

u is the error term

t is from 1985-2000

b) The next step is to generate a probability distribution of both the stressors separately. Assuming that both the variables follow a normal distribution with mean and standard deviation as given by 40 years of historical data, using Monte Carlo simulation a normal distribution is generated separately for both the stressors. That is, dT_i and dP_i values for i = 1 to 1000 is generated and then the respective probabilities associated with each dT_i and dP_i are calculated to develop different states of the world. Again, this is repeated for each of the 113 districts.

c) Using inputs from (a) and (b), and threshold yield values vulnerability is estimated once using equation (1) and once using equation (3). While using equation (1), sensitivity is estimated from equation (4) for each state of the world, and vulnerability is estimated as expected value of the sensitivity weighted by the current state of the system relative to the threshold. While using equation (3), yield in each state of the world is estimated using equation (4) and perturbations (i.e., dT_i and dP_i). The new yield thus calculated could fall below the threshold or above the threshold. The states in which the yield falls below the threshold is a bad state and all such bad states are aggregated along with their probabilities. In other words, vulnerability is simply an index of weighted probability of all the bad states.

With this background the following section provides brief discussion of the results.

4.0 Results

For better understanding of the results, the districts are classified into poor and non-poor districts in terms of their yields. All the high and medium productivity districts are termed 'non-poor' and the other districts in the medium-low, very low and low productivity groups are termed as 'poor'. A district is considered 'vulnerable' if the estimated vulnerability index (either through equation 1 or equation 3) is greater than the average vulnerability index.

Figure 3 shows the rice yields across the districts in the study area and Figure 4 shows their poverty status.

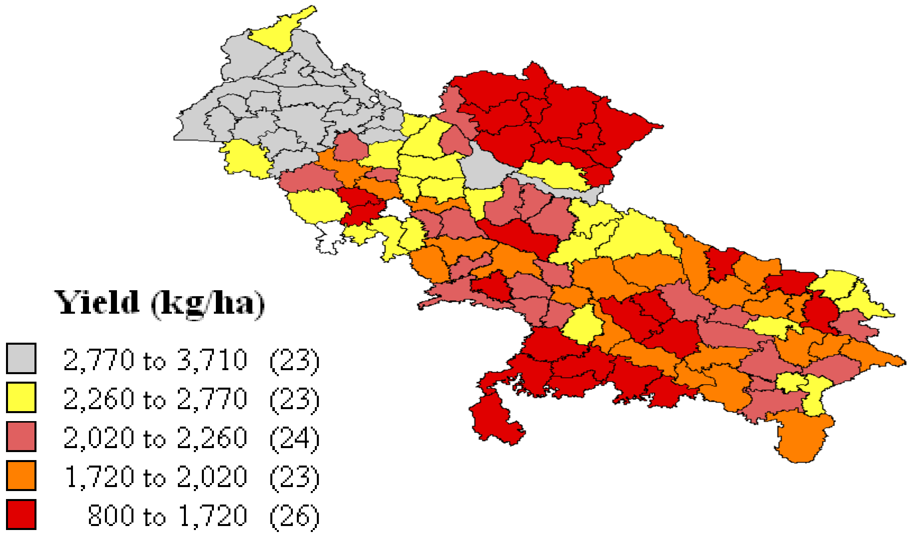

Figure 3. Rice Yields across Districts

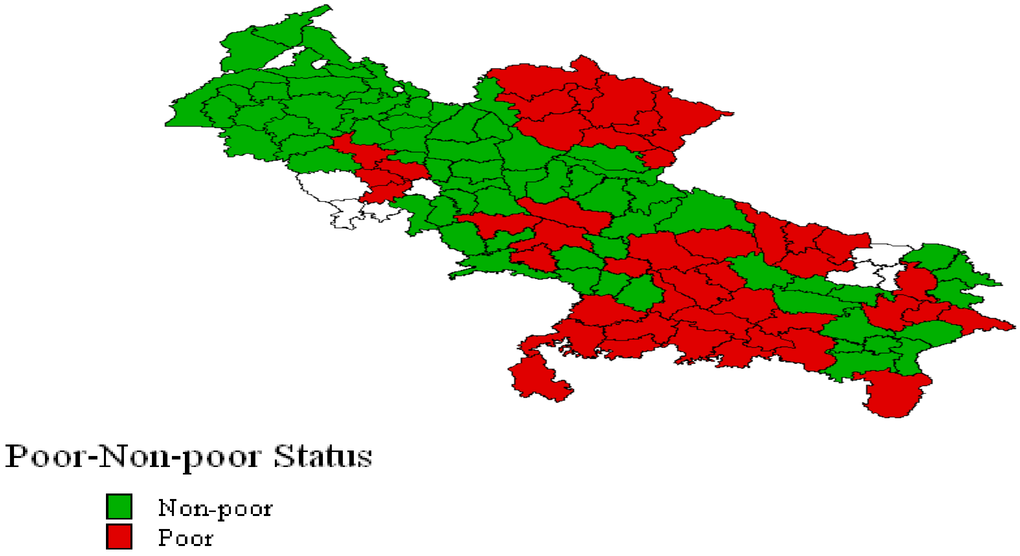

Figure 4. Poverty Status of Districts

Vulnerability to temperature variability estimated using Luers *et al*. (2003) approach (i.e., equation 1) is shown in figure 5.

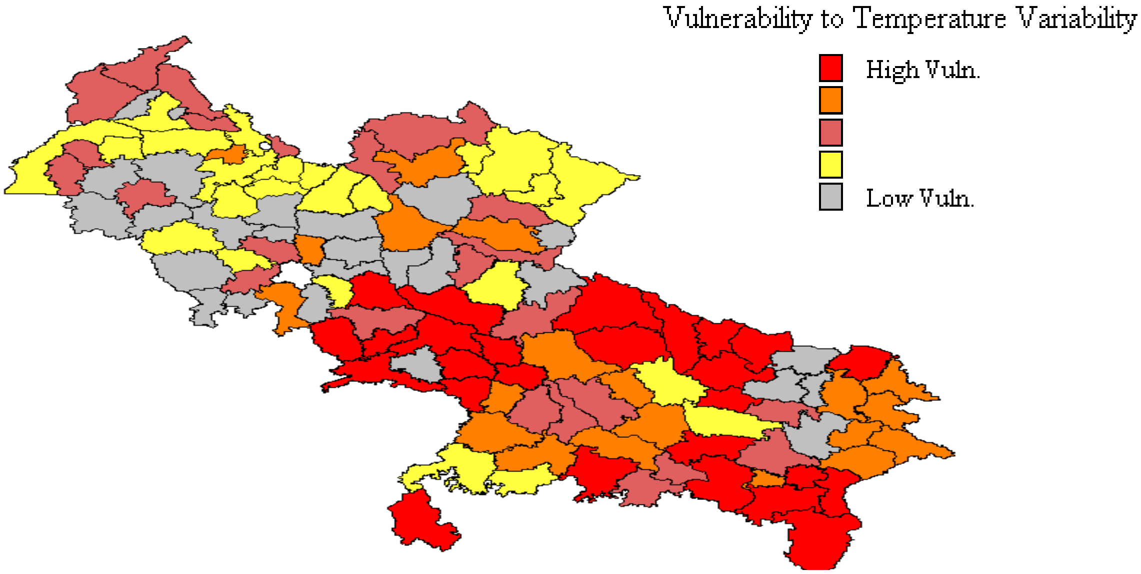

Figure 5. Vulnerability to Temperature Variability – Luers Approach

Comparing figures 4 and 5 it can be inferred that poor regions are not necessarily the only high vulnerable regions. A two-dimensional classification depicting the vulnerability status of the ‘poor’ and the ‘non-poor’ districts would be helpful for comparison. The poor districts being vulnerable and the non-poor districts being less vulnerable is common sense. A vulnerability assessment should highlight the vulnerability of non-poor districts and also direct resources away from poor districts which is not vulnerable. Figure 6 shows such two-way classification of poor and vulnerable districts corresponding to the vulnerability to temperature variability estimated using Luers approach. This figure confirms that poor districts need not necessarily be vulnerable, and at the same time, non-poor districts may not escape from vulnerability status.

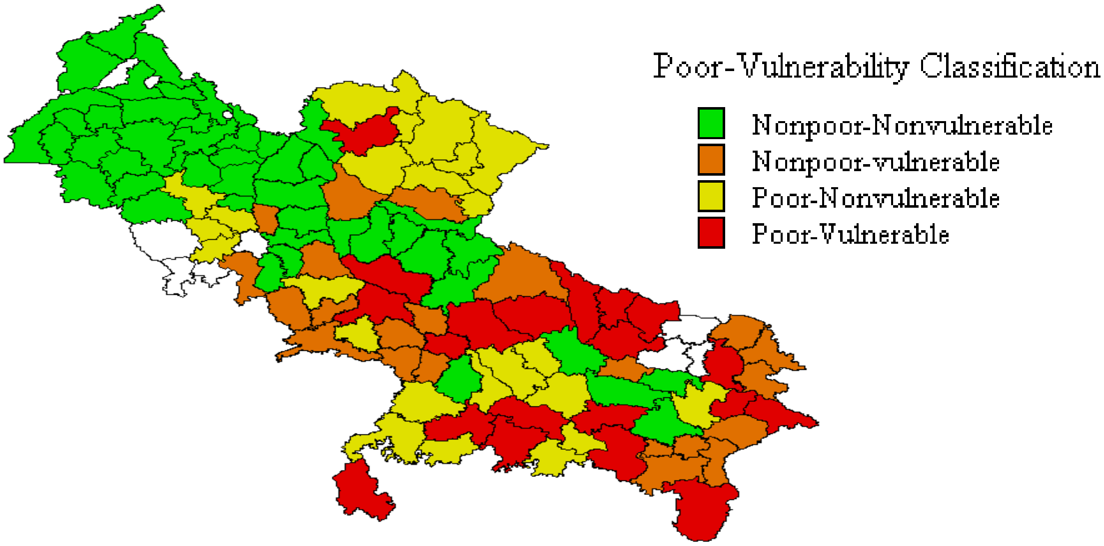

Figure 6. Poor-Vulnerability Classification – Luers Approach (Temperature Variability)

Comparison of Approaches

As mentioned in the previous section, vulnerability is also estimated using the so-called poverty approach (i.e., using equation 3). It is important to keep in mind that though both the approaches utilize similar inputs in vulnerability estimation, they estimate different aspects of vulnerability. While the poverty approach estimates vulnerability as the likelihood of a particular district becoming yield-wise 'poor' district in future due to the climate variability, the Luers approach estimates vulnerability as expected impact of climate variability on yield weighted by the relative position of the district with respect to the (yield-wise) poverty threshold.

Figure 7 shows two-way classification of poor and vulnerable districts corresponding to the vulnerability to temperature variability estimated using poverty approach. Comparison of figures 6 and 7 provides insights into the two vulnerability estimations. It is clear that vulnerability estimation based on poverty approach predicts poor districts on an average to be vulnerable also. On the other hand, under Luers approach there is greater chance for poor to non-vulnerable. Further, the Luers approach also highlights the likelihood of non-poor to become vulnerable in future. The key issue driving these results is the fact that poverty approach focuses only on the 'bad' states of the world, whereas the Luers approach considers all states of the world.

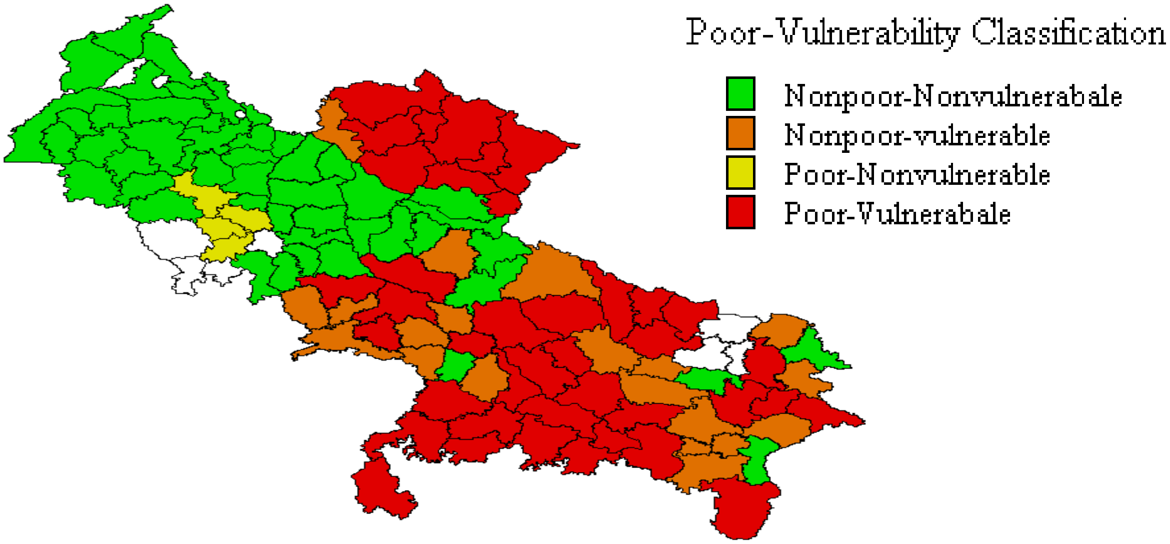

Figure 7. Poor-Vulnerability Classification – Poverty Approach (Temperature Variability)

Comparison of Stresses

To assess the relative importance of temperature and rainfall variability, vulnerability assessments are carried out separately with each of these stresses and also using the two different methodologies discussed in the previous section. The most and least vulnerable districts due to temperature and rainfall variability are presented in table 2. The results are based on poverty approach for vulnerability assessment.

Comparing the most vulnerable districts and least vulnerable districts under temperature variations and precipitation variations, it can be seen that the exact same districts are not vulnerable under both the scenarios. However, most of the districts which are vulnerable to temperature variations are vulnerable to precipitation variations as well. This is more clearly seen through relatively small difference in magnitude of the two vulnerability values implying that the extent of vulnerability does not vary greatly with respect to the two stressors. This result holds good even if the methodology of vulnerability assessment is changed.

Table 2. Most and Least Vulnerable Districts – Temperature and Rainfall Variability

Most Vulnerable		Least Vulnerable	
Temperature Variability	**Rainfall Variability**	**Temperature Variability**	**Rainfall Variability**
Deoria	Azamgarh	Ambala	Faridkot
Hamirpurup	Unnao	Bathinda	Firozpur
Gonda	Uttarkashi	Fatehabad	Moga
Allahabad	Shrawasti	Hisar	Muktsar
Pithoragarh	Chamoli	Jalandhar	Sirsa
Ballia	Ghazipur	Karnal	Nawanshahr
Almora	Pithoragarh	Kurukshetra	Fatehabad
Lalitpur	Sonbhadra	Ludhiana	Bathinda
Champawat	Rudraprayag	Mansa	Sangrur
Jhansi	Budaun	Patiala	Jalandhar
Jalaun	Mahoba	Rupnagar	Ludhiana
Banda	Almora	Sangrur	Patiala
Ghazipur	Lalitpur	Sirsa	Gurgaon
Shrawasti	Tehrigarhwal	Yamunanagar	Yamunanagar
Balrampur	Hamirpurup	Faridabad	Hisar
Bahraich	Ballia	Fatehgarhsahib	Rupnagar
Gorakhpur	Garhwal	Muktsar	Karnal
Sonbhadra	Mau	Moga	Ambala
Mau	Jhansi	Firozpur	Fatehgarhsahib
Chitrakoot	Jalaun	Panchkula	Faridabad

Comparison of Vulnerability to Present and Future Climate

The methodology detailed above calculates vulnerability as a function of current sensitivity of the system and current exposure to the stressor. However, future hazard and exposure to that hazard in the future are relevant in climate change discussions. The exposure to the stressor in this analysis is given by a normal distribution generated from the long run mean and standard deviation of the stressor. The yield levels are calculated for each of the 'state of the world' as given by every point of this normal distribution. The critical question is: "Is this Climate Change?" The temperature and precipitation values vary around a given mean and standard deviation and referred as climate variability. It is feasible that under changed climatic conditions, both mean and standard deviation of this distribution could change. Climate change projections will, to a large extent help in assessing what this new distribution would look like. In sum, depending on what the future has in store for us, the distribution of the stressor could be anything and it may be misleading to assume that the distribution is known from the past.

To account for actual climate change projections is beyond the scope of the present analysis. However, to highlight the importance of accounting for future exposure, the entire calculation of vulnerability is redone under an imaginary scenario where a 2 degree Celsius increase in temperature and a 15 percent increase in precipitation are hypothesized uniformly across all districts. Obviously, this is a purely imaginary scenario – temperature need not increase to that extent in the future, precipitation may not increase by 15 percent, it may decrease in many places as a matter of fact. Moreover, changes will certainly not be equal across the board. Also, more than a mere change in mean, many places will also experience more variability. The hypothetical climate change scenario used, however is expected to highlight the need for accounting for climate change explicitly in the vulnerability assessments.

Using poverty approach for vulnerability estimation and considering temperature variability, two-way poor-vulnerable classification is districts is carried out once with observed climate, and again with the hypothesized future climatic conditions. Figure 8 shows the two-way poor-vulnerability classification under these two cases. As it can be seen very clearly, under the current vulnerability assessment, not many districts fall in the poor non-vulnerable category. This is true in the future scenario as well. However, almost all non-poor districts are found to be not-vulnerable in the current scenario. But, under the hypothetical scenario where we consider future exposure, more non-poor districts which were found to be non-vulnerable are falling into the vulnerability net. This pattern is found for both temperature and precipitation variations. This is a very important implication for policy purposes and demonstrates that vulnerability assessments that ignore future exposure may be misleading.

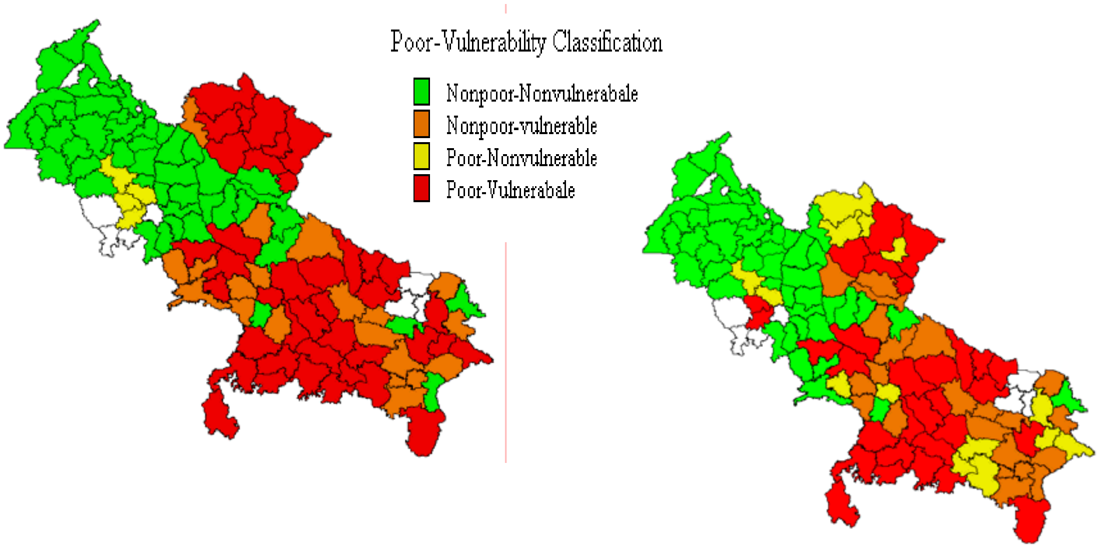

Figure 8. Poor-Vulnerability Classification – Current *vs* Future Exposure

5.0 Conclusions

This paper dealt with the notion of vulnerability specifically in the context of climate change. The focus was to develop and implement a vulnerability metric that can be generalized across many settings. Vulnerability has contested meanings derived from lot of disciplines and consequently varied methods of measuring it. Recognizing the disadvantages of the indicator-based approaches, this paper uses a generic metric that has its roots in development economics and calculates vulnerability as a function of sensitivity, exposure and the threshold level of outcome. Using this approach, vulnerability is calculated for 113 districts in Uttar Pradesh, Haryana, Punjab and Uttarkhand in India in terms of the impact of temperature and precipitation variation on rice yields. The districts are ranked separately according to their vulnerability to temperature and precipitation variation.

The main conclusion that emerges out of this analysis is that regions that are presently ‘poor’ need not become ‘vulnerable’ under climate change conditions. This has significant policy implications for the resource allocation.

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