SZENT ISTVÁN UNIVERSITY
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SOCIO-ECONOMICS OF CLIMATE CHANGE
(*Impact on Agriculture Land Use Changes in India*)

PHD THESIS

Written By

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GÖDÖLLŐ
2010

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Doctoral School

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~ No one attains perfection by merely giving up work. ~Bhagavad Gita

INTRODUCTION

Several empirical research works has been done to evaluate the socio-economics of climate change and its impact on agriculture production, land use changes and other socio-economic issues but mainly focused on the developed countries rather than developing world. In my research work, I focused on Indian situation. It has been commonly believed that developing countries are more vulnerable to climate change because of their reliance on low-capital agriculture. It has been assumed, but never tested, that low capital agriculture would have more difficulty adapting to climate changes. Even though the ability to project regional differences in impact is still emerging the consequences of climate change impact on agriculture land use are projected to be *more drastic* in the tropical region like India. The populations of the developing world are more vulnerable as they are not prepared to withstand a deleterious impact. The global economic impacts are likely to be negative for many developing countries for even the lowest global mean temperature increase. The impact of climate change will fall disproportionately upon developing countries and the poor populations within the countries, and thereby exacerbate inequities health status and access to adequate food, clean water and other resources. In addition, poverty and absence of institutions create conditions of low adaptive capacity in these countries. Most developing countries e.g. India, lack the necessary infrastructure to deal with such exigent situations as they are preoccupied with more pressing concerns such as malnutrition, drinking water supply, primary education, a rapidly growing young population and urbanization, lack of infrastructure, import dependence and the difficulties in maintaining a stable macro economy. Their environmental concerns are dominated by the problem of lack of access to technology and investment.

Why India Concerned?

India is second most populated country in the world, where the majority of *rural population is still dependent on agriculture for their livelihood and over 600 million farmers are involved in agriculture* related activities. *Agriculture and allied activities contribute about 30% to the gross domestic product of India*. *India has 52% of cultivable land and varied climates*. With arable land area of 168 million hectares, India ranks second only to the U.S. in size of agricultural area. India, a developing nation quite vulnerable to climate change, can also cause tremendous impact on world food demand.

Aim

The determination of targets has to be based on a profound analysis of several factors. The core elements, which can demonstrate the *vulnerability* in accordance with socio-economic of climate change impact on agriculture land use changes in Indian context, can be summarized the following way.

1. How *growth rate of agricultural production and yield varies according to the different climatic zones in India* and also how the socio-economic factors of climate change affect on it?
2. To analyze the *indicators of factor inputs on variation of key agricultural sector productivity and performance, incremental marginal impact of factor inputs of irrigation on agriculture land use changes in India.*

3. To analyze the relationship between the India's biggest socio-economic problems, namely *rural poverty and its relation with agricultural performance* include the impact of the other socio-economic and climatic factors influencing it.
4. To analyze also the *socio-economic factors and climate induced vulnerability index in the different part of India* in order to find out the most vulnerable regions, there adaptation and mitigation issues.

Hypothesis

India, the second largest populated and one of the fastest growing economy in the world, having several socio-economic issues, which cannot cope with the pace of economic growth. There is a commonly saying in India that "India lives in villages" and it is true that approximately 70% of the population are residing in rural areas and the tremendous growth in economy is does not truly benefits the rural people. The most important challenges India is facing today is poverty, reduction in agriculture production (mainly destruction of agricultural land due to urbanization, industrialization and other climatic effect) and frequent disasters because of climate change and vulnerability issues.

The hypothesis behind this research investigation is to determine, how the different major socio-economic indicators are varying according to climate change in India and also to find out the vulnerability index to determine the impact assessment. At the same time, comparative variations in production, yield, growth rates and other agricultural dimensions need to be investigated. Measuring the agricultural land use changes and effect of climate change, can provide detail idea about how the socio-economic of climate change phenomenon affect the agriculture land use change in India.

Summary of my most important hypothesis are given below:

1. Severity of climatic effect (most vulnerable regions or states) in particular regions in India caused drastic reduction in agriculture production and growth rate of yield.
2. Less dependency on modern irrigation technologies in the rural part of India caused severe impact on irrigation pattern in different states of India caused by socio-economic impacts of climate change.
3. Rural poverty (most important socio-economic factor for India) is not only related to agricultural performance of particular region or state but also greatly influenced by the other socio-economic and climatic factors.
4. Climate change vulnerability in different parts of India is directly related to the socio-economic status of the states e.g. less economic growth, infrastructure index, migratory situation, destruction of coastal agricultural land etc.

Material and Methods

Measuring the socio-economics of climate change impact on agriculture land use changes in India can be analyse and calculated in several ways. In my research work, I used following methods, which are given below:

1). Literatures analysis and its correlation to the chosen topic

During my research work, I follow several specific scientific research articles both National and internationally published. I found that more research related to this topic work has been done in the western world then in India related with this topic. I followed all those available and accessible research papers and compared the findings of them with my own research.

2). Document analysis

During my research studies the most important aspect was to get from the Indian governmental official data's and documents, which could provide me the with up-to-date information about the recent changes and trends of socio-economic issues in India, climate change impact on agriculture land use changes.

3.) Case study

It was necessary for me not only analyzing the development or impact assessment trends at national level but also comparing the findings and results with regional level too. For this, I selected India's biggest state, which located in different climatic zones with highly productive river basins, and is a part of Himalayan tracts and also one of the most vulnerable regions in India.

4). Comparative analysis

This analysis was also a very important part of my research studies because comparing different socio-economics, agriculture, land use and climatic characteristics and trends can give us broad views on impact assessment and also the vulnerability count. India is a geographically very large country and the second most populated in the world and that's why comparative analysis can be beneficial for future trends and assumptions.

5.). Quantitative and Statistical Methods

During my studies, I collected a bunch of datasets in order to quantify for result analysis. In addition to that I also used statistical methods mainly correlation and reggration analysis, cluster analysis to measure the vulnerability and vulnerable zones in India, which was very useful for the statistical description of my research work.

6). SWOT Analysis

SWOT analysis is a strategic planning method used to evaluate the strength, weaknesses, opportunities and threats involved in my research topic, which specify the goal of my thesis

and will identify the internal and external factors that are favourable and unfavourable to achieve my objectives and aims.

7). Interviews and personal consultations

I concluded interviews and personal consultations with national and international experts, also regional, national and international level which gave me great confidence and ideas to carry out my research work.

RESULTS

Self sufficiency in Indian food grain production and its sustainability is in ambiguity due to the climate variability and change that occurred in the recent past. About 43 % of India's geographical area is used for agricultural activity. Agriculture accounts for approximately 33 per cent of India's GDP and employs nearly 62 per cent of the population. It accounts for 8.56 % of India's exports. About one third of the cropland in India is irrigated, but rainfed agriculture is central to the Indian economy. Despite technological advances such as improved crop varieties and irrigation systems, weather and climate are still playing key role in Indian agricultural productivity thereby national prosperity.

Impact of climate change on agriculture will be one of the major deciding factors influencing the future food security of mankind on the earth. Agriculture is not only sensitive to climate change but at the same time is one of the major drivers for climate change. Understanding the weather changes over a period of time and adjusting the management practices towards achieving better harvest is a challenge to the growth of agricultural sector as a whole.

The climate sensitivity of agriculture is uncertain, as there is regional variation of rainfall, temperature, crops and cropping system, soils and management practices. The interannual variations in temperature and precipitation were much higher than the predicted changes in temperature and precipitation. The crop losses may increase if the predicted climate change increases the climate variability. Different crops respond differently as the global warming will have a complex impact.

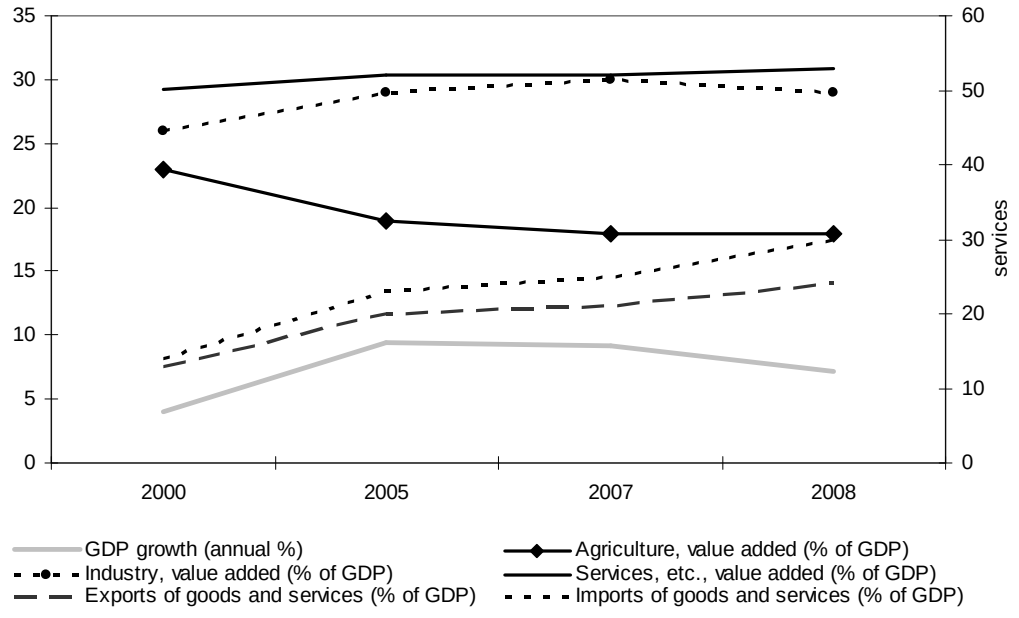
India, being a large country, experiences wide fluctuations in climatic conditions with cold winters in the North, tropical climate in South, arid region in West, wet climate in the East, marine climate in coastline and dry continental climate in interior. A likely impact of climate change on agricultural productivity in India is causing a great concern to the scientists and planners as it can hinder their attempts for achieving household food security. Food grain requirements in the country (both human and cattle) would reach about 300 mt in 2020. The question that is of great concern is that, with the alarming increase in GHG concentration and its expected impact on climate, will it be possible to achieve the targeted production?

I observed that during the past decades, significant changes in climate are observed over different regions of the country. For example, many parts of northern India show increase in minimum temperature by about 1^0C in *rabi* cropping season. However, mean temperatures are misleading as some of the individual regions could exhibit a larger variation with a larger impact on *rabi* crop production. I presented a case study of actual change in temperature in North India. They brought out that while the mean air temperatures over the wheat growing regions were high by 1.7^oC over a period of 15 days (January 16 to February 1), the actual temperature rise was 2.3 to 4.50C in the major wheat-producing region of Punjab and Haryana.

Through these studies I projected the serious effects of regional temperature on productivity of major crops. They further added that in view of the proportionate production changes in major food crops, viz., rice and wheat, over the years, the dependence on rice and wheat has increased considerably. Therefore, any factor that would influence the productivity through climatic change would affect the food security of the nation, as both these crops are sensitive to temperature variations. The arrival and performance of the monsoon is no insignificant

matter in India every year, and is avidly tracked by the national media. This is because most of the states in the Country are largely dependent on rainfall for irrigation. Any change in rainfall patterns poses a serious threat to agriculture, and therefore to the country's economy and food security. Owing to global warming, this already unpredictable weather system could become even more undependable**.** Semi-arid regions of western India are expected to receive higher than normal rainfall as temperatures soar, while central India will experience a decrease of between 10 and 20 per cent in winter rainfall by 2050. Agriculture will be adversely affected not only by an increase or decrease in the overall amounts of rainfall, but also by shifts in the timing of rainfall. For instance, over the last few years, the Chhattisgarh region has received less than its share of pre-monsoon showers in May and June. These showers are important to ensure adequate moisture in fields being prepared for rice crops. Agriculture will be worst affected in the coastal regions of Gujarat and Maharashtra, where agriculturally fertile areas are vulnerable to inundation and salinisation. Standing crop in these regions is also more likely to be damaged due to cyclonic activity. In Rajasthan, a 2^0C rise in temperature was estimated to reduce production of pearl millet by 10-15 per cent. The State of Madhya Pradesh, where soybean is grown on 77 per cent of all agricultural land, could dubiously benefit from an increase in carbon dioxide in the atmosphere. According to some studies, soybean yields could go up by as much as 50 per cent if the concentration of carbon dioxide in the atmosphere doubles. However, if this increase in carbon dioxide is accompanied by an increase in temperature, as expected, then soybean yields could actually decrease. If the maximum and minimum temperatures go up by 1^0C and 1.5^0C respectively, the gain in yield comes down to 35 per cent. If maximum and minimum temperatures rise by 3^0C and 3.5^0C, respectively then soybean yields will decrease by five per cent compared to 1998. Changes in the soil, pests and weeds brought by climate change will also affect agriculture in India. For instance, the amount of moisture in the soil will be affected by changes in factors such as precipitation, runoff and evaporation.

Figure 1: Main economic trends in India during 2001-2008.



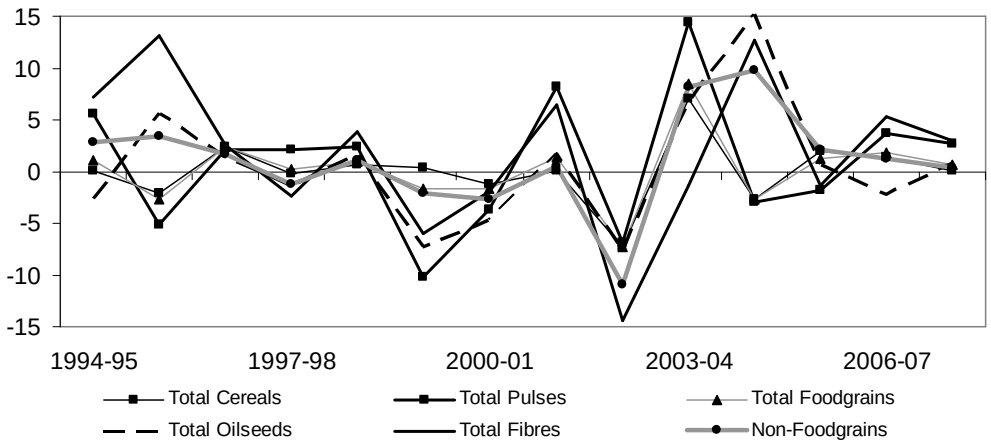
Source: Own construction based on Ministry of Finance India

From the statistical analysis of food production, it is evident that supply response of food production is greatly influenced by irrigation and fertilizer usage. Irrigation has been and is a crucial factor for reducing the fluctuation in food production in last decade. It is however, true that now with over 50% of rainfed the area under rainfall is still one of the most important factors determining average yield. Due to vagaries in rainfall, I observe fluctuation in yield. In the year 2006 out of 89 million tonnes of rice production nearly 30 million tonnes were produced in area without irrigation. In case of wheat, out of 56 million tonnes only 6 % of the total production comes from rain fed area.

There is also a growing concern about the growth rate of yield. In the period 1980-1990, yield of food grain was increasing at 3.2% per year but in the next decade the growth has slowed down to 1.7%. The slow growth in yield may be contributed by declining groundwater table, salinity intrusion and overuse of fertilizer. This slow growth of yield is prominent in the north zone where growth in food grain yield is not significantly higher compare to other geographic zones. This is also the region where fertilizer usage is very high and contributes more than 30% of the relative change in yield.

Figure 2: Growth rate of (i) area, (ii) production and (iii) yield of staple crops of India from 1994-95 to 2007-08

(i)



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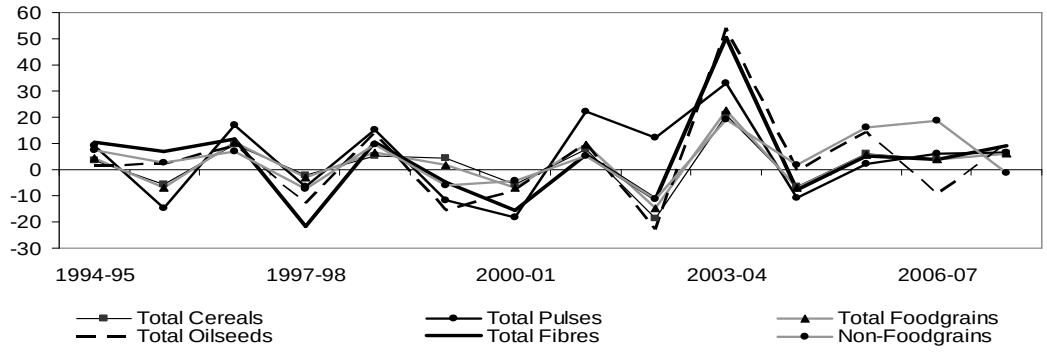
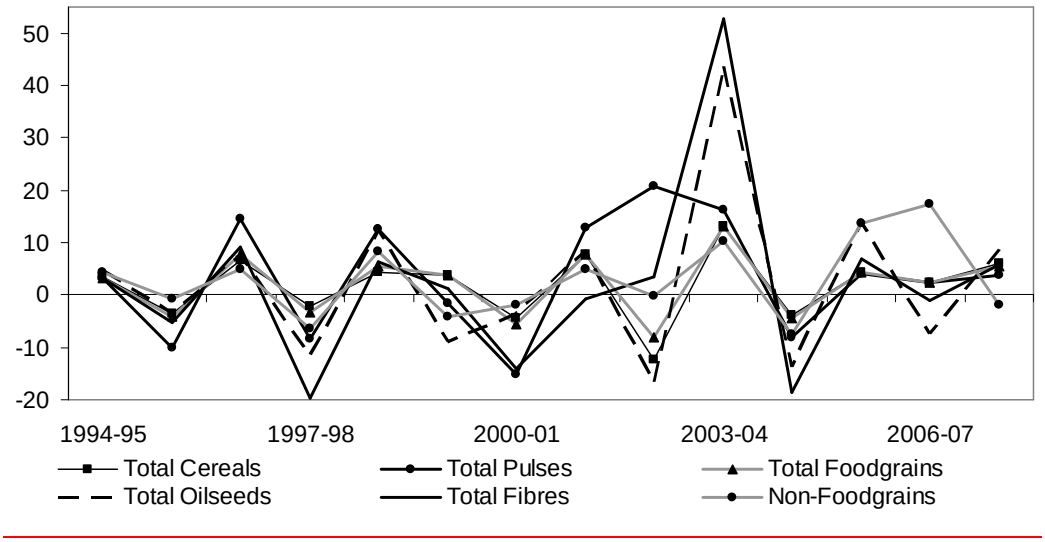


(iii)



Note: Non-Foodgrains are Feedgrains
Source: Own construction based on Ministry of Agriculture India

The incremental effect of factor inputs has been one of the controversial issues in literature of rural development. Declining international food prices have raised questions on the commonly held perception on usefulness of several factor inputs (such as irrigation, road, agriculture research, extension, etc.) in agriculture growth, and past policy thrust for maintaining regional food security (food production).Examination of cross-state panel data analysis for irrigation and related factor contribution to the agricultural growth and development in India quantifies the incremental benefits of major factor inputs (such as irrigation, crop technology and infrastructures) in over time variation of agricultural performance and agricultural productivity across the states in India discussing the policy implications of these findings. This is done using annual time series and cross section data of 14 major states of India for the period of 1970 to 2006, which accounts for more than 90 % of the agrarian economy of the country. It adopts fixed effect panel model with weighted least squared estimation technique (Generalized Least Square technique) to correct for scale and size effect related biases associated with state level aggregate data series across the states in India. *It proved my hypothesis that the severity of climatic effect (most vulnerable regions or*

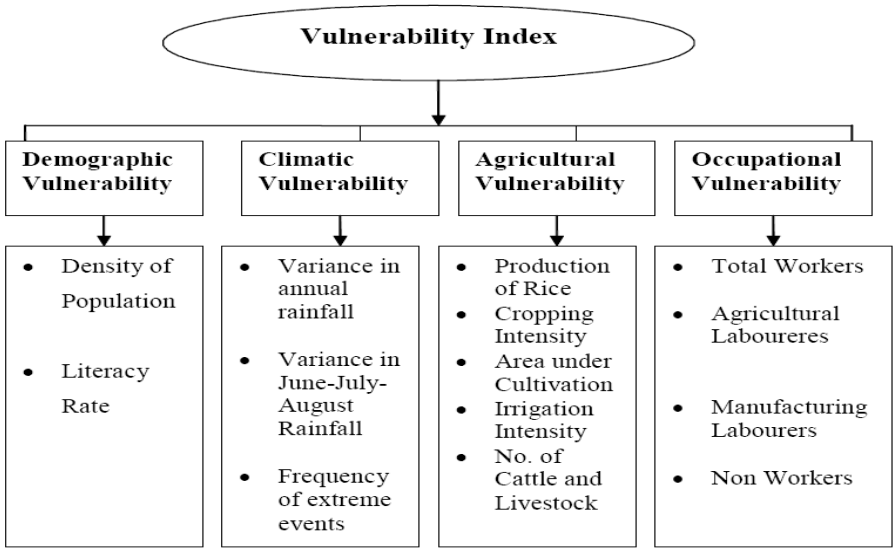
states) in particular regions in India caused drastic reduction in agriculture production and growth rate of yield also proved that the Less dependency on modern irrigation technologies in the rural part of India caused severe impact on irrigation pattern in different states of India caused by socio-economic impacts of climate change.

Given the facts about the likely impacts of climate change, India has several reasons to be concerned about climate change. India being a developing country is primarily dependent on climate sensitive factors like agriculture and forestry, which account for a major portion of its GDP and also has low financial adaptive capacity. This makes India more vulnerable. Although there is uncertainty about the degree of the impacts because of coexistence of many processes like presence of multiple climatic conditions, non climatic stress and regional scale variations there is bound to be some impact.

The research pertaining vulnerability from the extreme climatic events in India as well as the data on exposure indicate that the coastal districts on the East Coast experience extreme events such as storms and depressions more than districts on the western coast, with the exception of a few districts in Gujarat. Impacts of these events, apart from those related to life and property are likely to be on agriculture, infrastructure and on the population and human settlements of the area in concern. *The eastern coast districts are major producers of rice in India, and adverse effects of climate change will have an impact on production and availability of food grains in the country.* The research shows that these *shortfalls have the potential to create market imbalances which can further lead to fluctuations in the market and prices of food. Agricultural production* in these coastal areas is heavily dependent on climatic conditions, as despite the availability of irrigation facilities they are heavily dependent on rainfall.

The analysis carried out in my research points out that the clusters of districts with poor infrastructure and demographic development are also the regions of maximum vulnerability. Some districts exhibit very low rate of growth in infrastructure, alongside a high growth rate of population. Also these districts show a higher density of population. Hence any occurrence of extreme events is likely to be more catastrophic in nature for the people living in these districts. Moreover, the lower the district is in terms of infrastructure index and the growth of it, the more exposed it is to the potential damage from extreme events and hence people living in these regions are likely to be highly vulnerable. Lower levels of infrastructure will result in lower adaptive capacity of the people to hedge against the catastrophe. Furthermore, people living in absolute poverty will not be able to cope up with the challenges posed by climate change. *Therefore, the analysis carried out in my research suggests that climate change policies have to be integrated in to sustainable development strategies in general, and poverty alleviation measures, in particular.*

Figure 3: Sources and Dimensions of Vulnerability



Source: IPCC, 2007

From the analysis of the results obtained from the infrastructure and demographic sector, frequency of extreme events and the vulnerability index, I have many important observations. *The clusters of districts of low infrastructure and demographic development are also the regions of maximum vulnerability. The growth rate of infrastructure index is very low and growth rate of population is on the higher side. Also these districts show a high value for the density of population.* Hence any occurrence of extreme events is likely to be catastrophic in nature for the people. Also the low levels of infrastructure in these districts will have an impact on the adaptation levels of the people. Also the damages to physical infrastructure will be to a greater extent in these districts due to the high vulnerability. This will make the problem of adaptation more chronic in nature. *On the part of policy formulation a greater attention is required from policy makers to this problem. As pointed out in the result, low levels of development and high poverty in the areas is a much greater problem to be dealt with as this has a direct impact on the prospects of current and future vulnerability of the people living in these areas. It proved my hypothesis that Climate change vulnerability in different parts of India is directly related to the socio-economic status of the states e.g. less economic growth, infrastructure index, migratory situation, destruction of coastal agricultural land etc.*

It is clear that in the case of a developing country like India fundamental issues like alleviation of poverty and fulfilling the basic conditions for human development are of primary concern but the importance of climate change cannot be neglected. What is required is a development strategy that encompasses both these concerns. Therefore climate change policies have to be integrated in to sustainable development strategy such as control of pollution. Evidence of observed impacts of regional climate changes from socio-economic systems is much scanty than from physical and biological systems. Methodologically it is very difficult to separate climate effects from other factors such as technological change and economic development, because of the complexities of these systems. Vulnerability to climate change and climate variability is a function of exposure and adaptive capacity.

Exposure varies from region to region, sector to sector, and community-to-community and adaptive capacity may be even more variable. The adaptive capacity of socioeconomic systems also contributes to the difficulty of documenting effects of regional climate changes; observable effects may be adaptations to a climate change rather than direct impacts. A lot will depend on area in concern, the amount of economic activity, physical infrastructure, and social infrastructure of the area and also nature of disaster management policies formulated by the policy makers to hedge against the extreme impacts of climate change. Also the extent of the impacts will depend on the disaster mitigation strategies available at the area in concern. Also a more comprehensive study should try to capture the linkages between poverty and climate change. Poor people and poor countries find it difficult to cope with climate variability. Floods in Uttar Pradesh and Bihar for example challenge the poverty reduction programs. They have a negative impact also on the relief and rehabilitation efforts and result in loss of assets thereby reducing the ability of the poor to cope up with the impacts of climate change. Impacts from climate change severely threaten the developmental efforts and opportunities across developing countries. This increases the vulnerability of the people in developing countries like India. People living in poverty will not be able to cope with the challenges posed by climate change. The situation becomes devastating for the people living in abject poverty that is the people living significantly below poverty line. Actions to enhance the ability of the poor to cope up with climate change should aim not only to reduce poverty but also increase the resilience of the poor. It proves my hypothesis that the rural poverty is not only related to agricultural performance of particular region or state but also greatly influenced by the other socio-economic and climatic factors.

CONCLUSION AND RECOMMENDATIONS

The relationships between climate change and agriculture land use changes are complex and manifold. They involve climatic and environmental aspects, social and economic responses. These last can take either the form of autonomous reactions or of planned economic or technological policies. This picture is complicated: indeed climate change and agriculture interdependencies evolve dynamically over time, they often span over a large time and space scale and are still surrounded by large uncertainties. The environmental and the socio-economic dimensions are strongly interwined in modeling the relationship between climate change and agriculture land use changes. Both need to be accurately taken into account in order to eventually produce a reliable picture of the complexities involved.

Agriculture is one of the most important human activities. It is still one of the main sources of income and productive sector in developing countries like India. It provides a fundamental contribution to welfare and socioeconomic development. Accordingly, a relevant shock affecting the agricultural sector is likely to originate a whole set of responses in the socio-economic system. These responses span from the regional level up to the national economic level. They can be considered adaptation processes to the changing environment; in some cases they are autonomous reactions driven by self-regulatory mechanisms, in some other cases they respond to specific and planned policy interventions.

Agriculture is one sector, which is immediately affected by climate change, but it is expected that the impact on global agricultural production may be small. However, regional vulnerabilities to food deficits may increase. Short or long-term fluctuations in weather

patterns - climate variability and climate change - can influence crop yields and can force farmers to adopt new agricultural practices in response to altered climatic conditions. Climate variability / change, therefore, have a direct impact on food security. The potential effect of climate change on agriculture is the shifts in the sowing time and length of growing seasons geographically, which would alter planting and harvesting dates of crops and varieties currently used in a particular area. Seasonal precipitation distribution patterns and amounts could change due to climate change. With warmer temperatures, evapotranspiration rates would rise, which would call for much greater efficiency of water use. Also weed and insect pest ranges could shift. Perhaps most important of all, there is general agreement that in addition to changing climate, there would likely be increased variability in weather, which might mean more frequent extreme events such as heat waves, droughts and floods.

If no climate policy interventions are made to mitigate the effects of climate change on agriculture the result would be a significant decrease in potential yield in most tropical and subtropical regions due to increase in temperature. Similarly, in mid-latitudes, crop models indicate that warming of less than a few degree celsius and the associated increase in CO_2 concentrations will lead to positive responses in agricultural productivity. In tropical agricultural areas, similar assessments indicate that yields of some crops would decrease with even minimal increases in temperature because they are near their maximum temperature tolerance.

Understanding climate change and its implications on agricultural production is essential for the rural population in India as 65 to 70 percent of it is dependent on agriculture. With ever-increasing population over the last six decades, the country has become more vulnerable to climate change, which varies across regions and among social groups. Therefore, understanding the regional and local dimensions of vulnerability is extremely important to develop appropriate adaptation strategies. Also creating public awareness on climate change and its impacts on various agricultural production systems, the economy and the livelihoods of rural population is required to balance economic growth with resource conservation.

Climate change, it appears is now underway. Climate change is a global problem and India will also feel the heat. Nearly 700 million rural people in India directly depend on climate-sensitive sectors (agriculture, forests and fisheries) and natural resources (water, biodiversity, mangroves, coastal zones and grasslands) for their subsistence and livelihood. Under changing climate, food security of the Country might come under threat. In addition, the adaptive capacity of dry-land farmers, forest and coastal communities is low.

Climate change is likely to impact all the natural ecosystems as well as health. Increase in weather extremes like torrential rains, heat waves, cold waves and floods besides year-to-year variability in rainfall affects agricultural productivity significantly and leads to stagnation/ decline in production across various agro-climatic zones. To mitigate the climate change effects on agricultural production and productivity, a range of adaptive strategies need to be considered. Changing cropping calendars and pattern will be the immediate best available option with available crop varieties to mitigate the climate change impact. The options like introducing new cropping sequences, late or early maturing crop varieties depending on the available growing season, conserving soil moisture through appropriate tillage practices and efficient water harvesting techniques are also important. Developing heat and drought tolerant crop varieties by utilizing genetic resources that may be better adapted to new climatic and atmospheric conditions should be the long-term strategy. Genetic manipulation may also help to exploit the beneficial effects of increased CO_2 on crop growth and water use. One of the promising approaches would be gene pyramiding to enhance the adaptation capacity of plants to climatic change inputs (Mangala Rai, 2007). There is thus an urgent need to address the climate change and variability issues holistically through improving the natural resource base, diversifying cropping systems, adapting farming systems approach, strengthening of

extension system and institutional support. Latest improvements in biotechnology and information technologies need to be used for better agricultural planning and weather based management to enhance the agricultural productivity of the Country and meet the future challenges of climate change in the dryland regions of India.

Some Important Recommendations for Government of India:

1. Poverty reduction and economic growth can be the prime objectives of national policy.
2. Despite the uncertainties surrounding climate change, the risks of potentially adverse impacts on the food chain, coastal zones and increased occurrence of extreme events should be avoided by early action.
3. Creating a vulnerability profiles for India to climate change and agricultural trade liberalization is proposed at district level. The vulnerability mapping revealed regions of high double exposure.
4. Identification of national and international public policy measures supporting adaptation responses in regions of India vulnerable to climate change and globalization.

NEW FINDINGS

1. In India, growth rate of yield varies simultaneously depending on the climatic zones with the growth rate of irrigation patterns and fertilizer application. For example, the slow growth in yield is accompanied by declining ground water table, salinity intrusion and overuse of fertilizer. This slow growth of yield is prominent in the north zone where growth in food grain yield is not significantly higher compared to other geographic zones. This is also the region where fertilizer application is very high and contributing more than 30% of the relative change in yield.

2. By using the actually realized indicators of factor inputs on variation of key agricultural sector productivity and performances than the level of sector specific governmental spending used in several research studies, my analysis has factored out the incremental marginal impact of factor inputs in a better more reliable and more sophisticated way than past studies. My research study has also addressed some of the issues on marginal factor contribution in agriculture that were not addressed (unresolved) earlier. The findings from this research study contribute to methodological development on estimation of factors contribution to agriculture productivity growth, and to designing an effective and efficient investment and financing policies in irrigation and other sectors of agriculture and rural development in general. The research findings are equally applicable in the context of other developing countries, even outside of India, with similar constraints and opportunities for agricultural and rural development.

3. The relationship between rural poverty and agricultural performance is much dependent upon the level of aggregation at which the analysis if conducted with the all-India results in presenting a somewhat different picture from that obtained at the level of individual states. Analysis carried out at the state level shows that there may be processes at work in the rural economy which tends to increase poverty over time. These results are open to the interpretation that agricultural growth offsets the adverse impact to other factors so that only agriculture can grow fast enough, so it is likely to reduce the incidence of rural poverty. However, this interpretation rests crucially on the assumption that increased agricultural output can be obtained without exacerbating those unidentified factors which tend to increase rural poverty, and which are reflected in the time term in our regressions. It is in this context that the evidence from Uttar Pradesh is disquieting, although, again, there are a number of reasons why this evidence may be misleading.

4. The clusters of districts in India of low infrastructure and socio-economic development are also the regions of maximum vulnerability.

Summary

Climate change is one of the most important global environmental challenges, with implications for food production, water supply, health, energy, etc. Addressing climate change requires a good scientific understanding as well as coordinated action both at national and global level.

The issue of highest importance to developing countries is reducing the vulnerability of their natural and socio-economic systems to the projected climate change. India and other developing countries will face the challenge of promoting mitigation and adaptation strategies, bearing the cost of such an effort, and its implications for economic development.

Over time, there has been a visible shift in the global climate change discussions towards adaptation. Adaptation can complement mitigation as a cost-effective strategy to reduce climate change risks. The impact of climate change is projected to have different effects within and between countries. Mitigation and adaptation actions can, if appropriately designed, advance sustainable development and equity both within and across countries and between generations. One approach to balancing the attention on adaptation and mitigation strategies is to compare the costs and benefits of both the strategies. If adaptation of climate change could be carried out at negligible cost in a less expensive way, at least in the short-term, than any alternate strategy. Of course, there are complications in establishing the benefits of adaptation policies and consequent avoided damages. Furthermore, there are significant co-benefits of many mitigation and adaptation measures, which need to be estimated. The co-benefits could play a critical role in making decisions regarding the adoption of any mitigation or adaptation strategy.

The impact of mitigation will only be felt in the long run by the future generations. However, the impacts or benefits of adaptation measures are immediate and felt by the implementations of the measures. The regions implementing the mitigation measures could be different from the regions experiencing its impacts. The current generation of industrialized countries may invest in mitigation measures and the main beneficiaries may be the next generation largely in the developing countries. The choice between mitigation and adaptation strategies has spatial (geographic) and temporal (different generations) dimensions. An optimal mix of mitigation and adaptation strategies may elude the climate negotiations due to the spatial and temporal dimensions, as well as the differing perceptions of industrialized and developing countries. Under the Kyoto Protocol and UNFCCC, developing countries have insisted that Annex-I countries demonstrate commitment by promoting mitigation measures domestically and provide resources for adaptation measures in developing countries. However, over emphasis on adaptation might inhibit concerted mitigation actions by the Annex I governments, as adaptation measures are implemented and rewarded locally. Consequently, there is no incentive to participate in international negotiations, if a country considers itself to be able to fully adapt to climate change.

The Cost of addressing and not addressing climate change for India: India has potential to supply substantial mitigation at a relatively low price. Major opportunities exist both on the supply and demand side of energy, in case of carbon emissions. India is a large developing country with diverse climatic zones. The livelihood of vast population depends on climate-

sensitive economic sectors like agriculture, forestry and fisheries. The climate change vulnerability and impact studies in India assume high degree of uncertainty in the assessment due to '… limited understanding of many critical processes in the climate system, existence of multiple climatic and non-climatic stresses, regional-scale variations and nonlinearity …'. The costs of not addressing climate change or to adapt to it are very uncertain, but their welfare consequences are enormous. Early actions on adaptation therefore are prudent and consistent from the viewpoint of 'precautionary principle'. The future regime architecture can reduce the climate burden by giving greater emphasis to adaptation, e.g. via an Adaptation Protocol, whereby mandatory funding by industrialized countries could support adaptation activities in developing countries. Additional policy options like support for adaptation planning and implementation creation of a public-private insurance mechanism and alignment of climate funds and development assistance can be deployed for gaining added benefits. Some of the critical scientific issues that need to be addressed include the following:

- Many uncertainties continue to limit the ability to detect, attribute and understand the current climate change and to project what future climate changes may be, particularly at the regional level. Further, there is a need to link physical climate-biogeochemical models with models of the human system in order to provide better understanding of possible cause- effect-cause patterns linking human and non-human components of earth systems.
- Improved understanding of the exposure, sensitivity, adaptability and vulnerability of physical, ecological and social systems to climate change at regional and local level.
- Evaluation of climate mitigation options in the context of development, sustainability and equity at regional, national and global level in different sectors (energy and non-energy).
- To develop sustainable and equitable international protocols, mechanisms and financial arrangements to promote mitigation and adaptation to achieve the goals of Article 2 of the UNFCCC.

India is a large developing country with nearly 70% of the population depending directly on the climate sensitive sectors such as agriculture, fisheries and forests. The projected climate change under various scenarios is likely to have implications on food production, water supply, biodiversity and livelihoods. Thus, India has a significant stake in scientific advancement as well as an international understanding to promote mitigation and adaptation. This requires improved scientific understanding, capacity building, networking and broad consultation processes.

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