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Extent of vulnerability in wheat producing agro-ecologies of India: Tracking from indicators of cross-section and multi-dimension data

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ABSTRACT

India's geography, monsoon dependency and weather anomalies place wheat production prospects and sustainability at crossroads across agro-ecologies owing to its vulnerability. An attempt has been made to track the vulnerability in wheat producing regions for climate smart farming in India sourcing relevant historical data on multi-dimensional indicators for sensitivity, exposure and adaptive capacity. The composite vulnerability index has been estimated for 16 wheat growing states using the Intergovernmental Panel on Climate Change (IPCC) approach. First, the variables were normalised to make them unit free for comparison and second, weights were assigned to each variable across three dimensions (sensitivity, exposure and adaptive capacity) using the principal component analysis. Later, the regions were categorised into three groups based on the magnitude of the index *viz.,* high, moderate, and less. Jharkhand registered the highest sensitivity (0.61) while Punjab registered the lowest (0.18). Considering the exposure of regions to various climatic and weather variables in the wheat growing season (*Rabi*: November-April), it was found that Jharkhand had the highest exposure (0.48) and Punjab witnessed the lowest (0.30). In terms of adaptation to climate change, it was found that Maharashtra (0.63) had the highest adaptive capacity, followed by Haryana and Punjab. On the contrary, Jharkhand had the lowest adaptive capacity (0.21). Overall, the analysis of cross-sectional and multi-dimensional data indicated that Jharkhand is the most vulnerable region and Punjab is the least vulnerable region across wheat producing ecologies. Vulnerability mapping indicated that the magnitude of vulnerability is high in five regions (contributing 19% of total production), moderate in six regions (12% production) and low in five wheat growing regions (69% production). Regional prioritization has to be made *in lieu* of deviation in area and yield to minimize production losses. Further, adaptive measures and climate smart farming need to be practiced at farm and regional levels by formulating suitable policies and investment plans.

1. Introduction

Global warming is one of the alarming issues of the 21st century and the mean temperature is expected to increase more in the near future. Anthropogenic green house gas (GHG) emissions have increased since pre-industrial era and have led to unparalleled atmospheric concentrations of carbon dioxide, methane and nitrous oxide (Climate Change, 2014). Burning of fossil fuels and land use changes has boosted the quantities of GHGs and has the potential to alter the present climate system. The Intergovernmental Panel on Climate Change (IPCC) which was established during 1988 in response to the widespread human induced GHG emissions reported that among others, agriculture sector is going to be affected in a larger scale due to its vulnerable nature to climate change. The adverse effects are going to be more in the developing countries (Kato et al., 2011). However, the impact on productivity will be different among crops and regions. The yield levels are projected to increase and extend northwards, especially for cereals and winter crops in mid and high latitudes (Maracchi et al., 2005; Tuck et al., 2006; Olesen et al., 2007). Crops prevalent in plains of southern Europe *viz.* maize, sunflower and soybean could also become feasible at higher altitudes (Hildén et al., 2005; Audsley et al., 2006; Olesen et al., 2007). In this scenario, crop yield could increase by as much as 30% by 2050s, (Alexandrov et al., 2002; Ewert et al., 2005; Richter and Semenov, 2005; Audsley et al., 2006; Olesen et al., 2007).

In wheat, the cereal with maximum acreage in the world, climate change strongly influences the yield (Rao and Sinha, 1994; Ortiz et al., 2008) because of its sensitivity (Sendhil et al., 2016). The future climate scenarios evince that global warming may be beneficial in some

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regions, but could trim down the productivity in agro-ecologies where optimal temperature already exists. In certain regions like arid and tropics, wherein the likelihood of temperature matching with the physiological maxima for crops, further rise in temperature is expected to be detrimental as it would increase the heat stress and rate of evaporation. Alternatively, it has been predicted that an increase in the micro environment temperature by 2 °C in the mid-latitudes may increase the wheat output to the tune of 10% but in low-latitudes the yield levels could fall by the same amount (Gornall et al., 2010). The Indo-Gangetic Plains (IGPs) which accounts for 15% of global wheat production and comprises a part of the favorable, high potential, irrigated, low rainfall mega-environment might be reclassified as a heat-stressed, irrigated, short-season production mega-environment as a result of possible climate shifts by 2050 and this shift would also correspond to a significant reduction in wheat yields, unless appropriate cultivars and crop management practices are offered to and also are adopted by South Asian farmers (Ortiz et al., 2008).

Yield sensitivity to weather anomalies is a major concern in view of climate smart farming and is expected to have a negative effect on crop production especially in the vulnerable areas, thereby, affecting the country's food security (Sendhil et al., 2015; Sendhil et al., 2016; Sendhil et al., 2017b). India is highly vulnerable to climate change (World Bank, 2003; Rao et al., 2011; ECSJ, 2017) owing to its undulating topography which is clearly distinguished by the mighty Himalayan glaciated peaks and a long coastline; and a climate that ranges between temperate to tropical. As far as the impacts of global warming are concerned, the country is among the highly vulnerable groups and by far, agriculture sector is being affected largely. Indian agriculture, a livelihood source for about 58% of the population, forms the mainstay of its economy and is heavily dependent on vagaries of monsoons. Indian scientists from time to time have reported increasingly erratic monsoon rains, with more frequent and intense extreme events such as drought, cyclones and floods. Extreme rainfall events are likely to increase and altered trends across India have been noticed with respect to minimum temperatures (ECSJ, 2017). India is already experiencing these climate shifts which are being witnessed in the past few years and the variability of climate over the Indian sub-continent will continue to increase.

Vulnerability refers to the degree by which a region becomes susceptible to climate change. Literature on vulnerability assessment in different sectors and farm households are common, but to our knowledge, assessment of vulnerability using multi-dimension indicators to a particular crop in general and precisely cold loving plant like wheat which is highly sensitive to the climate change has not been done hitherto. In the milieu, to adapt and/or mitigate the climate change effects on wheat, an attempt has been made to track the degree of vulnerability and address the expected consequence that climate change may likely to inflict on wheat production from India. Further, the study is expected to help the policy makers to integrate vulnerable regions with relevant adaptation strategies and promote climate smart farming practices in all vulnerable regions to counter the ill-effects of climate change.

2. Material and methods

2.1. Study area

In India, wheat has been cultivated in 30.6 million hectares which falls in about 427 districts of 29 states (DES, 2017). In some states, particularly in South India like Tamil Nadu, Kerala, Andhra Pradesh and Karnataka only in a few pockets wheat is being cultivated. Barring a few states like Uttar Pradesh, Madhya Pradesh, Punjab, Rajasthan, Haryana and Bihar that accounts for about 87% of the crop area and 91% of production, the rest have marginal share (Ramdas et al., 2012). The present study has purposively chosen 16 wheat growing states to track the vulnerability status considering the data availability on different parameters and these states altogether contribute 99.39% share in total production.

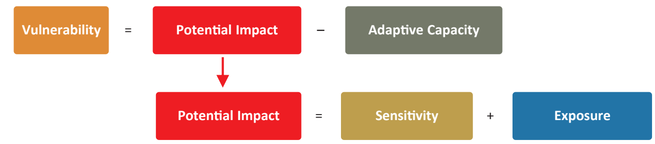

Fig. 1. Vulnerability and its determinants.

2.2. Vulnerability and its estimation

Vulnerability is the degree to which a region is susceptible to climatic risks and variability owing to the change in the climate over a period of time and is accounted by three indicators *viz.,* sensitivity, exposure and adaptive capacity (IPCC, 2007). Sensitivity is the degree to which a region responds to climate stimuli. Exposure is the degree to which a region is exposed to frequent risks and weather anomalies due to climate change. Sensitivity and exposure in combination termed as 'potential impact' which is highly detrimental to the region if the degree of the index is more. Alternatively, adaptive capacity is the ability of a region or production system to better adjust to the climatic risks, variability and impact due to climate change (Smit et al., 1999; Kumar et al., 2016). Ultimately, vulnerability index of a region is the degree of potential impact over adaptive capacity of that region (Fig. 1).

2.2.1. Data and sources

Secondary data on relevant variables have been coherently selected under sensitivity, exposure and adaptive capacity keeping in view of our study objectives, data availability, past studies (Gbetibouo and Ringler, 2009; Antwi-Agyei et al., 2012; Piya et al., 2012; Liu et al., 2013; Acheampong et al., 2014; Geng et al., 2014; Kumar et al., 2016) and experts opinion. The data were sourced from the Ministry of Agriculture and Farmers Welfare, Indian Meteorological Division, Indiastat portal, Ministry of Water Resources and other official publications and reports from the Government of India.

2.2.1.1. Variables on sensitivity and functional relationship. Sensitivity includes the response of the region to both problematic (positive functional relationship with sensitivity) as well beneficial stimuli (negative functional relationship with sensitivity) against climate change (Smit et al., 1999; IPCC, 2007). Under sensitivity both short-term and long-term changes which lead to vulnerability in wheat agro-ecologies have been taken into account and presented in Table 1 along with the expected functional relationship with sensitivity. Accordingly wheat area, production, and yield for the triennium ending (TE: Three years average) 2015–16 indicating the short-term spatial variation across 16 states having negative association with sensitivity; % change in area, production and yield for the TE 2006–07 to TE 2015–16; and, coefficient of variation in area, production and yield between TE 2006–07 and TE 2015–16 indicating the long-term inequality in wheat agro-ecologies exhibiting positive association with sensitivity were captured since there exists a significant regional disparity (Sharma et al., 2015). The potential loss due to climate variability from TE 2006–07 to TE 2015–16 was considered under sensitivity since it indicates the production loss across regions arising out of area deviation and yield deviation as well as their interaction effect using the formula developed by Kumar et al. (2016).

$$\text{Potential loss in wheat}_{\text{State}} = \frac{1}{t_n}\left[\sum_{t=1}^{n} Y_t(A_m - A_t) + \sum_{t=1}^{n} A_t(Y_m - Y_t) + \sum_{t=1}^{n} (A_m - A_t)(Y_m - Y_t)\right]$$