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# Climate Vulnerability in Rainfed Farming: Analysis from Indian Watersheds

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**Abstract:** India ranks first among the rainfed agricultural countries in the world. The impact of changing climate threatens rainfed food production as well as the food security of millions of people in the tropics and subtropics. The Government of India initiated Watershed Development Programmes (WDPs) for the overall development of these areas. We, therefore, established a comprehensive, location-specific, bottom-up tool to analyse and compare the climate vulnerability of watershed areas. For this, we deducted a new Climate Vulnerability Index for Rainfed Tropics ($CVI^{RFT}$) to evaluate the potential effectiveness of programmes to adapt to climate change impacts. The $CVI^{RFT}$ comprises of three dimensions of vulnerability, i.e., *adaptive capacity*, *exposure* and *sensitivity*. These dimensions consist of ten major components and 59 indicators with emphasis on rainfed farming and WDP interventions. To test the tool, we collected primary data through household surveys ($n$ = 215, split among three watershed communities) in Kerala. We show that there were strong variations in the *exposure* dimension, moderate in *sensitivity* and negligible in *adaptive capacity* across the watersheds. After analysing the major components under the dimensions, we suggest focusing on policy orientation towards redesigning of the WDPs with emphasis to economic diversification, livelihood strategies, social networking coupled with stakeholder participation, natural resource management and risk spread through credit and insurance flexibility. The $CVI^{RFT}$ is replicable to similar physio-geographic areas of rainfed farming, with the refinement of indicators suited to the locality.

**Keywords:** adaptive capacity; climate vulnerability; exposure; rainfed farming; sensitivity; watershed development programme

## 1. Introduction

Rainfed agricultural systems dominate much of tropical agriculture, and are extremely vulnerable to projected climate change. Nearly 80% of the global agriculture is based on rainfed farming [1]. Rural communities across the world report that rainfall has become more erratic, shorter and heavier within seasons, and that 'unseasonal' events such as heavier rains, drier spells, unusual storms and temperature fluctuations have increased [2]. Dependence on climate-sensitive activities, pessimistic projections for agricultural yield, falling production, poverty, food insecurity and limited capacity to adapt, exacerbate the vulnerability situation of rainfed farmers [3–7]. Moreover, tropical countries have large populations of poor smallholders [8] who live in a 'complex, diverse and risk-prone' system [9] which adds to their vulnerability [10].

India stands first among the rainfed agricultural countries of the world, with 66% of its total cropped area [11]. It is the second-largest producer of rice and wheat, staple food for millions of the world, while half of India's production is under rainfed [12]. In the past century, all over India, severe climatic changes were already observable: the surface temperature has increased by about 0.4 °C, and monsoon rainfalls were decreasing by 6–8% over north eastern India, Gujarat and Kerala [13]. The monsoon rainfall variations include delay in onset, long dry spells and early withdrawal, which strongly affect productivity in rainfed farming [14]. Moreover, it has been projected that unless people adapt their farming behaviour, there is a probability of 10–40% loss in crop production by 2080–2100, due to global warming [15]. Climate change will act as a hunger risk multiplier by negatively affecting food security, food stability, rural income, food prices and crop yields [3]. Thus, climate change vulnerability assessment in rainfed farming systems is an important tool in adaptation planning and decision-making to reduce the detrimental effects of climate change on the most vulnerable people.

Millions of the rainfed smallholder farmers will experience immediate hardship and hunger as a consequence of climate change, since they will be less able to make adequate decisions about when to sow, what to grow, and how to time inputs [16] along with having a low adaptive capacity [17]. As climate change impacts are increasingly observed and felt by smallholder farmers, there is an urgent need to identify approaches which enhance the adaptive capacity of farmers, their households and communities [8,18]. It is here that the importance of watershed level planning and development comes into play, by which the communities can better track and understand the importance and impacts of climate change and natural resource management in accordance with the local social system, compared to analysis of larger systems on regional or even country scale. This is why Watershed Development Programmes (WDPs) in India are potential tools to make a significant contribution to reduce vulnerability, enhance resilience and build adaptive capacities of rain fed farming communities to climate-induced shocks. Watershed development is a multi-sectoral intervention that aims at enhancing the potential of ecosystem resources and the socio-economic situation of the community in a specific natural landscape unit [19]. It refers to the conservation, regeneration and the judicious use of all the resources (natural and human) within the watershed area. Different studies revealed that WDPs have the capacity to reduce the risk associated with rainfed agriculture and to act as tools for disaster management [20,21]. Moreover, they are also valued as one of the best practices contributing to adaptation and mitigation [14]. Accordingly, climate change vulnerability assessments are necessary in watersheds to better understand structural weaknesses, improve the allocation of those resources that make a system vulnerable, better decision making and to monitor the effects of adaptation measures [22,23].

Several studies have examined climate change vulnerability in terms of specific climatic issues, contexts, social groups or ecosystems worldwide [24–27]. Indicator development is one of the methodologies to encapsulate complex reality of climate vulnerability for generating more scope and opportunities in terms of policy interventions [28]. Moreover, indicators provide information on matters of wider significance than what is actually measured or what can be made perceptible as a trend or phenomenon that is not immediately detectable [29]. Several indices have been developed to quantify vulnerability to climate change [30–34]. But there are very limited studies on climate change vulnerability among rainfed smallholders [8,35–37] or at watershed level, especially in the Indian context [14]. The existing studies in India focus on the vulnerability of farmers towards flood [30] or compared the vulnerability of rural indigenous mountainous communities [31]. Upgupta et al. [32] investigated the vulnerability of forests under the current climate, but excluded socio-economic aspects of the forest dependent communities. In addition, previous studies on climate change in watersheds have mainly focused on the biophysical aspects [38], geophysical vulnerability [39], ecosystem vulnerability [40], but less on the people living there. Gender dimensions of climate change [41] have almost always been neglected. However, women represent a disproportionate share of the poor and are thus highly vulnerable to climate change [42]. They are hindered from fully exploiting their potential due to lack of power, limited market opportunities, lack of knowledge and access to financial resources. Eastin [42] also found that increasing climatological disasters and shocks are associated with decline in women's socioeconomic rights. Moreover, more women die in natural calamities than men, especially in countries such as India, Indonesia, Sri Lanka and Bangladesh, where they are socio-economically disadvantaged [43]. Therefore, it is also necessary to examine location-specific gender vulnerability and discrimination to enhance the adaptive capacity of women to respond effectively.

It is difficult to formulate one-size-fits-all solution for all vulnerability assessment [44]. Moreover, it is widely accepted that climate vulnerability studies should explore the socio-economic and institutional factors in depth [45] and at bottom level [46]. Bottom up approaches offer opportunities for fine grained assessment [47] by integrating climate change considerations into existing decision making and management decisions. The impacts of climate change effects on smallholders will be locally specific and difficult to measure because of the complexity of farming systems, the complexity of agricultural and non-agricultural livelihood activities [27]. Hence, the main objectives of our study are (1) to develop and apply the Climate Vulnerability Index for Rainfed Tropics ($CVI^{RFT}$); and (2) to test the new $CVI^{RFT}$ for comparing the vulnerability of three watersheds in India that are characterised by the implementation of WDPs by different agencies. The methodology was developed and pilot tested in one of the watersheds [48] before extending it to the comparative application level presented here.

## 2. Materials and Methods

### *2.1. Climate Vulnerability Assessment Concepts*

According to Chambers [49], vulnerability has two sides: an external side of risks, shocks and stress to which an individual or household is exposed and an internal side, which is defenselessness. In climate change vulnerability assessment, the most vulnerable are considered to be those who are most exposed to hazards, who possess limited resources to cope, who are heavily dependent on subsistence activities involving the extraction natural resources and who have the least resilience to climate shocks [50]. The Government of India has started preparing an Action Plan on Climate Change since 2007, after the publication of Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4). The following definitions act as the principles for the basis of national and state level strategic action plans.

A system is vulnerable or susceptible if it is exposed and sensitive to the effects of climate change and at the same time, only has limited capacity to adapt [51] and vice versa [52]. Thus, building adaptive capacity enables communities to mobilise resources needed to reduce vulnerability [53]. A widely accepted definition is that vulnerability is a function of *exposure*, *sensitivity* and *adaptive capacity* [54–56].

Here, *exposure* is defined as the nature and degree to which the system is exposed to climatic variations [57] and *sensitivity* is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli [57]. *Adaptive capacity* is crucial to modify *exposure* to the risks, to absorb and to recover from the losses stemming from climate change [46]. *Adaptive capacity* is defined as the propensity or predisposition to be adversely affected [58]. The vulnerability research has emphasised social vulnerability, which concerns the social and economic determinants of the risks of undergoing climatic stress. Thus, efforts to reduce vulnerability stress the importance of decreasing the *sensitivity* and strengthening the *adaptive capacity* of local communities [59]. As the *adaptive capacity* varies between different contexts and systems [60], it is important to identify what builds *adaptive capacity* or what functions as barriers or limits to adaptation [61]. Therefore, the possibility of creating anticipatory *adaptive capacity* in advance of the *exposure* is required to reduce the impacts of future climate change. Moreover, it is closely linked with infrastructural, institutional, community, social, political, demographic, economic, educational, health, technological, and cognitive factors in influencing the capacity of communities to adapt to adverse climate effects [60,62–64].

*2.2. Climate Vulnerability Index*

We modified well-established approaches for estimating climate vulnerability and the existing indices according to the local situation, addressing rain fed farming systems in particular [31,33,65,66]. The $CVI^{RFT}$ developed here is based on the framework shown in Figure 1. It concentrates on the three aforementioned dimensions of vulnerability i.e., *adaptive capacity, sensitivity* and *exposure* (Table 1). For the development of the $CVI^{RFT}$, the three dimensions are subdivided into its major components. The *adaptive capacity* dimension comprises of five major components: Socio-Demographic Profile, Socio-Economic Assets, Livelihood Strategies, Agriculture and Social Networks. The second dimension is *sensitivity* with three major components: Water, Food and Health. The *exposure* dimension integrates two major components: 'Natural Disaster and Impact as well as Climate Variability. Each of these major components is subdivided into specific indicators. The major components and overall 59 indicators have been selected to capture the theoretical determinants of vulnerability based on literature, local situation and expert opinion at watershed level. After calculating the overall index, we assess dimensional vulnerability at the watershed level. A detailed description of the indicators under major components can be found in Table A1.

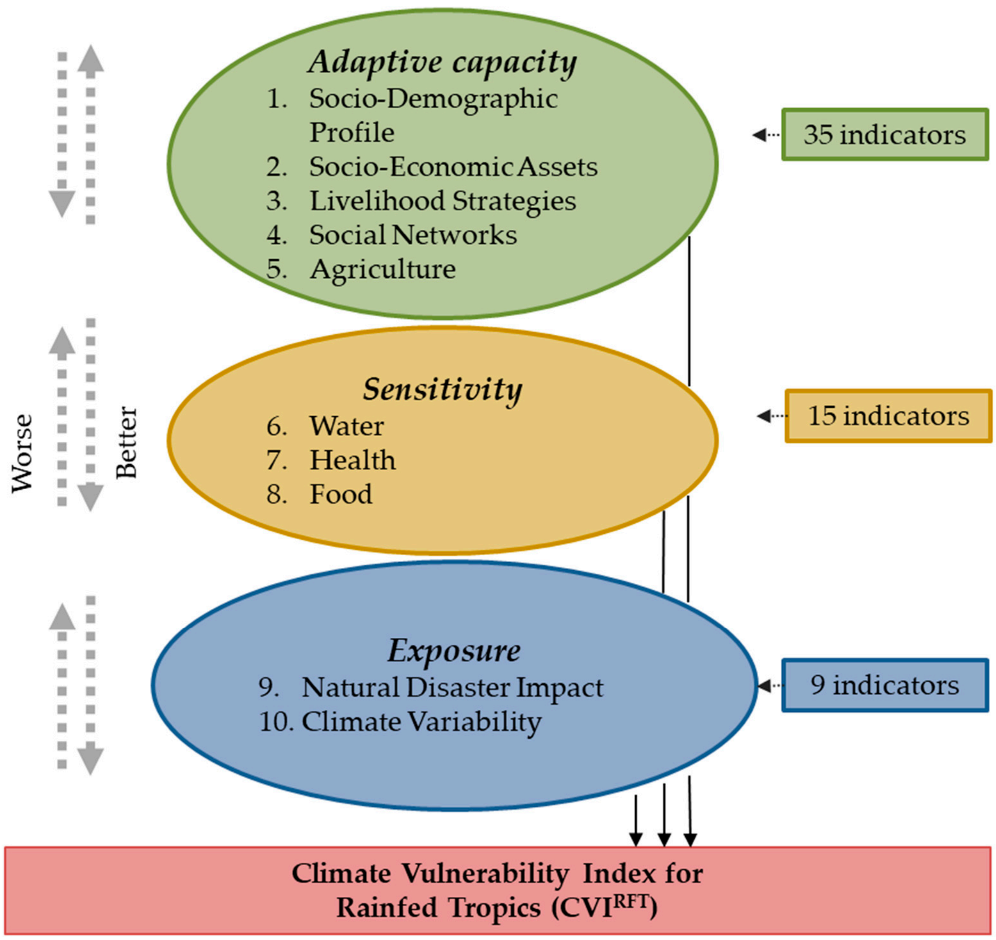


**Figure 1.** The composition of the Climate Vulnerability Index for Rainfed Tropics ($CVI^{RFT}$). The $CVI^{RFT}$ consists of the three dimensions *adaptive capacity*, *sensitivity* and *exposure*. Each dimension is made up of two to five major components (1–10). Overall, 59 indicators are used to determine the major components.

**Table 1.** Dimensions of Vulnerability, their ten major components and the 59 indicators involved for estimation of the $CVI^{RFT.}$

| Dimension of Vulnerability | Major Component | Indicator |
| --- | --- | --- |
| *Adaptive capacity* | 1. Socio-Demographic Profile | 1. Family dependency<br>2. House type diversity<br>3. Family decision<br>4. Poverty<br>5. Indebtedness<br>6. High income households<br>7. Male-headed households<br>8. Religious diversity |
| | 2. Socio-Economic Assets | 9. House hold asset possession<br>10. Farm asset possession<br>11. Average farm holding size<br>12. Water access |
| | 3. Livelihood Strategies | 13. Migration<br>14. New crop<br>15. Dependency on agriculture<br>16. Farm diversification<br>17. New livelihood strategies<br>18. Introduced livestock |
| | 4. Agriculture | 19. Rainfed farming<br>20. Net sown area<br>21. Crop diversification<br>22. Adoption of new varieties<br>23. Decline in farm production<br>24. Soil erosion perception<br>25. Non-adoption of soil and water conservation (SWC) works<br>26. Households with <0.2 ha of land |
| | 5. Social Networks | 27. Percent of beneficiaries<br>28. Cooperation<br>29. Membership in co-operative institutions<br>30. Help from others<br>31. Watershed committee (WC) membership<br>32. No beneficiary contribution<br>33. Lack of ICT access<br>34. Grass root planning<br>35. Trainings |
| *Sensitivity* | 6. Water | 36. Water scarcity<br>37. Dependency on water resources<br>38. Public water sources<br>39. Groundwater decline<br>40. Gender inequality<br>41. Decreased water availability<br>42. Water resource depletion |
| | 7. Health | 43. Waterborne diseases<br>44. New disease incidence<br>45. Poor quality drinking water<br>46. Sunburn<br>47. Death due to climatic variability |
| | 8. Food | 48. Off-farm dependency<br>49. Food insufficiency<br>50. Poor governmental support |

**Table 1.** *Cont.*

| Dimension of Vulnerability | Major Component | Indicator |
|---|---|---|
| *Exposure* | 9. Natural Disaster Impact | 51. Death or injury due to natural disaster<br>52. Crop loss<br>53. Property damage<br>54. Heavy wind |
| | 10. Climate Variability | 55. Temperature increase perception<br>56. Hot months increase perception<br>57. Erratic rainfall perception<br>58. Less rainy days perception<br>59. Extreme climate events |

The dotted grey arrows in Figure 1 indicate the direction of change in the dimensions and the resulting vulnerability situation. For example, a better *adaptive capacity* with a lower level of *sensitivity* and *exposure* contributes to a lower vulnerability situation, and vice versa. A brief description about the definition of the major components and the associated indicators can be found in the results section.

The variables used for indicator development were tested for correlations at a 99% confidence interval. The significant levels of these variables are plotted in Figure A1. Out of the 59 variables, on an average 13 variables per watershed showed correlations above 0.7. We found no typical pattern for a single watershed, but rather, mixed results across all watersheds. Apart from this general finding, we identified three pairs of variables that showed positive correlations (>0.7) in all three of the watersheds for certain major components: Socio-Economic Assets (variables: area owned & area sown), Livelihood Strategies (new activity, and change in livelihood strategies) and Climate Variability (perception about erratic rain fall, and increase in rain fall and decrease in rainfall). We decided to include these variables despite their potential autocorrelation in the composite index, as they are crucial for assessing the vulnerability index value under the respective major components and dimensions.

The indicators were measured on different scales, e.g., some of them are numbers or percentages, and others are indices. Therefore, they were normalised to a range between 0 and 1 as suggested by Hahn et al. [65]. Before that, the functional relationship of each indicator to vulnerability is considered whether it contributes to an increase or a decrease in the overall vulnerability. For indicators which decrease the vulnerability, the values were transferred so that we derived a positive (hypothetical) value from the actual value (e.g., 100 minus the indicator value in case of percentage units) (see Table A2) which contributes to increase in vulnerability.

For calculating the $\mathrm{CVI}^{\mathrm{RFT}}$, each major component contributes equally to the overall index [48,65]. The index scores for the major components are calculated by taking the simple average of the normalised indicators. Initially, the values of each indicator were normalised to form an index value using equation (Equation (1)):

$$\mathrm{Index}_{\mathrm{sw}} = \frac{\mathrm{S_w} - \mathrm{S_{min}}}{\mathrm{S_{max}} - \mathrm{S_{min}}} \tag{1}$$

where $\mathrm{S_w}$ is the original indicator value for the watershed community, and $\mathrm{S_{min}}$ and $\mathrm{S_{max}}$ are the minimum and maximum values, respectively. The next step after the normalisation is the calculation of the index score for the major components. For that, each indicator is averaged (Equation (2)):

$$\mathrm{M_w} = \frac{\sum_{i=1}^{n} \mathrm{Index}_{\mathrm{swi}}}{n} \tag{2}$$

where $\mathrm{M_w}$ is one of the major components under the three dimensions of vulnerability, the $\mathrm{Index}_{\mathrm{swi}}$ is the indexed indicator value of the watershed community, and n is the number of indicators under each major component.

After calculating the index for each major component, the next step was assigning the weights. The balanced weighted approach [65,67] is used in this study, where the number of indicators in each major component has been taken as the weight for calculating the $CVI^{RFT}$. In our study, the indicators are given equal weights because all the dimensions included in the $CVI^{RFT}$ are equally important and desirable in their own right for assessing the three dimensions of vulnerability i.e., *adaptive capacity*, *sensitivity* and *exposure*. According to Chowdhury [68], 'the a priori decision to adopt the technique of equal weighting for methodological purposes is often believed to make the choice of weights less subjective' and 'giving equal importance to all the variables is perfectly acceptable when there is no reason to do otherwise'. The weighted scores of the major components are averaged to calculate the final $CVI^{RFT}$ for each watershed. The overall $CVI^{RFT}$ for vulnerability [48] can then be expressed as

$$CVI^{RFT} = \frac{\sum_{i=1}^{10} W_{mi} M_{wi}}{\sum_{1=1}^{10} W_{mi}} \quad (3)$$

where, $W_{mi}$ is the weight and $M_{wi}$ is the average value of each major component. The $CVI^{RFT}$ is scaled from 0 to 1, i.e., from the least vulnerable to the most vulnerable. The calculation of *adaptive capacity*, *sensitivity* and *exposure* helps to compare and analyse the dimensional vulnerability of the three watersheds. *Adaptive capacity*, *sensitivity* and *exposure* are calculated according to Equations (4)–(6):

$$Adaptive\ capacity = \frac{W_{a1}SD + W_{a2}SE + W_{a3}LS + W_{a4}A + W_{a5}SN}{W_{a1+}W_{a2} + W_{a3} + W_{a4} + W_{a5}} \quad (4)$$

where $W_{a1}$, $W_{a2}$, $W_{a3}$, $W_{a4}$, $W_{a5}$ are the weights for the Socio-Demographic Profile (SD), Socio-Economic Assets (SE), Livelihood Strategies (LS), Agriculture (A) and Social Network (SN), respectively.

$$Sensitivity = \frac{W_{s1}H + W_{s2}F + W_{s3}Wa}{W_{s1} + W_{s2} + W_{s3}} \quad (5)$$

where $W_{s1}$, $W_{s2}$, and $W_{s3}$ are the weights for the components Health (H), Food (F) and Water (W), respectively.

$$Exposure = \frac{W_{e1}ND + W_{e2}CV}{W_{e1} + W_{e2}} \quad (6)$$

where $W_{e1}$ and $W_{e2}$ are the weights for Natural Disaster Impact (ND) and Climate Variability (CV), respectively. The dimensional vulnerability value varies between 0 and 1, where a higher value indicates greater vulnerability.

### 2.3. Study Area

Field data was collected from Kerala state to estimate the 59 indicators and to calculate the 10 major components, the three dimensions of vulnerability and finally the $CVI^{RFT}$. Kerala, located in the southwest tip of India between the Arabian Sea in the west and the Western Ghats mountains in the east (Figure 2), covers around 1.18% of the Indian landmass. It has a tropical monsoon climate with heavy annual rainfall of up to 3000 mm as it lies in the western windward slopes of the Western Ghats. Spatial and temporal variations in monsoon rainfall make the state extremely vulnerable to climate change [69]. The state faced 64 intense and short term droughts [70] during the past 100 years period even with the highest annual rainfall in India The temperature reaches up to 32 °C during March to April with a relative humidity of 73–89%.

Subsistence homestead farming is a key feature of the land use in this area. Out of the net cropped area of the state, 81% is rainfed [71]. Moreover, 40% of the total cropped area is prone to soil erosion [71]. With this background, we selected the Kerala state for the climate vulnerability assessment among rainfed smallholders.

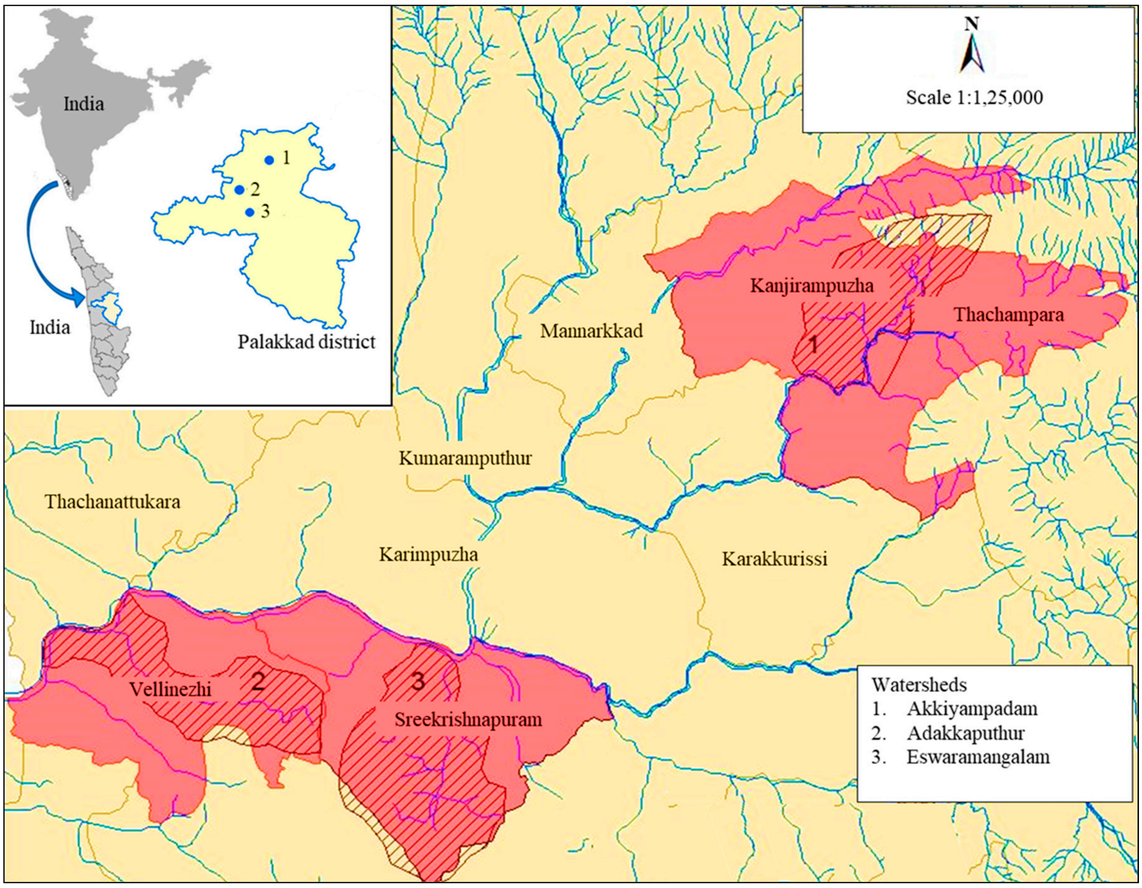


**Figure 2.** Location of the study area in Kerala, India.

Palakkad district, the study area, is listed as one of the highly vulnerable districts to climate change due to its specific geographic location, humid climate, high percentage of population, dependence on agriculture, a low ranking in the human development index, high social deprivation and a high degree of vulnerability to natural hazards like floods and droughts [72]. The district is known as the 'Granary of Kerala' as it is the highest producer of rice in the state. Moreover, 90% of the rice production comes from rainfed farming [73]. At the same time, the annual rainfall in this region is the lowest (1600 mm) among the districts of Kerala [69] due to the peculiar geographic conditions of the area coming under the Palakkad gap with landlocked physiography. The Palakkad Gap also moderates the summer temperatures of the district [74] where the daytime temperature often exceeds 40 °C while the maximum mean annual temperature of the state is 32 °C.

## 2.4. Watershed Development Programme

The newly developed $CVI^{RFT}$ was tested in three different settings. The three watersheds selected for the study are shown in Figure 2 and further described in Table 1. The respective WDPs in these watersheds have been implemented by three different agencies, i.e., Soil Survey and Conservation department that represents the State Government (SG), a Non-Governmental Organisation (NGO) and a Local-Self Government (LG).

In recent years, three main activities of the WDPs have been implemented in these watersheds: natural resource management, production system enhancement and livelihood support system activities. The natural resource management activities include construction of small check dams, farm ponds, contour bunding, river bank protection walls, moisture conservation pits and protection of wells. The production system enhancement included the distribution of new fruits, medical plants, crops and varieties as well as organic manure. The livelihood support system activities were concentrated on the women and landless in the area by mobilising self-help groups. The main livelihood activities introduced were rabbit rearing, livestock and poultry units. An overview of the watersheds described above is given in Table 2.

**Table 2.** Socio-economic and physical characteristics of the selected watersheds and the implemented Watershed Development Programmes.

| Criteria | Watersheds | | |
|---|---|---|---|
| **Name** | **Adakkaputhur** | **Akkiyampadam** | **Eswaramangalam** |
| Project implementing agency | SG | NGO | LG |
| Grama Panchayat | Vellinezhi | Kanjirampuzha | Sreekrishnapuram |
| Project period | 2003–2008 | 2009–2013 | 2007–2012 |
| Project fund | 26,485 US$ | 57,920 US$ | 82,456 US$ |
| Soil | Gravelly clay and sandy clay | Laterite | Laterite and alluvial |
| Population | 5742 | 7399 | 6469 |
| Households | 1243 | 1482 | 1198 |
| Literacy (%) | 87.3 | 98.0 | 98.9 |
| Farm size <1 ha (%) | 81 | 92 | 71 |
| Major crops | Rubber, paddy, arecanut, coconut and vegetables | Coconut, cashew, arecanut, rubber, tapioca and vegetables | Rubber, coconut, arecanut, banana and vegetables |

Source: Detailed project reports of Adakkaputhur, Akkiyampadam [75] and Eswaramangalam watersheds [76].

### *2.5. House Hold Surveys*

The household interviews were conducted during the period August–November 2015. In all watersheds, the WDP activities were completed before 2014. The cluster sampling method was used for the selection of farm households. The farmers were grouped into small, marginal, medium and large based on their landholding size. A farmer owning less than 2 ha of land is considered to be a smallholder farmer, which is the case for more than 80% of the farmers in the three selected watersheds. Out of the total 215 smallholder households covered in the field survey, 70 households were located each in SG and NGO, and 75 households in LG watershed. Interviews were conducted in Malayalam (local language) with the support of a local assistant. The interview schedule consisted of four broad sections: (i) basic information about the households; (ii) perception on *exposure* to climate change; (iii) perception on *sensitivity* to climate change; and (iv) present *adaptive capacity* to climate change.

## **3. Results and Discussion**

### *3.1. Dimensions of Vulnerability and the Climate Vulnerability Index*

According to the $CVI^{RFT}$, the differences between the LG, SG and NGO managed watershed are negligible (Figure 3). Nevertheless, a closer look into the three dimensions of vulnerability *adaptive capacity*, *sensitivity* and *exposure* reveal some interesting differences.

The highest *sensitivity* towards climate variability can be found for SG, while it was the lowest for LG. Water and Food components contribute to the high vulnerability values, and thus, to the highest *sensitivity* (Figure 4). The largest difference between the watersheds was reported for *exposure*. *Exposure* was more pronounced and on a similar level in LG and NGO, while SG depicted a substantially lower index value. Both, Natural Disasters and Climate Variability components account for these differences (Figure 4). Overall, *adaptive capacity* has the lowest variation among the watersheds, *sensitivity* has moderate and *exposure* the highest variability.

The following analysis of the major components, and the contributing indicators of the dimensions of vulnerability will help to identify the key areas to be considered in restructuring of WDP planning, decision making and implementation.

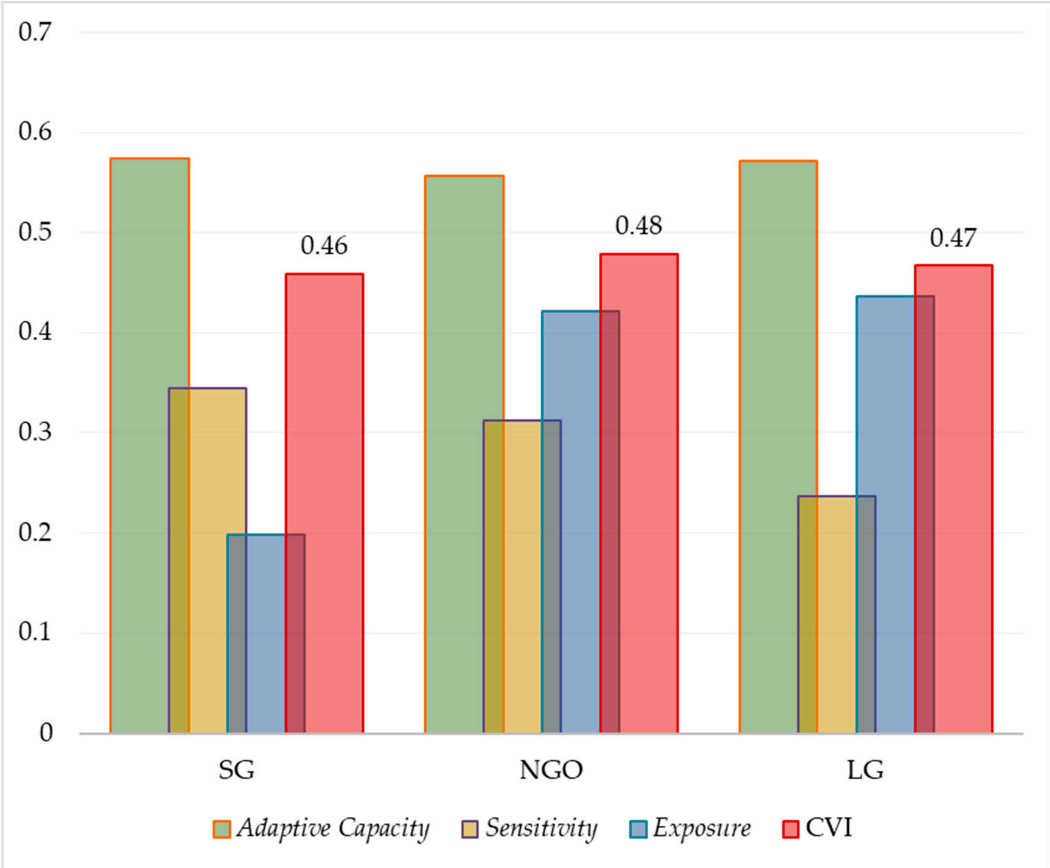


**Figure 3.** Dimensions of Vulnerability and the resulting $CVI^{RFT}$ of the three watersheds.

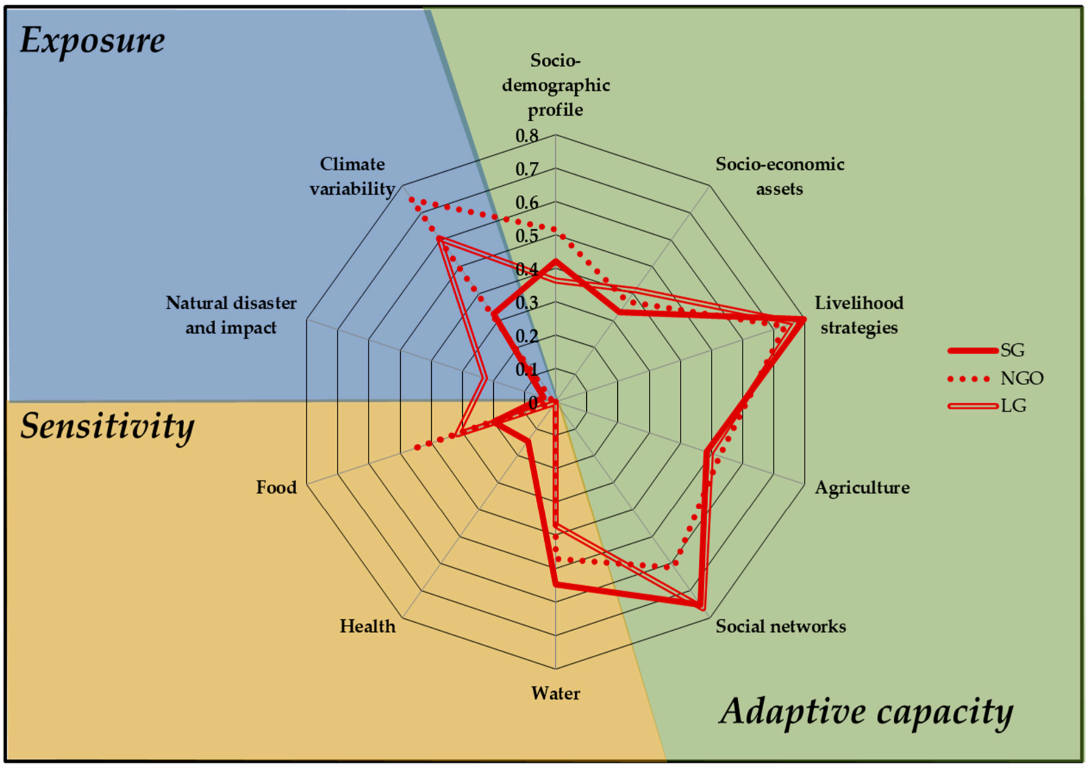


**Figure 4.** Comparison of average values of the ten major components for the three watersheds.

### *3.2. Major Components and Indicators*

#### 3.2.1. Adaptive Capacity

Livelihood Strategies and Social Networks are the major components of *adaptive capacity*, which exhibit relatively high values in all the three watersheds (Table 3). However, the indicators contribute in different proportions in the three regions (Table A3). Livelihood Strategies are the choices and activities that people make and undertake in pursuit of income, security, well-being, and other productive and reproductive goals [77]. Livelihood decisions may vary according to opportunities for access to, control over and use of local assets along with their capacity to make use of them for subsistence and/or income generating purposes [78]. The Livelihood Strategies of SG were the least diversified which contributed to a lesser *adaptive capacity* (Table 3, Figure 4). Not even a single household tried to introduce livestock in their farming (1.00, Table A3). The NGO households had somewhat more opportunities and accessibilities for diversification as the WDP intervened with poultry and cattle units for their beneficiaries and hold comparatively a lower vulnerability value. Venkateswarlu and Singh [14] also emphasised the importance of policy initiatives for economic diversification, diverse livelihood strategies and migration possibilities for strengthening the adaptive capacities of rainfed farmers in India.

**Table 3.** Indexed values for the major components of *adaptive capacity.*

| Major Components | SG | NGO | LG |
|---|---|---|---|
| 1.Socio-Demographic Profile | 0.42 | 0.48 | 0.37 |
| 2. Socio-Economic Assets | 0.33 | 0.37 | 0.41 |
| 3. Livelihood Strategies | 0.80 | 0.74 | 0.77 |
| 4. Agriculture | 0.48 | 0.52 | 0.50 |
| 5. Social Networks | 0.75 | 0.61 | 0.76 |

Marshalling and extending of social networks and relationships is also very important in increasing *adaptive capacity* [78]. Here, LG has the highest Social Networks vulnerability. 98.7% of the people complained that they never received any help from neighbours or government institutions during the crisis of the heavy storm in 2015. Moreover, only 28% of the households received benefits from the WDP and thus contributed to a higher vulnerability value (0.72, Table A3). The local credit institutions coupled with private institutions should be promoted to create *adaptive capacity* [14]. It is necessary to engage a diverse set of stakeholders operating at different levels and scales in networks to mobilise and facilitate information flows as a means to reduce vulnerability [79,80]. Thus, policy implications are essential in diversifying the livelihood strategies, to create financial mechanisms such as access to credit institutions, disaster insurance services and information services to tackle the envisaged climate change scenario [14]. These results are in line with the findings of Moench and Dixit [81] who conducted a study in South Asia on *adaptive capacity* and livelihood resilience.

NGO is the highest vulnerable watershed in terms of Agriculture. In this region, we found less crop diversification (0.36, Table A3) and farmers were complaining about the low productivity due to soil erosion. Even then, only 25% of the households adopted soil and water conservation works (0.76) offered by the WDP. In a nutshell, a majority of the farmers adopt no strategies for conserving soil and water to cope with potential climate change impacts, which stands in line with the findings of Touch et al. [27] for smallholder farmers in North-West Cambodia. Documentation of indigenous practices, existing best practices for production system along with long term strategic research and planning [14], the introduction of new crop varieties and natural resource management are essential practices to be considered for creating better adaptive capacity in the agriculture component.

Socio-economic factors play a key role in enhancing or constraining the existing *adaptive capacity* of farmers to cope with climate change [14]. Socio-Demographic Profile and Socio-Economic Assets hold lower vulnerability values in all three watersheds. Among the three watersheds, the NGO exhibited relatively higher Socio-Demographic vulnerability. A high religious diversity index (0.63) and family dependency ratio (0.51) (see Table A3) contribute to the highest value of vulnerability when compared to the other two watersheds. The previous research with regard to religion and climate change perceptions shows that there is an attitudinal difference to climate change and climate change policy across various religious groups [82–84]

Religious beliefs have a direct impact on how to deal with threats, either it is on the short-term (e.g., famine, water access) or long-term (climate change, land ownership). Thus, adaptation planning must aim to integrate cultural values to facilitate interventions that redress power imbalances and empower individuals to help themselves through religious organisations [6]. We, therefore, included religious diversity as one of the indicators. Moreover, the watershed inhabitants are from three major religious groups, i.e., Hindu, Muslim and Christian.

In LG, household asset possession (0.36) and farm asset possession (0.35) indices contribute to relatively higher value of Socio-Economic vulnerability (0.41) when compared to the other two watersheds (Tables 3 and A3). 96% of the households own less than 0.2 ha of land and have fewer opportunities for farm expansion. Thus, the lack of financial assets is one of the main factors inhibiting choices to climate change adaptation [7].

WDPs are one of the best tools to build *adaptive capacity* because of their interventions to promote livelihood, production system improvement, and natural resource management. Even then, there is an urgent need to bring out technological, institutional and operational changes at policy and practice level [19]. Nevertheless, people in our studied watersheds were reluctant to adopt new livelihood activities, especially to introduce livestock into their ongoing farm activities. Moreover, they were sceptical towards new crops and varieties despite having suitable soils and climatic conditions. It will be advantageous to intervene with on-farm trials, farmer field schools, climate smart extension strategies [27], field demonstration to promote new crops and drought resistant varieties, awareness creation on adjusting planting time [85], and diversification of farm and livelihoods for better preparing the local people for climate change impacts.

### 3.2.2. Sensitivity

Under the *sensitivity* dimension, three major components were analysed, i.e., Water, Health and Food, which are very basic and essential elements for any community (Table 4). The three watersheds exhibited relatively low indicator values for Health and Food components. This shows a positive sign towards reduced *sensitivity* to climate change (Figure 4).

**Table 4.** Indexed values for the major components of *sensitivity*.

| Major Components | SG | NGO | LG |
|---|---|---|---|
| 6. Water | 0.55 | 0.47 | 0.37 |
| 7. Health | 0.15 | 0.00 | 0.00 |
| 8. Food | 0.20 | 0.46 | 0.32 |

SG displays the highest vulnerability towards the component Water. Water scarcity was a serious problem in the watershed due to a strong groundwater decline (0.69, Table A3) and a decreased availability of drinking water compared to previous years. In total, 17% of the households were solely depending on public water sources for the daily routine. Pandey et al. [33] also observed that water vulnerability of rural households in Uttarakhand was mainly due to the water scarcity and high dependency on agriculture and natural resources for their living. The WDP further aims at soil and water conservation measures, which are one of the important adaptation measures [14,83]. Only 3% of the farmers adopted any kind of soil and water conservation activities in their field. Out of these 3%, 12% of the strategies were stone pitched contour bunds and moisture conservation pit offered through the WDP. As these strategies were expensive, the WDP has subsidised these interventions up to 90%. Nevertheless, only a minor fraction of farmers adopted one of these strategies.

During the field survey, one of the farmers expressed that 'we were not informed about soil and water conservation works and the committee has special concerns to some of the big farmers'. This can be addressed through public awareness campaigns about WDP activities, as well as the creation of Water Users Societies and women Self Help Groups, to strengthen effective water management through the community involvement [86]. Another reason for not adopting conservation efforts is resulting from small fragmented land holdings.

Groundwater decline and increased drinking water shortage were other major concerns. The paddy fields are reclaimed for either cash crops or construction purposes, because of agricultural labour shortage, increased labour charges and input price hikes. Improvements could be addressed via the state government by formulating strict rules and regulations, against paddy field conversion for non-agricultural purposes with support from competent local institutions responsible for enactment.

Regarding the Health component, there are many prevalent human diseases, which are linked to climate variabilities such as respiratory illnesses, altered transmission of infectious diseases such as cholera, malaria, and even malnutrition due to crop failures [3,87]. The Health components showed low vulnerability values in all the three watersheds except for the case of sunburns. The sunburn incidence is common in the Palakkad district and it happens because of a peculiar geographic condition called the Palakkad gap, i.e., a low mountain pass in the Western Ghats between Tamil Nadu and Kerala states. It is the only break in the Western Ghats, the rain shadow barrier, and the rain clouds are blown away making the district one of the most drought prone districts of Kerala. In the SG, people opined that there were an increasing influence of heat waves and sunburn incidence since the past two years which reduce their working hours outside during the day time. There were reports of sunburn in 2010 [88] as well as deaths in 2016 resulting from heat waves and associated dehydration. All these factors enhanced the climate vulnerability of the district.

There was a wider variation in the Food component vulnerability between the watersheds (Table 3). Climate variability and disasters can worsen the situation of vulnerable people during food and nutrition crisis. The NGO had the highest Food vulnerability value, because people opined that there was no improvement in the support from the government (0.94, Table A3) to achieve food security. Almost half of the households depended on off-farm sources for their daily needs, which show insufficient food from farm due to either low availability of agricultural land or due to dependency on other income sources. Here the NGO watershed is highly vulnerable because 67% of the households depend on off-farm food sources while in SG it is only 43%.

### 3.2.3. Exposure

The dimension *exposure* comprises of two major components, i.e., Natural Disaster Impact and Climate Variability (Table 5). Impacts of natural disasters such as floods, droughts, or earthquakes are partly dependent on the social system where they occur [89]. Reports on the occurrence of such disasters for the past ten years were obtained in the household surveys. Here, the LG depicts the highest value towards natural disasters because this watershed was affected by heavy wind in 2015, with severe crop losses and property damages (Table A3). Nevertheless, the indicator values of Natural Disaster Impact were comparatively low, likely due to the fact that no larger, life-threatening disasters occurred in the past decade.

**Table 5.** Indexed values for the major components of *exposure*.

| Major Components | SG | NGO | LG |
|---|---|---|---|
| 9. Natural Disaster Impact | 0.04 | 0.01 | 0.23 |
| 10. Climate Variability | 0.33 | 0.75 | 0.61 |

In contrast, values for Climate Variability score are substantially higher (Table 5). More than 60% of the crop yield variability, mainly of maize, wheat, soybean and rice can be explained by Climate Variability [90]. Farmers do perceive the climatic variations and try to adapt through local adaptation strategies [91]. As part of this major component, we considered the perception of people about an increase in temperature, hot months, the incidence of erratic rainfall and a decrease in rainy days during the last ten years (Table A3). We find that Climate Variability perceptions were more pronounced in NGO as compared to the other two watersheds. The households were much more concerned about the rise in temperature (0.94), hot months (0.93) and decrease in rainy days (0.91) (Table A3) compared to the other two watersheds. Smallholders were worried about a decline in production due to erratic rainfall with high temperatures and the occurrence of persistent droughts. Similar findings from North-West Cambodia [27] and Telangana region of India [92] indicated that farmers perceive erratic rainfall, dry spells and drought affect the crop yield. In LG, 50% of the households faced drought and water scarcity of about 3–6 months during the summer season.

People opined less physical and financial assistance during disaster emergencies. One of the solutions for this might be strengthening and equipping the local institutions and informal associations to tackle natural disasters. Residents participating in community-based adaptation actions are both knowledge holders and users. So, flexibility in key institutions that make up a local knowledge system is necessary for learning [93,94]. By working together in such kind of groups, people will be able to spread and share the risks and knowledge [95] along with proper channelled collective action to address the situation [31].

### 3.2.4. Comparison of Major Components

The major components for the three watersheds are compared in Figure 4. We found that the major component indices for Livelihood Strategies, Socio-Economic Assets and Agriculture were almost similar (<0.1 difference) in the three watersheds while there were stronger differences (between 0.1–0.2) in Socio-Demographic Profile, Social Networks, Water and Health. The strongest differences (>0.2) can be depicted for the components Climate Variability, Natural Disaster and Food.

The reason for the strong variations in Climate Variability and Natural Disaster is the varying perception of people about an increase in temperature (Table 3A) and hot months as well as the occurrence of less rainy days and erratic rainfall. People do strongly perceive climate variability and incidence of natural disasters but neither in the same intensity nor climatic parameter. Another concern is Food, where the NGO watershed exhibited strong variation because of poor government support to ensure food security in the area through Public Distribution System. This result is different from Pandey and Jha [31] where the people complained about low availability of agriculture land and productivity as a reason for Food vulnerability.

Overall, it would be interesting to study the performance of the $CVI^{RFT}$, its dimensions, major components and indicators across a wide range of socioeconomic and physio-geographic conditions. Knowledge about the average performance of watersheds with regard to these indices would allow detecting watershed types of particular vulnerability to climate change. However, in this study, we mainly introduced the concept of the $CVI^{RFT}$ and showed the functionality of the concept to investigate three watershed development programmes in India.

## 4. Conclusions

The new $CVI^{RFT}$ provides a straight forward approach to investigate the vulnerability of spatial entities to climate changes in a human dimension. It can be used as an effective tool in evaluating the vulnerability of rainfed regions in general with modification of contributing indicators according to the context and locality.

Since the derived $CVI^{RFT}$ values for the three watersheds are almost identical, an in-depth qualitative data analysis is proposed to identify the differences in performance of the considered implementing agencies. For example, focus group discussions and key informant interviews with emphasis on participatory approaches would provide unbiased detailed information on the functioning of WDPs. Furthermore, future research could focus on comparative vulnerability assessment of WDP communities with communities that are not supported by WDP programmes. Another issue that should be addressed in any survey-based index assessment is the issue of uncertainty and sensitivity. For the $CVI^{RFT}$, we were able to show the statistical significance of differences between dimensions and identify the main influencing major components that led to these differences [96].

High values of dimensions or major components indicate a neglect of the respective topic area in the design of WDPs. This can provide stakeholders and politicians with relevant information to act and address the identified deficiencies. The policy implications are crucial in restructuring the existing WDPs through concerted research and development efforts for novel location specific adaption strategies, documenting indigenous adaptation strategies, promoting the adoption of existing interventions and mobilising marginalised sections. For example, emphasis on adoption of new crops and resistant varieties suited to agro-climatic conditions and diversification of farm and livelihoods is needed while formulating action plans for implementation of the WDPs. Moreover, a timely and accurate weather forecasting system, an effective disaster management and awareness campaigns on natural resource management seem to be emergent needs of the communities. Criticism in the selection of our indicators could be the subjectivity in their definition. However, as we analysed 59 indicators in total, we are convinced that we span a large range of potentially relevant information. Further, the direction of the relationship between the indicators and vulnerability is subjective and could be interpreted differently. We used an equal weighting approach in constructing the composite index $CVI^{RFT}$. Future research on indicator development may concentrate on applying different weighting schemes and refinement of contributing indicators based on the location and the target group coupled with qualitative data analysis. Nevertheless, we discussed our framework in many workshops and think that the direction we identified is plausible. Finally, data evaluation obtained from questionnaires is prone to errors and false information given by the farmers, a feature that should be considered in the assessment of uncertainty of complex indicator systems such as the $CVI^{RFT}$.

**Author Contributions:** A.R.S. designed the research and drafted the manuscript. C.F. contributed to the statistical data analysis and writing of the manuscript. L.B. and T.A. guided the work, co-designed the research and provided extensive revisions during the preparation of the manuscript.

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**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix A

**Table A1.** List of indicators, their explanation and sources.

| Indicator | Explanation (Unit) | Relationship to Vulnerability | Source |
|---|---|---|---|
| 1. Family dependency | Ratio of population between 0–14 years and population of 60 years and above to the population between 15–59 years [-] | Increase | [97] |
| 2. House type diversity | Simpson's diversity index $(1 - D)$ [a] based on the type of house roof such as tiled or concrete [-] | Increase | New [d] |
| 3. Family decision | Literate household head [%] | Decrease | [31] |
| 4. Poverty | Families below poverty line [%] | Increase | New |
| 5. Indebtedness [b] | Families with debt [%] | Increase | New |
| 6. High income households | Households with income >2250 $/year [%] | Decrease | [98] |
| 7. Male headed households | Households with male as head of family [%] | Decrease | [31] |

**Table A1.** *Cont.*

| Indicator | Explanation (Unit) | Relationship to Vulnerability | Source |
|---|---|---|---|
| 8. Religious diversity | Simpson's diversity index (1 − D) [a] based on the religious belief of the family (Hindu, Muslim or Christian) [-] | Increase | New |
| 9. Household asset possession | Inverse of (no of household asset+1) [-] | Decrease | New |
| 10. Farm asset possession | Inverse of (no of farm asset +1) [-] | Decrease | New |
| 11. Average farm holding size | Inverse of (land holding size +1) [-] | Decrease | New |
| 12. Water access | Households with at least one water (well/pond) resource at home [%] | Decrease | New |
| 13. Migration | Households in which at least one member migrated for better income since last ten years [%] | Decrease | [31] |
| 14. New crops | Households introduced at least one new crop in the homestead/farming [%] | Decrease | [31] |
| 15. Dependence on agriculture | Households with agriculture as the only source of income [%] | Increase | [99] |
| 16. Farm diversification | Inverse of (types of enterprises+1) [-] | Increase | [99] |
| 17. New livelihood strategies | Households which adopted new livelihood strategies since the start of WDP [%] | Decrease | New |
| 18. Introduced livestock | Households which adopted livestock in farming since the start of WDP [%] | Decrease | New |
| 19. Rainfed farming | Households which has not following any irrigation methods [%] | Increase | New |
| 20. Net sown area | Cultivated land area [%] | Decrease | New |
| 21. Crop diversification | Inverse of (types of crops+1) [-] | Decrease | [65,99] |
| 22. Adoption of new varieties | Households which introduced new varieties in farming since the start of WDP [%] | Decrease | New |
| 23. Decline in farm production | Households reported decreasing trend in farm production [%] | Increase | [31] |
| 24. Soil erosion perception | Households opined moderate to severe soil erosion in their land [%] | Increase | New |
| 25. Non-adoption of SWC works | Households where farmers not adopted any SWC works [%] | Increase | New |
| 26. Households with <0.2 ha of land | Households with less than 0.2 ha of land [%] | Increase | New |
| 27. Percent of beneficiaries | Households received benefits from the WDP [%] | Decrease | New |
| 28. Cooperation | Households which provided help to others during distress [%] | Decrease | [31] |
| 29. Membership in co-operative institutions | Households which has membership in co-operative institutions [%] | Decrease | New |
| 30. Help from others | Households which received assistance during distress [%] | Decrease | [31] |
| 31. WC Membership | Households with members in WC [%] | Decrease | New |
| 32. No beneficiary contribution | Households that did not contribute any beneficiary share [%] | Increase | New |
| 33. Households lack ICT access | Households with no access to Information Communication Technology [%] | Increase | New |
| 34. Grass root planning | Households that participated in grass root planning [%] | Decrease | New |
| 35. Trainings | Households that received training on climate change [%] | Decrease | New |
| 36. Water scarcity | Households with problems of drinking water during summer [%] | Increase | |
| 37. Dependency on water resources | Households depend on other's water resources [%] | Increase | New |

**Table A1.** *Cont.*

| Indicator | Explanation (Unit) | Relationship to Vulnerability | Source |
| --- | --- | --- | --- |
| 38. Public water sources | Households depend on public tap for drinking water [%] | Increase | [99] |
| 39. Groundwater decline | Households reported decrease in ground water [%] | Increase | New |
| 40. Gender inequality | Households where female fetch potable water [%] | Increase | New |
| 41. Decreased water availability | Households reported decreased availability of water [%] | Increase | [100] |
| 42. Water resource depletion | Households reported severe depletion of water resources [%] | Increase | New |
| 43. Waterborne diseases | Households reported waterborne diseases to the family [%] | Increase | [33] |
| 44. New disease incidence | Households reported with new disease [%] | Increase | [31] |
| 45. Poor quality drinking water | Households reported decreased quality of drinking water [%] | Increase | New |
| 46. Sunburn | Households reported sun burn problems [%] | Increase | New |
| 47. Death due to climatic variability | Households with death due to climate variations especially heat waves and dehydration [%] | Increase | [65] |
| 48. Off-farm dependency | Households depend on off-farm supply for food [%] | Increase | [65] |
| 49. Food insufficiency | Households reported food insufficiency [%] | Increase | [99] |
| 50. Poor governmental support | Households reported poor support from Govt. through Public Distribution System (a network of fair price shops) [%] | Increase | New |
| 51. Death or injury due to natural disaster | Households with death or injury due to natural disasters, e.g., storm, flood, cyclone [%] | Increase | [31] |
| 52. Crop loss | Households reported crop loss [%] | Increase | [31] |
| 53. Property damage | Households reported housing or property damage [%] | Increase | [31] |
| 54. Heavy wind | Households reported heavy wind [%] | Increase | New |
| 55. Temperature increase perception | Households reported very high temperature increase [%] | Increase | New |
| 56. Hot months increase perception | Households reported hot months increase [%] | Increase | New |
| 57. Erratic rainfall perception | Households reported erratic rainfall [%] | Increase | New |
| 58. Less rainy days perception | Households reported less rainy days [%] | Increase | New |
| 59. Extreme climate events | Households reported at least one extreme climate event [%] | Increase | New |

[a] (1 − D), where D = $\sum n(n-1)/N(N-1)$ and $n$ = the number of households under different religion, N = total households; [b] Considered the worst case (i.e., indebted) situation for respondents who did not give information on debt status. [c] According to the Planning Commission of India a household that earns >2250$/year is classified a high-income class; [d] New = developed for this study.

**Table A2.** Indicators of major components with its actual (A) and hypothesised (H) values for the watersheds.

| Indicator | SG | | NGO | | LG | |
|---|---|---|---|---|---|---|
| | A | H | A | H | A | H |
| 1. Family dependency | 0.40 | 0.40 | 0.50 | 0.50 | 0.28 | 0.28 |
| 2. House type diversity | 0.51 | 0.51 | 0.58 | 0.58 | 0.52 | 0.52 |
| 3. Family decision | 91.43 | 8.57 | 90.00 | 10.00 | 92.00 | 8.00 |
| 4. Poverty | 41.43 | 41.43 | 37.14 | 37.14 | 0.48 | 0.48 |
| 5. Indebtedness | 80.00 | 80.00 | 65.71 | 65.71 | 58.67 | 58.67 |
| 6. High income households | 0.00 | 100.00 | 11.40 | 88.60 | 21.33 | 78.67 |
| 7. Male headed households | 85.71 | 14.29 | 87.14 | 12.86 | 89.33 | 10.67 |
| 8. Religious diversity | 0.00 | 0.00 | 0.63 | 0.63 | 0.08 | 0.08 |
| 9. Household asset possession | 0.14 | 0.14 | 0.16 | 0.16 | 0.13 | 0.13 |
| 10. Farm asset possession | 0.44 | 0.44 | 0.47 | 0.47 | 0.51 | 0.51 |
| 11. Average farm holding size | 0.81 | 0.81 | 0.82 | 0.82 | 0.86 | 0.86 |
| 12. Water access | 82.86 | 17.14 | 90.00 | 10.00 | 85.33 | 14.67 |
| 13. Migration | 0.00 | 100.00 | 2.86 | 97.14 | 4.00 | 96.00 |
| 14. New crops | 4.29 | 95.71 | 5.71 | 94.29 | 1.00 | 99.00 |
| 15. Dependence on agriculture | 12.86 | 12.86 | 5.71 | 5.71 | 7.00 | 7.00 |
| 16. Farm diversification | 0.74 | 0.74 | 0.69 | 0.69 | 0.75 | 0.75 |
| 17. New livelihood strategies | 4.29 | 95.71 | 12.86 | 87.14 | 3.00 | 97.00 |
| 18. Introduced livestock | 0.00 | 100.00 | 11.43 | 88.57 | 4.00 | 96.00 |
| 19. Rainfed farming | 20.00 | 20.00 | 42.90 | 42.90 | 28.00 | 28.00 |
| 20. Net sown area | 59.63 | 40.37 | 55.47 | 44.53 | 39.81 | 60.19 |
| 21. Crop diversification | 0.38 | 0.38 | 0.42 | 0.42 | 0.33 | 0.33 |
| 22. Adoption of new varieties | 1.43 | 98.57 | 1.43 | 98.57 | 1.33 | 98.67 |
| 23. Decline in farm production | 5.70 | 5.70 | 8.60 | 8.60 | 9.30 | 9.30 |
| 24. Soil erosion perception | 97.14 | 97.14 | 44.29 | 44.29 | 12.00 | 12.00 |
| 25. Non adoption of SWC works | 45.71 | 45.71 | 75.71 | 75.71 | 89.33 | 89.33 |
| 26. Households with <0.2 ha of land | 51.43 | 51.43 | 68.57 | 68.57 | 72.00 | 72.00 |
| 27. Percent of beneficiaries | 65.71 | 34.29 | 45.71 | 54.29 | 28.00 | 72.00 |
| 28. Cooperation | 2.86 | 97.14 | 12.86 | 87.14 | 1.33 | 98.67 |
| 29. Membership in co-operative institutions | 17.14 | 82.86 | 80.00 | 20.00 | 38.70 | 61.30 |
| 30. Help from others | 2.86 | 97.14 | 5.71 | 94.29 | 1.33 | 98.67 |
| 31. WC Membership | 7.14 | 92.86 | 5.71 | 94.29 | 6.70 | 93.30 |
| 32. No beneficiary contribution | 68.42 | 68.42 | 3.03 | 3.03 | 28.57 | 28.57 |
| 33. Households lack ICT access | 11.43 | 11.43 | 91.43 | 8.57 | 46.67 | 46.67 |
| 34. Grass root planning | 2.86 | 97.14 | 7.14 | 92.86 | 5.30 | 94.70 |
| 35. Trainings | 5.71 | 94.29 | 1.43 | 98.57 | 6.70 | 93.30 |
| 36. Water scarcity | 35.71 | 35.71 | 40.00 | 40.00 | 41.33 | 41.33 |
| 37. Dependency on water resources | 0.00 | 0.00 | 10.00 | 10.00 | 16.00 | 16.00 |
| 38. Public water sources | 17.14 | 17.14 | 2.86 | 2.86 | 10.66 | 10.66 |
| 39. Groundwater decline | 68.60 | 68.60 | 54.30 | 54.30 | 29.30 | 29.30 |
| 40. Gender inequality | 100.00 | 100.00 | 100.00 | 100.00 | 41.33 | 41.33 |
| 41. Decreased water availability | 70.00 | 70.00 | 25.70 | 25.70 | 29.30 | 29.30 |
| 42. Water resource depletion | 92.86 | 92.86 | 97.14 | 97.14 | 92.00 | 92.00 |
| 43. Waterborne diseases | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 44. New disease incidence | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 45. Poor quality drinking water | 1.43 | 1.43 | 0.00 | 0.00 | 0.00 | 0.00 |
| 46. Sunburn | 71.43 | 71.43 | 0.00 | 0.00 | 1.33 | 1.33 |
| 47. Death due to climatic variability | 0.00 | 0.000 | 0.00 | 0.00 | 0.00 | 0.00 |
| 48. Off-farm dependency | 52.86 | 52.86 | 42.86 | 42.86 | 66.67 | 66.67 |
| 49. Food insufficiency | 1.43 | 1.43 | 1.43 | 1.43 | 2.66 | 2.66 |
| 50. Poor governmental support | 5.71 | 5.71 | 94.30 | 94.30 | 25.30 | 25.30 |
| 51. Death or injury due to natural disaster | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 52. Crop loss | 11.43 | 11.43 | 4.29 | 4.29 | 21.33 | 21.33 |
| 53. Property damage | 0.00 | 0.00 | 0.00 | 0.00 | 13.33 | 13.33 |
| 54. Heavy wind | 2.86 | 2.86 | 0.00 | 0.00 | 56.00 | 56.00 |
| 55. Temperature increase perception | 60.00 | 60.00 | 94.30 | 94.30 | 98.70 | 98.70 |
| 56. Hot months increase perception | 58.50 | 58.50 | 92.90 | 92.90 | 97.30 | 97.30 |
| 57. Erratic rainfall perception | 15.70 | 15.70 | 91.40 | 91.40 | 24.00 | 24.00 |
| 58. Less rainy days perception | 17.10 | 17.10 | 91.40 | 91.40 | 25.40 | 25.40 |
| 59. Extreme climate events | 11.43 | 11.43 | 400.29 | 400.29 | 57.33 | 57.33 |

**Table A3.** Indexed values for the indicators under the dimensions.

| Dimension | Indicator | Indexed Value for | | |
|---|---|---|---|---|
| | | LG | SG | NGO |
| 1. *Adaptive capacity* | 1. Family dependency | 0.40 | 0.50 | 0.28 |
| | 2. House type diversity | 0.51 | 0.58 | 0.52 |
| | 3. Family decision | 0.09 | 0.10 | 0.08 |
| | 4. Poverty | 0.41 | 0.37 | 0.48 |
| | 5. Indebtedness | 0.80 | 0.66 | 0.59 |
| | 6. High income households | 1.00 | 0.89 | 0.79 |
| | 7. Male headed households | 0.14 | 0.13 | 0.11 |
| | 8. Religious diversity | 0.00 | 0.63 | 0.05 |
| | 9. Household asset possession | 0.27 | 0.28 | 0.36 |
| | 10. Farm asset possession | 0.17 | 0.34 | 0.35 |
| | 11. Average farm holding size | 0.72 | 0.77 | 0.81 |
| | 12. Water access | 0.17 | 0.10 | 0.1 |
| | 13. Migration | 1.00 | 0.97 | 0.96 |
| | 14. New crops | 0.96 | 0.94 | 0.99 |
| | 15. Dependence on agriculture | 0.13 | 0.06 | 0.07 |
| | 16. Farm diversification | 0.74 | 0.69 | 0.67 |
| | 17. New livelihood strategies | 0.96 | 0.87 | 0.97 |
| | 18. Introduced livestock | 1.00 | 0.89 | 0.96 |
| | 19. Rainfed farming | 0.20 | 0.43 | 0.28 |
| | 20. Net sown area | 0.40 | 0.45 | 0.40 |
| | 21. Crop diversification | 0.25 | 0.36 | 0.24 |
| | 22. Adoption of new varieties | 0.99 | 0.99 | 0.99 |
| | 23. Decline in farm production | 0.06 | 0.09 | 0.09 |
| | 24. Soil erosion perception | 0.97 | 0.44 | 0.12 |
| | 25. Non-adoption of SWC works | 0.46 | 0.76 | 0.89 |
| | 26. Households with <0.2 ha of land | 0.51 | 0.69 | 0.96 |
| | 27. Percent of beneficiaries | 0.34 | 0.54 | 0.72 |
| | 28. Cooperation | 0.97 | 0.87 | 0.99 |
| | 29. Membership in co-operative institutions | 0.83 | 0.20 | 0.61 |
| | 30. Help from others | 0.97 | 0.94 | 0.99 |
| | 31. WC Membership | 0.93 | 0.94 | 0.93 |
| | 32. No beneficiary contribution | 0.68 | 0.03 | 0.29 |
| | 33. Households lack ICT access | 0.11 | 0.09 | 0.47 |
| | 34. Grass root planning | 0.97 | 0.93 | 0.95 |
| | 35. Trainings | 0.94 | 0.99 | 0.93 |
| 2. *Sensitivity* | 36. Water scarcity | 0.36 | 0.40 | 0.41 |
| | 37. Dependency on water resources | 0.00 | 0.10 | 0.16 |
| | 38. Public water sources | 0.17 | 0.03 | 0.11 |
| | 39. Groundwater decline | 0.69 | 0.54 | 0.29 |
| | 40. Gender inequality | 1.00 | 1.00 | 0.41 |
| | 41. Decreased water availability | 0.70 | 0.26 | 0.29 |
| | 42. Water resource depletion | 0.93 | 0.97 | 0.92 |
| | 43. Waterborne diseases | 0.00 | 0.00 | 0.00 |
| | 44. New disease incidence | 0.00 | 0.00 | 0.00 |
| | 45. Poor quality drinking water | 0.01 | 0.00 | 0.00 |
| | 46. Sunburn | 0.71 | 0.00 | 0.01 |
| | 47. Death due to climatic variability | 0.00 | 0.00 | 0.00 |
| | 48. Off-farm dependency | 0.53 | 0.43 | 0.67 |
| | 49. Food insufficiency | 0.01 | 0.01 | 0.03 |
| | 50. Poor governmental support | 0.06 | 0.94 | 0.25 |
| 3. *Exposure* | 51. Death or injury due to natural disaster | 0.00 | 0.00 | 0.00 |
| | 52. Crop loss | 0.11 | 0.04 | 0.21 |
| | 53. Property damage | 0.00 | 0.00 | 0.13 |
| | 54. Heavy wind | 0.03 | 0.00 | 0.56 |
| | 55. Temperature increase perception | 0.60 | 0.94 | 0.99 |
| | 56. Hot months increase perception | 0.59 | 0.93 | 0.97 |
| | 57. Erratic rainfall perception | 0.16 | 0.91 | 0.24 |
| | 58. Less rainy days perception | 0.17 | 0.91 | 0.25 |
| | 59. Extreme climate events | 0.11 | 0.04 | 0.57 |

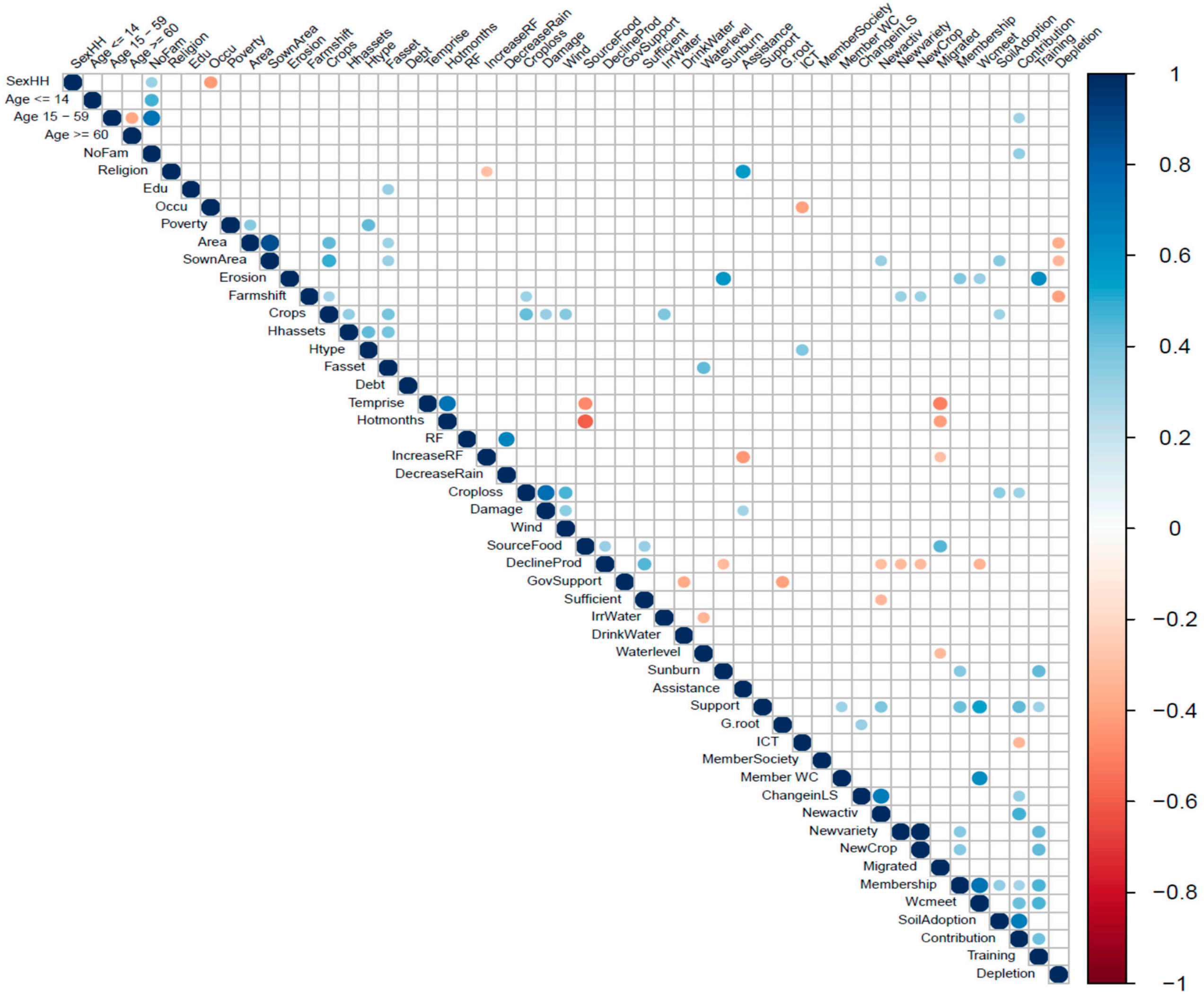


**Figure A1.** *Cont.*

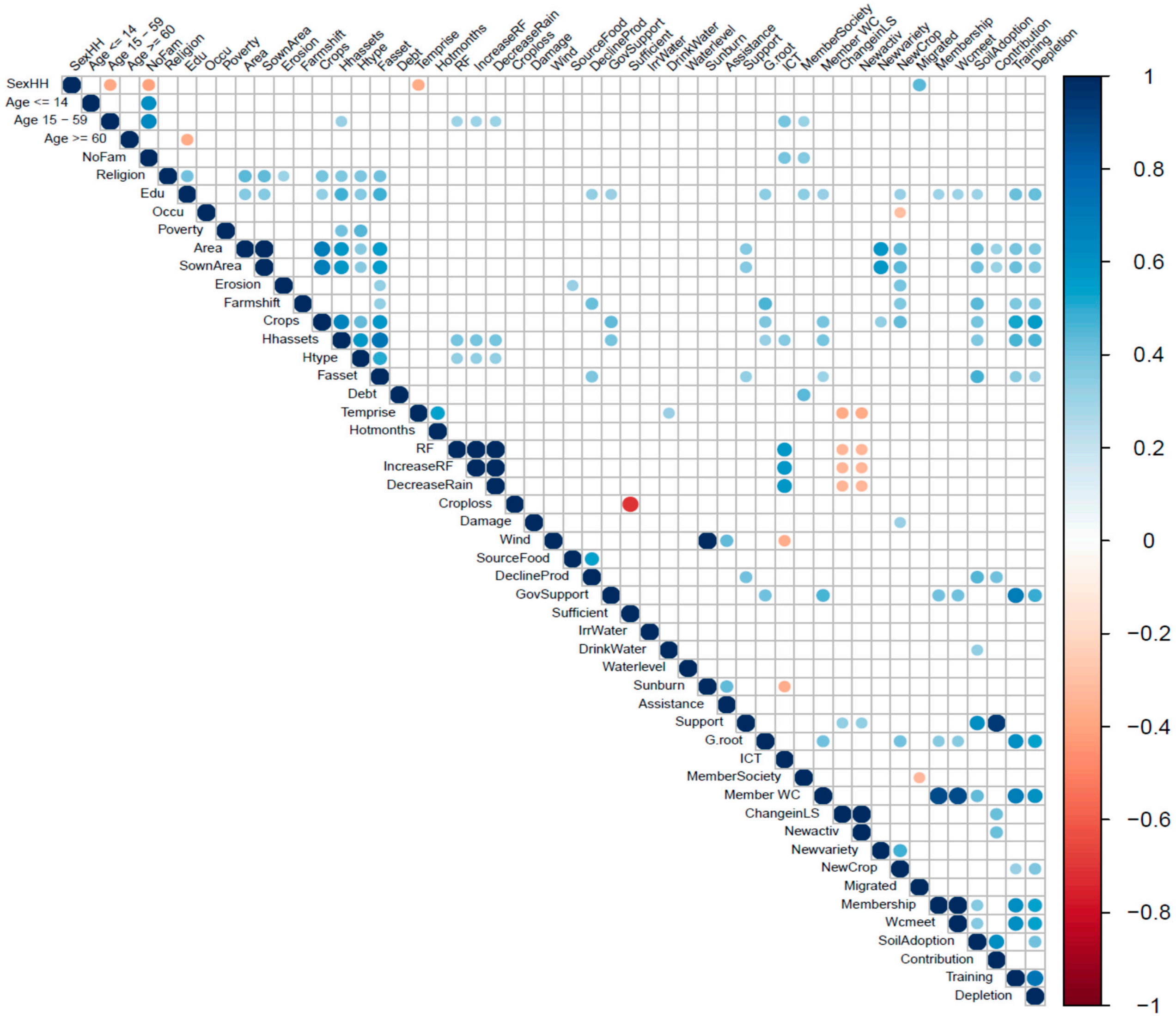


**Figure A1.** *Cont*.

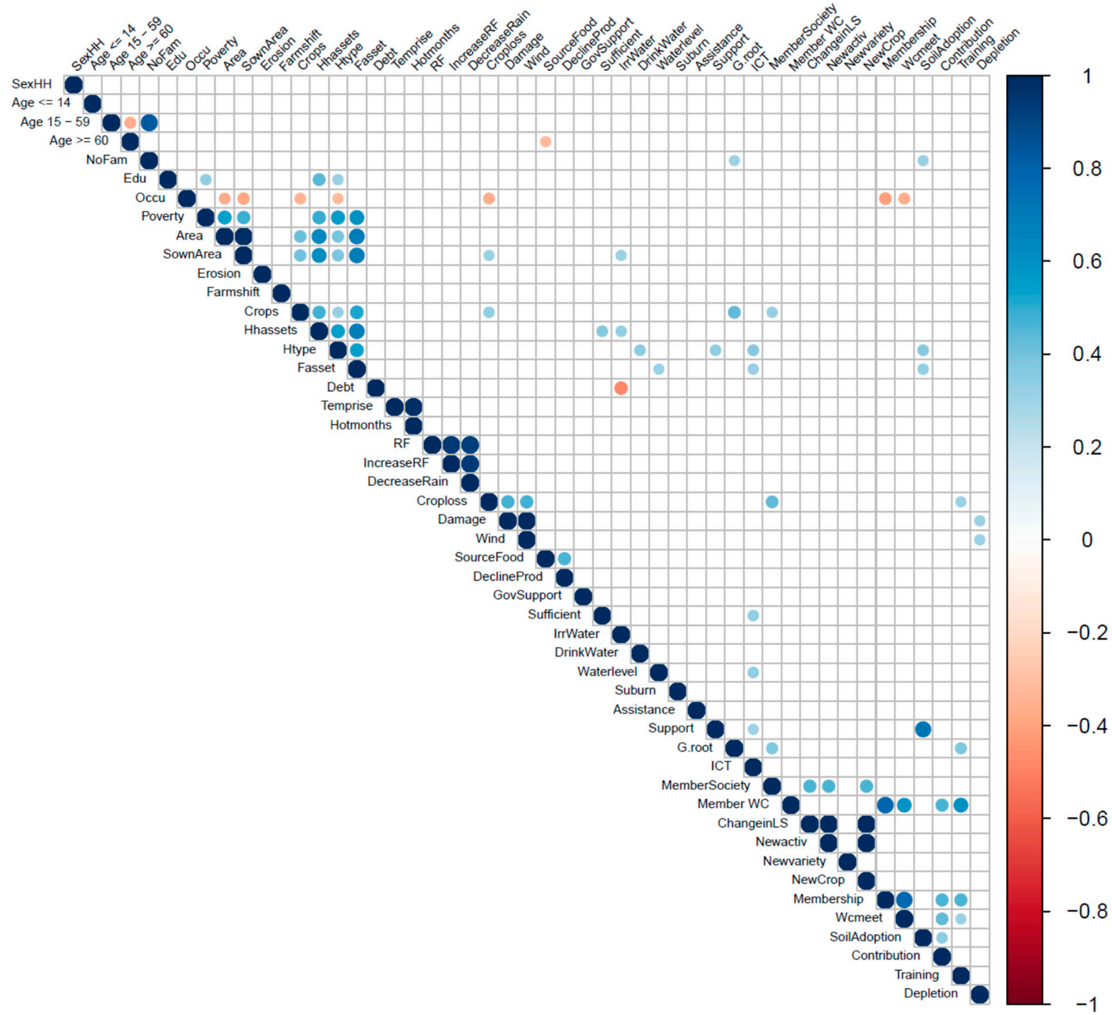


**Figure A1.** Correlation analysis of the 59 variables used for the calculation of indicators, significance at the 1% level for Local-Self Government (LG), Non-Governmental Organisation NGO and State Government (SG).

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