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Application of indicators for identifying climate change vulnerable areas in semi-arid regions of India

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ABSTRACT

This paper aims at assess district-wise vulnerability index of the state of Karnataka State, which is predominantly is rainfed and is highly susceptible to climatic variability. Secondary data on relevant indicators were collected to prepare indices *viz.*, crop production losses, exposure, sensitivity and adaptive capacity. Following normalization and using appropriate weights for indicators, these four indices were used for constructing vulnerability index, which can be used a rapid assessment method for prioritizing districts that need measures to moderate the detrimental impact of climate change. It has been observed that Climatic variability caused higher production losses in cereals, pulses and oilseeds in Davangere, Gulbarga and Raichur districts, respectively. Districts like Koppal, Raichur, Bijapur Gulbarga, Gadag, Bagalkote and Bellary were placed under extreme degree of exposure. As per the sensitivity index scores, Kolar district is the most sensitive. Further, Bengaluru (Urban), Dakshin Kannada and Kodagu are ranked first, second and third in terms of adaptive capacity in the state. Overall, vulnerability index scores indicate that Gulbarga, Koppal, Raichur, Bellary, Bagalkote, Bijapur and Belgaum are extremely vulnerable districts in the state. It was also estimated that around 70% of the cultivated area, which supports 60% and 67% of livestock and rural population of the state, respectively are facing 'extreme to high' level of vulnerability. The ranking based prioritization of the vulnerable areas calls for a holistic approach for each district or a group of districts to reduce their sensitivity, minimize exposure to rainfall variability through implementation of site-specific and leverage adaptive capacity through better health and education facilities, expansion of employment opportunities in other sectors or reducing over dependence on agriculture.

1. Introduction

The agriculture sector in developing countries is most vulnerable to the adverse impacts of climate change (Kato et al., 2011). Failure of farmers in adapting to changing climate will have a negative effect on agricultural productivity and food security (Rosenzweig and Hillel, 1998). India is highly vulnerable to climate change (World Bank, 2003; Rao et al., 2011), being one of the most drought-prone countries in the world (Mishra and Singh, 2010; Shetty et al., 2013). Within India, rainfed area constituting about 55% of the net sown area and supporting 66 and 40% livestock and human population of the country, and is highly susceptible to the harmful impact of climate change (Rao et al., 2011). These areas receive around 80% of the annual rainfall during a short span of four months (June to September), inter and intra annual variations and its distribution have a profound impact on the agricultural sector (Bhate et al., 2012). Low rainfall can reduce irrigation water supplies leading to decline in irrigated area in the subsequent season (Kumar et al., 2014). Inter-annual monsoon rainfall variability leads to large-scale droughts and floods resulting in a major effect on food grain production (Parthasarathy et al., 1992; Selvaraju, 2003; Kumar et al., 2014) and on the economy as whole (Kumar and Parikh, 2001). A typical example of monsoon rainfall and food grain production relationship is the year 2002–03 during which a 19% decline in monsoon rainfall in 2002 resulted in a steep decline of 18% in foodgrain production compared to year. Forecasts for 2020 using crop simulation models incorporating future projections warned that climate change is likely to reduce the production of wheat and rice in the range of 6–18% and 4–6%, respectively (Shetty et al., 2013). Vulnerability to climate change has been

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defined as the extent to which a system or society is prone, or at risk to, and unable to deal with the negative effects of climate change and variability (IPCC, 2007a,b). Presently, vulnerability assessment has become a tool for policy response to climatic variability since it helps identifying vulnerable regions/sections of society. For vulnerability assessment, indicator approach is the most commonly adopted method for quantifying as it combines socio-economic and biophysical factors contributing to vulnerability to climate change (Hebb and Mortsch, 2007). Vulnerability index can facilitate decision making and can be useful for setting targets and priorities as it provides a single-value, easy to comprehend estimate, and facilitates easy and meaningful monitoring and evaluation of progress (Briguglio, 2003). Therefore, indicators are being increasingly recognized as useful tools for policy making and public communication in conveying information on performance in diverse fields such as environment, economy, society or technological development (KEI, 2005). However, vulnerability assessment through indicators are constrained by: (a) subjective selection of variables; (b) not able to reflect the real situation, being average of sub-indices; (c) not able to explain the intra-regional status of vulnerability (Briguglio, 2003; Barnett et al., 2008) and (d) as the indicators do not explain the processes which shape vulnerability (Eriksen and Kelly, 2007). Yet, vulnerability assessment with the help of indicators is vital as it facilitates the identification of climate susceptible regions and, can act as an entry point for understanding and addressing the processes that cause and exacerbate vulnerability (Yohe and Tol, 2002; Brooks et al., 2005). Against this background, by combing socio-economic, climatic and production losses indicators, an attempt has been made to develop a composite index for assessing the district-wise vulnerability status of Karnataka, which is one of the most drought prone states in India.

2. Material and methods

2.1. Study area

Karnataka state is situated in southern western part of India and has the second highest area under arid land after Rajasthan and, agriculture is highly dependent on vagaries of the southwest and north east monsoon (Biradar and Sridhar, 2009). Of the net cultivated area (9.94 mha), 66% is rainfed (GoK, 2013) and therefore it is considered as highly vulnerable to climate change (BCCI-K, 2011). The south-west monsoon is the major rainy season during which the state receives about 80% of its rainfall. Hot and dry weather occurs from March to May with probability of mean maximum temperature exceeding 40 °C during the latter months. The temperature ranges from 20 to 32 °C and, 34–42 °C during winter and pre-monsoon season, respectively. Karnataka is projected to experience a warming of 1.8 and 2.2 °C by 2030, in minimum and maximum temperatures, respectively. The quantum of rainfall received is projected to decrease, especially South-West monsoon. The northern districts of the state are projected to experience increased incidence of drought by 10–80% in the *kharif* season and most of the Eastern districts will experience an increase in the frequency of droughts in the *rabi* season (BCCI-K, 2011).

2.2. Data

This study used district-wise time series data on area and yield (2000–01 to 2009–10) collected from the Directorate of Economics and Statistics, Karnataka and Ministry of agriculture, Government of India. Data pertaining to 29 districts of the state were collected under three major crop group viz., cereals (wheat, rice, sorghum, pearl millet, maize and minor millets), pulses (chick pea, horse gram, red gram, black gram, green gram, and some other minor pulses grown in the summer (*Kharif*) and *winter (Rabi)*) season and oilseeds (groundnut, sunflower, safflower, niger, rapeseed & mustard, castor, soy bean, linseed and sesame). The data for other indicators were collected from Central Ground Water Board (CGWB); Ministry of Water Resources, Government of India, Planning, Programme Monitoring and Statistics Department and Rural Development and Panchayathi Raj Department, Government of Karnataka.

2.3. De-trending of time-series data

According to Larson et al. (2004) and Antwi-Agyei et al. (2012), inter-annual fluctuations in sown area and yield of crops is due to long-term trend, which shows the impact of technological advancements (changes in management practices and use of new technologies) and short term factors (spatial and temporal variations of climatic parameters). Therefore, an important step for analyzing climate – yield relationships is to first remove long term or technological trends.

The trend effect in area and yield of a crop was captured with the help of a linear regression given in Eq. (1)

$$Z_t = \alpha + \beta t + \varepsilon_t \quad (1)$$

Where Z_t is the dependent variable (area or yield), α is intercept, β is parameter to be estimated, t is years and ε_t is residual with mean zero and variance σ^2.

To obtain the de-trended area or yield, the residuals were centered on mean area or yield ($\overline{z_t}$). De-trended data for the yield or area can be obtained by using Eq. (2).

$$Z_{dt} = \varepsilon_t + \overline{z_t} \quad (2)$$

Z_{dt} is de-trended area or yield. The de-trended production was computed by multiplying the de-trended area by the de-trended yield, and which has all the variations that can be attributed to climatic variability.

2.4. Normalization

Drawing on literature (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) appropriate indicators were chosen keeping in view of their relevance to the study area and availability of data. Since indicators are measured in different units, they therefore were subjected to normalization so as to bring their values within the comparable range between 0 and 1 (Vincent, 2004; Kumar et al., 2014).

Normalization is done based on the functional relationship of indicator with targeted index- sensitivity, exposure and adaptive capacity. If there is a positive relationship (increase in the target index with increase in the value of indicator) indicators are normalized following Eq. (3).

$$Y_{ij} = \frac{x_{ij} - Min\{x_{ij}\}}{Max\{x_{ij}\} - Min\{x_{ij}\}} \quad (3)$$

Where, Y_{ij} is the index for the ith indicator related to jth district, x_{ij} is the actual/observed value of ith indicator for jth district. $Max\{x_{ij}\}$ and $Min\{x_{ij}\}$ is the maximum and minimum value of ith indicator among all the L (J = 1,. . .., 29) districts, respectively. And if the variable has negative functional relationship, then use equation 4 was used.

$$Y_{ij} = \frac{Max\{x_{ij}\} - x_{ij}}{Max\{x_{ij}\} - Min\{x_{ij}\}} \quad (4)$$

Generally, there are different methods to assign weights to different indicators: (a) Assigning equal weights to indicators while computing an index (Vincent, 2004). However, it may be too arbitrary and might lead to underweighting of some important indicators, (b) Weights can be assigned based on expert judgments (Adger and Vincent, 2005), however this approach is often criticized for being too subjective, and is also often constrained by the availability of subject matter specialists or lack of consensus among the experts themselves (Gbetibouo and Ringler, 2009), (c) Assigning weights based on the principal component analysis (Nelson et al., 2010; Piya et al., 2012). We used principal component analysis to assign weights to different indicators of exposure, sensitivity and adaptive capacity index. In case of principal component analysis (PCA), the first principal component, which is a linear index of variables, has the largest amount of information common to all the variables (Filmer and Pritchett, 2001). Thus, the loadings from the first principal component corresponding to indicators were used as their weights for constructing the indices as given in Eq. (5).

$$Z_j = \frac{\sum_i^k Y_{ij} * w_i}{\sum_i^k w_i} \quad (5)$$

Z_j is the index score for the jth district; W_i is the weight corresponding to ith indicator; k is the total number of indicators ; *and* $\sum_i^k w_i$ is the summation of weights. Finally, quartile analysis was carried out for categorizing the district into different groups based on their index scores.

2.5. Crop production loss index (CPLI)

Any perturbation in agriculture can considerably affect food production systems and thereby increase the vulnerability especially for resource poor section of society-landless labourers, small and marginal farmers (Agarwal, 2007) since their livelihood depends on agriculture production in a particular year. Year to year variability in crop production can be expressed by ratio of expected to actual yield as suggested by Simelton et al. (2009); Antwi-Agyei et al. (2012) and Acheampong et al. (2014). However, we have measured crop production variability in terms of the extent of losses (deviation of actual production from the potential production) which can be considered as a robust indicator since it highlights the losses occurring due to climate variability. The highest yield and cropped area under a particular crop during the last 10 years were treated as potential area and yield for that crop, respectively. The reason for computing the potential yield and area separately, rather than potential production is that in rainfed areas climatic variations particularly the timing and quantum of rainfall influence crop production either by reduction in yield or acreage or both. Potential acreage (de-trended maximum acreage achieved during last 10 years) under any crop in a particular district is achieved after receiving an optimum rainfall/soil moisture at the time of sowing. On the other hand, the potential yield (detrended maximum yield achieved) was assumed to be equal to de-trended maximum yield achieved in last 10 years, when there was a sufficient and well distributed rainfall at different critical growth stages. Thus we developed a formula given by Eq. (6) to compute average production losses. This equation apart from measuring average production losses and, helps in segregating production losses into three groups *viz.*, area, and yield and interaction deviation effects, distinguishing the impact of area and yield deviation and also simultaneous deviations in both yield and area (interaction effect) at a time.

The segregation of potential loss for a crop-group for a district can be worked out as follows:

$$PL_i = \frac{1}{t_n}\left\{\sum_{t=1}^{n} Y_t\,(A_m - A_t) + \sum_{t=1}^{n} A_t\,(Y_m - Y_t) + \sum_{t=1}^{n} (A_m - A_t)(Y_m - Y_t)\right\} \quad (6)$$

$t = 1, 2, 3 \ldots\ldots 10$

Where, PL_i is average production losses for a crop in a particular district, Y_t and A_t is actual yield and area during ith year, respectively. A_m and Y_m are potential area and yield achieved during last 10 years, respectively and t is number of years. The losses incurred due to only reduction in sown area in a crop was termed as 'area deviation effect (ADE)' depicted by the first part $Y_t\,(A_m - A_t)$ in Eq. (6), and the part of loss attributed merely to reduction in yield was called a 'yield deviation effect (YDE)' and is represented by the second part $(A_t\,(Y_m - Y_t))$ and the reduction due to both area and yield was termed as 'interaction deviation effect (IDE)' depicted by third part $(A_m - A_t)(Y_m - Y_t)$. The advantage of segregation is that it gives an insight about the factor responsible for production losses which would help in crafting factor based strategies to minimize crop production losses or realizing the production potential of a crop in a particular district.

2.6. Sensitivity index and rationale for choosing its indicators

Sensitivity is the extent to which a system is either negatively or positively, directly or indirectly affected by climate change and variability (IPCC, 2007a,b) or is a degree to which a system is modified or affected by an internal or external disturbance or set of disturbances). This was captured with the help of indicators *viz.*, per cent rainfed area, percent population facing drinking water problems, level of groundwater exploitation, per cent degraded area; population density and per cent small and marginal farmers in a particular district. There is a noticeable variation among the districts with respect to these indicators, for instance, rainfed area as percentage of total cultivated area ranges from between a minimum 38% to a maximum of 98% in Shimoga and Kodagu districts, respectively. Rainfed areas are characterized by frequent droughts, land degradation, low rainwater use efficiency, poor infrastructure (Wani et al., 2009). The sensitivity of rainfed agriculture can be realized by the fact that even a decrease of one standard deviation from the mean annual rainfall often leads to a complete crop failure (Rockstrom and Falkenmark, 2000). Moreover, dry spells which generally involve 2–4 weeks of no rainfall during critical crop growth stages, causing partial or complete crop failure, often occur during every cropping season (Sharma et al., 2010). Higher the area under rainfed agriculture, higher will be the sensitivity to climatic variability. District or region with higher degraded land resources will experience greater negative impacts of climate variability and change (Gbetibouo and Ringler, 2009) as climate change may aggravate the risk of soil erosion and other degradation processes (Boardman, 2006) which deteriorates the quantity and quality of soil leading to losses in biological productivity, and thereby enhances bio-physical vulnerability (Das, 2013) that eventually has a negative impact on food production capacity. Available estimates show that about 46% of the state's area is degraded. Per cent degraded area of total geographical area of a district varies from the highest 88.1 for Koppal to a minimum of 11.4% in case of Shimoga (Maji et al., 2010). Further, it is also observed that about 8.6 mha (52.7%) area of the state suffers from soil loss exceeding 10 t ha^{-1} yr^{-1} (Ramamurthy et al., 2014). Additionally, as per the available estimates of the state, nearly 57% of the arable lands need protection and soil conservation and 10% of the total irrigated area in the state experiences the problems of water logging, salinity and alkalinity. Groundwater plays an important role in the state economy and, is also a major source of drinking water in the state. The stage of groundwater development (exploitation level of groundwater) has surpassed 100% in some districts (Kolar, Bengaluru urban, Chikkaballapura, Bengaluru rural, Ramanagara) and in other districts (Belgaum, Chitradurga and Bagalkote), it is reaching at an alarming rate near to 100% (CGWB, 2011). Moreover, declining groundwater has an adverse impact on its quality for drinking and therefore, adversely affects the areas depending highly on groundwater for drinking purposes. The environmental degradation caused by unsustainable development has aggravates the growing risks to for food security (Cao et al., 2015). The poor smallholder farmer who are highly dependent on agriculture for their livelihoods, are acutely vulnerable to shocks and stresses (Conway, 2009) since such farmers have less capital-intensive technologies and management practices to cope up with climatic variability. Thus, a region with a large number of small farmers would be more climate-sensitive (Gbetibouo and Ringler, 2009). A region with high population density is also considered as more sensitive to climate variability since a large number of people are exposed to climatic aberrations at a time; therefore, highly populated region will need greater humanitarian assistance at the time of a crisis (Gbetibouo and Ringler, 2009).

2.7. Exposure index and rationale for choosing its indicators

Exposure is defined as the degree to which a particular system is exposed to frequent drought (Fraser, 2007) a major threat and common feature of rainfed areas. The most vulnerable regions to climate are semi-arid regions where high temperatures and increase in rainfall variability could have significant negative impacts. Extreme departure from normal seasonal rainfall (droughts and floods) seriously affects agricultural output in a country like India and thereby adversely affects the economy (Mooley and Parthasarathy, 1984; Kripalani et al., 2003) since rainfed agriculture in the semi-arid and dry sub humid regions has to deal with extreme variability in rainfall, characterized by few rainfall events, high-intensity storms, and high frequency of dry spells and droughts (Wani et al., 2009). More than total rainfall, its distribution is more important particularly for rainfed crops). High variability of rainfall coupled with its skewed distribution increases the risk of crop failure and results in poor yields which in turn influences farmers' decision on investment on new technologies and level of input use (Pandey et al., 2000). Gore et al. (2010) estimated that the probability of moderate droughts and server droughts in the southern interior Karnataka are 7–26% and 1–3%, respectively whereas in north-interior Karnataka region the same are 9–28% and 14–6%, respectively. If a district is presently receiving relatively low rainfall with higher variability and, if there is a further decrease in rainfall and with an increase in its spatial and temporal variability, the area will suffer an adverse impact on agricultural production. Such a district is to be considered as highly exposed to climate variability. Apart from rainfall, temperature is an important variable influencing crop production especially for *rabi* season since an increase in temperature can reduce crop duration, increase crop respiration rates, alter photosynthate partitioning to economic products, affect the survival and distributions of pest populations, hasten nutrient mineralization in soils, decrease fertilizer use efficiencies, and increase evapotranspiration (Venkateshswarlu, 2012; Agarwal, 2007). In warmer regions, increasing temperatures will have a stronger negative impact (Schlenker and Lobell, 2010). More importantly, if increased temperature and decreased rainfall are predicted, there would be highly negative impacts on farm production especially in hot and water-scarce regions (Gbetibouo and Ringler, 2009). Keeping the implications of rainfall and temperate in view, this paper uses rainfall data for preparing exposure index which reflects the degree to which different districts were exposed to climatic variations. We captured climatic variations with the help of long-term rainfall data in terms of indicators namely, annual average *kharif* season rainfall; per cent change in mean *kharif* season rainfall; variability in *kharif* season rainfall; annual average *rabi* season rainfall; per cent change in annual average *rabi* season rainfall; variability in *rabi* season rainfall; projected change in maximum and minimum temperatures, variability in maximum and minimum temperatures.

2.8. Adaptive capacity index and rationale for choosing its indicators

Adaptive capacity is the ability of a system to reduce to moderate levels, the potential ill-effects of climate change and variability by either taking advantage of existing opportunities or undertaking measures to deal with its consequences (IPCC, 2007a,b). It is also defined as the ability of a system to cope with actual or expected stress, including its ability to initiate measures to prevent future damage (Brooks et al., 2005; Smit and Wandel, 2006). It is a function of several factors such as income, education, information access, skills, infrastructure and management capabilities (McCarthy, 2001; Tol and Yohe, 2007). It affects vulnerability by modulating exposure and sensitivity (Yohe and Tol 2002) by influencing both biophysical and social elements of a system (Eakin and Luers, 2006). Education has a strong link with high capability of adaptation of new technology, access to weather and market information and enhances knowledge of improved and modern farm practices and inputs, and thereby helps in reducing socio-economic vulnerability (Leichenko and O'Brien, 2002; Wood et al., 2014). Generally, it is believed that the poor sections of society are the worst victim of the decrease in food production and income (Das, 2013), which often reduce their assets through distress sale and consumption simultaneously and force them to forego their investments on health, nutrition, and education of children (Hoddinott, 2006). Farm size is an indicator of physical assets of a farmer and also reflects his financial capabilities for investing in climate resilient agricultural practices, which are the key to moderate the impact of climate change. Usually, smallholders due to acute land constraints are forced to engage themselves in low-paid wage activities relating to agriculture, animal husbandry and other non-farm activities to sustain their livelihood, and which leave them with little or no investment capacity at their own farm which is vital for shielding them from climatic variability. For small and marginal farmers' continuous dependence on agriculture, directly or indirectly, keeps them in a state of low assets and household wealth, consequently capital intensive-adaption measures to moderate the impact of climate change will not be carried out by the poor, which in turn, again translates into low level of income. Therefore, a region with a large number of small scale farmers will be more climate-sensitive than that with fewer small farmers (Gbetibouo and Ringler, 2009). It has been observed that regions with a high dependence on agriculture (higher share of agriculture in total GDP) are less economically diversified; this makes them more susceptible to climatic extremes and changes (Gbetibouo and Ringler, 2009). Further, less per capita income implies less capacity to cope with adverse situations caused by climate variability, and so a region or section of society with low per capita income is highly sensitive to climatic aberrations. A higher infant mortality rate reflects the poor state of availability of basic health services and facilities. Therefore, in the event of any health related problem caused by climate change, the region will not be able to cope with such challenges. Considering the relationship of the above mentioned factors with vulnerability, we estimated adaptive capacity of a district by combining the following indicators-per capita income, poverty incidence, education level, infant mortality rate, average size of landholding and per cent share of agriculture and allied sectors (fishery, animal husbandry and forestry) in the state's gross domestic product (SGDP).

2.9. Vulnerability index

Earlier studies estimated vulnerability in terms of either in biophysical index (Dixon et al., 1996; Lal et al., 1998; Klein and Nicholls, 1999; Levy et al., 2004) or economic index (Briguglio, 1995) or environmental (Kaly et al., 2003) vulnerability indices. However, all these earlier indices could not capture all the dimensions of vulnerability at a time, and IPCC (2001, 2007a,b) combined all the biophysical, economic and social dimensions measured with the help of indicators under the sub-indices *viz.*, exposure, sensitivity, and adaptive capacity. This index has the advantage of combining both "internal" factors (sensitivity and adaptive capacity) and "external" factors (exposure to shocks and stresses) affecting the vulnerability to climate change. Following this concept, vulnerability index for each district was computed by integrating a new crop production losses index, sensitivity index, exposure index and adaptive capacity as per Eq. (7):

$$VI_J = \left(EI_J + SI_J + CPLI_J\right) - AC_J \quad (7)$$

Where,

VI_J is vulnerability index for j^{th} district.
AC_J is adaptive capacity index for j^{th} district.
EI_J is composite exposure index for j^{th} district.
SI_J is sensitivity index for j^{th} district.
$CPLI_J$ is crop production loss index.

Thus, the value of vulnerability index depends on the relative robustness of indices given in Eq. (7). A district with higher score of vulnerability index would be considered as more vulnerable to climate change.

3. Results

3.1. Crop production losses index (CPLI)

The estimated values of crop production losses in cereals, oilseeds and pulses have been given in Table 1. Davangere, Mysore and Haveri districts incurred the maximum losses in cereal production to an extent of 283.8, 276.1 and 223.8 thousand tonnes per annum. Segregation of cereal production losses show that with 64.2 and 73.0% YDE (yield deviation effect) Davangere and Haveri are more prone to yield reduction, respectively whereas Mysore has been affected from losses due to higher year to year fluctuations in area under cereal crops as is evident by an area deviation effect (ADE) of 57.1%. Districts like Dakshina Kannada, Bidar, Dharwad, Udupi, Uttara Kannada, Gadag and Chitradurga had YDE value of more than 80% implying their high susceptibility to reduction in yield due to climate variability. On the other side, Mysore, Bellary and Mandya are highly prone to change in cropped area due to climatic variability as is evident from higher value of ADE (more than 50%). Overall, the reduction in yield of cereal crops is the major reason for losses in the cereal production (YDE 65.36%) in the state. The top six districts in terms of losses in oilseeds production are Raichur (10.1%), Bijapur (10.1%), Tumkur (8.6%), Chitradurga (8.5%), Bagalkote (7.8%) and Koppal (7.1%), accounted for more than half of the total losses. These districts, therefore, must be accorded priority for minimizing losses of oilseed production. Among these districts, Tumkur and Bijapur has relatively high YDE (62.9%) and ADE (58.4%), respectively, however, Raichur is equally prone to change in yield (YDE, 45.6%) and area (ADE, 44.4%). Oilseed production losses in the state can be attributed to almost equal reduction in acreage (ADE: 46.5%) and yield (YDE: 42.8%). These higher fluctuations in yields of oilseeds can be understood by the fact that around 79% of the total area under oilseeds is being grown under rainfed conditions (GOK, 2011). In case of pulses, Gulbarga is the worst affected district with production losses to the tune of 128 thousand tonnes per year, which is around 27.7% of the total losses occurring in the state. Surprisingly, Gulbarga along with the second most affected district i.e. Bijapur, accounts for around 46% of the total loss of pulses production in the state. The estimated production losses from cereal, oilseeds and pulses were normalized to construct cereal production loss index, oilseeds production loss index and pulses production loss index, respectively; the average score of these three indices was treated as crop production loss index (CPLI). As per CPLI scores, districts were also classified into four groups: extreme, high, medium and low degree of losses (Table 2). It reveals that more than 80% of the districts belonging to Northern Karnataka[1] are in the range of 'extreme to high degree of crop production losses whereas around 75% of districts of southern Karnataka were grouped in low to medium degree of crop production losses which shows that latter is relatively consistent in crop production.

3.2. Sensitivity index

The average value of the sensitivity index is 0.409 with standard deviation of 0.080 indicating noticeable inter-district disparities in the level of sensitivity to climatic variability (Table 3). Kolar was found to be the most sensitive district due to very high area under rainfed agriculture (85%), and alarmingly high abstraction of groundwater (170% stage of groundwater development) and around one thirds of the area is degraded. On the other extreme, Shimoga district was rated as the least sensitive on the account of higher irrigated area (70%) with safe status of groundwater resources and a very little degraded area (11%). Lastly, it can be said that Kolar, Bengaluru urban, Bellary, Davanagere, Ramanagara, Belgaum and Chikballapur were categorized as extremely sensitive districts of the state.

3.3. Exposure index

Average score of exposure index was 0.613 and, wide variations in exposure to climate variability are evident from the range of scores from 0.075 (minimum for Udipi district) to 0.861 (highest for Koppal district) as given in Table 4. Based on the exposure index scores, all the districts were grouped into four categories i.e. extreme, high, medium and low degree of exposure to climate change and variability. Districts like Koppal, Raichur, Bijapur Gulbarga, Gadag, Bagalkote and Bellary were grouped under extreme degree of exposure. The factors responsible for very high level of exposure are: *kharif* and *rabi* season rainfall are almost half (103 mm/annum) and two thirds (94 mm/annum) of the state's average seasonal rainfall, respectively. Moreover, during last decade, a five and six percent decline in seasonal rainfall *kharif* and *rabi* season was observed. Further, for these districts, projections show that there will be increase in maximum and minimum temperature to the tune of 2.1 and 2.3 °C, respectively, which are higher than the state level projections. On the other side, Hassan, Shimoga, Chikmagalur, Kodagu, Uttara Kannada, Dakshina Kannada and Udupi districts were grouped under low level of exposure on the account of receiving high seasonal rainfall with lower variation in rainfall and temperature.

3.4. Adaptive capacity index (ACI)

Bengaluru (Urban), Dakshin Kannada and Kodagu secured first (3.680), second (3.016) and third (2.785) places in terms of adaptive capacity (Table 5), due to higher per capita income which was noticeably 214, 49 and 75% higher in these districts, respectively over the state's average (INR 58,399) level of income (DES, Karnataka, 2011). Additionally, other factors namely, higher level of education, lower rate of infant mortality and poverty incidence

Table 1
District wise potential losses of cereals, oilseed and pulses production and its segregation into area, yield and interaction deviation effect.

District	Cereal production					Oilseed Production					Pulses Production				
	PL	ADE	YDE	IDE	DS	PL	ADE	YDE	IDE	DS	PL	ADE	YDE	IDE	DS
Bagalkote	145.8	17.6	72.5	9.8	5.0	57.8	51.0	38.4	10.6	7.8	22.8	28.8	49.0	22.1	4.9
Bengaluru Rural	39.1	27.7	56.5	15.8	1.3	3.9	61.5	22.7	15.8	0.5	3.4	36.9	56.5	6.7	0.7
Bengaluru Urban	30.7	20.3	65.3	14.4	1.0	0.3	52.2	40.4	7.4	0.0	8.6	23.6	58.1	18.3	1.8
Belgaum	221.0	22.8	69.0	8.1	7.5	49.3	41.5	52.7	5.8	6.6	17.0	35.7	50.7	13.7	3.7
Bellary	150.0	53.0	40.3	6.7	5.1	42.8	37.5	53.7	8.8	5.7	9.1	37.6	52.3	10.1	2.0
Bidar	36.9	9.9	87.9	2.2	1.3	23.6	48.4	42.5	9.1	3.2	22.7	15.8	81.0	3.2	4.9
Bijapur	148.6	36.6	51.5	11.9	5.1	75.6	58.4	32.2	9.4	10.1	51.9	46.7	38.8	14.5	11.2
Chamarajanaga	34.7	35.8	56.6	7.7	1.2	10.3	23.5	68.2	8.3	1.4	7.6	26.7	66.2	7.0	1.6
Chikballpur	70.3	16.2	78.2	5.6	2.4	16.9	46.6	32.4	21.0	2.3	3.5	35.6	53.8	10.6	0.8
Chikmagalur	58.2	33.1	49.4	17.5	2.0	9.7	31.4	54.6	14.0	1.3	2.3	31.5	62.7	5.9	0.5
Chitradurga	104.5	13.8	81.1	5.1	3.6	63.4	25.9	63.1	11.0	8.5	10.1	40.5	48.8	10.8	2.2
Dakshin Kannada	24.6	7.2	91.7	1.1	0.8	0.2	10.8	82.5	6.7	0.0	0.4	19.2	72.7	8.0	0.1
Davanagere	283.8	25.9	64.2	10.0	9.7	19.0	34.6	59.1	6.3	2.6	5.2	50.4	41.6	8.1	1.1
Dharwad	107.9	11.0	83.6	5.4	3.7	31.9	44.3	43.7	12.0	4.3	25.4	23.7	68.4	7.9	5.5
Gadag	84.0	10.6	81.4	8.0	2.9	33.3	33.4	56.8	9.8	4.5	28.6	24.9	55.4	19.8	6.2
Gulbarga	101.8	24.9	71.8	3.2	3.5	50.8	51.3	40.5	8.3	6.8	128.0	25.3	67.9	6.8	27.7
Hassan	107.1	19.9	76.3	3.8	3.7	8.1	30.0	55.6	14.4	1.1	5.6	39.2	52.4	8.5	1.2
Haveri	223.8	21.9	73.0	5.1	7.6	18.2	26.4	62.8	10.8	2.4	8.3	28.1	62.7	9.2	1.8
Kodagu	11.3	30.6	66.4	3.0	0.4	0.2	76.9	11.7	11.4	0.0	0.3	47.0	32.2	20.7	0.1
Kolar	52.5	31.2	51.6	17.2	1.8	11.2	45.8	37.3	16.9	1.5	3.5	32.8	56.4	10.7	0.8
Koppal	104.9	37.9	53.0	9.1	3.6	53.0	25.1	66.1	8.9	7.1	16.4	11.6	77.7	10.7	3.5
Mandya	124.4	50.5	39.4	10.0	4.2	7.2	66.6	17.7	15.6	1.0	18.3	48.2	36.4	15.3	3.9
Mysore	276.1	57.1	35.4	7.4	9.4	9.9	55.2	29.2	15.6	1.3	20.6	16.7	77.9	5.4	4.5
Raichur	55.3	20.0	75.8	4.2	1.9	75.6	45.6	44.4	9.9	10.1	18.7	48.1	42.6	9.3	4.0
Ramanagara	67.2	25.5	60.7	13.7	2.3	4.0	47.2	42.1	10.7	0.5	6.2	30.3	61.5	8.2	1.3
Shimoga	79.4	45.0	43.4	11.6	2.7	3.4	53.8	32.7	13.5	0.5	0.7	49.6	37.8	12.6	0.2
Tumkur	133.9	31.3	54.6	14.1	4.6	64.4	21.3	62.9	15.7	8.6	15.4	31.0	58.2	10.8	3.3
Udupi	18.7	16.4	82.3	1.3	0.6	0.6	43.2	52.4	4.4	0.1	1.6	24.7	66.0	9.3	0.3
Uttara Kannada	31.1	14.7	82.3	3.0	1.1	0.8	47.9	50.1	2.0	0.1	0.9	40.5	38.9	20.6	0.2
Notrth karnataka	**1411**	**23.4**	**70.2**	**6.4**	**48.3**	**513**	**42.6**	**48.7**	**8.8**	**68.7**	**350**	**30.6**	**57.1**	**12.3**	**75.6**
South karnataka	**1517**	**28.68**	**61.95**	**9.37**	**51.7**	**233**	**42.7**	**45.0**	**12.3**	**31.2**	**113**	**34.3**	**55.2**	**10.4**	**24.4**
State	**2928**	**26.5**	**65.4**	**8.1**	**100**	**745**	**42.7**	**46.5**	**10.8**	**100**	**463**	**32.8**	**56.0**	**11.2**	**100**

Notes: PL, ADE, YDE, IDE, DS stand for Potential Losses (thousand tones), Area Deviation Effect (% losses due deviation in area only), Yield Deviation Effect (% losses due to yield reductions), Interaction Deviation Effect (% losses due reduction area and yield both) and DS-district's share (%) in total losses in the state as a whole.

Table 2
District wise cereal, oilseed, pulses production losses index and crop production losses index (CPLI).

District	CLI	Rank	OLI	Rank	PLI	Rank	CPLI	Rank	Degree of Crop Production Losses
Gulbarga	0.332	14	0.672	7	1.000	1	0.668	1	Extreme
Bijapur	0.504	6	1.000	2	0.404	2	0.636	2	Extreme
Belgaum	0.769	4	0.651	8	0.131	10	0.517	3	Extreme
Bagalkot	0.494	7	0.764	5	0.176	5	0.478	4	Extreme
Tumkur	0.450	8	0.851	3	0.118	12	0.473	5	Extreme
Raichur	0.161	20	1.000	1	0.144	8	0.435	6	Extreme
Davanagere	1.000	1	0.250	13	0.038	20	0.429	7	Extreme
Mysore	0.971	2	0.130	18	0.159	7	0.420	8	High
Chitradurga	0.342	13	0.839	4	0.077	13	0.419	9	High
Koppal	0.344	12	0.701	6	0.126	11	0.390	10	High
Bellary	0.509	5	0.566	9	0.069	14	0.381	11	High
Haveri	0.780	3	0.239	14	0.063	16	0.361	12	High
Dharwad	0.354	10	0.421	11	0.196	4	0.324	13	High
Gadag	0.267	15	0.439	10	0.221	3	0.309	14	High
Mandya	0.415	9	0.093	21	0.140	9	0.216	15	High
Bidar	0.094	23	0.310	12	0.175	6	0.193	16	Medium
Hassan	0.352	11	0.105	20	0.041	19	0.166	17	Medium
Chikballpur	0.216	17	0.223	15	0.025	22	0.155	18	Medium
Kolar	0.151	21	0.146	16	0.025	21	0.107	19	Medium
Chikmagalur	0.172	19	0.126	19	0.015	24	0.105	20	Medium
Ramanagara	0.205	18	0.052	22	0.046	18	0.101	21	Medium
Shimoga	0.250	16	0.043	24	0.003	27	0.099	22	Medium
Chamarajanaga	0.086	24	0.134	17	0.057	17	0.092	23	Low
Bengaluru Rural	0.102	22	0.050	23	0.024	23	0.059	24	Low
Bengaluru Urban	0.071	26	0.002	27	0.064	15	0.046	25	Low
Uttar Kannada	0.073	25	0.008	25	0.004	26	0.020	26	Low
Dakshina Kannada	0.049	27	0.000	29	0.001	28	0.016	27	Low
Udupi	0.027	28	0.006	26	0.010	25	0.015	28	Low
Kodagu	0.000	29	0.000	28	0.000	29	0.000	29	Low

Notes: CLI, OLI, and PLI stand for cereal, oilseeds and pulses loss index, respectively. District having CPLI scores more than 0.454, 0.454–0.324, 0.324–0.103 and less than 0.103 were categorized as facing extreme, high, medium and low level of production losses due to climatic variability.

Table 3
District-wise sensitivity index scores and degree of sensitivity.

District	Rainfed area	Population Facing drinking water problems	Groundwater exploitation	Land degradation index	Population density	Share of small and marginal farmers	Sensitivity index	Rank	Degree of sensitivity
Kolar	0.527	0.306	0.123	0.126	0.030	0.644	0.577	1	Extreme
Bengaluru Urban	0.051	0.078	0.095	0.220	0.502	0.644	0.523	2	Extreme
Bellary	0.496	0.375	0.017	0.254	0.019	0.347	0.496	3	Extreme
Davanagere	0.213	0.353	0.052	0.325	0.023	0.512	0.485	4	Extreme
Ramanagara	0.419	0.006	0.069	0.244	0.020	0.710	0.482	5	Extreme
Belgaum	0.449	0.126	0.065	0.344	0.026	0.413	0.467	6	Extreme
Chikkaballapura	0.413	0.096	0.090	0.125	0.019	0.660	0.461	7	Extreme
Koppal	0.357	0.149	0.023	0.544	0.007	0.281	0.447	8	High
Chikmagalur	0.553	0.030	0.018	0.144	0.003	0.611	0.446	9	High
Mandya	0.076	0.272	0.018	0.120	0.027	0.825	0.439	10	High
Tumkur	0.372	0.218	0.056	0.173	0.014	0.495	0.436	11	High
Hassan	0.343	0.028	0.025	0.181	0.015	0.726	0.433	12	High
Uttara Kannada	0.406	0.001	0.004	0.150	0.001	0.726	0.423	13	High
Bengaluru Rural	0.208	0.029	0.087	0.239	0.036	0.677	0.419	14	High
Chamarajanagar	0.302	0.000	0.039	0.228	0.008	0.693	0.417	15	High
Kodagu	0.674	0.002	0.000	0.238	0.000	0.347	0.414	16	Medium
Chitradurga	0.460	0.091	0.064	0.266	0.007	0.363	0.411	17	Medium
Udupi	0.314	0.002	0.011	0.146	0.02	0.759	0.411	18	Medium
Bidar	0.530	0.031	0.043	0.241	0.021	0.363	0.404	19	Medium
Haveri	0.457	0.013	0.032	0.308	0.023	0.38	0.398	20	Medium
Dharawad	0.487	0.119	0.023	0.379	0.035	0.132	0.386	21	Medium
Gadag	0.425	0.266	0.055	0.263	0.011	0.149	0.384	22	Medium
Dakshina Kannada	0.097	0.013	0.019	0.201	0.038	0.759	0.371	23	Low
Mysore	0.153	0.080	0.014	0.092	0.036	0.726	0.362	24	Low
Gulbarga	0.595	0.216	0.015	0.039	0.012	0.149	0.337	25	Low
Raichur	0.305	0.142	0.009	0.195	0.017	0.264	0.306	26	Low
Bagalkote	0.044	0.094	0.060	0.407	0.018	0.248	0.286	27	Low
Bijapur	0.298	0.073	0.052	0.261	0.009	0.000	0.227	28	Low
Shimoga	0.000	0.005	0.007	0.000	0.009	0.627	0.213	29	Low
PCA weights	**0.674**	**0.375**	**0.123**	**0.544**	**0.502**	**0.825**	–	–	–

Note: District having sensitivity index scores more than 0.454, 0.454–0.417, 0.417–0.378 and less than 0.378 were categorized as facing extreme, high, medium and low level of sensitivity to climatic variability.

Table 4
District-wise score of exposure index.

District	MKSR	PCMKR	VKSR	PCMaxT	VMaxT	MRSR	PCMRSR	VRSR	PCMinT	VMinT	Exposure Index	Degree of Exposure
Koppal	0.890	0.085	0.656	0.840	0.628	0.895	0.162	0.656	0.696	0.552	0.861	Extreme
Raichur	0.877	0.127	0.387	0.906	0.681	0.885	0.217	0.472	0.857	0.601	0.854	Extreme
Bijapur	0.886	0.155	0.295	0.884	0.646	0.903	0.264	0.435	0.874	0.651	0.851	Extreme
Bagalkote	0.906	0.140	0.506	0.862	0.601	0.943	0.233	0.347	0.760	0.592	0.837	Extreme
Gadag	0.895	0.096	0.692	0.752	0.566	0.926	0.218	0.428	0.599	0.529	0.810	Extreme
Gulbarga	0.835	0.119	0.244	0.730	0.727	0.858	0.251	0.266	0.890	0.710	0.800	Extreme
Bellary	0.892	0.109	0.324	0.707	0.604	0.894	0.166	0.466	0.615	0.531	0.754	Extreme
Bidar	0.794	0.045	0.151	0.486	0.795	0.824	0.170	0.07	0.841	0.813	0.709	High
Bangalore Rural	0.875	0.120	0.470	0.442	0.523	0.817	0.249	0.483	0.453	0.424	0.690	High
Dharwad	0.860	0.090	0.429	0.575	0.490	0.916	0.185	0.28	0.485	0.499	0.683	High
Davanagere	0.882	0.039	0.455	0.597	0.490	0.906	0.150	0.406	0.437	0.367	0.672	High
Belgaum	0.825	0.060	0.420	0.597	0.573	0.878	0.082	0.155	0.534	0.576	0.668	High
Chitradurga	0.901	0.000	0.580	0.575	0.558	0.881	0.000	0.357	0.469	0.373	0.667	High
Mandya	0.911	0.097	0.595	0.641	0.410	0.848	0.136	0.374	0.404	0.242	0.662	High
Tumkur	0.879	0.066	0.430	0.553	0.545	0.829	0.147	0.368	0.453	0.37	0.659	High
Chamarajanagar	0.917	0.140	0.583	0.508	0.324	0.854	0.213	0.413	0.404	0.215	0.650	Medium
Haveri	0.854	0.084	0.439	0.575	0.408	0.908	0.194	0.295	0.421	0.389	0.649	Medium
Chickballapur	0.876	0.057	0.345	0.442	0.569	0.82	0.136	0.374	0.453	0.48	0.647	Medium
Ramanagar	0.873	0.111	0.448	0.464	0.444	0.781	0.186	0.416	0.437	0.319	0.636	Medium
Kolar	0.871	0.035	0.245	0.354	0.531	0.794	0.123	0.507	0.453	0.50	0.627	Medium
Bangalore Urban	0.853	0.077	0.391	0.376	0.467	0.780	0.168	0.362	0.453	0.403	0.615	Medium
Hassan	0.800	0.040	0.399	0.531	0.455	0.773	0.094	0.281	0.291	0.227	0.553	Medium
Mysore	0.895	0.086	0.283	0.597	0.378	0.860	0.103	0.203	0.34	0.148	0.553	Medium
Shimoga	0.588	0.041	0.402	0.442	0.258	0.631	0.069	0.345	0.275	0.228	0.466	Low
Chikmagalur	0.528	0.082	0.206	0.398	0.363	0.509	0.127	0.109	0.243	0.196	0.392	Low
Kodagu	0.359	0.112	0.242	0.221	0.641	0.320	0.159	0.000	0.129	0.067	0.32	Low
Uttara Kannada	0.219	0.101	0.082	0.332	0.231	0.278	0.110	0.160	0.291	0.354	0.306	Low
Dakshina Kannada	0.072	0.163	0.000	0.000	0.194	0.021	0.224	0.097	0.049	0.000	0.116	Low
Udupi	0.000	0.136	0.005	0.022	0.000	0.000	0.142	0.183	0.000	0.039	0.075	Low
PCA weights	**0.92**	**0.16**	**0.69**	**0.91**	**0.80**	**0.94**	**0.26**	**0.66**	**0.89**	**0.81**		

Notes: MKSR: mean kharif season rainfall, PCMKSR: Projected change in mean kharif season rainfall, VKSR: variability in kharif season rainfall, PCMaxT: projected change in maximum temperature, VMaxT: Variability in maximum temperature; MRSR: mean rabi season rainfall, PCMRSR: Projected change in mean rabi season rainfall, VRSR: Variability in rabi season rainfall, PCMaxT: Projected change in minimum temperature, VMinT: Variability in mini temperature. District having exposure index scores more than 0.732, 0.732–0.659, 0.659–0.553 and less than 0.553 were categorized under extreme, high, medium and low level of exposure.

Table 5
District-wise adaptive capacity index scores and degree of adaptive capacity (AC).

District	Poverty incidence	Infant mortality	Literacy	Per capita income	Size of landholding	Share of agriculture & allied in GDP	AC index	Rank	Degree of AC
Bengaluru Urban	0.708	0.810	0.737	0.772	0.153	0.501	0.879	1	Very high
Dakshina Kannada	0.706	0.833	0.740	0.268	0.077	0.391	0.720	2	Very high
Kodagu	0.708	0.671	0.580	0.347	0.478	0.000	0.664	3	Very high
Udupi	0.381	0.810	0.679	0.210	0.062	0.334	0.591	4	Very high
Bengaluru Rural	0.486	0.718	0.469	0.306	0.126	0.351	0.586	5	Very high
Dharwad	0.199	0.486	0.535	0.181	0.567	0.398	0.565	6	Very high
Uttara Kannada	0.425	0.671	0.620	0.079	0.044	0.306	0.512	7	High
Chikmagalur	0.501	0.695	0.494	0.117	0.224	0.094	0.507	8	High
Gadag	0.390	0.486	0.387	0.040	0.529	0.263	0.500	9	High
Mysore	0.489	0.648	0.318	0.157	0.094	0.338	0.488	10	High
Tumkur	0.528	0.579	0.364	0.043	0.275	0.235	0.483	11	High
Ramanagar	0.567	0.810	0.007	0.151	0.105	0.285	0.459	12	High
Hassan	0.550	0.648	0.406	0.063	0.099	0.157	0.459	13	High
Shimoga	0.273	0.556	0.527	0.080	0.180	0.289	0.455	14	High
Belgaum	0.280	0.602	0.354	0.068	0.339	0.229	0.447	15	Medium
Bijapur	0.370	0.417	0.177	0.030	0.644	0.179	0.434	16	Medium
Kolar	0.575	0.440	0.365	0.079	0.148	0.210	0.434	17	Medium
Davanagere	0.367	0.463	0.416	0.067	0.255	0.194	0.421	18	Medium
Mandya	0.475	0.741	0.254	0.027	0.000	0.159	0.395	19	Medium
Haveri	0.204	0.463	0.451	0.024	0.342	0.132	0.386	20	Medium
Chamarajanagar	0.706	0.602	0.017	0.001	0.120	0.092	0.367	21	Medium
Bidar	0.182	0.463	0.277	0.000	0.356	0.247	0.364	22	Medium
Chitradurga	0.000	0.463	0.351	0.022	0.381	0.247	0.349	23	Low
Bellary	0.092	0.232	0.172	0.159	0.393	0.343	0.332	24	Low
Bagalkote	0.171	0.255	0.235	0.056	0.448	0.152	0.314	25	Low
Gulbarga	0.149	0.278	0.136	0.009	0.474	0.249	0.309	26	Low
Chickballapur	0.575	0.000	0.253	0.029	0.138	0.148	0.273	27	Low
Raichur	0.141	0.208	0.000	0.013	0.445	0.246	0.251	28	Low
Koppal	0.094	0.000	0.179	0.060	0.417	0.153	0.216	29	Low
Weight (PCA)	0.71	0.83	0.74	0.77	0.64	0.50	–	–	–

Notes: District having adaptive capacity index scores more than 0.536, 0.536–0.447, 0.447–0.357 and less than 0.357 were categorized under very high, high, medium and low level of adaptive capacity.

helped these three districts in achieving better adaptive capacity status. In North Karnataka, around third-fourths of districts were placed under 'low to medium' category of adaptive capacity. Expectedly, around 60% of southern Karnataka's districts were found to exhibit 'high to very high' degree of adaptive capacity. A wide range in the values of ACI, ranging from a low of 0.902 for Koppal to a maximum of 3.680 for Bengaluru (urban), indicates the prevailing huge inter-district disparities in adaptive capacity.

3.5. *Vulnerability index (VI)*

The relative strength and interaction of crop production losses, sensitivity, exposure and adaptive capacity index determines the score of vulnerability index, and thereby the level of vulnerability of a particular district (Table 6). Gulbarga district was rated as the most vulnerable district of the state (vulnerable index score, 1.495), on account of low adaptive capacity (26th rank) coupled with high exposure level (6th rank) and CPLI (1st rank) scores. On the contrary, Dakshin Kannada was the safest district in terms of vulnerability with VI score of 0.217. In addition to Gulbarga, other districts, namely Koppal, Raichur, Bellary, Bagalkote, Bijapur, Belgaum, Devangere and Chitradurga were also grouped under 'extreme degree' of vulnerability with their scores of 1.482, 1.344, 1.299, 1.286, 1.281, 1.205, 1.165 and 1.147, respectively. On the contrary, district like Chikmagalur, Shimoga, Bengaluru urban, Uttara Kannada, Kodagu, Udupi and Dakshina Kannada were found to be exhibit low degree of vulnerability with their scores ranging from −0.217 to 0.436. Assessing the extent of population facing different level of vulnerability is considered a necessary step to assist in decision-making and to orient adaptation efforts. It is, therefore, necessary that to show that: how much agricultural area, human population, (especially rural population) and livestock population

Table 6
District-wise vulnerability index scores and degree of vulnerability.

District	Vulnerability index	Rank	Degree of vulnerability
Gulbarga	1.4953	1	EXTREME
Koppal	1.4822	2	EXTREME
Raichur	1.3438	3	EXTREME
Bellary	1.2986	4	EXTREME
Bagalkote	1.2864	5	EXTREME
Bijapur	1.2811	6	EXTREME
Belgaum	1.2052	7	EXTREME
Davanagere	1.1651	8	High
Chitradurga	1.1471	9	High
Tumkur	1.0852	10	High
Haveri	1.0225	11	High
Gadag	1.0027	12	High
Chikballpur	0.9899	13	High
Bidar	0.9417	14	High
Mandya	0.9218	15	Medium
Kolar	0.8771	16	Medium
Mysore	0.8468	17	Medium
Dharwad	0.8285	18	Medium
Chamarajanaga	0.7916	19	Medium
Ramanagara	0.7601	20	Medium
Hassan	0.6926	21	Medium
Bengaluru Rural	0.5818	22	Medium
Chikmagalur	0.4364	23	Low
Shimoga	0.3229	24	Low
Bengaluru Urban	0.305	25	Low
Uttara Kannada	0.2455	26	Low
Kodagu	0.0697	27	Low
Udup	−0.0898	28	Low
Dakshina Kannada	−0.2166	29	Low

Note: District having adaptive capacity index scores more than 1.185, 1.185–0.922, 0.922–0.509 and less than 0.509 were categorized under extreme, high, medium and low level of vulnerability.

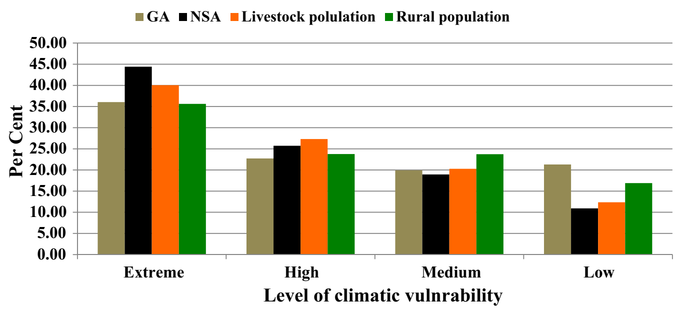

Fig. 1. Percent of geographical area (GA), cultivated area (net sown area), livestock population and rural population under different degree of vulnerability.

are expected to suffer with ill-effects of vulnerability caused by climatic variability and/or change. Our study concludes that almost 70% of the cultivated area, which supports 60 and 67% of livestock and rural population of the state are under the threat of 'extreme to high' level of vulnerability to climate change (Fig. 1).

4. Discussion

We assessed vulnerability of different districts of state of Karnataka to climate change with the combination of four sub-indices-crop production losses, exposure, sensitivity and adaptive capacity. Crop production is vulnerable to climatic variability and causes year-to-year fluctuations in crop yields (Ray et al., 2015), and the extent of variability is high and conspicuous in rainfed areas. This is also evident in our analysis wherein there was high correlation (0.69, $P < 0.01$) between scores of exposure and crop production losses index. The same can be seen in case of districts like Gulbarga, Bijapur, Belgaum, Bagalkote and Raichur which were categorized in extreme degree of CPLI and exposure index. In case of estimated cereal production losses, it was observed that reduction in yields was the main reason for losses, since about 23, 43, and 60% of area under rice, wheat and maize, respectively is rainfed, and moreover, coarse cereals and minor millets which share 45% of total area under cereal crops are mostly (> 90% area) grown as rainfed (GoK, 2013). The policy implication of estimation of crop production losses index is realized from the fact that districts categorized under extreme degree of crop production losses alone account for 41% of the total crop production losses in the state with the breakup being 37, 47 and 56% share in the total losses occurring in cereals, oilseeds and pulses production, respectively. These districts, therefore, must be given due attention by policy makers to minimize crop production losses. Districts having relatively high dependence on rainfall coupled with higher level of groundwater exploitation and proportion of degraded area are observed to be highly sensitive to climate change.

Further, adaptive capacity is mainly determined by the level of per capita income, education level and health status. Since Bengaluru (Urban) outperformed all the other districts of the state in terms of indicators governing the level of adaptive capacity, it led the district to occupy first rank in the state. Based on the climatic variability index, BCCI-K (2011) placed Bijapur, Gulbarga Tumkur and Raichur in first, second, third and fourth rank, respectively. Similarly, the exposure index constructed by our study also reveals that Bijapur, Gulbarga and Raichur are placed in 'extreme' category of exposure. However, in our case, Tumkur was categorized under 'high' degree of exposure that can be attributed to the difference in set of indicators used for constructing exposure index. In case of vulnerability index, our results also mirror the findings of BCCI-K (2011) using a different composite index (a combination of demographic and social, occupational, agricultural and climatic variability index). In their study, Gulbarga, Raichur and Bijapur were ranked as first, second and third, respectively and we also categorized all these districts under 'extreme' degree of vulnerability. The results have also shown that in northern Karnataka except Dharwad and Uttar Kannada, all other districts were placed under 'extreme to high' level of vulnerability status. Similarly, O'Brien et al. (2004) studied the district-wise status of vulnerability to climate change and observed that most districts of northern Karnataka were in the 'high to highest' level of climate vulnerability. Further, they also reported that Northern Karnataka was placed in the category of double exposure which means that such areas are likely to experience negative impacts of both climate change and economic globalization. Further, in a national study, Rao et al. (2011) also reported that around third-fourth of all districts of Karnataka were categorized under 'very high to high' level of vulnerability. In another study, Kumar et al. (2014) reported that a majority of northern Karnataka's districts have 'poor economic efficiency' in comparison to southern districts of the state. Similar disparities were also observed by Suryanarayana (2009).

5. Conclusions

This paper has identified climate change related vulnerable areas in the Karnataka state using vulnerability index, which is expected to enable policy makers and planners in articulating systematic, holistic and understandable information, and help in setting priorities. The study revealed that Gulbarga is most prone to crop production losses; Kolar is the most sensitive and Koppal has the highest level of exposure to climate change. Overall, Gulbarga is most vulnerable district in the state. From management and planning point of view, districts incurring a sizeable losses of cereal, oilseeds and pulses production should be given attention and policies may be formulated reckoning with the area and yield deviation effects for minimizing losses. For minimizing yield and area instability, adaptive measures need to be taken at crop production, farm and regional levels by formulating suitable agricultural policies and investment plans. In rainfed areas, interventions should focus on moderating the adverse impact of exposure by appropriate and judicious use of rainwater for enhancing *in-situ* soil moisture conservation. By trapping rainfall with the help of appropriate farm-level soil and water conservation measures yield of different crops can be increased by 10–47% (Venkateswarlu, 2011). Small-scale water harvesting structures has a large potential for increasing food production by enabling partial/supplemental irrigation when water is most needed by the crops (Sharma et al., 2010; Wani et al., 2009). Sharma et al. (2010) advocated that with the help of supplemental irrigation rainfed, production can be increased by more than 12% under traditional practices. However, by applying a single supplemental irrigation coupled with improved management practices, yields of rainfed crops can be increased by as high as 50%. Further, crop level measures (altering date of planting and multiple-stress-drought varieties, crop rotation, short duration varieties) farm level measures (farm pond, micro-irrigation systems, groundwater recharge filters, soil and water conservation structures) such as better land use management crop diversification (inclusion of some cash crops) and income diversification (livestock rearing, diverting some family members to non-farm jobs) are also very important for moderating the adverse impact of climate change (Agarwal, 2003; Bantilan and Anupama, 2002). Some regional level measures for enhancing adaptive capacity and minimizing sensitivity should taken, for instance introduction of crop insurance, increasing access to up-to-date weather information system, timely and speedy relief mechanisms (Ranuzzi and Srivastava, 2012). Under increasing variability of climate, a holistic approach like watershed management, which renders multiple benefits-sustainable crop production, natural resource conservation, groundwater recharge and drought moderation, which are vital to combat the climatic variability need to be followed.The sensitivity of particular regions can be moderated by containing degradation of existing productive lands and reclamation of degraded areas with appropriate technologies. Further, scientific land use planning must be promoted in degradation prone area by striking an appropriate balance between environmental sustainability and economic viability, development that combines environmental and economic perspectives coupled with appropriate compensation to affected populations can improve both nature and society (Cao et al., 2009). There is need to implement more focused and targeted progarmme and schemes, particularly in the areas for sustaining livelihood to deal with challenges of climate change.

North Karnataka[1] includes 12 districts of the state viz., Bidar, Gulberga, Yagir, Bijapur, Raichur, Bagalkot, Belgaum, Koppal, Bellary, Gadag, Dharwad, Uttarakannada. For analysis purpose very considering Yagir districts a part of Gulbarga since it is a new districts does not has required data sets separately.

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