Multi-scale vulnerability assessment for adaptation planning

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Vulnerability of communities and natural ecosystems, to potential impacts of climate change in developing countries like India, and the need for adaptation are rapidly emerging as central issues in the debate around policy responses to climate change. The present study presents an approach to identify and prioritize the most vulnerable districts, villages and households in Karnataka State, through a multi-scale assessment of inherent vulnerability to current climate variability. It also identifies the drivers of inherent vulnerability, thereby providing a tool for developing and mainstreaming adaptation strategies, in ongoing developmental or dedicated adaptation programmes. The multi-scale assessment was made for all 30 districts at the state level in Karnataka, about 1220 villages in Chikballapur district, and at the household level for two villages – Gundlapalli and Saddapalli – in Bagepalli taluk of Chikballapur district. At the district, village and household levels, low levels of education and skills are the dominant factors contributing to vulnerability. At the village and household level, the lack of income diversification and livelihood support institutions are key drivers of vulnerability. The approach of multi-scale vulnerability assessment facilitates identification and prioritization of the drivers of vulnerability at different scales, to focus adaptation interventions to address these drivers.

Keywords: Adaptation, climate variability, coping strategies, inherent vulnerability, multi-scale assessment.

Introduction

IN its most basic sense, vulnerability conveys the idea of susceptibility to damage or harm, but significant debate exists around how to characterize vulnerability in theory and practice[1]. Several studies classify vulnerability research into three streams: vulnerability as exposure (conditions that make people or places vulnerable to hazard); vulnerability as a social condition (measure of resilience to hazards), and finally, the integration of potential exposures and societal resilience with specific focus on places or regions[2,3].

The Fifth Assessment Report of the IPCC[4] defines vulnerability as 'the propensity or predisposition to be adversely affected'. It also elaborates that vulnerability encompasses a variety of concepts, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. In particular, the report differentiates between vulnerability (predisposition of a system to be adversely affected) and exposure (the presence of a system in places that could be adversely affected). The differences arise from non-climatic factors and from multidimensional inequalities, often produced by uneven development processes[4]. Vulnerability and exposure vary over time and across geographic contexts. Changes in poverty or socio-economic status, ethnic composition, age structure, and governance have had a significant influence on the outcome of past crises associated with climate-related hazards[5–7]. Climate-related hazards exacerbate other stressors, often with negative outcomes for livelihoods, especially for people living in poverty[8].

Since a compendium of several factors and mechanisms cause or counteract to determine it, the concept of vulnerability is difficult to illustrate with certainty. Many attempts have been made, mostly through vulnerability assessments to better understand the complex mechanisms that determine vulnerability[9–15]. The main purpose of vulnerability assessment is to identify and prioritize regions and sectors, which are likely to be adversely impacted by climate change, and to enable mainstream development of adaptation strategies in the broader developmental context. Vulnerability assessments aim not only to identify the systems or households most at risk, but also to understand the reason[16]. Through vulnerability assessments, the government can provide short-term relief to those who are inherently most vulnerable and help build long-term resilience to current climate variability and future climate change, instead of adopting generic adaptation strategies, which would undoubtedly require more investment both in terms of finances and human resources.

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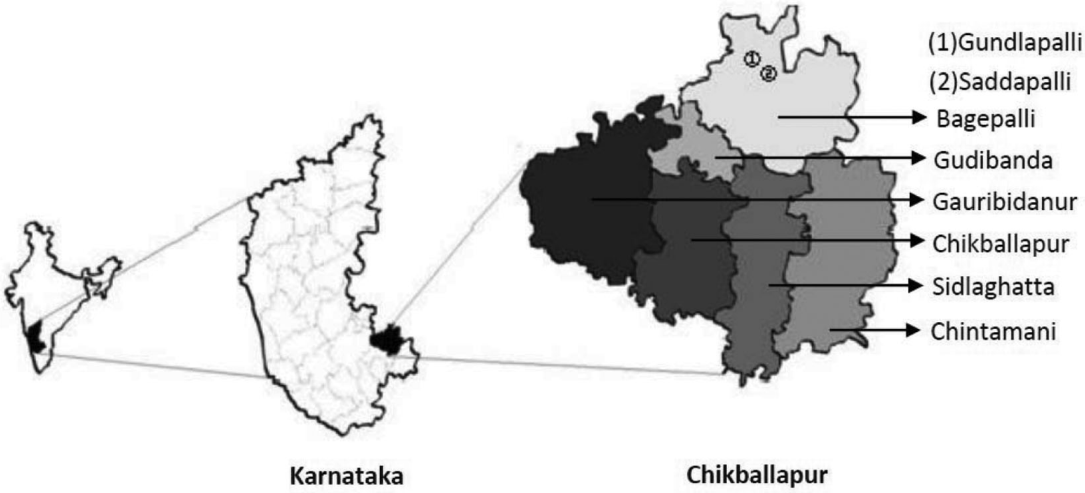

Figure 1. Study districts, block and villages for vulnerability assessment (maps are not to scale).

It is important to understand the regional heterogeneity within environmental and socio-economic conditions, for designing policies and programmes that are tailored to particular contexts[17–19]. This would help differentiate and enrich generic policies for vulnerability reduction with regard to particular social groups or exposure to specific stresses[20]. Furthermore, climate change-induced perturbations, whether socio-economic or ecological, will likely produce meso-scale effects[21,22] yet be mediated by multi-scalar processes[23]. Agrawal[21] and Birkenholtz[23] have highlighted the need for an investigative approach that can extend to multiple scales within an affected region. The absence of theory to address this challenge in current vulnerability research is a 'surprising gap in middle-range theory of climate change vulnerability research'[23].

Recognizing the need for such a multi-scale assessment, the present study was conducted in the state of Karnataka, at district, village and household levels in 2012 and inherent vulnerability profiles were developed at these three different scales to aid development of targeted strategies to enhance resilience and provide recommendations.

Study design and features of the study area

The study area is depicted in Figure 1.

District level assessment for Karnataka

All the districts were selected for assessing the inherent socio-economic vulnerability to current climate variability, which not only consider socio-economic indicators, but also includes agricultural parameters (Annexure 1), as agriculture is the main source of livelihoods for a majority of the population.

The rationale for selection of Karnataka for this assessment, is the dominance of rainfed agriculture (with nearly seven million hectares as of 2009–10), accounting for nearly 70% of the cultivated land in the state[24,25] and the fact that majority of the taluks (157 out of 220 taluks) in the state are drought-prone and were affected by drought in 2012 (ref. 26). Details on the rationale for selection of Karnataka for the assessment of inherent vulnerability and rainfall data are available from Kattumuri *et al.*[27].

Village level assessment for Chikballapur district (Figure 1)

A total of 1220 villages were assessed to develop an inherent socio-economic vulnerability profile to current climate variability, including bio-physical and socio-economic indicators.

The normal annual rainfall in the district ranges from 848 mm in the west to 651 mm in the east and averages to around 756 mm. There are no perennial rivers and the district is drained by seasonal rivers[28], 73% is rainfed and since it is drought-prone, the district is characterized by low cropping as well as irrigation intensity[29]. The Central Ground Water Board[28] states that 91% of the groundwater resources in the district are currently over-exploited. According to the Karnataka Climate Change Action Plan[30], the coefficient of variation, of the inter-annual variability of rainfall over the district is high (91%). Also according to the Drought Monitoring Cell[31], in the past twelve years (2001–2012), only four years recorded rainfall above the average normal, with six out of the remaining eight years declared as drought years (2002, 2003, 2004, 2006, 2009 and 2012). The rationale for selection of Chikballapur district for assessing inherent vulnerability is given by Kattumuri *et al.*[27].

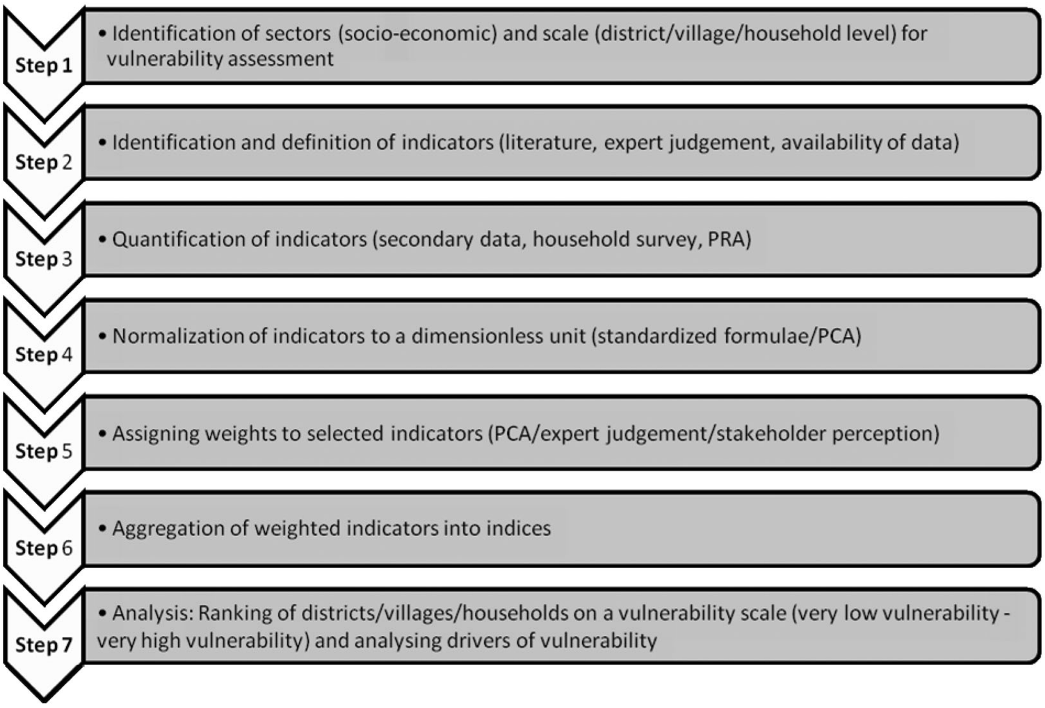

Figure 2. Overall approach to vulnerability assessment.

Household level assessment for two villages in Chikballapur district

Two villages were selected from Bagepalli taluk of Chikballapur district (Figure 1), and a census survey was conducted to prepare an inherent socio-economic vulnerability profile of each household to current climate variability. The recorded mean annual rainfall in Bagepalli block over an eleven-year period indicated only three years as normal. Five out of the eleven years (2001 to 2004 and 2006), received an average annual rainfall of 333 mm below the normal, with consecutive years recording a deviation of –30% to –54% from the normal, indicating severe drought. The criteria for selection of the two villages, Gundlapalli and Saddapalli included: availability of irrigation in one and a predominantly rainfed system in another; and proximity of villages (about 4 km), to ensure similar exposure to climate risks and variations such as drought or delayed rainfall, enabling comparison. Groundwater extracted through borewells is the main source of irrigation in both the villages; however, Gundlapalli has more area under irrigation as compared to Saddapalli, where agriculture is predominantly rainfed.

Overall approach to vulnerability assessment

The study of vulnerability in the empirical literature illustrates that many methods and approaches are used in vulnerability assessments[1]. In this study, socio-economic vulnerability was assessed using an index-based method, by aggregating several indicators that influence vulnerability of a particular system, community or region to current climate variability. Despite a few limitations including data availability, robustness of indicators to address complexities, the use of indicators and indices to understand vulnerability continues to garner momentum[8]. The focus is thus on articulating a quantitative function that can be used to reliably link system attributes (in this case socio-economic) to vulnerability outcomes (e.g. yield decline, loss in land value or economic returns, or a decline in resource quality)[16,32]. The advantage of developing a specific metric is the potential, at least in theory, to test relationships ex-post using numerical analyses or empirical data to estimate a system's resilience or vulnerability to specific threats[16], in this case recurring droughts and variable rainfall patterns.

An indicator represents the sensitivity or adaptive capacity of a system, community or region. Figure 2 provides the overall approach for inherent vulnerability assessment. Socio-economic vulnerability indices (SVI) were developed based on the selected indicators that are representative of the educational status, institutional support, status of agriculture and natural resource base, and provisions for alternate sources of income at the district, village and household levels. These indices capture the inherent vulnerability of all the districts in a state, all the villages in a district and all households in a particular village.

Approach for vulnerability assessment at the district level in Karnataka

SVI was constructed at the district level utilizing data from the 2011 Census of India and Statistical Abstract of Karnataka (DES) for the years 2008–09, 2009–10 and 2010–11, and indicators were selected through expert consultation and literature review[33–38]. Ten indicators were selected: population density; percentage of SC and ST population; literacy rate (%); percentage of marginal land holders (<1 ha); percentage of non-workers; livestock units/100,000 population; per capita income (three-year average); cropping intensity (%); percentage irrigated area to total cropped area (three year average); and total area under fruit crops (ha). The rationale for selection of these indicators is given in Annexure 1. The districts were ranked from 1 to 30, where 1 is most vulnerable and 30 the least vulnerable. The districts were further categorized into five groups (1 to 5, with each group comprising of six districts), where 1 indicates low vulnerability and 5 very high vulnerability.

Normalization of indicators for district level socio-economic vulnerability assessment

Principle component analysis (PCA) was conducted to identify the variability among the selected indicators. PCA helps generate weights, based on the assumption that there are common factors that explain variance. Varimax rotation was performed on the results of the PCA to associate each variable to at least one factor since the initial results warranted rotation. Only factors with eigen values greater than one were included in the analysis. The rotated factor analysis generated three factors, with eigen values greater than 1, which accounted for approximately 67% of the total cumulative variance in the data set compiled for assessment of SVI (Annexure 2).

- Factor-1 accounted for the largest variance (about 31%) including indicators of population density, percentage of literacy rate, livestock unit/100,000 population and per capita income.
- Factor-2 accounted for 20% of the variation and is an aggregate of percentage of SC and ST population, percentage of marginal land holders and total area under fruit crops.
- Factor-3 accounted for 16% of the variation and is composed of three variables namely, percentage of non-workers, cropping intensity and percentage of irrigated area.

Weighting and socio-economic index development at the district level

Weighting is the process of assigning weights to selected indicators in order to express the significance of their contribution to vulnerability. Weights for the three factors were calculated using the formula

$$E_{(X \text{ or } Y \text{ or } Z)}/E_X + E_Y + E_Z,$$

where E_X is the eigen value for the Xth factor (value >1); E_Y is the eigen value for the Yth factor (value >1); E_Z is the eigen value for the Zth factor (value >1).

The weights calculated using these formulae were

$$\text{weight for factor-1 } (W_1) = E_1/(E_1 + E_2 + E_3) = 3.531/(3.531 + 1.825 + 1.328) = 0.528,$$
$$\text{weight for factor-2 } (W_2) = E_2/(E_1 + E_2 + E_3) = 1.825/(3.531 + 1.825 + 1.328) = 0.273,$$
$$\text{weight for factor-3 } (W_3) = E_3/(E_1 + E_2 + E_3) = 1.328/(3.531 + 1.825 + 1.328) = 0.199.$$

The SVI value for each district was calculated using the formula

$$(W_1 * \text{factor-1}) + (W_2 * \text{factor-2}) + (W_3 * \text{factor-3}),$$

where W_1, W_2 and W_3 are the weights calculated for factors 1, 2 and 3 as mentioned above and factor-1, factor-2 and factor-3 are the unit less values generated for each factor by running PCA (Annexure 3).

Approach for vulnerability assessment at the village level

SVI was constructed at the village level, utilizing 2001 and 2011 census data, in which the villages were ranked on a vulnerability scale of 1 to 5, where 1 indicates very low vulnerability and 5 indicates very high vulnerability. The 2011 census data, however, was restricted to only demographic and occupational indicators. In order to include more bio-physical indicators, agricultural and forestry parameters were incorporated into the analysis from the 2001 census data, on the assumption that land use patterns do not change very drastically over a decade.

SVI for 1220 selected villages in Chikballapur district was constructed by considering 5 indicators. Of these 5 indicators, 3 were constructed by aggregating 2 to 4 sub-indicators. Indicators were selected based on expert judgement and availability of data. The indicators are: extent of irrigation; education/skill level; livelihood support institutions (sub-indicators: banking facility and credit societies); land available for grazing and collection of fuelwood and NTFP (sub-indicators: cultivable wasteland (ha) and forest area/household (ha/household)); diversification of income sources (sub-indicators: cultivators (%), agricultural labourers (%), workers employed in household industries (%) and other workers (%)). The rationale for selection of indicators and their functional relationship with climate variability are given in Annexure 4.

Normalization of indicators for village level socio-economic vulnerability assessment

Based on the functional relationship of an indicator to climate variability, it was normalized using one of the 2 formulae given below[39]. If an indicator has ↓ functional relationship, then vulnerability increases with decrease in the value of the indicator, i.e. lower the value of the indicator greater is the vulnerability to climate variability. Similarly, if an indicator has ↑ functional relationship, then vulnerability increases with increase in the value of the indicator.

Normalization of indicators having ↑ functional relationship with climate variability using the formula

$$Y_{ij} = X_{ij} - \text{Min}\{X_{ij}\}/\text{Max}\{X_{ij}\} - \text{Min}\{X_{ij}\}.$$

Normalization of indicators having ↓ functional relationship with climate variability using the formula

$$Y_{ij} = \text{Max}\{X_{ij}\} - X_{ij}/\text{Max}\{X_{ij}\} - \text{Min}\{X_{ij}\},$$

where Y_{ij} is the normalized value of the indicator i, corresponding to the village j, X_{ij} the value of the indicator i, corresponding to the village j, $\text{Max}\{X_{ij}\}$ the maximum value of indicator i, among the 1220 selected villages and $\text{Min}\{X_{ij}\}$ is the minimum value of indicator i, among the 1220 selected villages.

Normalized values of indicators lie between zero and one (one having the maximum influence on vulnerability and zero having least or no influence on vulnerability).

Weighting and socio-economic index development at the village level

Weights were assigned to all indicators and sub-indicators (Annexure 5) by several experts, including NGOs, government officials and researchers, so it adds up to a 100%. The assigned weights are then multiplied by the normalized values of indicators for every village. SVI was developed by aggregating the weighted, normalized values of indicators for each village. The 1220 villages are ranked by multiplying the index values of each village with 5, arriving at a vulnerability scale of 1 to 5, where 1 is very low vulnerability and 5 is very high vulnerability.

Vulnerability assessment at the household level in Gundlapalli and Saddapalli villages

For the household level vulnerability assessment, SVI was constructed by aggregating several indicators that influence the socio-economic status of resident households in the study villages. Indicators were quantified by conducting a census survey in the study villages using structured questionnaires. The survey was conducted in 2012, and since the study villages border the state of Andhra Pradesh, the surveys were conducted in both Telugu and Kannada, depending on the household's language preference.

Selection of indicators and rationale

To make the two study villages comparable, indicators common to both villages, were selected. SVI at this scale tries to capture the extent to which a household can cope and adapt to climate variability and extremes by gauging its inherent ability to access alternate sources of employment, support institutions, etc., through use of indicators and sub-indicators: diversification of income sources [sub-indicators: number of sources of income, types of livestock owned (number), total number of livestock owned, number of useful agro-forestry tree species grown, total number of useful agro-forestry trees owned, number of days of wage employment, percentage household income from other (non-agricultural) sources (%) and participation in MGNREGA (yes/no)]; education/skill level [proportion of educated members (at least till class 7), proportion of employed members, proportion of skilled labourers and proportion of household members migrating seasonally]; livelihood support institutions [financial institutions that provide loans (yes/no), self-help groups (yes/no)]. The rationale for selection of indicators and their functional relationship with climate change are given in Annexure 6.

Normalization, weighting and index development

The indicators selected for socio-economic vulnerability assessment at the household level were normalized utilizing the same formulae that were used to normalize indicators at the village level. Weights were assigned by households from both villages through PRA (Participatory Rural Appraisal) of a mixed group of households (large farmers, small farmers, marginal farmers and landless labourers) for indicators and sub-indicators (Annexure 7). Participants were asked to give weights to the indicators on a scale of 1 to 100, such that the total of all the weights equal 100.

SVI was developed using the same method employed to develop SVI at the village level. Vulnerability index values lie between 0 and 1 for each household in the two study villages. Households were further ranked on a vulnerability scale of 1 to 5, by multiplying the index values with 5, where, 1 is very low vulnerability and 5 is very high vulnerability.

Results and discussion

The results of the multi-scale assessment are presented in three parts: (i) district level, (ii) village level and (iii) household level.

Socio-economic vulnerability assessment at the district level, Karnataka

Agriculture is a dominant livelihood activity in the state and therefore significant agriculture related indicators were included in this assessment (Annexure 1). The ten indicators were distributed among three factors as indicated by a rotated factor analysis. The normalized, weighted values of each of the factors were aggregated to arrive at a composite index value for each district, where lower the index value, higher is the vulnerability. Figure 3 depicts the socio-economically vulnerable districts of Karnataka. A composite SVI value of –1.0952 to –0.3761 (category 5) indicates very high vulnerability, –0.3678 to –0.2247 (category 4) indicates high vulnerability, –0.1299 to –0.0125 (category 3) indicates moderate vulnerability, 0.0489 to 0.3632 (category 2) indicates low vulnerability and 0.3703 to 2.0211 (category 1) indicates very low vulnerability. The SVI values derived from PCA are provided in Annexure 3.

According to Figure 3, Yadgir, Chitradurga, Raichur, Chamarajanagar, Chikballapur and Tumkur, are category 5 on the SVI scale and thus are the five most socio-economically vulnerable districts in the state. Bangalore Urban, Dakshina Kannada, Udupi, Dharwad, Uttara Kannada and Bangalore Rural, districts are characterized by very low socio-economic vulnerability in Karnataka and are category 1 on the SVI scale.

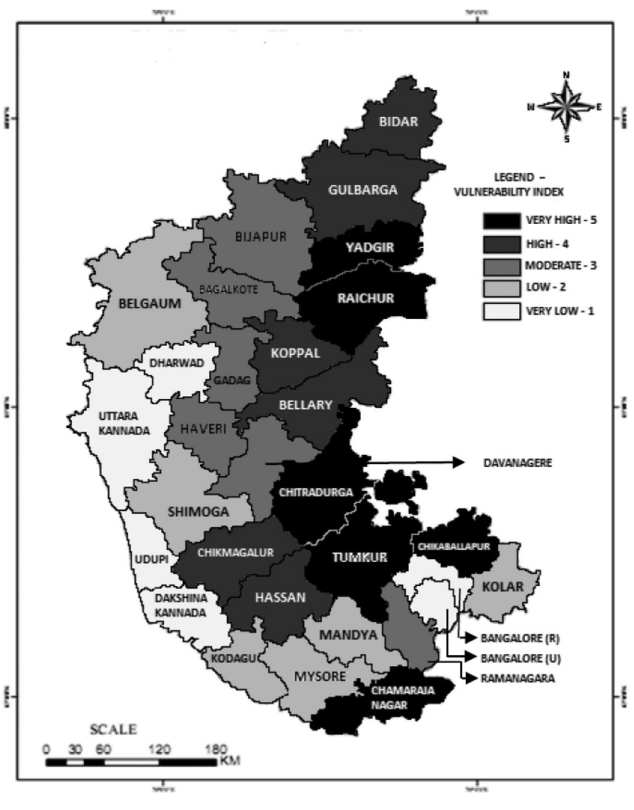

Figure 3. Distribution of districts on a socio-economic vulnerability scale.

Drivers of socio-economic vulnerability at the district level

According to this study indicators on population density, literacy rate, livestock unit/100,000 population and per capita income are the major drivers of socio-economic vulnerability in the districts of Karnataka.

High population densities lead to increased competition for finite natural resources, starting a vicious cycle of poverty and resource degradation[40,41], further leading to significant increase in the sensitivity of rural populations to climate extremes such as floods and droughts, current climate variability, as well as future climate change. Similarly, reduced literacy in a given population, reduces their ability to access and comprehend information necessary for adaptation to climate variability[42]. Livestock are known to provide an alternate source of income, ensuring income security in times of distress[43]. As such, districts with high population densities, low literacy rates, low livestock populations and lower per capita incomes have higher vulnerability and are ranked accordingly.

The contribution of the remaining indicators to enhancing or lowering vulnerability is not as significant as the indicators that compose factor-1 (Figure 4).

Socio-economic vulnerability assessment at the village level

In this assessment, the majority (89%) of the villages in Chikballapur district were ranked highly vulnerable, 10% were ranked moderately vulnerable and less than 1% ranked 2 and 5, indicating low and very high vulnerability respectively (Table 1). None of the villages ranked 1 (very low vulnerability). As Chikballapur district was identified as one of the most vulnerable districts in Karnataka, the village level assessment of the inherent vulnerability strengthens the district level findings. Based on this assessment, for immediate and targeted adaptation policy implementation, 1089 villages out of 1220 in Chikballapur district could be selected.

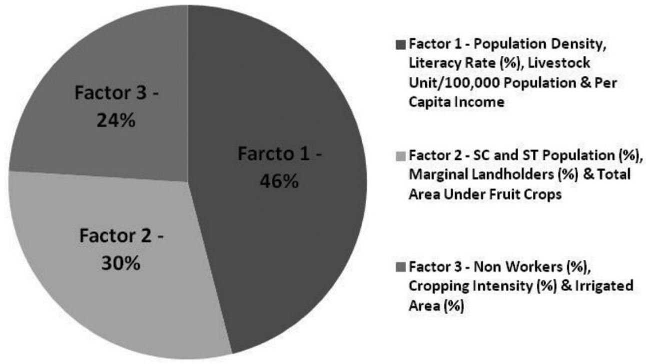

Figure 4. Drivers of socio-economic vulnerability at the district level, Karnataka.

Table 1. Number and percentage of villages from different blocks of Chikballapur ranked on the socio-economic vulnerability index scale

	Socio-economic vulnerability index scale							
Blocks	2 (Low)		3 (Moderate)		4 (High)		5 (Very high)	
Gauribidanur	0	0%	20	15%	112	85%	0	0%
Chikballapur	0	0%	23	10%	197	89%	2	1%
Gudibanda	1	1%	7	8%	77	91%	0	0%
Bagepalli	0	0%	12	6%	200	94%	0	0%
Sidlaghatta	0	0%	43	18%	199	82%	0	0%
Chintamani	0	0%	23	7%	304	93%	0	0%
Overall	1	0.08%	128	10.5%	1089	89.3%	2	0.16%

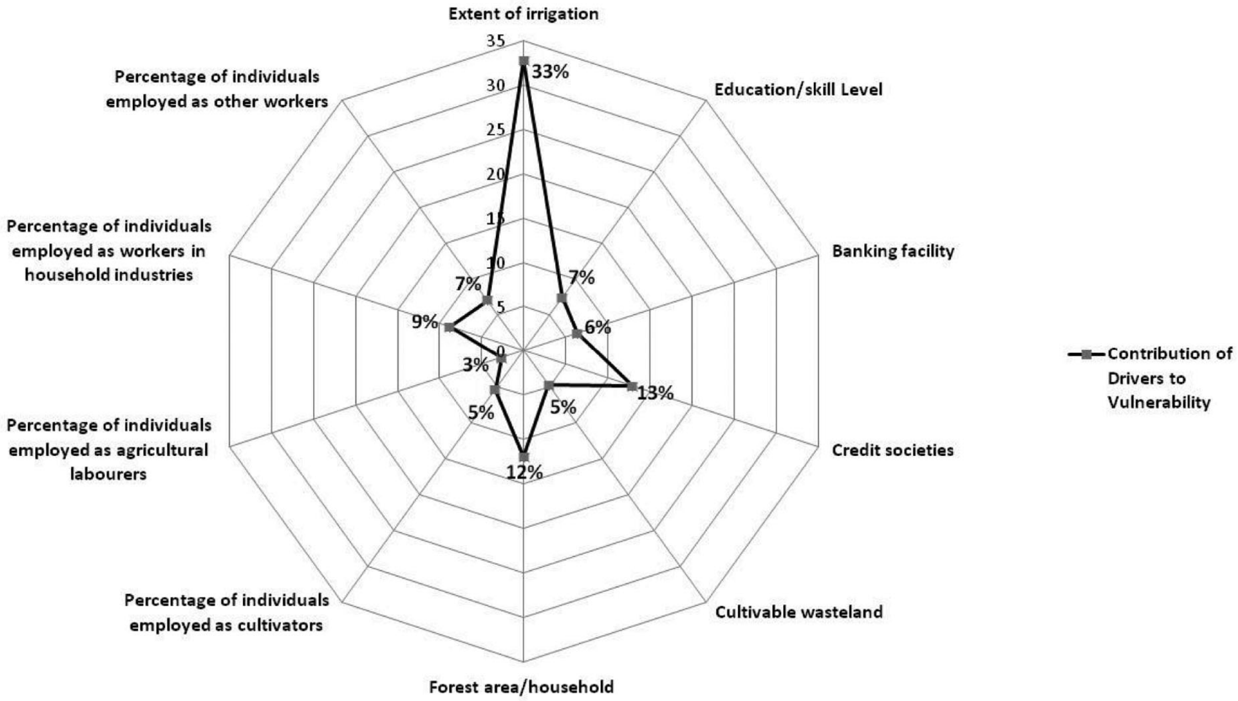

Figure 5. Drivers of socio-economic vulnerability at a village level.

The distribution of villages in six selected blocks on the SVI scale is similar to the overall distribution of villages in the district on the same scale, with majority of villages ranking highly vulnerable within a block (82% in Sidlaghatta block to 94% in Bagepalli block). Further, 7% to 18% of the villages in the selected blocks were ranked 3, and only one village (1%) in Gudibanda block ranked 2, indicating low vulnerability and 2 villages (2%) in Chikballapur block ranked 5, indicating very high vulnerability.

Factors contributing to socio-economic vulnerability at the village level

The average SVI value of the villages of Chikballapur district is 0.77 or 77%, ranking 4 on the SVI scale, indicating high vulnerability. Irrigation has been known to provide a buffer to farmers in semi-arid regions to the effects of recurrent droughts and erratic rainfall patterns[44], reducing the vulnerability of agricultural production to such climate risks and variability. Reduced extent of irrigation, contributed an average of 33% to the average socio-economic vulnerability (77%) of the 1220 villages in Chikballapur district, explained in Figure 5. Majority of villages in Chikballapur district are predominantly rainfed with low percentage of area under irrigation[28], making them highly vulnerable to climate variation[45]. Lack of diversification of income sources (23%), livelihood support institutions (20%), land available for grazing, collection of fuelwood and NTFP (17%), and low education/skill level (7%), also contribute significantly to the overall average socio-economic vulnerability of the selected villages.

This clearly indicates that hazard potential is either moderated or enhanced by a geographic filter (site and situation of the place, proximity) in this case the semi-arid, drought-prone, predominantly rainfed villages of Chikballapur are found to be inherently socio-economically vulnerable, as the main source of employment and income (agriculture) in the villages, is strongly dependent on climatic factors.

Vulnerability assessment at the household level in the study villages of Bagepalli taluk

Household level vulnerability assessment based on stakeholder perceptions recorded through structured household surveys and PRA were used to develop an SVI at the individual household level for all households in the two selected villages of Bagepalli taluk. The overall socio-economic vulnerability profile of households in Gundlapalli shows that 50% are highly vulnerable, while in Saddapalli, the majority of households are only moderately vulnerable (74%) with a rank of 3 (Figure 6). The rest of the households in Gundlapalli have moderate (39%) or low vulnerability (13%).

Socio-economic vulnerability of households according to their landholdings

An analysis of SVI, considering the landholding of households as landless, marginal (0.1 to 2.5 acre), small (2.5 to 5 acre) and large (>5 acre) is presented in Table 2.

None of the households in either of the study villages ranked 1 and 5 (very low and very high vulnerability). The three landless households in Gundlapalli were found to be moderately vulnerable, as they pursued non-climate sensitive sources of employment, and thus have income security, lowering their vulnerability to climate risks. The majority of the marginal farming households in Gundlapalli and Saddapalli (13 and 35 households respectively) ranked 3, indicating moderate vulnerability. Among the small farmers, majority of the households in Gundlapalli (15) were found to be highly vulnerable and in Saddapalli (10) were found to be moderately vulnerable. Large farmers in both villages also demonstrated the same distribution on the SVI scale.

Factors contributing to socio-economic vulnerability at the household level in the study villages, Bagepalli taluk

To construct a comparable SVI at household level, three indicators (each a composite of several sub-indicators) were selected in both the study villages. The average SVI value in Gundlapalli is 67% and it is 66% in Saddapalli, both ranking 3 on the SVI scale, indicating moderate vulnerability. The lack or reduced diversification of income sources contributed 39% to SVI in Gundlapalli and 44% in Saddapalli, reduced education/skill level contributed 30% in Gundlapalli and 29% in Saddapalli, and lack of livelihood support institutions contributed 31% in Gundlapalli and 27% in Saddapalli (Figure 7).

The contribution of sub-indicators to overall socio-economic vulnerability at the household level is presented as a radar plot, where the weights and significance of each sub-indicator's contribution to inherent vulnerability are plotted as a radar plot, and the dimensions of vulnerability are represented by spokes of the plot – greater the significance, further away from the centre of the plot (Figure 8). In Gundlapalli and Saddapalli, out of eight sub-indicators composing diversification of income sources, only one sub-indicator (reduced number of days of wage employment) contributed (to a certain extent (>5%)) to vulnerability. However, due to the importance of wage labour during summer months in Saddapalli a higher weight was assigned to this sub-indicator by representative households from this village and the reduced availability of wage labour contributed 8% more, towards socio-economic vulnerability in Saddapalli. Wage employment provides an alternate source of income to households dependent on agriculture.

Lower percentage of household income from other sources (non-climate dependent sources of employment and usually skilled labour), another sub-indicator of diversification of income sources contributed 9% to SVI in Gundlapalli and 8% in Saddapalli. Reduced proportion of

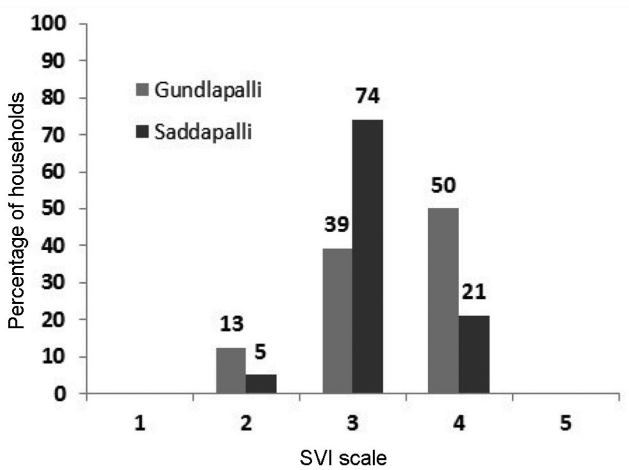

Figure 6. Socio-economic vulnerability profile of households in the study villages.

Table 2. Number of households ranked on the socio-economic vulnerability index scale according to their landholdings

Rank	Villages	Landholding			
		Landless	Marginal	Small	Large
Rank 2	Gundlapalli	0	3	4	0
	Saddapalli	0	1	1	1
Rank 3	Gundlapalli	3	13	9	1
	Saddapalli	0	35	10	4
Rank 4	Gundlapalli	0	6	15	2
	Saddapalli	0	12	2	0

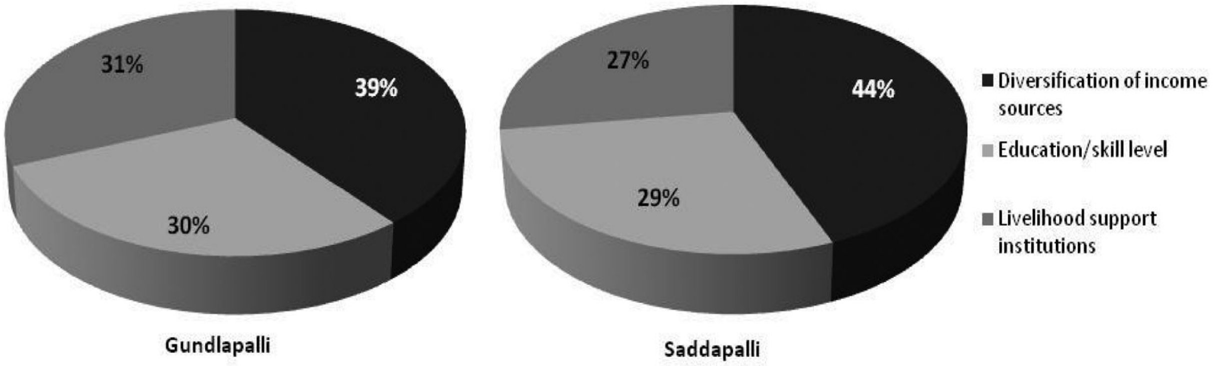

Figure 7. Drivers of socio-economic vulnerability (indicators) at household level in Gundlapalli and Saddapalli.

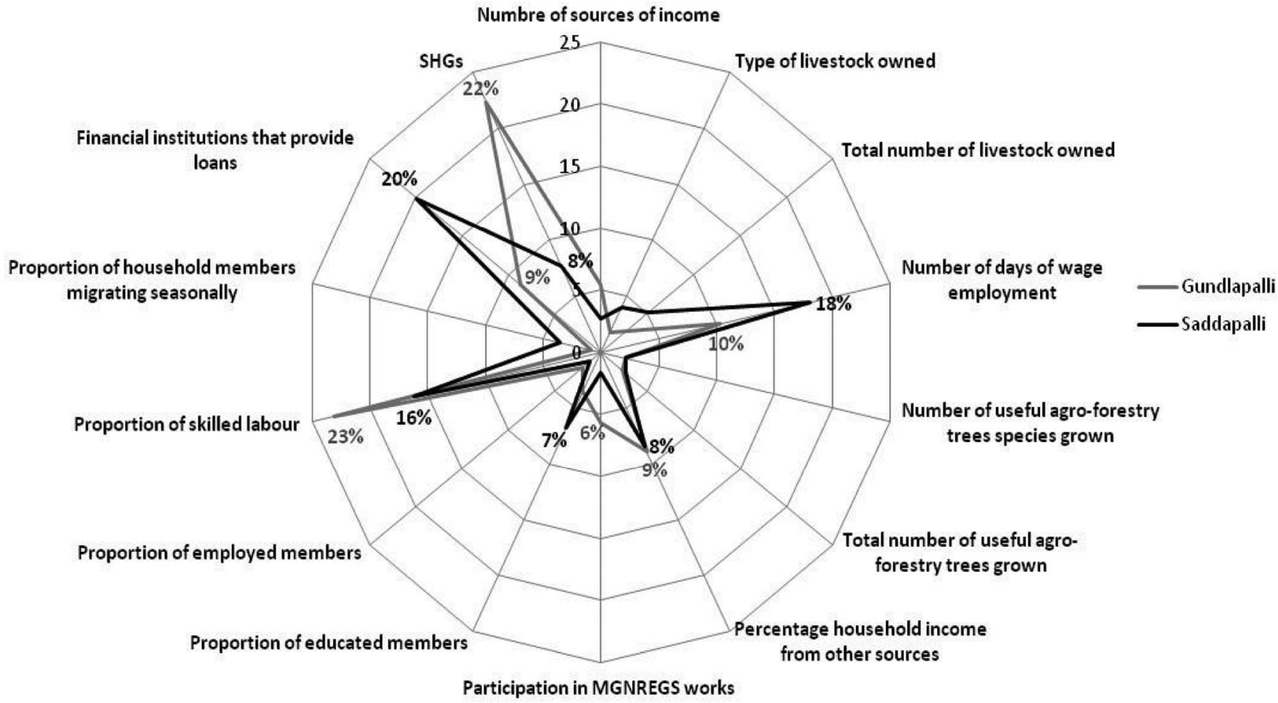

Figure 8. Drivers of socio-economic vulnerability at household level in Gundlapalli and Saddapalli (sub-indicators).

skilled labour/household, a sub-indicator of education/skill level contributed significantly to vulnerability in both the study villages; however, it contributed 7% more in Gundlapalli than in Saddapalli, as households in Gundlapalli assigned a higher weight to this sub-indicator due to its importance in providing a secure source of income to households, irrespective of climate variability.

The two sub-indicators of livelihood support institutions, financial institutions that provide loans and self-help groups (SHGs), also contributed significantly to SVI. The reduced availability of financial institutions that provide loans contributed 11% more in Saddapalli than in Gundlapalli, and lack of functioning SHGs contributed 22% to vulnerability in Gundlapalli.

Addressing vulnerability through targeted adaptation

The Government of Karnataka may want to address the drivers of vulnerability to climate variability, in order to reduce vulnerability, and to build resilience to long-term climate change. Since most governments face resource constraints in addressing the impacts of climate variability and climate change[46], this study demonstrates an approach to prioritize districts, villages and households for implementation of adaptation interventions where they are most needed (Figure 9).

This study has identified six of the most vulnerable districts in Karnataka and the drivers of vulnerability at

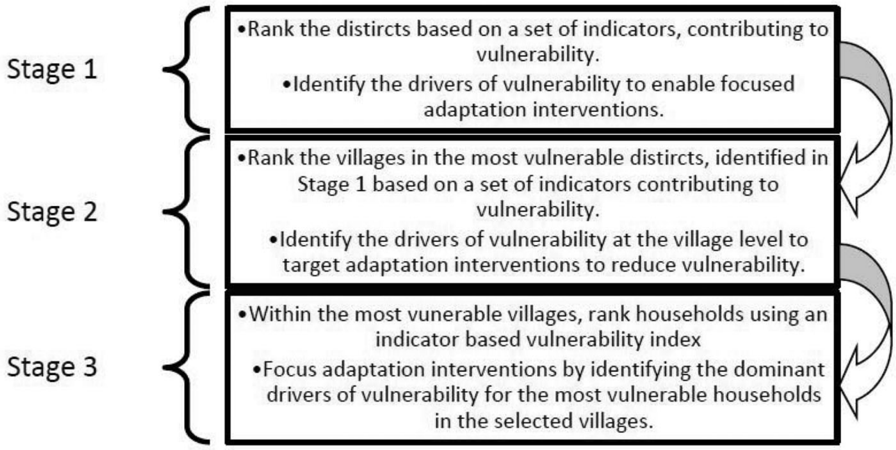

Figure 9. Approach to multi-scale vulnerability assessment for implementation of adaptation strategies.

Annexure 1. Indicators selected for construction of SVI at the district level and rationale for selection

Indicators	Rationale
Population density	Population density determines the extent of dependency and per capita availability of finite resources. High density could lead to degradation of resources, further lowering the adaptive capacity.
Percentage of SC and ST population	These communities are known to be poor and vulnerable, both socially, as well as economically.
Literacy rate (%)	Determines the extent of access to knowledge and information that could potentially enable adaptation to climate variability.
Percentage of marginal land holders (<1 ha)	Marginal landholders are known to have low social and economic capital and thus inherently have lower adaptive capacities.
Percentage of non-workers	An indicator of the number of dependents in a region. Higher the number, lower the earning capacity and income compared to expenditure, increasing the sensitivity to climate extremes.
Livestock units/100,000 population	Livestock provides an alternate source of income and assists in crop production, also sale of livestock during distress provides households with a coping strategy.
Per capita income (3 year average)	A direct indicator signifying the inherent adaptive capacity or sensitivity of people in a particular region.
Cropping intensity (%)	Increased agricultural production provides increased annual incomes, enhancing the adaptive capacity of people.
Percentage irrigated area to total cropped area (3 year average)	Crop production with irrigation is less sensitive to delayed rainfall or droughts.
Total area under fruit crops (ha)	Alternative source of farm-based income reduces sensitivity to climate variability and increases adaptive capacity.

the district level: (i) Yadgir, Chitradurga, Raichur, Chamarajanagar, Chikballapur and Tumkur are the most vulnerable districts in Karnataka; and (ii) low per capita income, high population density, low literacy rate and low livestock holding were found to be the major drivers of socio-economic vulnerability in the identified districts. Thus, strengthening and stringently enforcing state literacy policy, especially to increase female literacy rates by introducing new schools/colleges in less accessible areas, strengthening diversification of income sources, other than agriculture (livestock, skill-based jobs with market linkages and government support), controlling population growth by family planning and awareness, are paramount to lower the vulnerability of these districts of Karnataka[40–43,46,47].

In order to increase the efficiency of adaptation programmes implemented in the most vulnerable districts, it would be necessary to identify the most inherently vulnerable villages in that district, based on their socio-economic status and natural resource base.

As an example, this study considered Chikballapur district, identified as one of the most vulnerable districts in Karnataka, and ranked the villages on a vulnerability scale and also identified the drivers of vulnerability. It is clear from this assessment that (i) 1089 villages, accounting for 89% of the total number of villages in the district were found to be highly vulnerable; and (ii) reduced extent of irrigation, lack of diversification of income sources and livelihood support institutions, reduced availability of land for grazing and collection of fuelwood and NTFP, and low education/skill levels contributed significantly to the socio-economic vulnerability of these villages. In a drought-prone district such as Chikballapur, where agriculture is the main source of livelihood, efforts need to be concentrated on water management and harvesting systems to improve resilience[9]. As mentioned

Annexure 2. Total variance explained by PCA for socio-economic vulnerability

	Initial eigen values		Rotation sums of squared loadings	
Factors (indicators)	Total	Percentage variance	Total	Percentage variance
Factor 1: Population density, percentage of literacy rate, livestock unit/100,000 population and per capita income	3.531	35.307	3.086	30.856
Factor 2: Percentage of socially backward community populations, percentage of marginal land holders and total area under fruit crops	1.825	18.247	2.032	20.315
Factor 3: Percentage of non-workers, cropping intensity and percentage of irrigated area	1.328	13.284	1.567	15.666
Factor 4	0.995	9.953		
Factor 5	0.795	7.949		
Factor 6	0.651	6.507		
Factor 7	0.355	3.545		
Factor 8	0.234	2.341		
Factor 9	0.163	1.629		
Factor 10	0.124	1.238		
Total	10	100		

Annexure 3. SVI values and ranks for each district

	Factor 1	Factor 2	Factor 3		
Districts	(E_1)*=3.53	(E_2)* = 1.82	(E_3)* = 1.32	Composite index	Rank
Yadgir	–1.4647	–1.2176	0.0553	–1.0952	1
Chitradurga	–0.7278	–0.7424	–1.6660	–0.9182	2
Raichur	–0.8808	–1.3046	0.0125	–0.8190	3
Chamarajanagar	–0.7335	–0.2774	–0.5385	–0.5702	4
Chikballapur	–0.5914	0.3343	–1.5872	–0.5364	5
Tumkur	–0.7033	0.6696	–0.9432	–0.3761	6
Chikmagalur	–0.1782	0.0340	–1.4241	–0.3678	7
Koppal	–0.4457	–0.6864	0.2939	–0.3644	8
Hassan	–0.6769	0.5739	–0.6387	–0.3278	9
Bidar	0.2911	–1.5959	–0.0977	–0.3013	10
Gulbarga	0.1991	–1.4325	0.1460	–0.2569	11
Bellary	–0.1886	–0.7484	0.3989	–0.2247	12
Gadag	0.2242	–1.1114	0.2768	–0.1299	13
Ramanagara	–0.3164	1.0652	–1.0845	–0.0917	14
Davanagere	–0.3537	–0.0738	0.5905	–0.0897	15
Bagalkot	–0.4631	–0.3315	1.3301	–0.0708	16
Haveri	0.1526	–0.4582	–0.1074	–0.0658	17
Bijapur	–0.0531	–0.5579	0.8446	–0.0125	18
Kolar	–0.2010	1.3257	–1.0409	0.0489	19
Kodagu	0.9383	–0.4084	–1.6853	0.0493	20
Mandya	–0.6866	1.0867	0.6148	0.0561	21
Belgaum	–0.2871	0.2015	1.4086	0.1831	22
Shimoga	–0.6208	1.1761	1.1372	0.2191	23
Mysuru	0.1396	–0.0234	1.4892	0.3632	24
Bengaluru (R)	0.7940	0.4613	–0.8811	0.3703	25
Uttara Kannada	0.3738	0.9583	0.5949	0.5773	26
Dharwad	1.1340	–0.7334	1.8957	0.7754	27
Udupi	0.5460	1.6941	0.6713	0.8843	28
Dakshina Kannada	0.5001	2.5343	0.5759	1.0705	29
Bengaluru (U)	4.2800	–0.4116	–0.6419	2.0211	30

*E_1 is the eigen value for the factor 1 (value >1); E_2 is the eigen value for the factor 2 (value >1); E_3 is the eigen value for the factor 3 (value >1).

earlier in this article, irrigation is known to buffer against climate variability[48], thus sustainable water management in semi-arid regions like Chikballapur is crucial and can be achieved through construction of water harvesting structures, developing water budgets for communities or villages solely dependent on rainfall and usage of efficient irrigation provisioning technologies. There is also a need to improve literacy rates, increase diversification of

Annexure 4. Indicators and sub-indicators selected and rationale for selection for construction of SVI at village level

Indicators	Sub-indicators	Functional relationship	Rationale
Extent of irrigation: Percentage area irrigated in villages (%)		↓	Crop production in villages with higher proportion of irrigated area is less sensitive to delayed rainfall or droughts.
Education/skill level: Literacy rate in villages (%)		↓	Determines the extent of access to knowledge and information, enabling adaptation to climate variability.
Livelihood support institutions (Yes/No)	Banking facility	↓	Legal financial institutions providing communities with financial aid in times of climate extremes reduces their sensitivity.
	Credit societies	↓	
Land available for grazing and collection of fuelwood and NTFP	Cultivable wasteland (ha)	↓	Measuring inherent adaptive capacity: availability of livelihood options through extraction of fodder, fuelwood, and NTFPs from village commons.
	Forest area/household (ha/household)	↓	
Diversification of income sources	Cultivators (%)	↑	Supplementing income from cultivation by engaging in agricultural labour, household industries and other non-climate dependent works to reduce vulnerability to extreme climate events.
	Agricultural labourers (%)	↑	
	Workers employed in household industries (%)	↓	
	Other workers (%)	↓	

Annexure 5. Average weights assigned to indicators and sub-indicators by experts for village level vulnerability assessment

Indicators	Average weights assigned to indicators	Sub-indicators	Average weights assigned to sub-indicators
Extent of irrigation	26	–	–
Education/skill level	16	–	–
Livelihood support institutions	16	Banking facility	33
		Credit societies	67
		Total	100%
Land available for grazing and collection of fuelwood and NTFP	13	Cultivable wasteland	29
		Forest area/household	71
		Total	100%
Diversification of income sources	29	Cultivators	33
		Agricultural labourers	20
		Workers employed in household industries	24
		Other workers	23
Total	100%	Total	100%

income sources (skill based, non-climate dependent source of income, to provide income security), and protection and restoration of common lands for grazing and NTFP collection.

Adaptation programmes implemented for specific target groups, based on their inherent levels of vulnerability in a particular village, could potentially be the most efficient community based adaptation strategy. Once the most vulnerable districts and villages have been identified, the most vulnerable households in each of those villages should be the top priority of any adaptation programme. As an example, this study selected two highly vulnerable villages identified by the village level vulnerability assessment, from Chikballapur district and ranked households from these villages on a socio-economic vulnerability scale and determined the drivers of vulnerability, as well as the coping strategies: (i) majority of households in the irrigated village (Gundlapalli) were found to be highly vulnerable, whereas majority of households in the predominantly rainfed village (Saddapalli) were found to be moderately vulnerable; (ii) in both villages, marginal farmers scored moderately on the vulnerability scale and not high, as one would expect; (iii) reduced number of days of wage labour, income from other sources of employment, number of educated members and skilled labourers per household and lack of legal financial institutions that provide loans, were the significant drivers for vulnerability at the household level in Saddapalli. Gundlapalli has a similar set of drivers (Figure 8), but also includes reduced participation of households in government schemes like MGNREGS and lack of SHGs. In drought-prone regions such as these, where groundwater is the only source of water for domestic and irrigation purposes, this water resource is brazenly overexploited with negligible attempts made to restore and sustainably manage it. As such, agriculture in Gundlapalli is heavily dependent on groundwater sources, which have gradually become seasonal and in the light of a drought or delayed rainfall, these sources of irrigation have started to fail, thus reducing crop yields or resulting in total crop failure. These farmers have not developed any adaptation mechanism to deal with such variations in climate as they were previously dependent on irrigation to help them cope.

Annexure 6. List of indicators and sub-indicators, functional relationship to climate variability and rationale for selection of indicators to construct SVI at the household level

Indicators	Sub-indicators	Functional relationship	Rationale
Diversification of income sources	Number of sources of income	↓	More than one source of income, will assures income security in the event of crop loss/failure.
	Types of livestock owned (number)	↓	Livestock provide an alternate source of income and assist in crop production, also sale of livestock during distress provide households with a coping strategy.
	Total number of livestock owned	↓	
	Number of useful agro-forestry tree species grown	↓	Economically beneficial agro-forestry trees are more resilient to climate variability, providing assured yields, alternate source of income, NTFPs, fodder and fuelwood.
	Total number of useful agro-forestry trees owned	↓	
	Number of days of wage employment	↓	Wage labour, income from other non-climate dependent sources and employment under MGNREGA provides households with income security.
	Percentage household income from other (non-agricultural) sources (%)	↓	
	Participation in MGNREGA (Yes/No)	↓	
Education/skill level	Proportion of educated members (At least till class 7)	↓	Literacy indicates capacity to access and utilize information to reduce vulnerability.
	Proportion of employed members	↓	Determines that household's capacity to adapt to climate variability
	Proportion of skilled labourers	↓	Skilled work is non-climate dependent and provides income security.
	Proportion of household members migrating seasonally	↑	Seasonal migration of male members for employment, reduces the coping capacities of household members left behind who are still dependent on climate-dependent sources of income.
Livelihood support institutions	Financial institutions that provide loans (Yes/No)	↓	Enhanced adaptive capacity, due to presence of support institutions that help mitigate losses.
	Self Help Groups (Yes/No)	↓	

Annexure 7. Weights assigned to indicators and sub-indicators composing SVI by representative households from both the study villages

Socio-economic vulnerability index					
	Weights			Weights	
Indicators	Gundlapalli	Saddapalli	Sub-indicators	Gundlapalli	Saddapalli
Diversification of income sources	38	40	Number of sources of income	20	10
			Types of livestock owned	5	10
			Total number of livestock owned	5	10
			Number of useful agro-forestry tree species grown	20	30
			Total number of useful agro-forestry trees owned	5	5
			Number of days of wage employment	5	5
			Percentage household income from other sources	20	15
			Participation in MGNREGA	20	15
			Total	100%	100%
Education/skill level	36	40	Proportion of educated members	10	15
			Proportion of employed members	10	5
			Proportion of skilled labourers	50	30
			Proportion of household members migrating seasonally	30	50
			Total	100%	100%
Livelihood support institutions	26	20	Financial institutions that provide loans	30	70
			Self help groups	70	30
Total	100%	100%	Total	100%	100%

Farmers in Saddapalli have developed many coping strategies such as delaying time of sowing, changing cropping pattern according to rainfall intensity, using trap crops against pests, leaving croplands fallow, distress sale of assets, pursuing other sources of employment, including daily wage and migration to towns and cities, as they do not and have not had enough water resources for irrigation to help buffer the impacts of climate variations. As such, they are currently more resilient to climate variations and scored moderately on the vulnerability scale, as compared to farmers in Gundlapalli, who scored high on the vulnerability scale.

Similarly, one would expect marginal farmers to be the most vulnerable in a community, as they own very small parcels of land and thus have low net financial capital to help them cope in times of distress[49]. This is based on the assumption that these farmers are tied down to their lands. This study found that since their land holdings are small, there is relatively low initial investment into agriculture, and thus in case of droughts or other climate risks, marginal farmers simply leave their lands fallow and pursue alternate sources of income, to sustain their households. This is not the case for small and large farmers, as their investment in agriculture is much greater and they cannot abandon their lands. Thus, relatively, a majority of marginal framers scored moderately on the vulnerability scale as compared to the small and large farmers, in both the study villages.

However, their coping strategies are based on short-term considerations, survival needs, lack of information and imperfect foresight, worsening degradation of both socio-economic status and natural resource base, thereby diminishing future adaptive capacity and livelihood options[27]. As such, small and marginal farmers in Saddapalli will be more vulnerable to future climate change, than farmers in Gundlapalli, as they implement destructive spontaneous coping strategies like sale of productive assets in times of distress, leaving land fallow, migration, etc., in order to address the impacts of current climate variations.

By taking into account the heterogeneity of conditions at various scales, this study provides impetus for assessing vulnerability at different scales. The methodology outlined here enables integration in cases where relevant information exists at district, block and local scales, or alternatively, the underlying processes tie-in with the processes captured at higher scales[50]. At all three scales, low levels of education and skills have contributed significantly to vulnerability. As the scale of assessment becomes finer and focuses on village and household level, lack of income diversification and livelihood support institutions are the significant drivers of socio-economic vulnerability. However, efforts to reduce vulnerability have a greater chance of success if it reflects multi-dimensional conditions of vulnerability and taken together, the findings at various scales should be regarded as being complementary to each other, instead of any one scale being considered the most important.

Conclusions

The above analysis at district, village and household level provides comprehensive profiling of vulnerability in Karnataka at multiple scales. Most significantly, it provides an opportunity for policymakers to target resilience enhancing, and adaptation strategies effectively through provisioning of robust information derived from: (i) development of an integrated livelihood framework that includes social, economic and biophysical factors, and (ii) use of effective engagement with stakeholders to determine critical vulnerability generating mechanisms at multiple scales. Providing policymakers effective information on vulnerability is fundamental to tackling the issue of climate change and climate variability. Vulnerability of different economic sectors, regions, human settlements and ecological communities to a changing climate has been the impetus behind significant investments in research and policy development regarding climate adaptation and the mitigation of greenhouse gas emission[51].

In the case of Chikballapur district, resilience building and adaptation programmes, such as provisioning of sustainable water harvesting methods, improving literacy rates, provisioning of alternate sources of income and restoration of grazing lands, will be significantly more effective if targeted toward the most vulnerable villages and households first.

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