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## **Climate change vulnerability assessment among rainfed smallholder farmers: a case analysis from Indian watersheds**

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### **Declaration**

I declare that the dissertation here submitted is entirely my own work, written without any illegitimate help by any third party and solely with materials as indicated in the dissertation. I have indicated in the text where I have used texts from already published sources, either word for word or in substance, and where I have made statements based on oral information given to me. At all times during the investigations carried out by me and described in the dissertation, I have followed the principles of good scientific practice as defined in the “Statutes of the Justus Liebig University Giessen for the Safeguarding of Good Scientific Practice”.

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## Abbreviations

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CRED	Center for Research on Epidemiology of Disasters
CVI <sup>RFT</sup>	Climate Vulnerability Index for Rainfed Farming in the Tropics
DAAD	Deutscher Akademischer Austauschdienst
FAO	Food and Agricultural Organisation
GDP	Gross Domestic Product
GOI	Government of India
IPCC	Intergovernmental Panel on Climate Change
IPCC TAR	Intergovernmental Panel on Climate Change Third Assessment Report
LG	Local self-Government
ND	Natural Disaster
NGO	Non-Governmental Organisation
PDS	Public Distribution System
SAT	Semi-Arid Tropics
SG	State Government
WC	Watershed Committee
WDP	Watershed Development Programme
WDT	Watershed Development Team
WSD	Watershed

## Zusammenfassung

Der Klimawandel und seine unvermeidlichen Auswirkungen sind weltweit spürbar. Die Bewertung der Vulnerabilität dient als wichtiges Planungsinstrument, um die mit dem Klimawandel verbundenen Risiken zu definieren, bessere Strategien zu entwickeln und standortspezifische Anpassungsstrategien zu identifizieren. Weltweit wird der größten Teil der Nahrungsmittelproduktion durch Regenfeldbau erwirtschaftet. Diese Anbauweise wird von Kleinbauern dominiert, welche als besonders anfällig für den Klimawandel gelten. Bisher gibt es nur wenige Studien, die sich mit der Anfälligkeit von Kleinbauern gegenüber dem Klimawandel im tropischen Regenfeldbau befassen. Dies gilt insbesondere für Indien, einem Land, das besonders stark vom Klimawandel betroffen sein wird. Die vorliegende Studie konzentriert sich auf die Bewertung der Klimaanfälligkeit von Kleinbauern in drei Einzugsgebieten in Kerala, dem südlichsten Bundesstaat Indiens. In jedem dieser Einzugsgebiete existiert ein Watershed Development Programme (WDP) zu Anpassung an den Klimawandel.

Für die Bewertung der Klimaanfälligkeit von Kleinbauern sind vor allem Anpassungsfähigkeit, Empfindlichkeit und Exposition grundlegende Determinanten. Basierend auf diesem Ansatz wird ein Bewertungsmaß, der Climate Vulnerability Index for Rainfed Farming in Tropics ( $CVI^{RFT}$ ), entwickelt, der speziell die Gefährdung von Bauern in landwirtschaftlich dominierten tropischen Regionen mit Regenfeldbau misst. Der entwickelte  $CVI^{RFT}$  umfasst drei Dimensionen der Klimaanfälligkeit und wird durch zehn Hauptkomponenten beschrieben, die sich aus 59 einzelnen Indikatoren zusammensetzen. Da das Bewertungsmaß nur einen Teil des Gesamtbildes der Klimaanfälligkeit liefert, ist es wichtig herauszufinden, ob sich ein signifikanter Unterschied zwischen den drei Wassereinzugsgebieten beobachten lässt. Dies wird mit Hilfe einer Bootstrap-Sampling Methode untersucht. Darüber hinaus wird eine Leave-One-Out-Sensitivitätsanalyse durchgeführt, um die Robustheit des  $CVI^{RFT}$  zu bewerten. Des Weiteren spielt die wahrgenommene Klimaveränderung durch die Landwirte eine Schlüsselrolle bei der Wahl der von ihnen gewählten Anpassungsstrategie. Die Determinanten, die die Wahl dieser Strategie beeinflussen, werden mithilfe eines binären logistischen Regressionsmodells geschätzt. Die für die Studie verwendeten Daten basieren auf 215 Haushaltsbefragungen, 6 Fokusgruppen-Diskussionen sowie 6 Interviews, die sich auf die drei Einzugsgebiete verteilen.

Ein Vergleich der  $CVI^{RFT}$ -Werte zeigt lediglich eine geringe Abweichung der drei untersuchten Einzugsgebiete. Dabei wird deutlich, dass das Einzugsgebiet mit einem von der

Landesregierung (SG) organisierten WDP vergleichsweise am wenigsten gefährdet ist, gefolgt von dem Gebiet, in dem eine Nichtregierungsorganisation (NGO) das WDP leitet. Eine etwas größere Gefährdung liegt in dem Gebiet vor, in dem eine lokale Selbstverwaltung (LG) die Implementierung des WDP leitet. Die Sensitivitätsanalyse des  $CVI^{RFT}$  ergibt, dass es jedoch keinen signifikanten Unterschied in der Anpassungsfähigkeit zwischen den drei WDPs gibt. Allerdings finden sich signifikante Unterschiede in den drei Dimensionen der Klimaempfindlichkeit. Darüber hinaus zeigt die Sensitivitätsanalyse des Index, dass die beiden Hauptkomponenten "Livelihood Strategies" und "Social Network" als die wichtigsten Einflussfaktoren der Vulnerabilität angesehen werden können.

Eine weitergehende Untersuchung zur Wahrnehmung des Klimawandels ergibt, dass eine überwiegende Mehrheit der Haushalte in den drei Untersuchungsgebieten einen mittleren bis hohen Anstieg der Durchschnittstemperatur und einen Anstieg der Temperaturen in den heißen Monaten wahrnimmt. Darüber hinaus wird deutlich, dass ein Anstieg der Niederschläge von mehr als 98% der Befragten in den drei Regionen erkannt wird. Allerdings unterscheiden sich die Kleinbauern in Bezug auf die Anzahl und die Auswahl der Anpassungsstrategien zur Bewältigung des wahrgenommenen Klimawandels erheblich. Das binäre Logistikkmodell zeigt, dass verschiedene Bestimmungsfaktoren die Anpassungsstrategien maßgeblich beeinflussen, wie z. B. die landwirtschaftliche Erfahrung, ob ein Haushalt männlich geführt wird, oder wie hoch die Frauenbeteiligung und der Bildungsstand sowie die Betriebsgröße und der Viehbestand ist. Letztendlich kann geschlussfolgert werden, dass die von den WDPs erbrachten Dienstleistungen nicht ausreichen, um einen effektiven Anpassungsprozess der Kleinbauern zu ermöglichen. Hier bedarf es einer Umstrukturierung der WDPs in sektorale Pläne und Maßnahmen.

Das entwickelte Bewertungsmaß des  $CVI^{RFT}$  ist grundsätzlich replizierbar, sollte jedoch auf Grundlage der jeweiligen Region und der Zielgruppe verfeinert werden, um die Bewertung der Klimaanfälligkeit zu verbessern. Der  $CVI^{RFT}$  könnte somit als sinnvolles Instrument zur Entwicklung von Anpassungsstrategien an den Klimawandel unter besonderer Berücksichtigung sozioökonomischer Merkmale dienen.

## Summary

Climate change and its unavoidable impacts are being felt around the world which is why vulnerability assessments are essential planning tools for defining the climate change associated risks, for generating better policies as well as for identifying location specific adaptation strategies. Tropical rainfed agriculture is of specific interest as it holds the majority of world food production, dominated by smallholder farming which are notably vulnerable to climate change. However, only few studies have been conducted on the vulnerability of smallholders in the rainfed tropics, especially in India, a country that will be particularly affected by climate change. This study focuses on climate vulnerability assessment among smallholder farms in three Watershed Development Programme (WDP) areas of Kerala, the southernmost state of India

The integrated climate vulnerability approach considers vulnerability as a function of three dimensions of vulnerability: *adaptive capacity*, *sensitivity* and *exposure*. Based on this approach a composite index, Climate Vulnerability Index for Rainfed Farming in Tropics (CVI<sup>RFT</sup>), is developed that specifically measures the vulnerability of farmers in agriculturally dominated tropical regions. As a composite index provides only a single big picture, it is essential to know if the three observed watersheds are significantly different in terms of their index value. For the assessment of robustness of the CVI<sup>RFT</sup>, a bootstrap sampling and a leave-one-out sensitivity analysis is carried out. The perceptions of farmers play a key role in determining the choices of adaptation strategies and thus the adoption process. To find out the determinants of the small holder's adaptation strategies, a binary logistic regression model is used.

The primary data used for the study was collected through 215 household surveys, 6 focus group discussions and 6 key informant interviews split among the three watershed areas. The CVI<sup>RFT</sup> comprises of three dimensions of vulnerability and the dimensions are described by 10 major components, consisting of 59 individual indicators. The watersheds show small variation in the CVI<sup>RFT</sup> values when compared. Among them, the watershed area with a WDP organized by the State Government (SG) is comparatively the least vulnerable followed by the one where a Non-Governmental Organisation (NGO) is heading the WDP. The highest vulnerability is found in the watershed where a Local self Government (LG) is leading the WDP implementation. The sensitivity analysis of CVI<sup>RFT</sup> revealed that there is no significant difference in the *adaptive capacity* between the three watersheds while there are significant differences in the *sensitivity* and the *exposure* dimensions. Furthermore, the sensitivity analysis of the index shows that 'Livelihood Strategies' and 'Social Network' are the most

influencing major components of vulnerability. The perception study reveals that a vast majority of the households in the three study areas perceived a medium to high level of rise in average temperature and an increase in hot months. In addition, it is evident that an increase in rainfall is recognized by more than 98% of the survey participants over the three regions. However, farmers differ considerably in terms of the quantity and the selection of adaptation strategies to cope with perceived climate change. The binary logistic model depicts that various determining factors significantly affect the adaptation strategies, as for example, farming experience, male-headed households, women's participation, education, farm size and livestock. The services rendered by the WDPs are not sufficient for an effective adaptation process by the smallholders and restructuring in sectoral wise plans and interventions is needed.

The climate vulnerability assessment study is the first of its kind at watershed level, with emphasis on socio-economic factors. The composite index is replicable to further climate vulnerability assessment context, with refinement of indicators based on the locality and the targeted group. Thus,  $CVI^{RFT}$  is a meaningful tool to develop watershed interventions and climate change adaptation strategies with a strong consideration of socio-economic characteristics.

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# **Chapter 1**

## **Extended summary**

## **1.1 Introduction**

Climate change is a growing and undeniable threat to the humanity. According to the Intergovernmental Panel on Climate Change (IPCC, 2018), global warming is likely to reach 1.5°C between 2030 and 2050 if it continues to increase at the current rate. Furthermore, sea level rise and changes in rainfall patterns over the tropics will increase the risk of flooding (Wheeler, 2011). These impacts and associated changes will vary across locations, sectors and populations. Moreover, agriculture is one of the most sensitive sectors to climate variability (Wheeler, 2011) irrespective of the locality. South Asia and Southern Africa are listed as two regions that will suffer negative impacts on several crops that are important to large food-insecure human populations (Lobell et al., 2008). The significant and direct impacts are likely to be borne by smallholder rainfed farmers in these regions (Sivakumar and Stefanski, 2011), while they play a major role in raising agricultural development and poverty reduction. It is estimated that 80% of the world's farms are smallholder farms which account for only 12% of the agricultural land (Lowder et al., 2016). These farmers would face an immediate, ever-growing risk of increased crop failure, reduced availability of marine and forest products (Dev, 2012) as well as other stressors like natural resource degradation, infectious diseases and nutritional deficiencies (Lowder et al., 2016). Thus, the uncertain future for the hundreds of millions of the world's poor draw urgent attention and implications for research and policy by assessing their climate change impacts, vulnerability, identifying knowledge gaps, adaptation and mitigation strategies.

### ***1.1.1 Climate change in India***

In the South Asian countries India, Bangladesh and Nepal, the heavy monsoon rains of 2017 resulted in unprecedented flooding affecting over 45 million people (Nexus, 2017). India faces further climate extremes such as hailstorms, droughts and heat waves and is listed as one of the world's most vulnerable countries to climate change (Cruz et al., 2007). The magnitude and frequency of extreme rainfall in central India have increased three fold over 1950 to 2015 while at the same time the total amount of rainfall declined (Roxy et al., 2017; Singh et al., 2014). This trend has been firmly attributed to climate change (Nexus, 2017). In the past century, all over India, severe 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 (Government of India, 2008). India has been experiencing prolonged droughts and flood conditions at least once in every year. According to the Center for Research on Epidemiology of Disasters (2016), droughts in India have affected 1,061

million people while floods affected 847 million people over the period of 1900-2015 (CRED, 2016). It has been projected by the IPCC 5<sup>th</sup> Assessment Report that unless people adapt, there is a probability of 10-40% loss in crop production in India by 2080-2100 due to global warming.

### ***1.1.2 Problem statement***

Most of the tropical countries own a large share of poor smallholder farmers (Harvey et al., 2014). Moreover, these poorest countries depend on rainfed agriculture for their food production. Around 2.5 billion people living in the rural areas are relying on farming as their main source of income (FAO, 2013) and 84% of them are smallholders (Lowder et al., 2016). Smallholder farmers own less than 2.0 ha of farmland, but produce 70% of the world's food (FAO, 2013). Furthermore, a majority of these farmers live in the rainfed areas which are characterized by rainfall variability, temperature fluctuations and frequent drought. For many smallholders in the rainfed tropics, climate change is a daily reality that threatens their source of livelihood: agriculture. Thus, they are disproportionately vulnerable to the impacts of climate change as a result of poverty, reliance on natural resources and limited capacity to adopt new livelihood strategies (Fischer et al., 2005; Lobo et al., 2017; Sivakumar and Stefanski, 2011). Furthermore, their limited resources and inability to make adequate decisions of farming practices prevent them from coping with climate-induced shocks (Frank and Penrose-Buckley, 2012; Harvey et al., 2014) which in turn adds to their vulnerability (Jarvis et al., 2011). As a consequence, millions of these farmers will be affected by immediate hardship and hunger in the near future. As the climate change impacts are increasingly observed and felt by smallholder farmers (Amare and Simane, 2017; Yila and Resurreccion, 2013) there is an urgent need for climate vulnerability assessment, and identification of approaches and strategies which enhance the adaptive capacity of farmers, their households and communities (Frank and Penrose-Buckley, 2012; Harvey et al., 2014; Sivakumar and Stefanski, 2011).

India ranks first among the rainfed agricultural countries of the world, with 66% of its total cropped area (Planning Commission, 2012) and 40% of the food production. 83% of Indian farmers are smallholders which use only 44% of the total cultivated land (Dev, 2012). Nonetheless, they account for 41% of India's food production (Dev, 2012). India is the second largest producer of rice in the world, with rice being the most important staple food in the rainfed regions. More than 50% of the rice production comes from rainfed smallholder farmers (Singh et al., 2017). Thus, any detrimental effects of climate change would affect

food security from local to the global level (Singh et al., 2017). It is challenging to transform rainfed agriculture into sustainable productive system and to better adapt to the impacts of climate change. Thus, climate change vulnerability assessment and adaptation strategies for smallholders in rainfed areas are highly important in the Indian context.

The Government of India has given high priority to holistic Watershed Development Programmes (WDPs) as a potential tool to make a significant contribution to reduce vulnerability, enhance resilience and build adaptive capacities of rainfed farming communities. WDPs aim to restore degraded watersheds in rainfed regions to increase their capacity to capture and store rainwater, reduce soil erosion, and improve soil nutrient and carbon content so they can produce greater agricultural yields and other benefits' (Gray and Srinidhi, 2013). A watershed is a topographically delineated area that is drained by a stream system. Moreover, it is also a hydrological response unit, a biophysical unit, and a holistic ecosystem in terms of the materials, energy, and information that flows within it (Wang et al., 2016). Watershed management is an ever-evolving practice that involves the management of land, water, biota, and other resources in a defined area for ecological, social, and economic purposes (Wang et al., 2016). WDPs are listed as one of the disaster management tools with integration of climate change aspects into its ongoing efforts. Thus, it is mandatory to give special attention to location-specific knowledge for better adaptation strategies (Wisner, 2010). For this, existing policies and programmes such as WDPs need to be fine-tuned with respect to technology, processes and institutions to make the watersheds more resilient to variability and extreme climate risks (Samuel et al., 2015). Nevertheless, little is known about the climate vulnerability assessment with emphasis on socio-economic aspects on the Indian watershed level. The present study will fill this gap by assessing and comparing the climate change vulnerability and existing adaptation strategies among three WDP areas of South India.

#### 1.1.2.1 Climate vulnerability assessments

Studies on climate vulnerability assessment and adaptation have been undertaken on specific climatic issues, contexts, social groups or ecosystems worldwide (Berger et al., 2017; Berhanu and Beyene, 2015; Chaliha et al., 2012; Debela et al., 2015; Gbetibouo, 2009; Gbetibouo et al., 2010; Pandey and Bardsley, 2015; Pandey and Jha, 2012; Phuong et al., 2017; Piya et al., 2015; Tonmoy et al., 2014; Touch et al., 2017; Upgupta et al., 2015). However, most of these studies are restricted to a given context and specific location at either the national, sub-national or regional level (Cutter et al., 2003). These studies explored the

socio-economic and institutional factors at bottom level according to the locale of study and thus, it is difficult to derive holistic one-size-fits-all solution for vulnerability assessment (Gbetibouo et al., 2010; Hinkel, 2011; Kuriakose et al., 2017; Vincent and Cull, 2010). Available studies on climate vulnerability in India, for example, focus on specific issues or sectors such as farmer's vulnerability towards flood (Chaliha et al., 2012), socio-ecological vulnerability of mountainous smallholders (Pandey et al., 2015), rural mountainous Himalayan communities (Pandey and Jha, 2012), water vulnerability at household level (Pandey et al., 2015) and Himalayan forest (Upgupta et al., 2015). These studies emphasize the need for further location specific vulnerability assessment on different contexts and groups with the integration of socioeconomic factors at bottom level. Thus the present study emphasise specifically on smallholder farmers at watershed level in rainfed areas of India.

There exist a vast number of studies on rainfed farming and vulnerability worldwide (Al-Bakri et al., 2011; Alemaw and Simalenga, 2015; Coe and Stern, 2011; Gopinath et al., 2012; Mongi et al., 2010; Touch et al., 2017). Despite, there is a research gap in perception of climate change vulnerability assessment and adaptation strategies among Indian smallholders at the watershed level. Moreover, previous studies on climate change in watersheds have mainly been focused on the biophysical aspects (Jose et al., 1996), geophysical vulnerability (Saizen and Kobayashi, 2013), and ecosystem vulnerability (Rice et al., 2017), rather than socio-economic aspects of climate vulnerability.

The present study concentrates on climate change vulnerability assessment among smallholder farmers especially in three different WDP areas of South India by developing a composite Climate Vulnerability Index for Rainfed Farming in Tropics (CVI<sup>RFT</sup>) with emphasis on farmer's perception and adaptation strategies. The study is the first kind of it in case of the climate change vulnerability, perception of various climatic parameters and adaptation strategies in watershed development programme areas.

#### 1.1.2.2 Sensitivity analysis of indices

Indicator-based assessments are one of the methodologies to encapsulate the complex reality of climate vulnerability for generating more scope and opportunities in terms of policy interventions. These indicators provide information on matters of wider significance than what is actually measured or make a trend or phenomenon perceptible that is not immediately detectable (Allen Hammond et al., 1995). Several of such indices have already been introduced in climate vulnerability assessment. However, all of them are not specifically

adapted to be used in rainfed systems (Chaliha et al., 2012; Pandey and Jha, 2012; Upgupta et al., 2015). These indices mainly concentrate on the small (community) scale and vulnerability towards a specific natural calamity. Specific indicators relevant to smallholder farmers and rainfed agriculture have been neglected so far in the research on climate vulnerability indices. Current climate change vulnerability assessment studies based on indices often end up with policy suggestions for improved adaptation strategies and mitigation solutions. However, the indices used in the past studies do not explore the robustness of comparisons or significant differences of indicators of vulnerability (Eakin and Luers, 2006). Even though uncertainty and sensitivity analysis were done for other composite indices like the Technology Achievement Index (Saisana et al., 2005), Social Vulnerability Index (Schmidtlein et al., 2008; Tate, 2012), Human Development Index (Aguna and Kovacevic, 2010) at national to global level, similar uncertainty assessment for climate vulnerability indices are still missing. This is even more surprising as a closer look into the literature reveals that that uncertainty is an unavoidable factor for composite indices (Preston et al., 2011; Tonmoy et al., 2014). Accordingly, the composite indicator's 'simple big picture' may direct to misleading non-robust policy messages if they are not interpreted in combination with the sub-indicators (Saisana et al., 2005). The value of a composite indicator is not a simple number, but a distribution of values. Thus, it emphasizes the need and urgency to conduct sensitivity analysis of CVI<sup>RFT</sup> rather than merely developing another composite index for policy implications.

As one of the few examples, Shukla et al., (2016) have evaluated the robustness of inherent vulnerability ranks to compare mountainous agricultural communities in Uttarakhand state of India. In this context, the present study aims for a more rigorous sensitivity analysis of the developed CVI<sup>RFT</sup> to get a detailed look into the different components that make up the composite index. Through this systematic analysis of the CVI<sup>RFT</sup>, the study is able to provide information on specific driving factors which contribute to the adverse effects of climate change vulnerability.

### 1.1.2.3 Perception of climate change impact

A successful understanding of the climate change impact is not only limited to the assessment of vulnerability and various climate change related parameters. Rather, an understanding of the role of these parameters by the farmers who are being affected (Ayanlade et al., 2017) is also critical. Farmers cope with the climate change impacts based on their perception of

climate change variability (Abid et al., 2015). Incorporating their understandings equally helps the farmers and the policy makers to prepare local response action or adaptation strategies to anticipated impacts of climate change (Adimassu and Kessler, 2016; Ayanlade et al., 2017). In case of smallholder climate change vulnerability, there exists a wide gap between scientist's analysis of global climate change and rural farmer's awareness (Ayanlade et al., 2017).

There exists a large number of studies that deal with climate change perception (Banerjee, 2015; Juana et al., 2013; Mamba et al., 2016; Uddin et al., 2017; Udmale et al., 2014), determinants of adaptation strategies (Banerjee, 2015; Bennett, 2015; Benson et al., 2015; Burney et al., 2014; Deressa et al., 2009; Gbetibouo et al., 2010; Mamba et al., 2016; Ndamani et al., 2016; Yila and Resurreccion, 2013), and barriers that hinder adaptation strategies across various countries among farmers (Alemayehu and Bewket, 2017). The main research studies undertaken in India include farmer's perception of climate change and adaptation strategies in the Semi-Arid Tropics (SAT) of South India (Dhanya and Ramachandran, 2016), and impacts of climate change in the SAT of Maharashtra and Andhra Pradesh (Banerjee, 2015). Banerjee (2015), also studied the adoption decisions of farmers specifically in improved water management and perceived capacity across villages in Maharashtra and Andhra Pradesh. Such kind of studies can assist policy makers, donors and researchers to better understand the situation and thus lead to efforts to reduce the adverse effects and vulnerability due to climate change. However, there exists limited research in this regard at Indian watershed level. Hence, this study analyses the perception of smallholders on climate change impact and the determinants of climate change adaptation strategies by the small holders.

## **1.2 Research objectives**

Vulnerability assessment is used to identify the most vulnerable sections in the community and the underlying factors which contribute to the vulnerability. Furthermore, it helps to evaluate the existing plans and thus to formulate new plans to cope up with climate change. The perception of farmers and existing adaptation strategies will provide information for better policies and effective adaptation strategies to fight with the impacts of climate change. Hence, the overall objective of this study is to develop and apply the CVI<sup>RFT</sup> that is particularly adapted to conditions of rainfed agriculture and smallholder farming. The general objective can be subdivided in three objectives, which will be addressed in separate chapters in this dissertation.

- Objective 1: Assess and compare the climate change vulnerability of rainfed smallholders in watershed areas by developing a composite index.
- Objective 2: Evaluate dimensions, major components and single indicators of the CVI<sup>RFT</sup> through sensitivity analysis.
- Objective 3: Analyze the perception of climate change and its influence on the driving factors of adaptation strategies adoption by the watershed households.

### **1.3 Theoretical framework**

Climate vulnerability, adaptation strategies and WDPs are the core topics examined in this research. Vulnerability is the function of three dimensions i.e. *adaptive capacity*, *exposure* and *sensitivity*. For adoption of suitable adaptation strategies, at first farmers should perceive climatic variations and thus the perception affect the adaptation decision process. Furthermore, WDPs enhances the adaptive capacity of the rainfed areas by ensuring grassroot level participation in decision making and implementation of various interventions. The following sections deal with the theoretical framework of each core topic in detail.

#### ***1.3.1 Climate vulnerability concept***

Vulnerability is a measure of possible future harm (Wolf et al., 2013) and can be defined as the inability of a system to withstand against the perturbations of external stressors. It is a concept that has been used in different research backgrounds (Adger, 2006; Smit and Wandel, 2006). According to Proag (2014), the concept of vulnerability implies a measure of risk associated with the physical, social and economic aspects and implications resulting from the system's ability to cope with the resulting event. Vulnerability can be individual or social level (Adger 1999). Social vulnerability is the susceptibility of social groups or society to potential losses from extreme events and the ability to absorb and withstand impacts (Cutter et al., 2003).

This dissertation has followed the climate change vulnerability approach proposed by IPCC. According to IPCC (2001), climate change vulnerability is 'the degree, to which a system is susceptible to, or unable to cope with the adverse effects of climate change, including climate variability and extremes'. It is a function of the character, magnitude, and rate of climatic variation to which a system is exposed, its *sensitivity*, and its *adaptive capacity* (McCarthy, 2001). According to Aleksandrova et al., (2014), *exposure* is the presence of people, livelihoods, environmental services, infrastructure, socio-economic assets in places that could be adversely affected. IPCC (2001) defines *exposure* as the nature and degree to which a

system is exposed to significant climatic variations. *Adaptive capacity* is the ability of a society or systems to modify its characteristics or behaviour so as to cope better with changes in external conditions (Füssel and Klein, 2006). Under *ceteris paribus* conditions, *adaptive capacity* and vulnerability are negatively correlated. The *sensitivity* of a system denotes the dose – response relationship between its exposure to climatic stimuli and the resulting impacts (Füssel and Klein, 2006).

### ***1.3.2 Adaptation strategies***

According to IPCC Third Assessment Report (IPCC TAR, 2001), adaptation is the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (Thornes, 2002). The adaptation is a complex process with interconnected factors and actors which includes the interaction with environment, resources and institutions (Adger, 2006). Moreover, it is the key factor which shapes the future severity of climate change impacts on food production. Therefore, it is crucial for a farmer to perceive climate change and variability first and then identify the appropriate adaptation measures in a second step (Maddison, 2007).

Perception is the process of receiving external stimuli and converting them in to psychological responsiveness (Ban and Hawkins, 1996) based on the past and present situation. In climate vulnerability scenarios, farmers perceive specific weather parameters, such as the onset of the monsoon, increases in temperature, or unpredictability of seasons. The distribution, periodicity and effectiveness of rainfall and temperature fluctuations affect the farmer's decision to grow crops and thus, its success of farming. Without adaptation, it is difficult to survive with farming especially for smallholders who depend solely on farming and natural resources for their livelihood. Thus, 'adaptation in agriculture is the norm than the exception' (Rosenzweig and Tubiello, 2007).

Farmers adapt according to agricultural systems, location (Rosenzweig and Tubiello, 2007) and the perceived change in climatic conditions (Mamba et al., 2016; Uddin et al., 2017). The studies indicate that farmers adapt to existing climate change situation in different ways such as crop and varietal selection (Dhanya and Ramachandran, 2016; Hassan and Nhemachena, 2008; Ndambiri et al., 2013), adjusting sowing and planting dates (Deressa et al., 2009; Mengistu, 2011; Ravi Shanker, K et al., 2013), shift in cropping patterns (Banerjee, 2014), livestock introduction (Ndambiri et al., 2013; Yila and Resurreccion, 2013), water management practices (Banerjee, 2015; Burney et al., 2014), soil conservation (Deressa et al.,

2009), and migration (Ravi Shanker et al., 2013). The present study helps to identify a few more location specific adaptation strategies followed by smallholders in the watershed area other than the existing interventions by WDPs.

### ***1.3.3 Watershed development programmes in India***

Watershed development is deeply rooted in the culture and social structure of India (Symle et al., 2014). The evolution of watershed management dates back 800 BC and the first written reference can be found in the Atharva Veda (Wang et al., 2016). 'Watershed Development Programmes in India focus to restore degraded watersheds in rainfed regions which carry the bulk of rural poor of the country at the same time provide food for 40% of the population (Gray and Srinidhi, 2013). These areas represent 65% of the arable land in India and produce 55% of the country's agricultural output (Planning Commission, 2012). Rainfed regions deserve special attention as these areas hold the greatest unutilized potential for growth.

Watershed development and planning were initiated by Government of India (GOI) in the late 1970s, for dryland development in the form of Drought Prone Area Programme (1973) followed by Desert Development Programme (1978), and Integrated Waste Land Development Projects scheme (1989) (Gray and Srinidhi, 2013). The main objective was to facilitate and improve the living condition of rainfed degraded lands across the country (Bhandari et al., 2007). In 1994, GOI established a common operational guideline for strategies and expenditure norms for National WDPs in Rainfed Areas. According to these Watershed Areas Rainfed Agricultural Systems Approach guidelines (Government of India, 2008), the main elements of the guiding principles are conservation of natural resources, *in situ* (on-site) moisture conservation, sustainable farming system, adoption of ridge to valley approach, due emphasis on production enhancement activities and livelihood support for landless families, democratic decentralization in decision making, mobilization of community, direct funding to the community, contributory approach to empower the community and empowerment of women. As the size and scope of the WDPs increase every year, the scrutiny over the programme is critical and of high interest (Symle et al., 2014).

WDPs are executed by selected Project Implementing Agencies and supported by a Watershed Development Team (WDT) consists of various subject matter specialists. A Watershed Committee (WC) is formed at the watershed level with elected members among the inhabitants. It carries out the day-to-day activities of the watershed development project

in consultation with the WDT. The progress of the WDP is monitored by district level and state level nodal agencies.

#### **1.4 Research design and methods**

In this section, the methodological structures, description about the study area and data collection are briefly described.

##### ***1.4.1 Research design***

An embedded research design is used in this dissertation where qualitative data is embedded with a major quantitative case study design. The embedded design is a mixed-methods approach where the researcher combines the collection and analysis of both qualitative and quantitative data within a traditional qualitative or quantitative research design (Caracelli & Greene, 1997). The quantitative data in this study is collected from 215 household surveys. The selection of composite index components as well as discussion of results is supported by qualitative data collected through key informant interviews and focus group discussions.

##### ***1.4.2 Study area***

Kerala is the southwest state of India with the highest national human development index, literacy rate, and sex ratio. It is the south-west coastal region of India and spreads over an area of 38,863km<sup>2</sup> (1.2% of India's total area). It is with the highest density of population, 859 persons/km<sup>2</sup> and with less urban agglomerations compared to other states (Government of Kerala, 2014). The state is mainly divided into three physiographic units: highland (600 m and above), midland (300-600 m) and low land (below 300 m). The agricultural sector contributes 10.88% of the GDP 84% of the agriculture area is rainfed and Kerala is listed as one of the highly vulnerable states with the threat of heavy rainfall, drought and sea water inundation.

###### ***1.4.2.1 Climate***

Tropical monsoon climate with the highest rainfall in India (3000 mm) and hot summer reaching 38°C as well as high humidity prevail in Kerala. Past studies have shown that the state experiences erratic rainfall distributions with a declining trend in the southwest monsoon and an increase in post monsoon season (Guhathakurta and Rajeevan, 2008; Krishnakumar et al., 2009). Moreover, there is also a shift in the thermal and moisture regime from wetness to dryness within the humid climate (Prasada et al., 2010). Despite the high annual rainfall the state faced 64 intense and short term droughts (Krishnakumar et al., 2009)

during the past 100 years. During the southwest Monsoon 2018, the state recorded more than 37% excess rainfall within two months (June-July). It triggered extraordinary flooding, landslides, killed more than 350 people and evolved in a major a calamity.

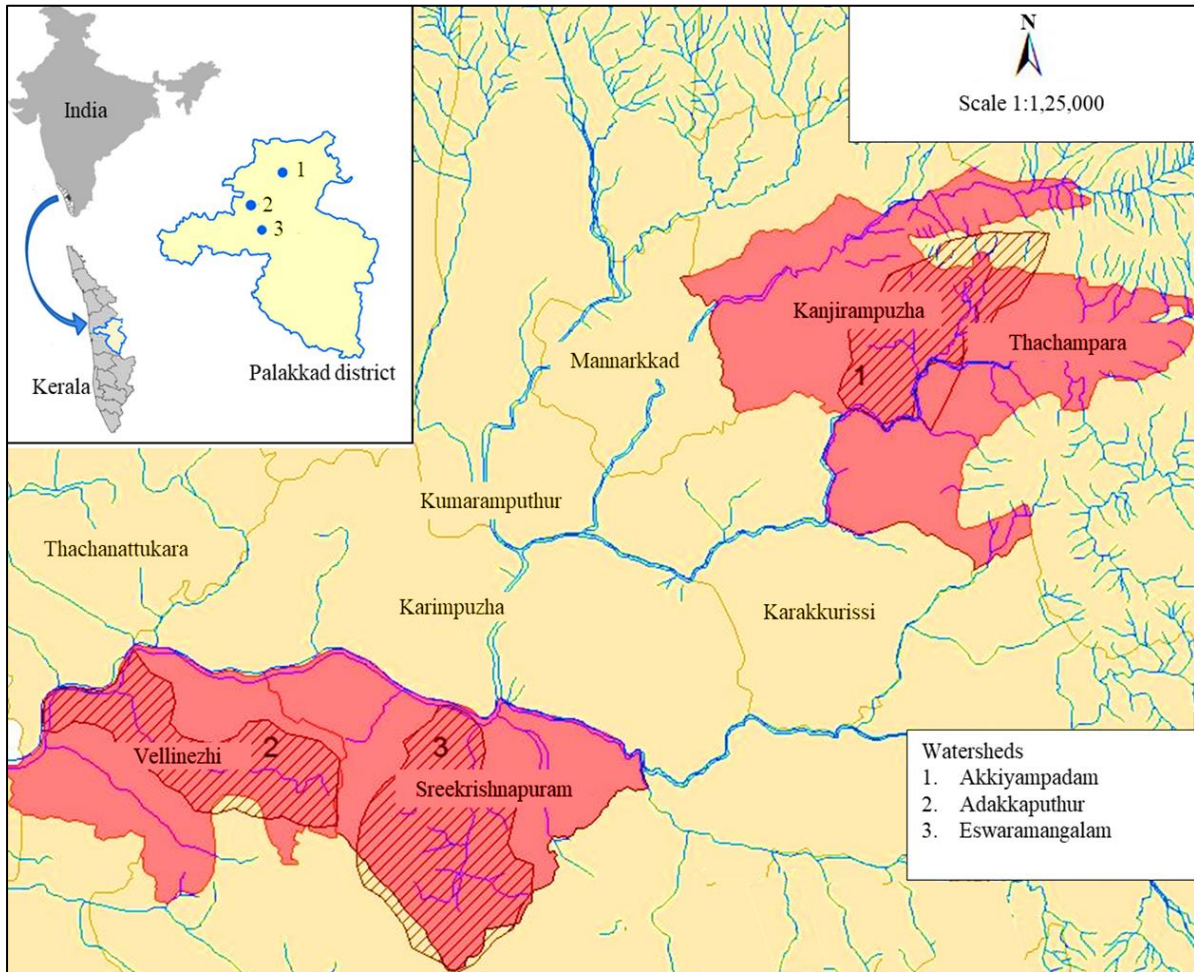


Figure 1. Location of the study area (Raghavan Sathyan *et al.*, 2018)

#### 1.4.2.2 Land use

Subsistence homestead farming is a key feature of the land use in the state. The total cultivable area is 68% while 58% of the total area is used for cultivation (Government of Kerala, 2017). Thus there is little scope for extensive agriculture. The major crops include rice, tapioca, pulses and cash crops such as cashew, rubber, pepper, coconut, tea, and coffee. Out of the net cropped area of the state, 81% is rainfed and 40% of the total cropped area is prone to soil erosion (Government of Kerala, 2016). All these factors contribute to the present climate change vulnerability of the state.

### 1.4.2.3 Watersheds

Palakkad district, one of the fourteen districts, is the largest district in Kerala (4,482 km<sup>2</sup>). It 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 relative low ranking in the human development index, high social deprivation and a high degree of vulnerability to natural hazards like floods and droughts (Government of Kerala, 2014). The district is known as the ‘Granary of Kerala’ as it is the highest producer of rice in the state. Moreover, 90% of its rice production comes from rainfed farming (Prasada et al., 2010). At the same time, the annual rainfall in this region is the lowest (1600 mm) among the districts of Kerala (Nair et al., 2014) 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 (Nikhil Raj and Azeez, 2012) where the daytime temperature often exceeds 40°C while the maximum mean annual temperature of the state is 32°C.

The three watersheds selected for the study were Adakkaputhur, Akkiyampadam, and Eswaramangalam (Figure 1). The main watershed development activities undertaken can be subdivided to Natural Resource Management, Production System enhancement, and Livelihood Support System activities. The NRM activities include construction of small check dams, farm ponds, stone pitched contour bunds and earthen bunds, river bank protection walls, moisture conservation pits and protection walls of wells. The PS enhancement activities include the distribution of fruit seedlings, medicinal plants, news crops and varieties as well as organic manure. The LSS activities were concentrated on the women and landless in the area by mobilizing self-help groups. The main livelihood activities introduced were rabbit rearing, livestock and poultry units.

Table 1. Basic details about the three watershed areas

Criteria		Watersheds		
Basic information	Name	Adakkaputhur	Akkiyampadam	Eswaramangalam
	Implementing Agency	SG	NGO	LG
	Grama Panchayat	Vellinezhi	Kanjirampuzha	Sreekrishnapuram
	Treatment area (ha)	350	520	590

## Chapter 1: Extended summary

	Project period	2003-2008	2009-2013	2007-2012
	Project fund	26,485 US\$	57,920 US\$	82,456 US\$
Physiography	Elevation (m)	90-140	90-210	60-160
	Soil	Gravelly clay and sandy clay	Laterite	Laterite and alluvial
	Water table (m)	3-15	8-12	12-15
	Structures of water storage (number)	163 open wells, 14 ponds	648 open wells, 11 ponds, 1 canal, 12 tanks	698 open wells, 5 ponds, 5 small streams, 2 canals
Socio-demography	Population	5,742	7,399	6,469
	Households	1,243	1,482	1,198
	Literacy (%)	87.27	98.00	98.90
Agriculture	Marginal farms <1ha (%)	81	92	71
	Major crops	Rubber, paddy, arecanut, coconut & vegetables	Coconut, cashew, arecanut, rubber, tapioca & vegetables	Rubber, coconut, arecanut, banana & vegetables

(Raghavan Sathyan et al., 2018)

### ***1.4.3 Data collection***

The semi-structured household interviews were conducted during the period August-November 2015. The stratified random sampling method was used for the selection of farm households. The farmers were grouped into small, medium and large based on the landholding size. More than 80% of the farmers in the selected watersheds were smallholder farms (<2 ha of landholding). Out of the total 215 households covered in the field survey, 70 households were located in SG and NGO and 75 households in LG watersheds. Interviews were conducted in Malayalam (local language) with the support of a local assistant. In addition to the questionnaire field survey, six focus group discussions and six key informant interviews have been conducted to get more insight into the adaptation strategies followed by farmers.

Once arrived in the watersheds, the Project Implementing Agencies, the Community Development Society members, the Grama Panchayat (local government authority)

Secretary, the Agricultural Officer, and the elected Grama Panchayat members were consulted to explain the purpose of the study and to obtain information regarding the households in the watershed area. 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. Secondary data mainly came from reviewing of literature and gathering of historical data of climatic parameters (temperature and rainfall), detailed project reports and documents from various government and nongovernmental offices. All questions (primary data) and secondary data required for the survey have been identified based on a thorough literature research and discussions with experts in the field of questionnaire surveys.

### **1.5 Thesis structure and organization**

This cumulative dissertation includes three peer reviewed scientific articles and a submitted paper for publication. It is structured as follows.

Chapter 2 (Article 1) introduces the newly developed CVI<sup>RFT</sup> and its application at single watershed level. It provides detailed information on the contributing dimensions, major components and indicators of the composite index.

Chapter 3 (Article 2) provides a further theoretical as well as detailed application level of CVI<sup>RFT</sup> for the comparative assessment of climate vulnerability in three different watershed areas. It helps to analyse the vulnerability components and dimensions in detail to assess the level of vulnerability between the WDP areas and thus can be seen as a guide to frame policy suggestions and proposals for restructuring the WDP.

Chapter 4 (Article 3) presents a sensitivity analysis of the developed CVI<sup>RFT</sup>. It helps to identify the significant differences in the vulnerability among the watersheds and contributing indicators of vulnerability.

Chapter 5 focuses on the perception of farmers on various climate change parameters and the various determinants of the adaptation strategies among the smallholders.

### **1.6 Summary of results**

#### ***1.6.1 Development of a Climate Vulnerability Index for rainfed areas***

Raghavan Sathyan, A., Aenis, T., & Breuer, L. 2016. Participatory vulnerability analysis of watershed development programmes as a basis for climate change adaptation strategies in Kerala, India. *Journal of Environmental Research and Development*, 11(01), 196–209.

Raghavan Sathyan, A., Funk, C., Aenis, T. & Breuer, L. 2018. Climate vulnerability in rainfed farming: analysis from Indian watersheds. *Sustainability*. 10(9):3357. <https://doi.org/10.3390/su10093357>

Note: Initial results were published by Sathyan et al. (2016) in the Journal of Environmental Research and Development as a single case study (one watershed) to show the applicability of the index (Chapter 2). In the following, a comparative detailed assessment between the three watersheds was published by Sathyan et al. (2018) in the journal Sustainability (Chapter 3).

To assess the climate vulnerability of the watersheds, the  $CVI^{RFT}$  was developed which integrates three different dimensions of vulnerability, ten major components, and 59 indicators. The major components and relevant indicators had been selected to capture the theoretical determinants of vulnerability based on literature, local situation and expert opinion at watershed level with its varying relative contribution towards the vulnerability. The *adaptive capacity* dimension comprises of five major components: socio-demographic profile, socio-economic assets, livelihood strategies, agriculture, and social networks. These five major components consist of a total of 35 indicators. The second dimension is *sensitivity* with three major components: water, food, and health. It comprises of 15 indicators. The *exposure* dimension integrates two major components: natural disaster and impact as well as climate variability, with a total of nine indicators. In this research, indicators under the *exposure* dimension were measured according to people's perceptions on magnitude and frequency of climate variability and extreme events. The indicators were measured on different scales, e.g. some of them are numbers or percentages and others are indices. Therefore, they are normalized to a range of 0...1 as proposed by Hahn et al. (2009). Before that, the functional relationship of each indicator was considered whether it contributes positively or negatively to the overall vulnerability. For indicators with a negative relationship, it is hypothesized that they decrease the vulnerability, so that derived the hypothesized value from the actual value (e.g. 100 minus index value in case of percentage units). The  $CVI^{RFT}$  value varies between 0 and 1, where 0 indicates the lowest vulnerability and 1 the highest.

A single case study was conducted in Eswaramangalam watershed where the WDP implemented by the LG and it showed a rather high vulnerability value (0.45). The *Adaptive capacity* dimension contributed the highest to the overall vulnerability index while *sensitivity* contributed the least. While considering the *exposure* dimension, climate variability perceptions of the farmers were very high in case of 'rise in temperature (0.987)' and 'hot months perception index (0.920)'. Even though the WDP aims for livelihood support system and production system improvement, vulnerability indicators 'livelihood strategies, social networks and agriculture' contributed the highest to the *adaptive capacity* vulnerability value.

The comparative vulnerability assessment between the three watersheds revealed that the overall CVI<sup>RFT</sup>s were rather similar, while there were substantial variations in the dimensions, major components, and indicators. The largest difference between the watersheds was given 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. Overall, *adaptive capacity* has the lowest variation among the watersheds while *sensitivity* has moderate and *exposure* the highest variability. However, the differences in the CVI<sup>RFT</sup>s were very small as there were only minor differences among the watersheds implemented by the different agencies. Furthermore, an in-depth analysis of the dimensions, major components and indicators were carried out to assess the significant differences among the major components and its contributing indicators.

### **1.6.2 Sensitivity analysis of CVI<sup>RFT</sup>**

Raghavan Sathyan, A., Funk, C., Aenis, T., Winker, P. and Breuer, L. 2018. Sensitivity analysis of a climate vulnerability index - a case study from Indian watershed development programs. *Climate Change Responses*. 5:1. <https://doi.org/10.1186/s40665-018-0037-z>

Many studies confirm that uncertainty is an unavoidable factor for composite indices (Preston et al., 2011; Tonmoy et al., 2014). The reason is that the value of a composite indicator is not a simple number, but a distribution of values. The composite indicator's 'simple big picture' may direct to misleading non-robust policy messages if they are not interpreted in combination with the indicators. An index can be better communicated to policy makers, stakeholders and decision makers when the sensitivity of the input factors is taken into consideration. Thus, sensitivity analysis examines the robustness, i.e. the degree of influence of each indicator on the index output, thereby revealing which input choices are most or least influential.

The second objective of the PhD study was to analyse and compare the climate vulnerability of the three examined WDPs in more detail. For this, the study uses a bootstrap sampling and a leave-one-out sensitivity analysis. After introducing and computing the CVI<sup>RFT</sup>, it was essential to know if the three observed programmes were significantly different from each other or not. In general, one could use a two sample difference in the mean test for comparing mean values. Nevertheless, the usually computed Z-score or t-test was not applicable to this circumstance by merely having one observed value without knowing the underlying data generating process of the computed parameters. Thus, it was decided to use bootstrapping method as an alternative way of obtaining the distribution and comparing the test statistics of

interest. Introduced by (Efron, 1979) and Efron & Tibshirani (1986), bootstrap sampling has become increasingly popular in all sorts of econometric applications. The leave-one-out sensitivity analysis has been conducted which means that we repeatedly computed the  $CVI^{RFT}$  again by leaving out one major component at a time. This allows for a more detailed look at the importance of the individual indicators. So far, only a local sensitivity analysis was performed to evaluate the robustness of inherent vulnerability ranks for mountain agricultural communities in Himalaya (Shukla et al., 2016).

The study put forward two major features of vulnerability in the watersheds. First and foremost, there were no significant differences in the *adaptive capacity* between the three communities while there were significant differences in *sensitivity* and *exposure* dimensions. This emphasizes that the WDPs have equal opportunity to improve and thus enhance the *adaptive capacity* of the community through region-specific policies. Secondly, the sensitivity analysis of the  $CVI^{RFT}$  showed that 'Livelihood Strategies' and 'Social Network' were the most influencing major components of vulnerability in all the watersheds. It suggests improvement of indicators under these major components. This stands in line with the results of others (Shukla et al., 2016) who found that 'livelihood dependency' and 'institutional capacity' were the components which influenced the vulnerability ranking of villages in the Uttarakhand state of India the most. The study ends with general policy suggestions for improved adaptation strategies and mitigation solutions on the watershed level.

### ***1.6.3 Perception and driving factors of adaptation strategies***

Raghavan Sathyan, A., Funk, C., Winker, P. and Breuer, L. 2018. Changing climate - changing livelihood: Farmer's perceptions and adaptation strategies (manuscript to be submitted to Journal of Environmental Management)

The studies on perceptions of climate change and adaptation strategies reveal the importance of location specific adaptation strategies (Banerjee, 2015; Dhanya and Ramachandran, 2016) and policies with respect to farmer's concerns and responses regarding climate variability. The main objective in this work was to analyse the adaptation measures used by farmers in response to perceived climate change. Nevertheless, there exists a distinct difference between perceiving climate change and an actual use of adaptation measures in their farming process.

The perceptions of farmers were collected from households based on five questions: Did the household perceive a considerable rise in temperature over the past few years? Did the household perceive a substantial increase in hot months? Did the household perceive erratic

monsoons during the last years? Did the household notice a substantial decrease in rainy days? The results were heterogeneous between the five questions and the three regions. Nevertheless a vast majority of households perceived at least a medium to high change in either of the above categories.

Farmers perceived a medium to high level of ‘considerable rise in temperature’ and ‘increase in hot months’. Similar results were reported in Bundi district of Rajasthan (Dhaka et al., 2010) and Maharashtra and Andhra Pradesh (Banerjee, 2014; Ravi Shanker, K et al., 2013).

More than 66% of the households opined a medium to high level of perception in the ‘increase in rainfall’ parameter and 87% had experienced a low to medium level ‘erratic monsoon’ incidence. Farmers in Andhra Pradesh opined a decrease in rainfall in general, while at the same time facing heavy, irregular and unpredictable rains (Banerjee, 2014; Mengistu, 2011; Ravi Shanker, K et al., 2013).

There exists a considerable variation for the three watersheds when it comes to the actual use of adaptation strategies. The vast majority of households perceive a high rise in temperature and a high increase in hot months in the LG watershed. This might be one of the reasons, why the LG watershed is focusing more on crop diversification than the other two. Information Communication Technology, Cooperatives, and Self Help Groups are far more important than in the SG and LG watersheds. Thus, our household survey results reveal that, in general, the households are using various adaptation methods simultaneously.

The study also shows that there are various factors that significantly affect the adaptation strategies used by the households. For instance, more experienced farmers are more likely to engage in changing their farming pattern, while they are less likely to seek social assistance. In addition, male-headed households are found to be more engaged in using new technologies and farming practices while women’s participation in social activities and attendance of meetings are more likely. Furthermore, education, farm size and owning livestock can be seen as three important factors for a household to engage in cooperatives. Thus, it is concluded that farmers in all the WDPs are well aware of the fact that the climatic conditions are changing and measures should be and partially have been undertaken to overcome the potential negative effects.

Another concern is the socio-economic status of the households with an emphasis on wealth assets. The results strongly support this statement as the study revealed a mostly positive relationship between household assets and various adaptation strategies. Furthermore, it is

widely accepted in the literature that the poorest ones that are the least equipped when it comes to dealing with long-term climate change in order to maintain their current livelihood (Bryan et al., 2013; Hahn et al., 2009; Jiri et al., 2017). Those households with a high level of assets are innovative and keen in accessing information related to weather and climatic parameters, social networking institutions such as cooperatives and SHGs as well as new and modern technologies for irrigation and soil and water conservation.

### **1.7 Conclusions and future research**

The study developed a  $CVI^{RFT}$  and carried out a sensitivity analysis to measure the climate change vulnerability of rainfed smallholders in watershed areas of the southernmost state of India, Kerala. Based on the aforementioned results obtained, this section concludes with a number of ideas and remarks to extend the analysis of climate vulnerability and index based approaches in the future.

#### *Improvements of the $CVI^{RFT}$*

As index development involves different steps such as indicator selection, variable transformation, weighting, aggregation and plausible subjectivity on selection (Tate, 2012), further refinement of the index composition and construction method might be essential to improve the reliability and accuracy of the index results. Future research may concentrate on in-depth qualitative analysis, and refinement of contributing indicators with different weighing schemes based on the locale and targeted group. In this case, the composite index might need to undergo necessary modifications in the contributing indicators according to the purpose and locality. Criticism in the selection of the current indicators could be the subjectivity in their definition. Further, the direction of the relationship between the indicators and vulnerability is subjective and could be interpreted differently.

#### *Uncertainty assessment*

Data evaluation obtained from questionnaires is prone to several errors, including false information given by the respondents (farmers), a feature that should be considered in the assessment of the uncertainty of complex indicator systems such as the  $CVI^{RFT}$ .

The present study compared the vulnerability of only three WDPs in a single district. The  $CVI^{RFT}$  should be quantified to a larger number of watersheds in different districts all over the state. This would help to identify and focus on watershed specific issues and district specific strategies for climate change adaptation planning.

The study concentrated on three WDP implementing agencies, i.e SG, NGO and LG without replications. To better investigate the effectiveness of the different agencies in implementing WDPs, more case studies per implementing agencies of WDP are needed to allow a comparison on the effectiveness and efficiency of the agencies themselves. The WDP of the current watersheds intervened the areas already, and climate change adaptation strategies especially in natural resource management and enhancing the production system activities have already been started. So, the current analysis misses a real ‘control’ watershed. Future studies should consider such a ‘non WDP’ impacted watershed.

### *Improvements of WDPs*

The services rendered by the WDPs were only partly sufficient for an effective adaptation process by a large part of the population. Even though WDPs aim particularly on natural resource management and production system enhancement, only very few households adopted soil and water conservation measures such as contour bunds and moisture conservation pits, livestock introduction and diversification of existing farming practices. For this, vertical and horizontal integration of the institutions as well as effective public-private partnerships coupled with community involvement are necessary for collaborating the adaptation process at different levels of households.

However, results also suggest that policy makers and donors should support and help the households to better understand and adopt the most effective adaptation strategies in building resilience against climate-induced shocks. Some of the determinants are institutional in nature as for example the educational status and extension services. This could be covered in terms of access, expansion of efficient infrastructure and better services with respect to its institutional nature. Moreover, a closer look at the indigenous adaptation strategies is necessary for facilitating the adoption process and future location specific research developments. Future research may also concentrate on an in-depth qualitative analysis into the barriers of adoption processes in smallholders and rainfed agriculture in the tropics.

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## **Chapter 2**

Raghavan Sathyan, A., Aenis, T. and Breuer, L. 2016. Participatory Vulnerability Analysis of Watershed Development Programmes as a Basis for Climate Change Adaptation Strategies in Kerala, India. *Journal of Environmental Research & Development*, 11 (1), 196-209.

## **PARTICIPATORY VULNERABILITY ANALYSIS OF WATERSHED DEVELOPMENT PROGRAMMES AS A BASIS FOR CLIMATE CHANGE ADAPTATION STRATEGIES IN KERALA, INDIA**

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### **ABSTRACT**

This paper analyses vulnerability towards climate change on community level in Kerala, India. The aim is to develop a climate vulnerability index in a participatory way. A case study was conducted in a watershed, which was implemented by Grama Panchayat (i.e. bottom level self-government institution). The data is collected through household surveys, key informant interviews and focus group discussions. The composite index comprises of three dimensions of vulnerability adaptive capacity, sensitivity, exposure and its ten major components : socio-demographic profile, socio-economic assets, agricultural, livelihood, social networks, health, food, water, climate variability and natural disasters. The results show that despite the programme aims at livelihood support and natural resource management, average vulnerability indices on livelihood strategies and social networks contributes the most to the overall vulnerability index. The vulnerability due to adaptive capacity indicators/subcomponents holds the highest value among the three dimensions of climate vulnerability. The results demand urgent need for location specific micro level planning of the watershed programmes with emphasis on activities to address water scarcity, soil and water conservation, farm diversification, production enhancement and livelihood alternatives for better coping strategies and resilience. This method can be used to compare the climate vulnerability of different watershed communities implemented by various agencies for better policy implication.

**Key Words :** Adaptive capacity, Climate Variability Index (CVI), Participatory vulnerability analysis, Sensitivity, Watershed management

### **INTRODUCTION**

Global temperature increases of several degree Celsius in the late 21<sup>st</sup> century, with increasing food demand and large risks to food security, reduced renewable surface water and groundwater resources in most dry subtropical regions will be intensifying the competition for water<sup>1</sup>. However, adequate emission reductions are impossible in the near future, so it is an indispensable necessity of the communities to adapt to climate change and variability especially in the developing nations. People

living in the developing countries are closer to the margin of tolerance to changing precipitation patterns, increased climate variability and extreme weather events than those are living in developed countries and thus more vulnerable to their effects<sup>2</sup>.

According to the Maplecroft<sup>3</sup> Climate Change Vulnerability Index, which evaluates the sensitivity of populations, the physical exposure of countries, and the governmental capacity to adapt to climate change over the next 30 years, India stands second among the growth economies under extreme risk category. The Centre for Climate Energy

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Solutions<sup>4</sup> report states that India is the fourth largest greenhouse gas emitter, accounting for 5.8% of global emissions.

In India, 53% of the population depend on agriculture for their living. Among these, 55% of farmers rely on rain-fed system in which delayed, deficient or erratic rains leads to severe reduction in production and productivity with resource degradation and misutilisation<sup>5</sup>. It has been projected by the IPCC 5<sup>th</sup> Assessment Report that unless people adapt, there is a probability of 10-40% loss in crop production in India by 2080-2100 due to global warming.

Previous climate change studies conducted in India focus on gender based adaptation to climate change<sup>6</sup>, climate variability and farmer's vulnerability in flood prone district of Assam<sup>7</sup> climate vulnerability assessment in Himalayan communities<sup>8,9</sup>, perception and knowledge level of climate issues<sup>10</sup> and climate change impacts on coastal ecosystem<sup>11</sup>. However, it is widely accepted that climate vulnerability studies should explore the socio-economic and institutional factors in depth<sup>12</sup>, at local level<sup>13</sup> and with the integration of a sustainable livelihood approach that addresses the issue of sensitivity and adaptive capacity to climate change to a certain extent<sup>14</sup>. There is enormous heterogeneity within the districts with respect to resource access, poverty and coping strategies<sup>12</sup>. So, assessments at more disaggregated levels or at community level, which evaluate the potential programme/policy effectiveness<sup>14</sup>, must be done. Moreover, Wisner<sup>15</sup> suggests integration of climate change aspects into ongoing efforts to give special attention to location specific knowledge for better adaptation strategies.

Watershed Development (WSD) programmes are such important strategies to adapt with climate variability and extreme climate events. They can build adaptive capacity and resilience among the rural communities<sup>16</sup> especially in rain fed areas. According to Samuel et al.<sup>16</sup>, watershed development is a multi-sectoral intervention aimed at enhancing the potential of ecosystem resources and the

socio-economic situation of the community in a specific landscape unit. Various studies on watershed impact evaluation reveal that WSD programmes have the capacity to reduce the risk associated with rain fed agriculture and as a tool for disaster management<sup>17, 18</sup>. There exists a large body of literature on climate vulnerability assessment by developing indicators. But the practical applications with active involvement of community stakeholders to reduce vulnerabilities of people to climate change and variability's are rarely undertaken. According to Smit and Wandel<sup>19</sup>, participatory vulnerability assessments enable recognition of multiple stimuli beyond climate, also including other stimuli such as political, cultural, economic, institutional and technological forces over time, scale and individuals. Therefore, it will be more action oriented if these stimuli are included to assess the vulnerability status.

### AIMS AND OBJECTIVES

To assess the climate vulnerability through a participatory-bottom up approach vis-à-vis the development of a vulnerability index at watershed community level. This approach is a triangulation which integrates information from multiple sources<sup>19</sup>, including active participation of various stakeholders. The selected watershed programme had been implemented by one of the Grama Panchayats, which is the local self-government institution at bottom level, in Kerala state of India.

### MATERIAL AND METHODS

#### Description of the study area

Kerala is the South Western state in India, which is severely threatened by climate change. It is unique in social, economic, environmental and physical conditions such as high population density, integrated farming system, humid tropical monsoon with excessive rainfall and hot summers<sup>20</sup>. Kerala is known as the 'Gate way of the summer' monsoon to India and it is one of the wettest places in the world, where annual rainfall is of

the order of 3000mm<sup>21</sup>. Homestead farming is a key feature of land use in this area, which includes a large number of species grown such as spices, medicinal plants, plantation trees, fruit plants, vegetables and tuber crops. In recent years, there is a major shift in rainfall pattern in Kerala, with significant decreases of the southwest monsoon<sup>22- 24</sup>, and increases of the northeast monsoon in Kerala<sup>23</sup>.

Palakkad is listed as one of the highly vulnerable districts to climate change in Kerala due to its specific geographic location, humid climate, high percentage of population relying on agriculture, a low ranking in the human development index, high social deprivation and a high degree of vulnerability to natural hazards like flood and drought with impacts on biodiversity and human life. The annual rainfall in this region is comparatively lesser than other parts of the state. Daytime temperatures often exceed 40°C in Palakkad with reports of sunburn in 2010<sup>25</sup>.

The watershed selected for the study was Eswaramangalam watershed implemented by Sreekrishnapuram Grama Panchayat. The Eswaramangalam watershed lies between 10°53'05" to 10°54'05" N and 76°24'02" to 76°26'07" E, located in Sreekrishnapuram Panchayat. The total watershed area is 626 ha. The watershed can be divided in to hilly areas, slopes and valleys with an average slope of 18°. The main soil types are fertile Alluvial Soil, low gravelly Red soil and Red soil. The main irrigation structures include wells, canals and ponds. The major crops cultivated in the area include paddy rice, rubber, coconut, banana and arecanut.

#### **Vulnerability framework**

This part of the paper develops conceptual framework to analyze the components of vulnerability and their relations. Vulnerability is the degree to which a system is susceptible to, or unable to cope with, the adverse effects of climate change, including climate variability and extremes<sup>26</sup>. Moreover, vulnerability is an integrated measure of the expected magnitude of adverse effects to a system caused by a

given level of certain external stressors<sup>27</sup>. This external dimension is represented as exposure which relates to the nature and degree to which a system is exposed to significant climatic variations while the sensitivity of a system to climate change reflects the degree to which a system is affected, either adversely or beneficially, by climate variability or change. It shows the responsiveness of a system to climate change<sup>28</sup> and a sensitive system is affected by even small climatic variations. Vulnerability assessment is a common tool for indicating the potential for harm to occur within human and ecological systems in response to global climate change<sup>29</sup>.

Adaptive capacity is the ability of a system to adjust to climate change to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.<sup>26</sup> It is intrinsically linked with socio-economic factors of the system with other determinants such as institutions, knowledge and technology<sup>30</sup>. Adaptation is the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

Measurement of vulnerability includes social processes as well as material outcomes within the system<sup>31</sup>, which makes the quantification process difficult. The Climate Vulnerability Index (CVI) used here is developed based on the framework given in **Fig. 1**. It implies that a system is vulnerable if it is exposed and sensitive to the effects of climate change and at the same time has only limited capacity to adapt.<sup>2</sup> On the contrary, a system is less vulnerable if it is less exposed, less sensitive or has a strong adaptive capacity.<sup>19</sup> Therefore, building adaptive capacity enables communities to mobilise resources needed to reduce vulnerability and adapt to climate change<sup>32</sup>.

The approach aims to include all sectors of stakeholders in WSD programme to suggest future adaptation strategies. The Climate Vulnerability Index is based on three dimensions of vulnerability and its ten components as given in **Fig. 1**.

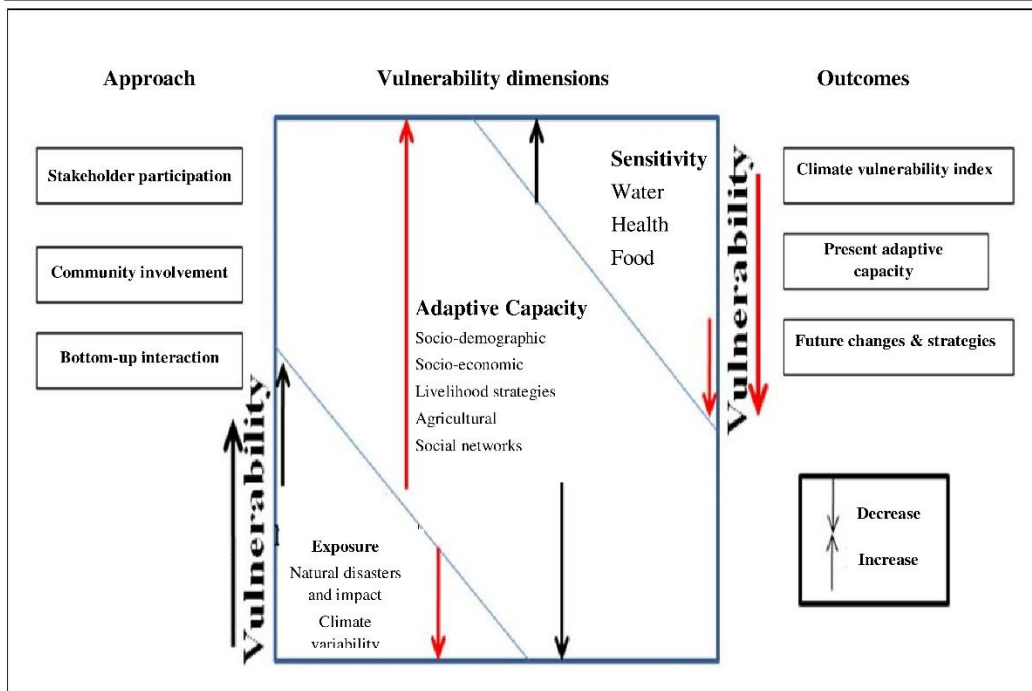


Fig. 1 : Framework for participatory climate vulnerability analysis

#### Description of the index

The proposed CVI includes three different dimensions: adaptive capacity, sensitivity and exposure. Each dimension comprises of major components and under which relevant indicators or subcomponents specific to the watershed area are included. These subcomponents and indicators are developed based on literature review. They were then pretested and checked within key informant interviews. For example, under adaptive capacity dimension there are five major components namely socio-demographic profile, socioeconomic assets, livelihood strategies, agricultural and social networks. The major components and its subcomponents are depicted in Table 1. For calculating CVI, each major component contributes equally to the overall index<sup>14</sup> while each major component is calculated based on weighted average approach<sup>33</sup>. The subcomponents/ indicators are measured on different scales, and were therefore normalized between 0 and 1 to form an index<sup>14</sup>. Before that, the functional relationship of each sub-component/ indicator is considered whether it contributes positively or negatively to the

overall vulnerability. For subcomponent/ indicators with a negative relationship it has been hypothesized to decrease the vulnerability by using (100-index value) and given in Table 1. Following, the values of each subcomponent/indicator are normalized using the equation (Eq. 1).

$$Index_{sw} = \frac{S_w - S_{min}}{S_{max} - S_{min}} \quad \text{Eq. 1}$$

where,

$S_w$  is the original subcomponent/indicator value for the watershed community,

$S_{min}$  and  $S_{max}$  are the minimum and maximum values for the subcomponent/indicator.

After the standardization, each subcomponent/indicator is averaged to calculate its value.

$$M_w = \frac{\sum_{i=1}^n Index_{swi}}{n} \quad \text{Eq. 2}$$

where,

$M_w$  is one of the major components under the three dimensions of vulnerability,

$Index_{swi}$  is the subcomponent value of the watershed community and

$n$  is the number of subcomponents under major component.

**Table 1 : Climate Vulnerability Index (CVI) : Dimensions, major components, subcomponents and results for normalised values of subcomponents and average indicator values for major components**

		Subcomponent/indicator	Explanation	Unit	Value	Rel.	Hypoth. value	Norm.value	AVI	CVI
Dimension Adaptive Capacity	M. component Socio- demographic profile	Family dependency index	Ratio of population between 0-14 yrs and >60 yrs with population between 15-59 yrs	-	0.28	+ve	0.28	0.283	0.362	0.450
		House type diversity	Simpson's diversity index (1-D)#	-	0.52	+ve	0.52	0.522		
		Family decision	% literate household head	%	92.00	-ve	8.00	0.080	991.0	
		Poverty	% families below poverty line	%	0.48	+ve	0.48	0.480		
		Indebtedness*	% families with debt	%	58.67	+ve	58.67	0.587		
		High income households	% households with income of >2250 \$/yr	%	21.33	-ve	78.67	0.787		
		Male headed households	% households with male as head of the family	%	89.33	-ve	10.67	0.107		
		Religious diversity	Simpson's diversity index#	-	0.05	+ve	0.05	0.053		
		House hold asset possession	Inverse of (household asset+1)	1/n	0.13	-ve	0.13	0.130		
		Farm asset possession	Inverse of (farm asset +1)	1/n	0.51	-ve	0.51	0.510		
		Average farm holding size\$	Average landholding size	ha	0.21	-ve	0.21	-0.121		
Own water resources	% households with atleast one water resource	%	85.33	-ve	14.67	0.147				

Component Livelihood strategies	Migration	% households in which atleast one member migrated for better income	%	4.00	-ve	96.00	0.960	697.0
	Introduced new crop	% households introduced atleast one new crop in farming	%	1.00	-ve	99.00	0.990	
	Depend on agriculture for income	% households with agriculture as the only source of income	%	7.00	+ve	7.00	0.070	
	Farm diversification	Inverse of (types of enterprises+1)	1/n	0.75	+ve	0.75	0.665	
	New livelihood strategies adoption	% households which adopted new livelihood strategies since last 5 yrs	%	3.00	-ve	97.00	0.970	
	Introduced livestock	% households which adopted livestock in farming since last 5yrs	%	4.00	-ve	96.00	0.960	
Component Agricultural	Rainfed farming	% households which has not following any irrigation methods	%	28.00	+ve	28.00	0.280	605.0
	Net sown area	% cultivated land area	%	59.49	-ve	40.51	0.405	
	Crop diversification	Inverse of(types of crops+1)	1/n	0.33	-ve	0.33	0.330	
	Adopt new crop varieties	% households which introduced new varieties in farming	%	1.33	-ve	98.67	0.987	
	Decline in Farm production	% households reported decreasing trend in farm production	%	9.30	+ve	9.30	0.093	

Component Social networks	Soil erosion perception	% households opined moderate to severe soil erosion in their land	%	12.00	+ve	12.00	0.120	497.0
	Soil and water conservation works	% households where farmers not adopted soil and water conservation	%	89.33	+ve	89.33	0.893	
	Households with <0.2 ha of land	% households with less than 0.2 ha of land	%	72.00	+ve	72.00	0.960	
	Beneficiaries	% households received benefits from the WSD Programme	%	28.00	-ve	72.00	0.720	497.0
	Cooperation	% households provided help to others during distress	%	1.33	-ve	98.67	0.987	
	Membership in cooperative institution	% households which has membership in societies	%	38.70	-ve	61.30	0.613	
	Received help from others	% households which received assistance	%	1.33	-ve	98.67	0.987	
	Watershed committee membership	% households with members in WS committee	%	6.70	-ve	93.30	0.933	
	No beneficiary contribution	% farmer's not contributed any beneficiary share	%	28.57	+ve	28.57	0.286	
	Lack Information Communication Technology access	% households with no access to ICT	%	46.67	+ve	46.67	0.467	
	Participation in Grass root planning	% Farmers participated in grass root planning	%	5.30	-ve	94.70	0.947	
	Trainings	% farmers received training on climate change	%	6.70	-ve	93.30	0.933	

Dimension sensitivity	Component Water	Water scarcity	% households with problems of drinking water during summer	%	41.33	+ve	41.33	0.413	137.0
		Dependency on water resources	% households depend on other's water resources	%	16.00	+ve	16.00	0.160	
		Public water sources	% households depend on public tap for drinking water	%	10.66	+ve	10.66	0.107	
		Groundwater decline	% households reported decrease in groundwater	%	29.30	+ve	29.30	0.293	
		Gender inequality	% households where female fetch potable water	%	41.33	+ve	41.33	0.413	
		Decreased availability of water	% households reported decreased availability of water	%	29.30	+ve	29.30	0.293	
		Water source depletion	% households reported severe depletion of water resources	%	92.00	+ve	92.00	0.920	
	Component Health	Waterborne diseases	% households reported waterborne diseases to the family	%	0.00	+ve	0.00	0.000	300.0
		New disease incidence	% households reported with new disease	%	0.00	+ve	0.00	0.000	
		Poor quality drinking water	% households reported decreased quality of drinking water	%	0.00	+ve	0.00	0.000	
		Sunburn	% households with sun burn problems reported	%	1.33	+ve	1.33	0.013	
		Death due to climatic variabilities	% households with death due to climate variations	%	0.00	+ve	0.00	0.000	

Dimension exposure	Component Food	Off-farm dependency	% households depends only on off-farm for food	%	66.67	+ve	66.67	0.667	0.315
		Food insufficiency	% households reported food insufficiency	%	2.66	+ve	2.66	0.027	
		Poor support from government	% households reported poor support from government through PDS	%	25.30	+ve	25.30	0.253	
	Component Natural disaster & impact	Death or injury due to natural disaster	% households with death or injury due to natural disaster	%	0.00	+ve	0.00	0.000	0.2210
		Crop loss	% households reported crop loss	%	21.33	+ve	21.33	0.213	
		Housing or property damage	% households reported housing or property damage	%	13.33	+ve	13.33	0.133	
		Heavy wind	% households reported heavy wind	%	56.00	+ve	56.00	0.560	
	Component Climate variability	Temperature increase perception	% households reported very high temperature increase	%	98.70	+ve	98.70	0.987	0.595
		Hot months increase perception	% households reported hot months increase	%	92.00	+ve	92.00	0.920	
		Erratic rainfall perception	% households reported erratic rainfall	%	24.00	+ve	24.00	0.240	
		Less rainy days perception	% households reported less rainy days	%	25.40	+ve	25.40	0.254	
		Extreme climate events	% households reported at least one extreme climate event	%	57.33	+ve	57.33	0.573	

Note : <sup>#</sup>(1-D), where  $D = \sum n(n-1)/N(N-1)$  and n=the number of households under different religion, N=total households; <sup>\*</sup> Considered the worst case situation for respondents who didn't give information on debt status. Considered all of them as indebted; <sup>§</sup>When the average farm holding size increases the vulnerability decreases, it shows negative relationship and standardisation is done by equation  $Index_{sw} = (S_{min} - S_w) / (S_{max} - S_{min})$  as it is an absolute number, not percent or ratio.

After calculating the major component, the next step is assigning weights. The balanced weighted approach<sup>33,14</sup> has been used in this study. The number of subcomponents under major components has been taken as the weight for calculating the index for major dimensions. For example the index for Adaptive capacity (Ada. cap), Sensitivity (Sen) and Exposure (Exp), has been calculated according to Eqs. 3, 4 and 5 :

$$Ada.cap = \frac{W_{a1}SD + W_{a2}SE + W_{a3}LS + W_{a4}A + W_{a5}SN}{W_{a1} + W_{a2} + W_{a3} + W_{a4} + W_{a5}} \quad \text{Eq. 3}$$

where

$W_{a1}$ ,  $W_{a2}$ ,  $W_{a3}$ ,  $W_{a4}$ ,  $W_{a5}$  are the weights for socio-demographic profile, socio-economic assets, livelihood strategies, agricultural and social network, respectively.

$$Sen = \frac{W_{s1}H + W_{s2}F + W_{s3}Wa}{W_{s1} + W_{s2} + W_{s3}} \quad \text{Eq. 4}$$

where,

$W_{s1}$ ,  $W_{s2}$  and  $W_{s3}$  are the weights for the components health, food and water, respectively.

$$Exp = \frac{W_{e1}ND + W_{e2}CV}{W_{e1} + W_{e2}} \quad \text{Eq. 5}$$

where,

$W_{e1}$  and  $W_{e2}$  are the weights for natural disaster and climate variability respectively. The indicator values vary between 0 and 1 and may be interpreted as 0 for least vulnerable and 1 for the most vulnerable.

Then, the overall index for vulnerability can be expressed as :

$$CVI_w = \frac{\sum_{i=1}^{10} W_{mi} M_{wi}}{\sum_{i=1}^{10} W_{mi}} \quad \text{Eq. 6}$$

where,

$W_{mi}$  is the weight and

$M_{wi}$  is the average value of each major component.

#### Household surveys

The first step was the selection of a watershed, which completed the project activities before the year 2010. For that we contacted the Western Ghat Development Cell, Palakkad. The household interviews were conducted by us with the help of an assistant to survey within the watershed boundaries. Once arrived in the village, the Community Development

Society members, the Grama Panchayat Secretary and elected Grama Panchayat members were consulted to explain the purpose of the study and to obtain information regarding the households. Cluster sampling method was used in the selection of farm households: small, medium and large farmers: (n=75) with the help of primary and secondary data from Agricultural Office of the watershed area. Maximum care has taken to include all sectors of respondents : farmers, landless, labourers, self-help group members and women. A few key informant interviews were conducted namely with Panchayat President, Agricultural Officer, elected members of Panchayat, Community Development Society member of women self-help group, progressive farmers and secretary of the watershed committee to triangulate the response obtained from household surveys. Two focus group discussions were conducted with men and women group each to get an overview about the implementation of the programme and its impact on climate variability risk mitigation and adaptation strategies.

## RESULTS AND DISCUSSION

**Table 1** also shows results of the subcomponents/indicator values, hypothesized values, normalized values and the average values of the watershed community. Under socio-demographic components, there are eight subcomponents and among these, high income household indicator holds the highest value (0.787) because only 21.3% of the households earn higher income for their living. Religious diversity index (0.053) contributes least to the socio-demographic vulnerability indicator as 97.3% of the households believe in Hinduism, reflecting homogeneity in the belief system. The family dependency index (0.283) shows a positive sign, but the feeder category (0-14years) is only 28% and it is not a good sign for economic growth of the area. Furthermore, 48% of the households are below poverty line while rural poverty for the whole state is 7.3%<sup>34</sup>. It clearly depicts the economic deprivation of the area, which has a positive functional relationship to the climate vulnerability.

Socio-economic vulnerability of the area contributes less to the overall vulnerability index. The farm asset possession index (0.510) is the highest contributing factor to the socio economic vulnerability. The average farm holding size is 0.2 ha which even less than the per capita availability of land in the state of Kerala (0.23 ha)<sup>34</sup>. 85.3% of the households possess their own water holding structures for routine activities, which contribute positive to the adaptive capacity.

Livelihood strategy component has a major share (0.660) in the vulnerability value because households are reluctant to adopt new crops and even in farm diversification. Even in the midst of these negativities, only 7% of the farmers depend solely on agriculture for income.

The agricultural vulnerability status also indicates higher value (0.509) with less adoption in new varieties and soil-water conservation activities. Eventhough the WSD programme concentrates on soil and water conservation works almost 90% of all households have not adopted any of such activities in their farm because of small holding size i.e. 72% of the households own less than 0.2 ha of land. The soil erosion perception index (0.120) shows a low value, may be due to negligence and unawareness of the farmers on the extent of erosion that happens on their fields.

Social networking status indicates the highest contribution (0.764) towards overall climate vulnerability. Over the last two decades, decentralized planning has been institutionalized in Kerala with the “Panchayati Raj” system of administration and implementation. Despite of this, only 5.3% of the households participated in the grass root level planning. The households expressed reluctance to opine that they received help from others. Only 1.3% admitted that they seek help from neighbours, family members or governmental institutions.

Among the sensitivity major components, water contributes the highest (0.455) to the average vulnerability. 41.3% of the households face scarcity of water during drought season, the scarcity period varies between 2-6 months. These households depend on neighbour's well

or public tap for drinking water during this period and water fetching is the sole responsibility of women in the house. 10.7% of the households depend on public tap and 16% of them depend on other's water sources for routine water requirements. 9.3% of the households reported decline in groundwater compared to past years. Severe depletion of natural water sources (0.92) also play a key role in contributing to the sensitivity dimension.

Health components show a positive trend to increase the resilience of watershed communities with the lowest vulnerability score (0.003). There were no new disease incidence, waterborne diseases and complaints on poor quality drinking water. A few cases of sunburn incidence were reported by the households, indicating a temperature increase compared to previous years.

Among food components, off-farm food dependency indicator (66.67) contributes the highest to the average vulnerability (0.315), which shows the dependency of the households to off-farm sources than on-farm sources. 97.3% of the households benefit from the Public Distribution System mainly as food grains, sugar and kerosene, despite 25.3% of the total respondents opined poor support from government. Only a very small percentage of households (2.7%) reported food insufficiency also contributes positively to the resilience of the community.

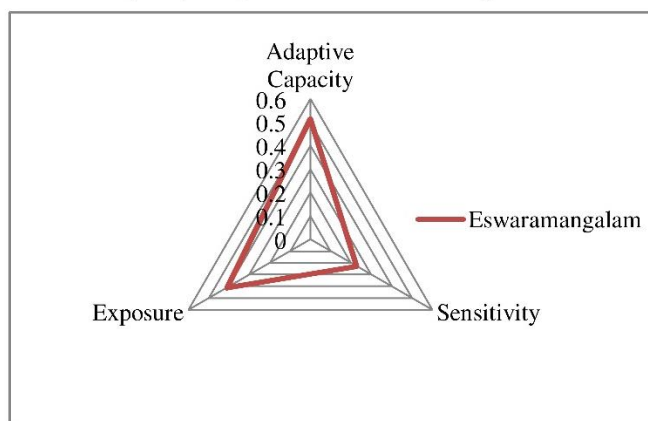
Natural disasters due to extreme events were reported in the area during 2014 in the form of heavy wind and it resulted in severe crop loss (21.3%) and property loss (13.3%). Even though there was a heavy wind incidence, only 56% of the households reported the incidence. This might be because they remaining households did not suffer from any kind of losses. During focus group discussion one of the affected farmers opined we are not receiving any compensation from the authorities and the information is purely biased. Many of the households applied for relief fund for the disaster, but even after two years of the incidence they could not get any response from the Government.

Climate variability perceptions was more pronounced in temperature (0.987) and hot

months perception indices (0.920). The extreme climate events perception index (0.573) also contributes to the average natural disaster and impact index (0.595) because of the heavy wind incidence in the watershed area. Erratic rainfall perception (0.240) and less rainy days perception (0.254) were lower and more or less similar compared to other subcomponents.

The vulnerability contributed by adaptive capacity (0.514), sensitivity (0.230) and

exposure (0.411) are plotted in **Fig. 2** to clearly illustrate the dimensional contribution. The adaptive capacity contributed the highest to the overall vulnerability index while sensitivity holds the least value. The CVI for Eswaramangalam watershed is 0.450 which is rather high. The CVI for a single watershed can be expanded to comparative CVI assessment of multiple watersheds to provide deeper insights in to the three dimensions. This will be carried out in future part of the research.



**Fig. 2 :** Vulnerability triangle diagram of the three dimensions of Climate Vulnerability Index

### CONCLUSION

The study quantitatively evaluated the climate vulnerability at watershed community level in one of the highly vulnerable districts of Kerala state, India. For this assessment, ten major components were identified based on the locality and the programme objective, under the three dimensions of vulnerability : adaptive capacity, sensitivity. First and foremost, despite the watershed programme aims for livelihood support system and production system improvement, vulnerability due to livelihood strategies, social networks and agricultural contributes the highest to the adaptive capacity vulnerability dimension. Policy makers should give priority to develop location specific policies and thus to address climate change and variability at the bottom level. Socio-demographic profile vulnerability reveals that, priority should be given to incooperate more income generating activities to address rural poverty and indebtedness.

The farmers in the watershed area are very reluctant to adopt new crops, varieties and livestock into their farming. It may be solved by enacting measures to promote new crops suited to the agro-climatic conditions, drought resistant varieties and stimulate diversification of farm and livelihoods while formulating the action plans for implementation of the watershed programmes. Moreover, the programme aims on soil and water conservation measures while few farmers perceive the importance of soil erosion and adoption of such activities. This can be addressed through conducting more awareness programmes to convey the importance of protecting natural resources for present and future generations. Water scarcity and depletion of natural resource are major contributing components to the overall sensitivity of the watershed area. Kerala is the state which receives the highest average rainfall and even in the midst of plenty of water, many regions faces extreme water scarcity. Indeed, this should be considered as

one of main agenda in future to include, for example rainwater harvesting structures in the WSD programme.

Limitations of our study include the subjectivity in selection of subcomponents, the direction of relationship between the subcomponents and vulnerability. Future work of this research should try to incorporate the sensitivity of the indices for assessing the variability in the data. Also, comparison to other watersheds is needed to place results in a larger context.

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## Chapter 3

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Article

# 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 deduced a new Climate Vulnerability Index for Rainfed Tropics (CVI<sup>RFT</sup>) to evaluate the potential effectiveness of programmes to adapt to climate change impacts. The CVI<sup>RFT</sup> 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<sup>RFT</sup> 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<sup>RFT</sup>); and (2) to test the new CVI<sup>RFT</sup> 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.

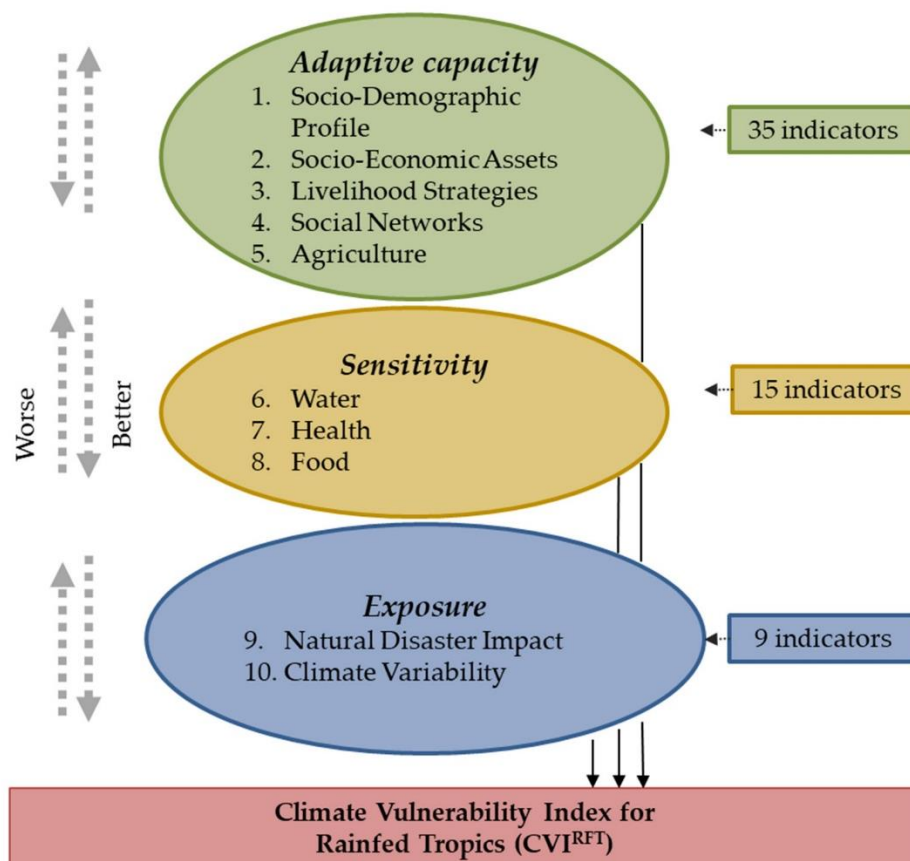
A system is vulnerable or susceptible if it is exposed and sensitive to the effects of climate change and at the same time, only has limited capacity to adapt [51] and vice versa [52]. Thus, building adaptive capacity enables communities to mobilise resources needed to reduce vulnerability [53]. A widely 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<sup>RFT</sup> 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<sup>RFT</sup>, 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<sup>RFT</sup>). The CVI<sup>RFT</sup> 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<sup>RFT</sup>.

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

Table 1. Cont.

Dimension of Vulnerability	Major Component	Indicator
Exposure	9. Natural Disaster Impact	51. Death or injury due to natural disaster 52. Crop loss 53. Property damage 54. Heavy wind
	10. Climate Variability	55. Temperature increase perception 56. Hot months increase perception 57. Erratic rainfall perception 58. Less rainy days perception 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  $CVI^{RFT}$ , 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)):

$$Index_{sw} = \frac{S_w - S_{min}}{S_{max} - S_{min}} \quad (1)$$

where  $S_w$  is the original indicator value for the watershed community, and  $S_{min}$  and  $S_{max}$  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)):

$$M_w = \frac{\sum_{i=1}^n Index_{swi}}{n} \quad (2)$$

where  $M_w$  is one of the major components under the three dimensions of vulnerability, the  $Index_{swi}$  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

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

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.

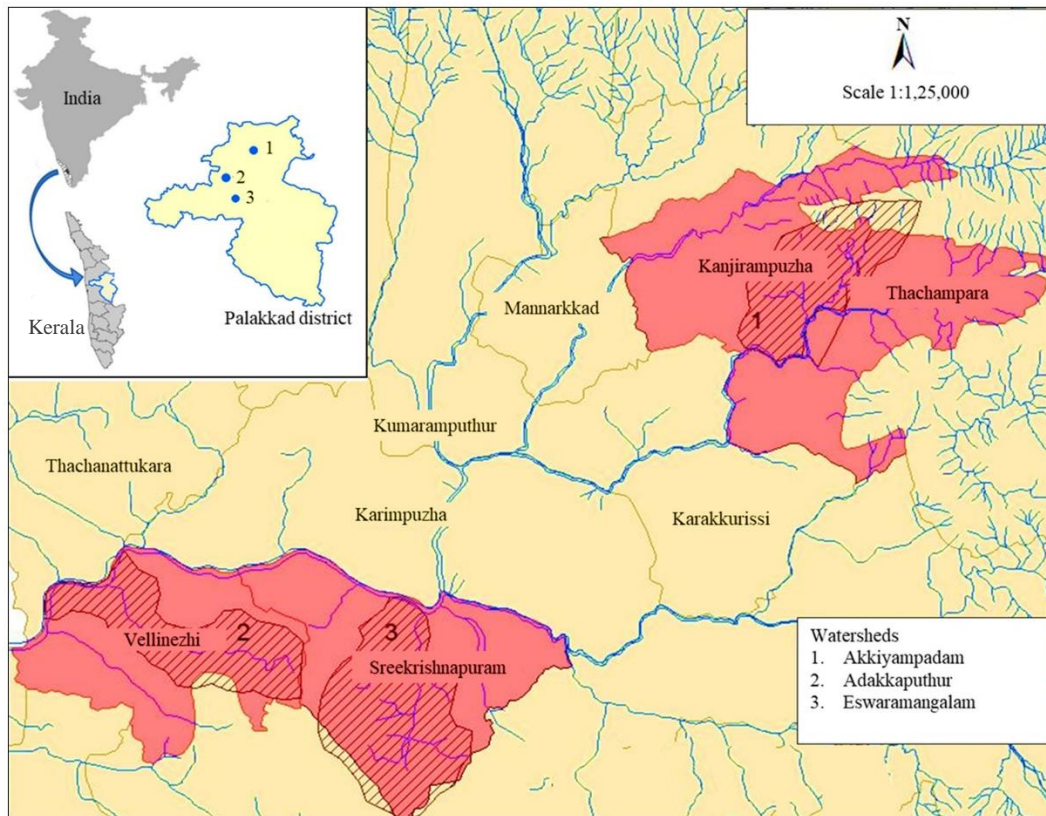
$$Exposure = \frac{W_{e1}ND + W_{e2}CV}{W_{e1} + W_{e2}} \quad (6)$$

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<sup>RFT</sup> 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		
	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<sup>RFT</sup>, 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.

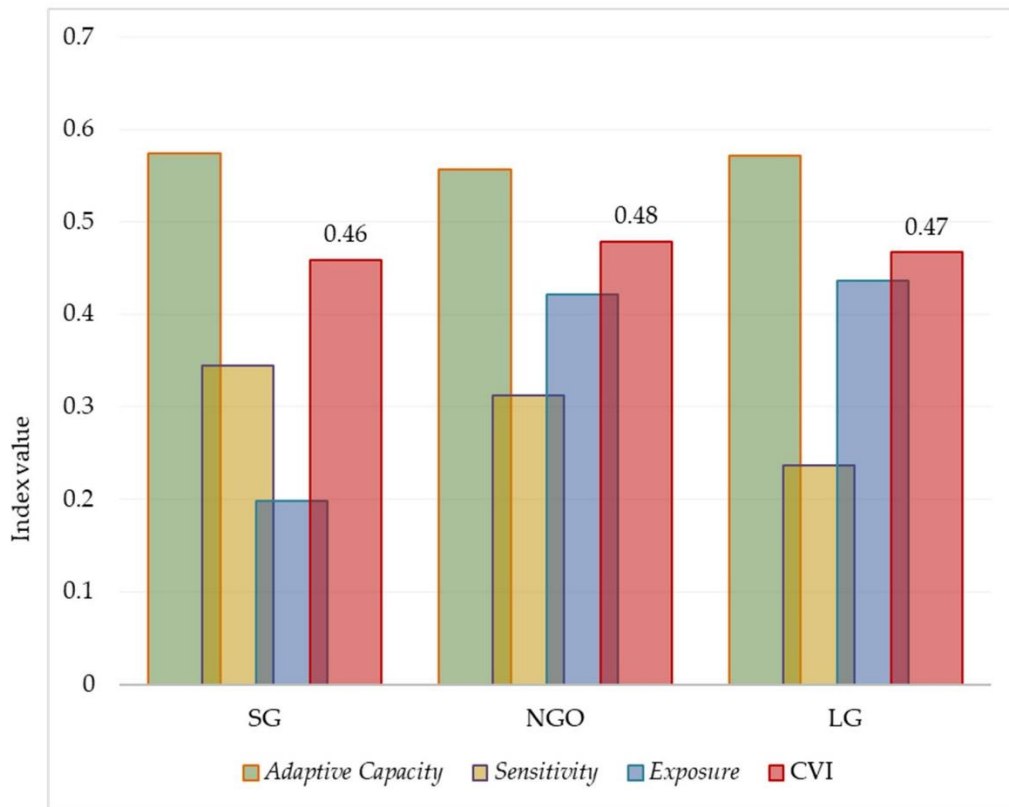


Figure 3. Dimensions of Vulnerability and the resulting CVI<sup>RFT</sup> of the three watersheds.

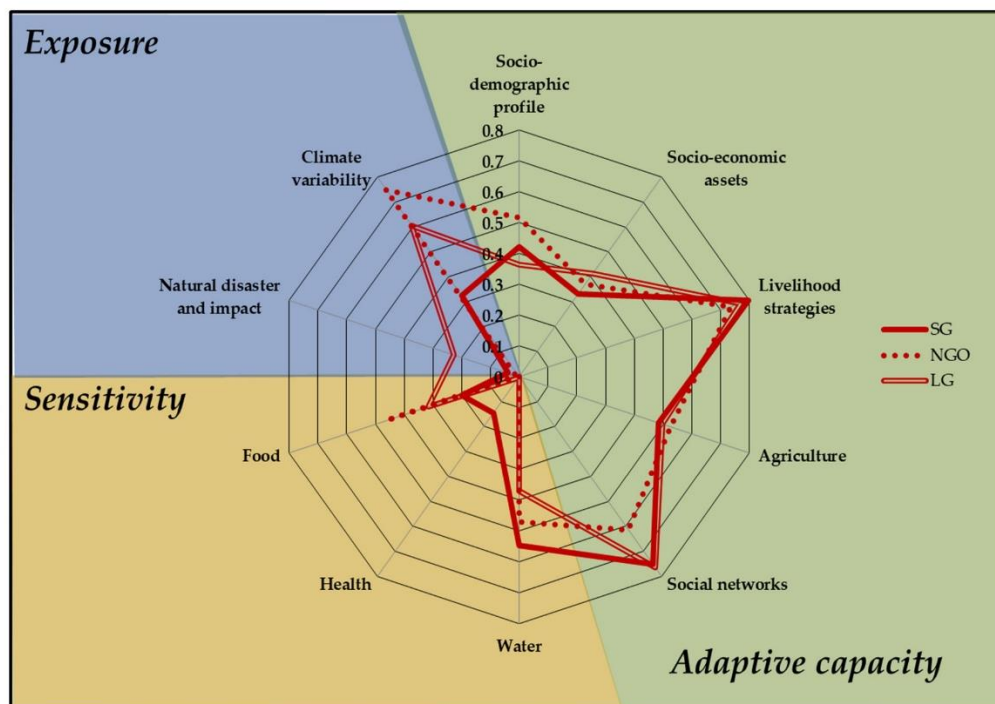


Figure 4. Comparison of average values of the ten major components for the three watersheds.

### 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<sup>RFT</sup>, 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 adaptation 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<sup>RFT</sup>. 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<sup>RFT</sup>.

**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 <sup>d</sup>
3. Family decision	Literate household head [%]	Decrease	[31]
4. Poverty	Families below poverty line [%]	Increase	New
5. Indebtedness <sup>b</sup>	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

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

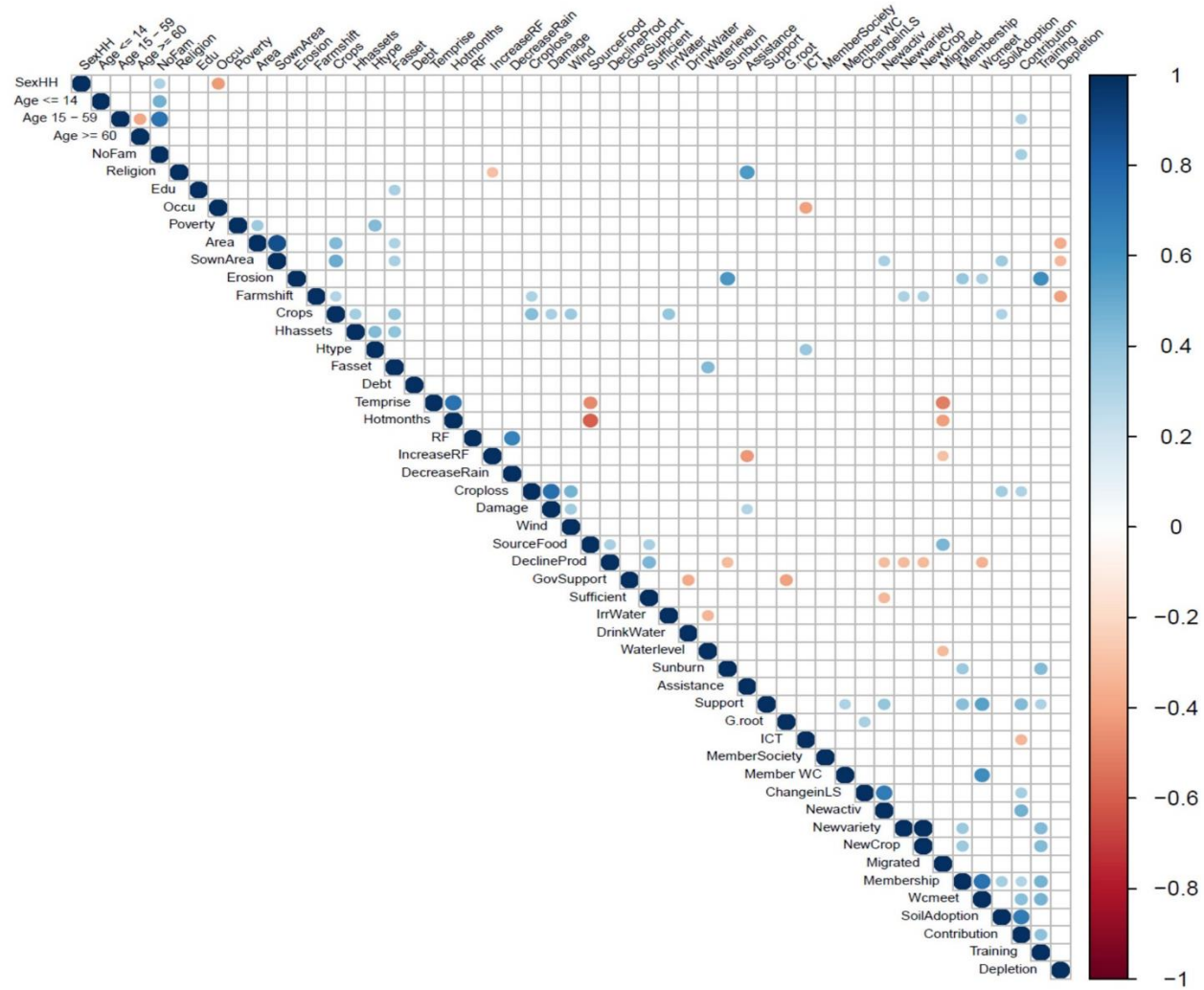


Figure A1. Cont.

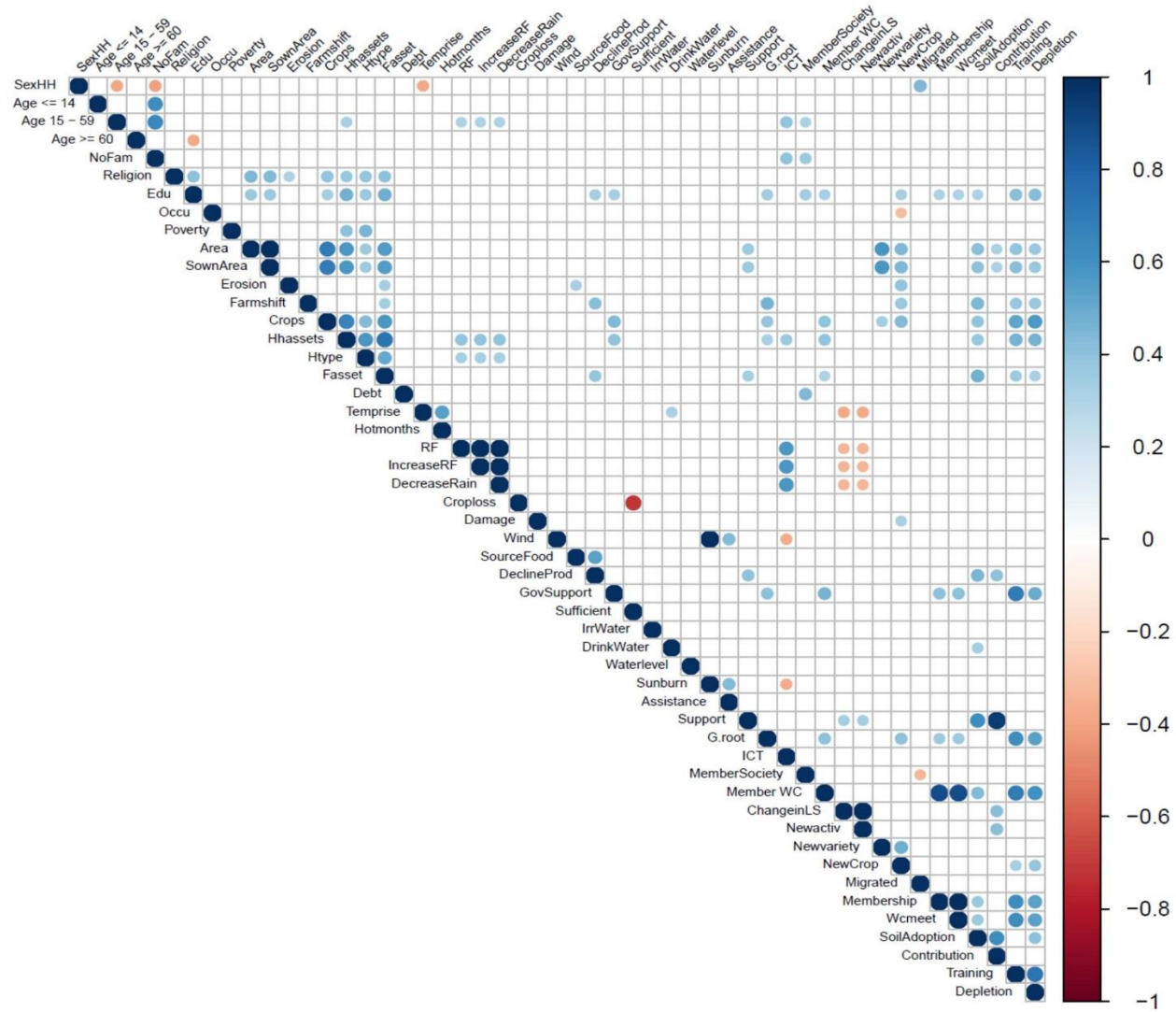
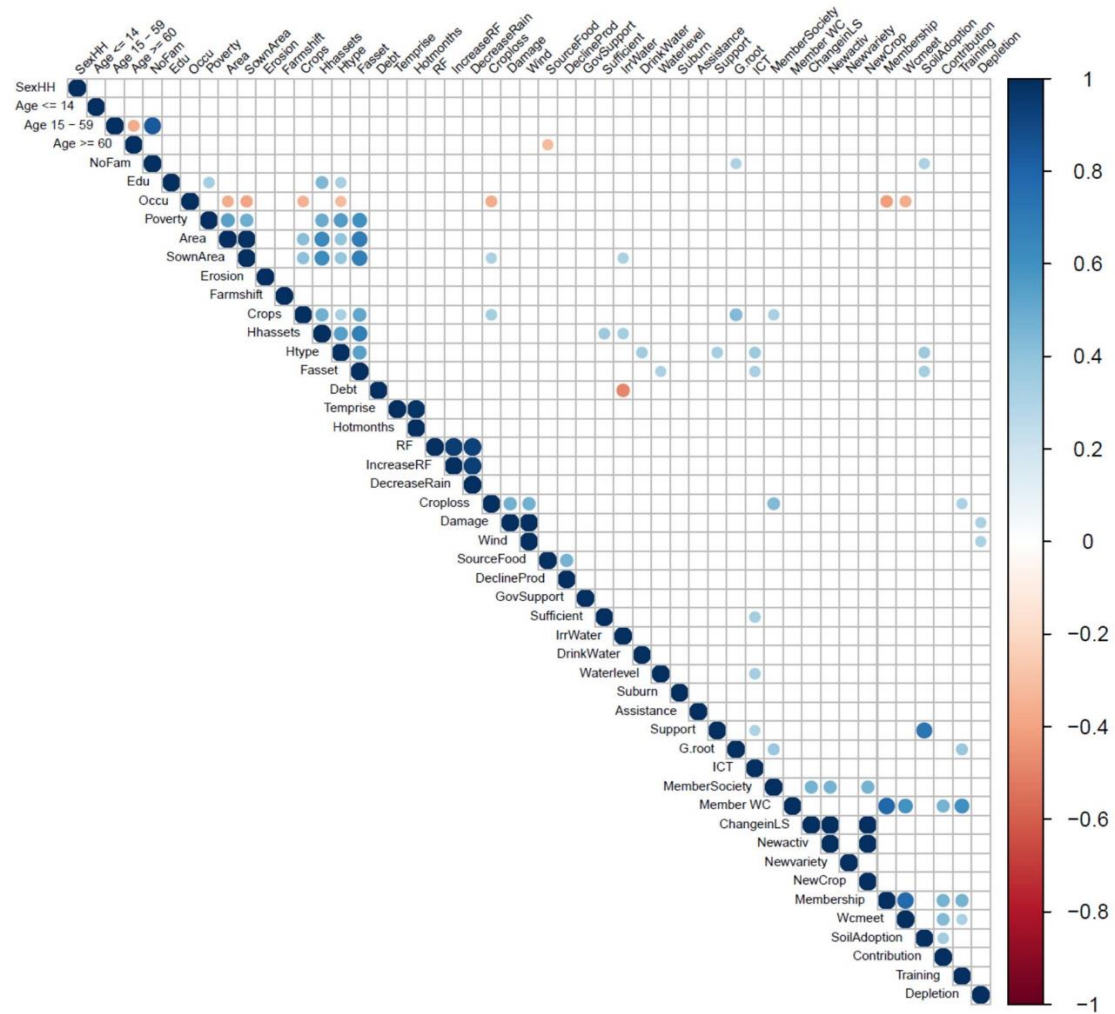


Figure A1. Cont.  
69



**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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## Chapter 4

Raghavan Sathyan, A., Funk, C., Aenis, T., Winker, P. and Breuer, L. 2018. Sensitivity Analysis of a Climate Vulnerability Index - A Case Study from Indian Watershed Development Programmes. *Climate Change Responses*, 5: 1. <https://doi.org/10.1186/s40665-018-0037-z>.

## RESEARCH

## Open Access



# Sensitivity analysis of a climate vulnerability index - a case study from Indian watershed development programmes

Archana Raghavan Sathyan<sup>1\*†</sup>, Christoph Funk<sup>2†</sup>, Thomas Aenis<sup>3</sup>, Peter Winker<sup>2,4</sup> and Lutz Breuer<sup>1,4</sup>**Abstract**

**Background:** This paper presents a detailed analysis of a composite Climate Vulnerability Index (CVI) to examine and compare climate change vulnerability and its dimensions adaptive capacity, sensitivity and exposure. Thereby, we are mainly interested on climate change vulnerability at community-level watershed development programmes and how the different implementing agencies could help to address the problems associated with climate change in future planning and implementation.

**Method:** The primary data used for this study was obtained from household surveys ( $n = 215$ ) in three watershed communities of Kerala, India. We use bootstrap sampling and a leave-one-out sensitivity analysis to compare the climate vulnerability of the three examined watersheds in detail. By introducing the bootstrapping method and sensitivity analysis into the research field of climate vulnerability, the paper describes significant differences in CVI values and the influencing indicators to the overall vulnerability at the watershed community level.

**Results:** The results show that there are significant differences in the exposure and sensitivity dimensions of vulnerability even if the overall CVI shows less variability and no significant differences among the three watersheds. The sensitivity analysis emphasizes that 'Livelihood Strategies' and 'Social Network' are the most influencing major components of vulnerability. This suggests that implementing agencies should focus on these two major components in order to improve the watershed development programmes.

**Conclusion:** The bootstrapping approach is transferable to evaluate the degree of influence of indicators on a composite index like the CVI. Moreover, it allows us to evaluate the potential effectiveness of various other climate change programmes where the evaluation is commonly done by field surveys. This thereby helps to increase the credibility in the examination of the impacts of climate change at different scales in order to find key areas for better policy planning.

**Keywords:** Bootstrapping, Climate change adaptation, Climate vulnerability assessment, Climate vulnerability index, Sensitivity analysis, Uncertainty analysis, Watershed development

**Background**

Climate change adaptation strategies are given high priority in developing countries due to their social, technological and financial resource scarcity for adapting to anticipated climate change and variability [1]. One billion

people in Asia could face water shortage which leads to drought and land degradation by the 2050s [2]. By 2030, these countries will require about USD 28-67 billion to enable proper and timely adaptation to climate change depending on the geographical, social, cultural, economic and political situation [1]. Therefore, quantification of vulnerability is very important to help the vulnerable regions in the prioritisation and planning of activities to tackle the impacts of climate change [3].

Although vulnerability is not a directly observable phenomenon, because of the policy-driven needs and

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assessments [3, 4], researchers have proposed and applied a set or composite of proxy indicators to quantify the vulnerability [5, 6]. Composite indices are analytical, communicative and collaborative tools which help to raise awareness, support decision making, facilitate planning and policy development through improved understanding of a complex multidimensional problem [7, 8]. This gets even more complicated when assessments of continual stress like climate change are taken into account. Moreover, it can be more challenging when local geographical, ecological and socio-economical contexts vary substantially within a given area of interest [7]. Thus, it would be unwise to adopt a national level index approach to local scale study and vice versa [9] without adequate modifications and adjustments [10]. In addition, available indices are limited in their applicability by considerable subjectivity and uncertainties in the selection of indicators [7, 8, 11, 12], their weights [4, 6], as well as by the availability of data at various scales and in space [8, 13].

There are a number of previous studies on quantifying and comparing vulnerability in terms of an index [6, 13–18]. Analysing climate vulnerability and research into the development of appropriate indicators has gained awareness since the groundbreaking paper of Smit and Wandel [19] and the IPCC assessment report published in 2007 [2]. To date, the majority of these studies have focused merely on developing a Climate Vulnerability Index (CVI) for specific climatic disasters such as droughts or floods and for specific communities. In addition, these studies were proposing policy suggestions for improved adaptation strategies and mitigation solutions. However, the CVIs used in the past studies do not explore the robustness of comparisons, significant differences of vulnerability indicators [20] or the significance of the associated policy messages at local to community level [7]. While a number of general, regional and subject-specific indicators have been developed [21], we found less work that investigated or at least discussed the issue of uncertainty. Already in 2011, Preston et al. [22] stated that “Unfortunately, the tendency within vulnerability assessments is to neglect the issue of uncertainty almost entirely—an occurrence that is likely to undermine the uptake of vulnerability assessments in decision support.” [22].

There are a few uncertainty and sensitivity analyses done for other composite indices like the Technology Achievement Index [12], Composite Learning Index [23], Social Vulnerability Index [24, 25], Human Development Index [26] and Environmental Performance Index [27] at national to global level. These studies confirm that uncertainty is an unavoidable factor for composite indices [21, 22]. The reason is that the value of a composite indicator is not a simple number, but a distribution of values. According to Saisana et al. [12], the composite

indicator’s ‘simple big picture’ may direct to misleading non-robust policy messages if they are not interpreted in combination with the sub-indicators. Thus, it emphasizes the need and urgency to conduct sensitivity analysis of CVI rather than merely developing a composite index for policy implications.

Sensitivity analysis examines the robustness, i.e. the degree of influence of each indicator on the index output, thereby revealing which input choices are most or least influential [25]. Shukla et al. [28] have evaluated solely the robustness of inherent vulnerability ranks to compare mountainous agricultural communities in Uttarakhand state of India. Uncertainty in the estimation of climate vulnerability can have several sources. The selection of the composite indicator is one of these sources. Vulnerability is largely depending on the composition and construction of the method applied, as was shown in a multi-index method intercomparison [29]. In case spatial assessment is conducted, the variability of input data introduce a further component, i.e. the spatial uncertainty [22]. Additional uncertainty can arise through weighing the various indicators or components that are used in the estimation of the vulnerability indices [29, 30]. The question remains, how much uncertainty is introduced by a single indicator into the assessment of vulnerability and how much a single (or several) indicator affects the overall outcome. Just recently in parallel to our work, Fernandez et al. [31] investigated the effect of particular indicators on the overall outcome of their index. They studied the substitutional power of indicators by various aggregation schemes. Our study takes a different approach. By adopting the bootstrap methodology we aim at identifying the robustness of our calculated index in view of the selection of input data, in our case the survey data. Through this systematic analysis of the CVI, we are able to provide the specific driving factors which contribute to the adverse effects of climate change.

For this study, we considered the CVI developed at Indian watershed community level. We are specifically interested in the climate vulnerability at watershed household level to identify the main drivers of climate change vulnerability and thus how the different implementing agencies could help to address the problems associated with climate change in future planning and implementation. In addition, we believe that climate change is particularly noticeable at this aggregation level and illustrate the differences between the Watershed Development Programmes (WDP). Fifty-five percent of Indian farmers rely on rainfed systems in which ‘delayed, deficient or erratic rains’ lead to a severe decline in productivity [32, 33]. Another stressor, climate change, affects weather patterns, availability of water, temperature and soil moisture, thereby resulting in low crop yields and degraded land with increased sensitivity of food-insecure

households [3]. To change the situation of these rain-fed areas, the Government of India initiated WDPs in 1973-74. WDP refer to the conservation, regeneration and the judicious use of all the resources - natural (like land, water, plants, animals) and human - within the watershed area. Samuel et al. [34] indicate that community-led watershed development has the potential to make a significant contribution to reduce the vulnerability, enhance resilience and build adaptive capacities of communities to climate-induced shocks. Moreover, integration of climate change aspects into ongoing development efforts with special attention to location specific knowledge is required for better adaptation strategies [35]. For this, policies and programmes need to be fine tuned with respect to technology, processes and institutions to make the watersheds more resilient to variability and extreme climate risks [34]. The assessment of vulnerability at the watershed community level has just recently begun.

A preliminary study has been conducted by us among three watershed communities in Kerala, the southernmost state of India [36]. The implementation of the programme was done by three different agencies: the State Government (SG) through the department of Soil Survey & Conservation, a Non-Governmental Organization (NGO) and the Local Self-Government (LG). Our approach used primary data collected from household surveys ( $n = 215$ ) to construct the index. Qualitative data obtained through Focus Group Discussions (FGDs) and Key Informant Interviews was used to support the results. Through a theory driven and deductive approach [37], the best possible location specific indicators were identified and aggregated at watershed community level under the three dimensions of vulnerability: adaptive capacity, sensitivity and exposure to form the index [6, 9]. Under these three dimensions, 10 major components and 59 sub-indicators for the major components were identified. The major components were calculated as an average score of the sub-indicators [6]. The CVI is then estimated as the weighted average of the major components [8]. The number of sub-indicators in each major component has been taken as the weight for calculating the CVI. More detailed information on the computation methods of the individual sub-indicators can be found in Raghavan Sathyan et al. [36] and in Additional file 1: Table A2. However, the CVIs for the three watershed communities were rather similar, while there were differences in the dimensions and major components. The results show that the watershed implemented by the NGO exhibits relatively the highest vulnerability, followed by the LG and SG. The largest difference between the watersheds was found for the exposure. Exposure was more pronounced and on a similar level in LG and NGO, while the SG depicts a substantially lower index value. As the derived CVI values for the three watersheds are almost similar, an in-depth data analysis

is necessary to identify the degree of influence of each indicator on the CVI output.

Given this background, the main objective of this paper is to develop and to apply a method to investigate the further applicability of the CVI. Despite the obvious similarities of the CVI values, we hypothesize that there exist significant differences between the dimensions and its major components for the three WDPs. The focus thereof is to explore and compare the CVIs of the three examined WDPs in more detail by obtaining the distribution and computing significant differences through bootstrapping.

Thus, we contribute to the literature in two ways. First, by introducing the use of the bootstrapping method in this field of climate vulnerability research, and second, by analysing and comparing the CVIs based on the major components in detail. Thereby, we derive a reliable statement about the significance of our results and the most influencing indicators of the CVI. The approach can be replicated to evaluate the potential effectiveness of watershed programmes, climate change adaptation programmes and to analyse the plausible impacts of climate change at local community level.

## Methods

### Theoretical framework

Vulnerability has been conceptualised and understood under various contexts. In the words of McCarty et al. [38] vulnerability to climate change is the degree to which a system is susceptible to or unable to cope with adverse effects of climate change including climate variability and extremes. It is a function of adaptive capacity, sensitivity and exposure dimensions [39]. The term 'exposure' indicates the nature and degree to which the system is exposed to climatic variations and extreme events [40]. The system's susceptibility to such kind of exposures makes it sensitive and thus vulnerable to climate change [40, 41]. But the ability of systems, institutions, humans and other organisms to adjust to potential damage via taking advantage of opportunities and thus responding to consequences make them adaptive. Thus, by increasing the adaptive capacity, the opportunity of systems to manage varying ranges and magnitudes of climate improves [19]. In a nutshell, a system is vulnerable if it is exposed and sensitive to the effects of climate change with limited adaptive capacity and vice versa [37, 42]. Hence, development programmes play a decisive role when it comes to facilitate the enhancement of adaptive capacity of the system and thus reduce the sensitivity to climate change by programmes specific interventions.

### Study area

Kerala state lies between the Arabian Sea in the west and the Western Ghats Mountains in the east. The state is

divided into three physiographically distinct regions: the eastern highlands, the central midlands and the western lowlands. It is unique in its socio-economic conditions such as high population density (859 persons/km<sup>2</sup>), high literacy (93%) with heavy unemployment, highly developed health care system and rapid urbanization [43]. Kerala experiences tropical monsoon climate with heavy annual rainfall of 3000 mm. In recent years, there is both spatial and temporal variation in monsoon rainfall [44] along with more intense short term droughts [45] compared to the previous years. The temperature reaches up to more than 32°C during March to April with a relative humidity of 73–89%. Any sort of climate change will be detrimental to thermo-sensitive crops like cardamom, coffee, tea, cocoa and black pepper cultivation in Kerala and other cropping patterns in the state [46]. In recent years, the state faces deterioration of natural resources, increased number of landslides, severe forest and biodiversity degradation, soil erosion, lower river water quality, conversion of paddy lands, water scarcity and decrease in productivity which is accelerated by the climate change dimension. Forty percent of the total cropped area is prone to soil erosion. This underlines the importance of integrated soil and water conservation programmes in Kerala on watershed basis [43]. Among the 14 districts of Kerala, Palakkad is listed as one of the highly vulnerable districts to climate change due to its specific geographic location, humid climate, high percentage of population relying on agriculture, low ranking in the human development index, high social deprivation and high degree of vulnerability to natural hazards like flood and drought with impacts on human life [43]. Thus, the district was purposively selected for the study. Based on the WDP completion year and the implementing agencies, Adakkaputhur (A. Puthur), Akkiyampadam (A. Padam) and Eswaramangalam (E. Mangalam) watersheds, implemented by SG, NGO, LG respectively, have been selected for the study. Table 1 summarizes some basic facts about these WDPs.

Each WDP is implemented according to certain guidelines issued by the central/state government. Here, the SG implemented WDP was under the National Watershed Development Project for Rainfed Areas, while the NGO and LG implemented WDPs were under the Western Ghat Development Programme. There were differences in the mode of project administration, implementation and major activities as given in Table 2. The main WDP activities carried out in the watersheds were under Natural Resource Management (NRM) which aims at conservation of soil, water and biomass, Production System Management (PSM) to increase the area and productivity and Livelihood Support System (LSS) activities to support landless and marginal sections of the community with an alternative source of income.

#### Household survey

The watersheds selected for the study have completed all the programmes activities before 2014. The household interviews were conducted during the period from August to November 2015. Out of the total 215 households covered in the field survey, 70 households were in A. Puthur (SG), 70 households in A. Padam (NGO) and 75 households in E. Mangalam (LG). Hereafter, the three watersheds are denoted as SG, NGO and LG corresponding to the names of the respective implementing agencies of WDP for better readability. The sampling method used for selection of households was cluster sampling. Based on the secondary data collected from the agricultural office of the locality, we categorized the farmers into small, marginal, medium and large farmers. Within these categories purposive selection was done to include at least one respondent from labourers, self-help group members, watershed committee members and women. To get an overview of the implementation of the programmes, two FGDs were conducted with men and women groups in each watershed. The discussions were centered on climate related extremes and contribution of the WDP activities on climate variability risk mitigation and adaptation strategies. The outcome of the FGDs were used to support the forthcoming results part.

#### Bootstrapping method

The focus of our research is to analyse and compare the climate vulnerability of the three examined WDPs in more detail. For this, we use bootstrap sampling and a leave-one-out sensitivity analysis. After introducing and computing the CVI, we are particularly interested to know if the three observed programmes are significantly different from each other or not. In general, one could use a two sample difference in the mean test for comparing mean values. Nevertheless, the usually computed Z-score or t-test is not applicable to our circumstances as we merely have one observed value without knowing the underlying data generating process of our computed parameters. In addition, there is a reason to believe that asymptotic theory provides a poor guide to the precision of our computed values as the assumption of independence might be violated.

We decided to use the bootstrapping method as an alternative way of obtaining the distribution and comparing the test statistics of interest. Introduced by Efron [47] and Efron and Tibshirani [48], bootstrap sampling has become increasingly popular in all sorts of econometric applications. Bootstrapping provides a way of finding the sampling distribution for the observed sample. The main advantage of bootstrapping is that we do not need to make an assumption about the underlying data generating process. This follows the basic idea that all information of the

**Table 1** Basic information about the watersheds under study

Criteria	A. Puthur	A. Padam	E. Mangalam
Basic Information	350	520	590
Total treatment area (ha)			
Local Self-Government (Grama Panchayat)	Pookottukaavu & Vellinezhi	Kanjirampuzha	Sreekrishnapuram
Project implementing agency	State Government (SG) through the department of soil Survey & Conservation	Non-Governmental Organization (NGO)	Local Self-Government (LG)
Project period	2003-2008	2009-2013	2007-2012
Project fund	26485 US\$	57920 US\$	82456 US\$
Socio-demography			
Population	5742	7399	6469
Households	1243	1482	1198
Literacy (%)	87.27	98.00	98.90
Educational institutions	2	3	6
Hospitals	2	2	3
Agriculture			
Marginal farmers <1ha (%)	81	92	71
Major crops	Rubber, paddy, arecanut, coconut, pepper, banana, vegetables	Coconut, arecanut, paddy, rubber, tapioca banana, pepper, vegetables	Rubber, coconut, arecanut, banana, vegetables
Livestock	Cow, goat, poultry	Cow, goat, poultry	Cow, goat, buffalo, rabbit, poultry

Source: Project reports of A. Puthur, A. Padam [57] and E. Mangalam [58] watersheds

**Table 2** The major differences in the WDPs and its implementation in the three watershed areas

Criteria	SG	NGO	LG
Objective of WDP	Holistic and sustainable development of watershed	Eco-restoration and eco-preservation	Eco-restoration and eco-preservation
Components	Development (77.5%) and management components (22.5%)	Watershed development (80%), forestry (10%) and other activities (10%)	Watershed development (80%), forestry (10%) and other activities (10%)
Major activities (% of total fund)	NRM-50% PSM- 20% LSS-7.5%	NRM-72% PSM- 5% LSS-3%	NRM-72% PSM- 5% LSS-3%
Implementation	Soil Conservation Officer through watershed committee	NGO through watershed committee and project facilitator	Grama Panchayat President through the agricultural officer and the user group
Watershed Committee	11 members	> 30 members	> 30 members
Watershed Committee meeting	Every month	Every month	Every month

Source: [43, 59]

true and unknown data generating process is included in the observed sample. If this is the case, then resampling from the observed sample is the same as randomly drawing from the data generating process of the population itself. Thus, bootstrapping allows for statistical inference based on the sampling distributions of the sample statistic of interest.

Suppose we observe the realisation  $\mathbf{x} = (x_1, x_2, \dots, x_n)$  as the outcome of an independent and identically distributed (iid) random variable  $X = (X_1, X_2, \dots, X_n)$  of the unknown Cumulative Distribution Function (CDF)  $F$ . In general, we are interested in some population parameter  $\theta = t(F)$  that is some function of the true and unknown distribution. Thus,  $\hat{\theta}_n = t(\hat{F}_n)$  is the calculated estimate of  $\theta$  from which we would like to draw inference statements. Thereby,  $\hat{F}_n$  denotes the Empirical Distribution Function (EDF) of our observed random sample with size  $n$ . The EDF is an estimate for  $F$  and is defined as the discrete distribution that puts a probability  $1/n$  on each observed value  $\mathbf{x}$ . We can use the EDF for bootstrapping since all information about  $F$  is contained in  $\mathbf{x}$  as e.g. shown by Efron and Tibshirani [48]. Thus, we define the bootstrap sample  $\mathbf{x}^* = (x_1^*, x_2^*, \dots, x_n^*)$  to be an iid sample of size  $n$  that is drawn with replacement from  $\hat{F}_n$  of our observed sample  $\mathbf{x}$ . The algorithm for the non-parametric bootstrap applied can in general be described in four steps:

1. Sample a new data set  $\mathbf{x}^*$  of size  $n$  with replacement from  $\mathbf{x}$ .
2. Compute the statistic of interest,  $\hat{\theta}^* = t(\hat{F}^*)$ , for this resample.
3. Repeat the steps 1 and 2  $N$  times, where  $N$  denotes the number of bootstrap replications.
4. Use the EDF of  $(\hat{\theta}_1^*, \dots, \hat{\theta}_N^*)$  as an approximation for the true distribution of  $\hat{\theta}$ .

Additional and more detailed information on the use and limitations of bootstrapping in econometrics can for example be found in Horowitz [49], Davidson and MacKinnon [50] and MacKinnon [51].

Based on the household surveys performed for SG, NGO and LG watershed we proceed as follows. First, we create  $N = 10,000$  bootstrap samples by sampling with replacement from the original household surveys. To be more precise, we resample the interviewed families while holding constant the answers given by each family. Thus, each new sample has the same size as the original sample we obtained for the three regions and the same structure of the answers given by the individual family. Secondly, we calculated the 59 sub-indicators for each resample as proposed by Raghavan Sathyan et al. [36]. The resulting EDF allows us in a third step to draw conclusions about the shape, mean and variance of the individual sub-indicators.

In addition, we now are able to examine the differences between the three programmes and make a statement about the statistical significance of difference in this context. The latter will be done by constructing a Confidence Interval (CI) for the parameter of interest. One could use the bootstrap percentile interval method for this purpose. This is done by ordering the bootstrap replications  $\hat{\theta}$  such that  $\hat{\theta}_1 < \dots < \hat{\theta}_N$ . Afterwards, the upper and lower confidence bounds for the significance level  $\alpha$  are computed as the  $N \cdot \alpha/2$ -th and  $N \cdot (1 - \alpha/2)$ -th ordered element. This yields the CI  $[\hat{\theta}_{N \cdot \alpha/2}, \hat{\theta}_{N \cdot (1 - \alpha/2)}]$ . Generally, this will be an appropriate solution if the observed distribution is symmetric.

Nevertheless, if the distribution is skewed or heavily tailed, the percentile interval will be too narrow. Thus, we use the bias corrected and accelerated percentile method ( $BC_a$ ), which has a smaller coverage error in this situation [52]. Now, we can use the  $BC_a$  CI to test whether

the difference between the CVI of any two regions A and B is significantly different from zero. Therefore, we compute the bootstrap distribution of the difference between A and B by subtracting  $\hat{\theta}_A$  from  $\hat{\theta}_B$ . Thus, we can use an approximate two-sided test of a null hypothesis of the form  $H_0 = \hat{\theta}_A - \hat{\theta}_B = 0$  vs. the alternative hypothesis  $H_1 = \hat{\theta}_A - \hat{\theta}_B \neq 0$ . Then, we construct the  $BC_a$  CI for the difference distribution under the null hypothesis. We reject  $H_0$  on the significance level  $\alpha$  if 0 lies outside the computed CI.

## Results

In order to evaluate the climate change adaptation strategies of the three investigated watershed programmes, the bootstrap results will be discussed first. Subsequently, the distribution of the CVIs, the three dimensions adaptive capacity, sensitivity and exposure as well as the ten major components will be examined using descriptive statistics. Thereby, we can address a systematic distortion of the evaluated components and get a first insight into the driving factors of the vulnerability. Moreover, we discuss if there exists a significant difference between the WDPs using the two-sided bootstrap test described above. Furthermore, we conducted a sensitivity analysis to identify the importance of the ten major components on the overall CVIs using a leave-one-out sensitivity analysis.

### Descriptive analysis

Figure 1 shows the box plots for the ten major components sorted by the three dimensions. When comparing the individual components of the adaptive capacity in Fig. 1a-e, one can observe that the median values are to some extent different between the regions while the variation seems to be comparable over all major components.

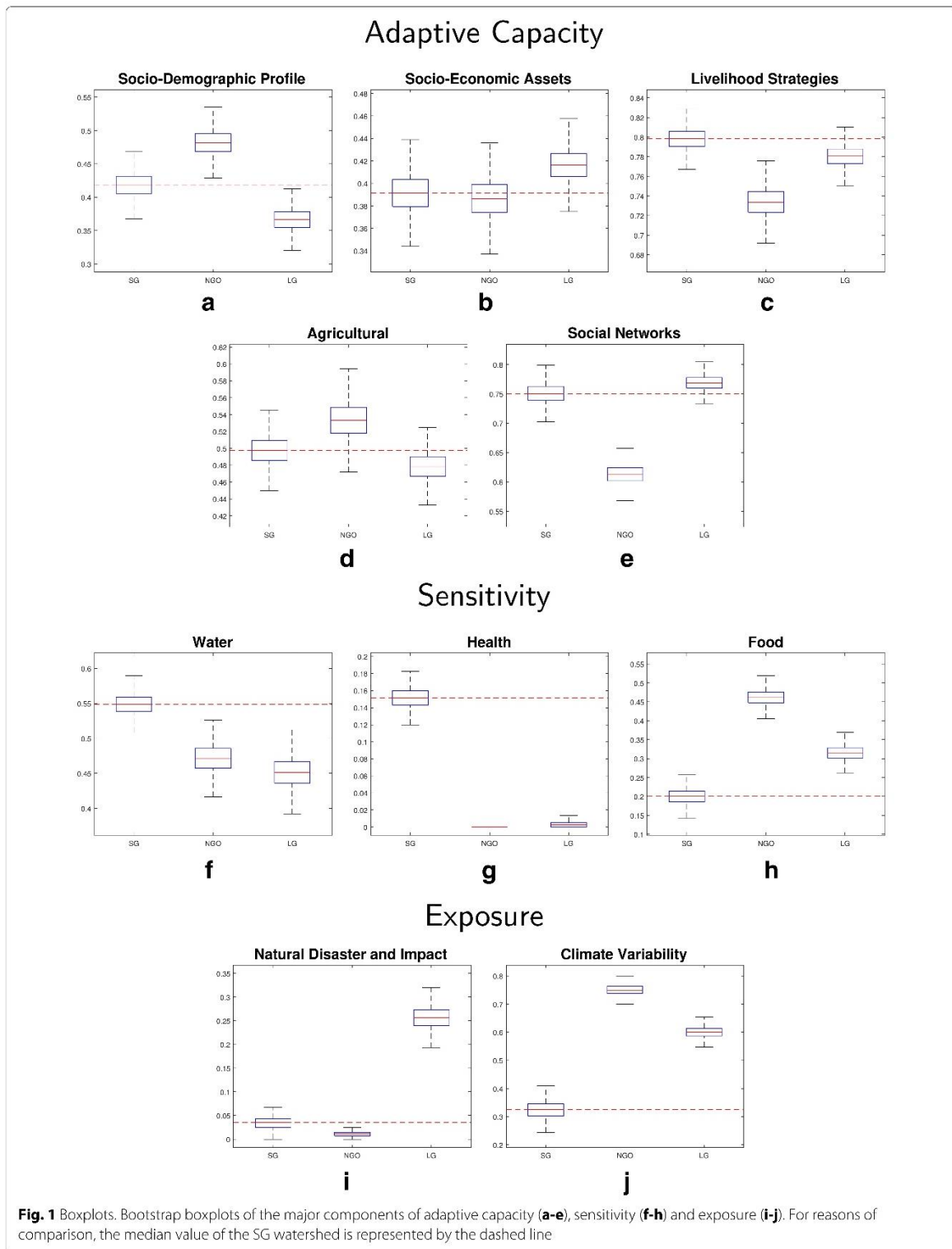
Of particular importance is that the strong overlap of the range between the whiskers for 'Socio-Economic Assets', 'Livelihood Strategies' and 'Agricultural' provides an initial indication that these components might not be significantly different. This does not hold for the 'Socio-Demographic Profile' and 'Social Network'. Here, there appears to be a noticeable difference between the medians. In addition, there seems to be a general tendency of the median of SG and LG watersheds to being closer together than NGO. A different picture emerges for the sensitivity and exposure dimension shown in Fig. 1f-h and i, j. While the component 'Water' displays an overlap between the regions, 'Food' and 'Climate Variability' seem to differ substantially. The components 'Health' and 'Natural Disaster and Impact' are problematic in a different sense. Due to the highly homogeneous answers given by the families in the original sample, the bootstrap distribution reveals gaps and therefore deviates from the other distributions. For instance, all of the interviewed families

in the NGO implemented watershed responded that there were no health issues in their region. Thus, if there is no or little variability in the data, the bootstrap method reveals limitations since almost all of the variation of the bootstrap distributions comes from the original sample. Thus, even increasing the number of bootstrap samples would not enlarge the variation substantially in this situation.

Next, we consider the three different dimensions of vulnerability and the CVIs in more detail. Table 3 summarizes the location and control parameters of the respective distributions. Although the mean of the CVI values and adaptive capacity are close together for the three regions, sensitivity and exposure demonstrate a distinct difference in relation to the mean vulnerability. Furthermore, six out of the twelve bootstrap distributions are not normally distributed on a significance level based on a Jarque-Bera Test. Figure 2 visualizes the difference between the distributions with a histogram and kernel density plot. The kernel density plots display a kernel density which has been estimated using a triangular kernel with a bandwidth of  $j = 0.9T^{0.2} \cdot \min(\sigma, IQR/1.34)$  suggested by [53], where IQR denotes the Inter Quartile Range. Thereby, we emphasize that there might be a significant difference for the mean values at least for exposure (c) and in parts for sensitivity (d). At the same time CVI (a) and adaptive capacity (b) plots indicate no significant differences between the WDPs.

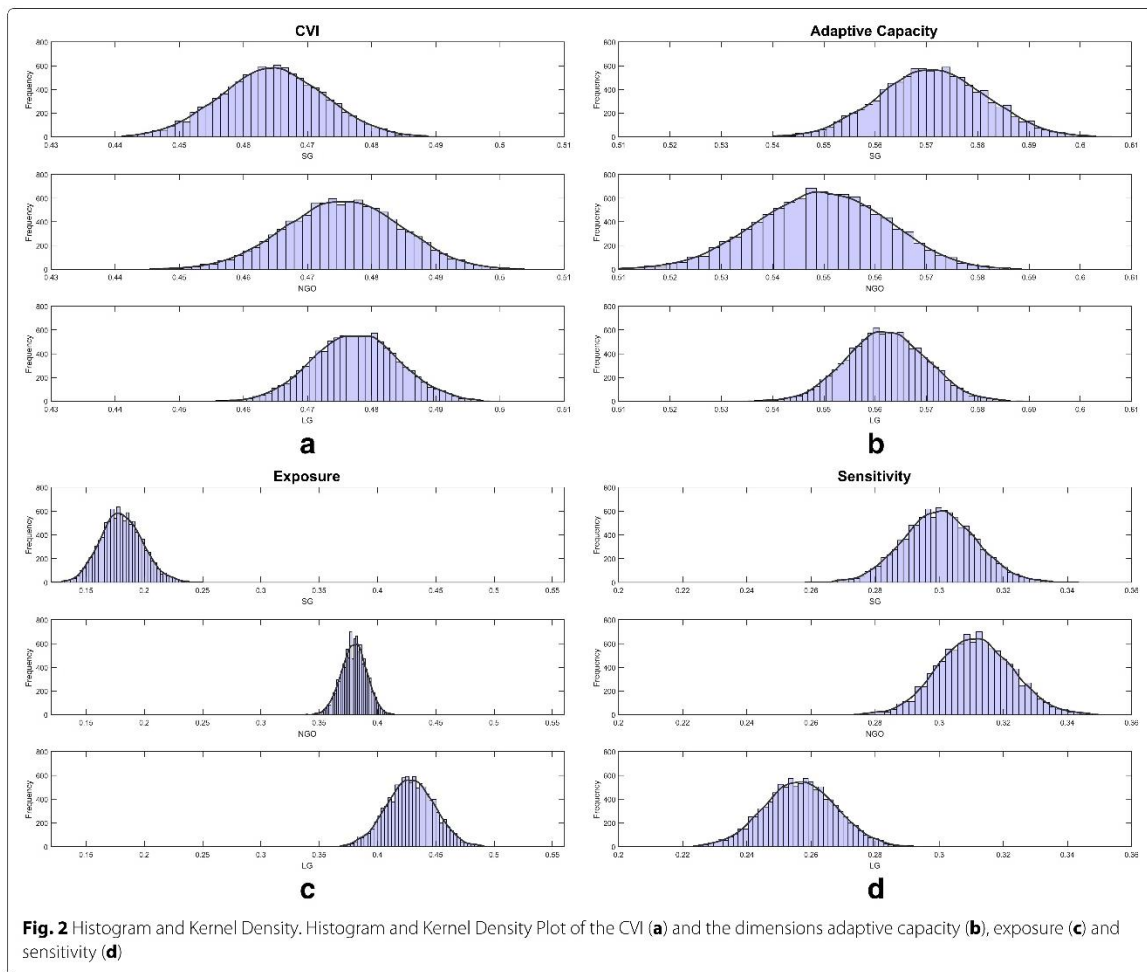
### Significant differences

The significant differences will be examined based on the two-sided test described in the method section. Table 4 summarizes the mean values and the significance of the three null hypotheses:  $H_0 = \hat{\theta}_{SG} - \hat{\theta}_{NGO}$ ,  $H_0 = \hat{\theta}_{SG} - \hat{\theta}_{LG}$  and  $H_0 = \hat{\theta}_{NGO} - \hat{\theta}_{LG}$ . The results confirm our initial impression that the three regions are not significantly different in terms of their overall CVIs. Nevertheless, we find significant regional variations for most of the major components as well as for the dimensions, exposure and sensitivity; except for adaptive capacity. At the same time there are significant differences in a few major components of adaptive capacity between the programmes. The major components of the dimension adaptive capacity, 'Socio-Demographic Profile' and in parts 'Livelihood Strategies' and 'Social Network' display significant differences between the three watershed programmes. Aside from 'Socio-Demographic Profile', there is no significant difference for any of the major components between SG implemented and LG implemented watersheds for the adaptive capacity dimension, which again confirms our initial statement that these two regions and WDPs respectively seem to be similar. The major component 'Food' under the sensitivity dimension exhibits significant differences between the three programmes while the other components 'Water' and 'Health' show significant



**Table 3** Statistical summary of the distributions of the dimensions and the CVI

Index	Watersheds	Mean	Median	Std.	Skewness	Kurtosis	Normality
Adaptive	SG	0.5712	0.5712	0.0104	0.0345	2.9170	Yes
Capacity	NGO	0.5496	0.5496	0.0126	-0.0943	2.9436	No
	LG	0.5622	0.5621	0.0077	0.0083	3.0005	Yes
Sensitivity	SG	0.3001	0.3001	0.0113	0.0482	3.0407	Yes
	NGO	0.3112	0.3111	0.0116	0.0481	3.0744	No
	LG	0.2566	0.2566	0.0110	0.0096	2.8875	Yes
Exposure	SG	0.1804	0.1800	0.0179	0.1570	3.0464	No
	NGO	0.3797	0.3800	0.0108	-0.1042	3.0506	No
	LG	0.4283	0.4283	0.0203	0.0145	2.9148	Yes
CVI	SG	0.4645	0.4645	0.0080	0.0260	2.9037	Yes
	NGO	0.4755	0.4756	0.0090	-0.0697	2.9413	No
	LG	0.4776	0.4775	0.0066	0.0236	2.8828	No



**Fig. 2** Histogram and Kernel Density. Histogram and Kernel Density Plot of the CVI (a) and the dimensions adaptive capacity (b), exposure (c) and sensitivity (d)

**Table 4** Significant differences between major components, dimensions and the CVI

Division	Subdivision	$\hat{\theta}_{SG} - \hat{\theta}_{NGO}$	$\hat{\theta}_{SG} - \hat{\theta}_{LG}$	$\hat{\theta}_{NGO} - \hat{\theta}_{LG}$
Major components	Socio-Demographic profile	<b>-0.0632</b>	<b>0.0519</b>	<b>0.1152</b>
	Socio-Economic Assets	0.0049	-0.0247	-0.0296
	Livelihood Strategies	<b>0.0643</b>	0.0175	<b>-0.0468</b>
	Agricultural	-0.0355	0.0190	0.0544*
	Social Network	<b>0.1379</b>	-0.0184	<b>-0.1564</b>
	Water	<b>0.0773</b>	<b>0.0975</b>	0.0202
	Health	<b>0.1516</b>	<b>0.1489</b>	-0.0027
	Food	<b>-0.2620</b>	<b>-0.1158</b>	<b>0.1462</b>
	Natural Disaster	0.0250**	<b>-0.2209</b>	<b>-0.2459</b>
	Climate Variability	<b>-0.4235</b>	<b>-0.2747</b>	<b>0.1488</b>
Dimensions	Adaptive Capacity	0.0217	0.0091	-0.0126
	Exposure	<b>-0.1993</b>	<b>-0.2478</b>	<b>-0.0486</b>
	Sensitivity	-0.0110	<b>0.0435</b>	<b>0.0546</b>
Index	CVI	-0.0110	-0.0130	-0.0021

Bold values denote a significance level of  $P < 0.01$ , \*\* and \* 0.05 and 0.1, respectively

differences only in part. To be precise, there is no significant difference between WDPs implemented by NGO and LG in the 'Water' and 'Health' components. Under the exposure dimension, the 'Climate Variability' component is significantly different in all of the three watersheds.

Additional file 1: Table A1 depicts the results of all components based on the mean of the bootstrap distributions. Thereby, the indicator values for the sub-indicators 'Family dependency index', 'Poverty index', 'Indebtedness index', 'Percent of high income household' and 'Religious diversity index' show high variation among the watersheds.

For instance, the 'Family dependency ratio' was the highest for the WDP implemented by NGO (0.506) while the LG WDP had the least (0.285). In NGO, 40% of the households had to take care of members aged above 60 years in addition to the school attending children. The increased number of young children and ailing elderly people demand lots of time, resources and energy from the earning members in the family and particularly the women [54]. This reduces the adaptive capacity and thus adds to the climate vulnerability. In addition, 80% of the interviewed households were in debt in the SG implemented watershed while only 59% in the LG implemented faced this problem.

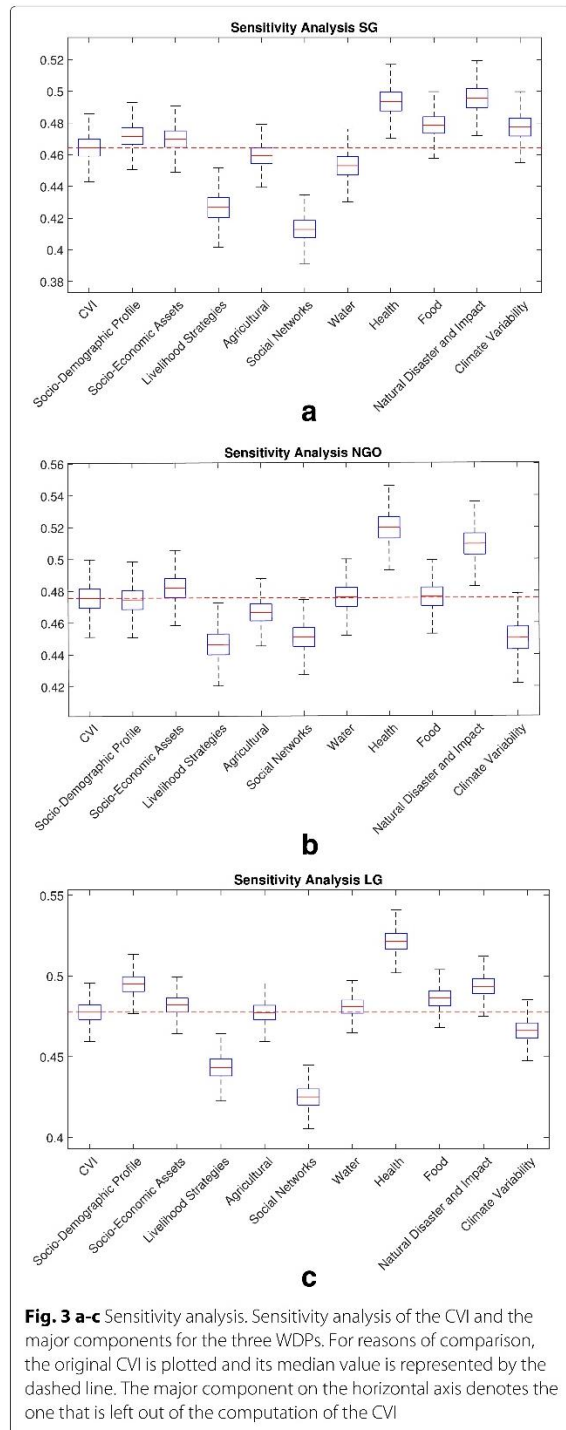
In the SG WDP, most of the crop loans availed were utilized for non-productive purposes. Hence, the families could often not pay back their loans on time. This again emphasizes, that there exists a great variation in the major component 'Socio-Demographic Profile' between the three watershed programmes. While considering the

major component 'Social Networks', we found distinct variations in the sub-indicators among the three watersheds. The 'Percent of beneficiaries', 'Percentage of households with membership in cooperative institutions' and 'No beneficiary contribution' were with wider variations compared to other sub-indicators. Twenty-eight percent of the households received some kind of benefit from the programme in the LG watershed while there was a greater share (66%) for the SG watershed. Among the beneficiaries in SG, 68% were neither aware about the beneficiary contribution nor contributed their share for the activities undertaken in their fields. Only 3% of the beneficiaries in the NGO watershed have not contributed to their part for benefits. This variability contributes to the significant differences in the 'Social Network' component among the three watersheds.

Moreover, the LG watershed reacts significantly less in terms of 'sensitivity' as compared to SG and NGO. Due to the aggregation/construction scheme of all the indicators, we find no difference between the latter two. Although there exist significant differences for all three major components, 'Water' and 'Health' offset the oppositely directed value of 'Food' almost completely. The sub-indicators 'Poor support from the government' contributed to this variability in the 'Food' component. Ninety-four percent of the households in the NGO watershed opined that there were no improvements in government support for food sufficiency enhancement in general and through the Public Distribution System (fair price shops for food grains) in specific. But only 6% of the households in the SG watershed were in disagreement with government support. This wider variation in opinion could explain the significant difference in the 'Food' component. Furthermore, the LG watershed reacts most vulnerable to the exposure dimension, followed by the NGO and SG watershed communities. This is not surprising as the LG watershed was heavily affected by wind in 2015 which led to crop loss and property damage while the other two were not affected by such catastrophes. In the SG watershed, only 60% of the households opined Medium-High and High temperature increase during the last ten years while it was 94% and even 99% for the NGO and LG watersheds, respectively. Extreme climate event incidences were the highest in the LG watershed with an index value of 0.573 while the least was 0.043 in NGO. In addition, 'Climate Variability' is also significantly different between the three regions. The SG implemented watershed is least affected followed by the LG and NGO watersheds.

#### Sensitivity analysis

We complete our study by conducting a leave-one-out sensitivity analysis which means that we compute the CVI again by leaving out one major component at a time. This



**Fig. 3 a-c** Sensitivity analysis. Sensitivity analysis of the CVI and the major components for the three WDPs. For reasons of comparison, the original CVI is plotted and its median value is represented by the dashed line. The major component on the horizontal axis denotes the one that is left out of the computation of the CVI

allows for a more detailed look at the importance of the individual indicators. We use the already familiar boxplots in Fig. 3 to summarize the main findings.

For reasons of comparison, the original CVI is plotted and its median value is represented by the dashed line. Except for the 'Socio-Demographic Profile', 'Climate Variability' and 'Water', we find consistent results for the direction of change of all other major components on the CVIs of the three watershed programmes. Thus, 'Socio-Economic Assets', 'Health', 'Food' and 'Natural Disaster and Impact' when left out of the computation, lead to a higher CVI. Thus at present watershed community level, these components are contributing well to the non-vulnerable situation. On the other hand, if we neglect these major components and sub-indicators, it seemingly leads to a more vulnerable community. In addition, 'Livelihood Strategies', 'Agricultural' and 'Social Network' have a diminishing effect on the overall CVI for all three regions. It indicates that at present it holds a high vulnerable index value. Consequently, these are the major areas where policy interventions should be performed. Of particular relevance seems to be 'Livelihood Strategies' and 'Social Network' for the vulnerability analysis. These components have a negative effect and increase the vulnerability of the observed region.

In addition, we find differences between the regions for the remaining major components. While the 'Socio-Demographic Profile' has a negative effect in SG and LG, it is positive for NGO on the vulnerability. 'Water' has a positive impact in SG, almost none in NGO and a negative one for LG watershed. Furthermore, a higher 'Climate Variability' leads to an increase in vulnerability in NGO and LG, while the effect is opposite for SG. Especially, the effects of 'Livelihood Strategies' and 'Social Network' on the overall CVI leave room for improvement of the adaptation strategies and allows us to draw policy implications for the three watershed programmes in the discussion part.

## Discussion

Composite indices are an analytical, communicative, and collaborative tool, which help to raise awareness and improve understanding of a complex, multidimensional issue. An index can be better communicated to policy makers, stakeholders and decision makers when the sensitivity of the input factors are taken into consideration. When it comes to the reduction of climate vulnerability, community-level watershed programmes play an important role to build up adaptive capacities to climate induced shocks [34]. Thus, the main focus of our research was to do an in-depth analysis of the already developed CVI, a composite indicator, of three WDPs implemented by different agencies. Here, we assessed the vulnerability based on its three dimensions adaptive capacity, sensitivity and exposure. We have investigated the significant differences between the CVIs, its dimensions and done sensitivity analysis of the CVI for the three watershed communities.

To our knowledge, this is the first time of such a thorough statistical analyses of CVI other than local sensitivity analysis performed to address the change in the ranks of inherent vulnerability of mountain agricultural communities at village level done by Shukla et al. [28]. Their main consideration was based solely on adaptive capacity and sensitivity of the communities. In contrast to Shukla et al. [28], we focused on the sensitivity analysis of the CVI and addressed the systematic distortions of the evaluated components, which allowed us to identify the driving factors of vulnerability.

Our study put forward two major features of vulnerability in the WDP areas. First and foremost, there are no significant differences in the adaptive capacity between the three communities while there are significant differences in sensitivity and exposure dimensions. The WDPs have equal opportunity to improve and enhance the adaptive capacity of the community through region-specific policies. Pandey and Jha [15] assessed and compared the vulnerability of lower Himalayan households, but stated only minor differences in the CVI and component values. One of the main limitations of the study was statistical variability. In addition, Chaliha et al. [14] investigated the vulnerability in villages of flood prone district of Assam, India. The authors faced the problem of missing some of the indicator values in the field survey as well as carrying out the normalisation of the indicators throughout. Even though it was a bottom up level study useful for microlevel planning, the limitations have greater influence in formulating efficient adaptation measures to flood in the district.

Secondly, the sensitivity analysis of the CVI shows that 'Livelihood Strategies' and 'Social Network' are the most influencing major components of vulnerability in all the watersheds. This suggests that one should focus on these two major components in order to improve the WDPs. Policy makers may enact measures to promote diversification of livelihoods, ensure peoples participation in developmental programmes, promote capacity building programmes to augment social capital and improve access to information technology for better communication. This stands in line with the results of Shukla et al. [28] that 'Livelihood Dependency' and 'Institutional Capacity' were the sub-dimensions which influenced the vulnerability ranking of villages in Uttarakhand state of India. The statistical property consideration of vulnerability dimensions and underlying indicators provide clear motivation to focus on the key areas of interventions [25]. A single aggregate index representation of climate vulnerability dimensions like adaptive capacity may be appealing for policy makers but would be inaccurate and highly misleading [9]. Moreover, vulnerability assessments based on indicators are not robust to changes in the assumptions with respect to the substitution or compensation between

the indicators [31]. Thus a continual process of refinement is essential so that the indicators and the index have the greatest possible validity and thus utility [13].

There are other components of uncertainty which need to be explored in future research such as data uncertainty, uncertainty in building a composite index such as alternative normalisation methods for sub-indicator values and different weighting approaches of the sub-indicators. This study used household surveys for primary data collection. Even though survey research has expanded to address complex substantive issues, there has been a growing reluctance among many households to participate in surveys. The demographics, economic conditions, environmental influences, culture and societal differences such as average household size, or percentage of young children may have influenced our survey leading to wrong judgement by interviewers and interviewees. This in turn leads to increased uncertainty about the performance of survey design, challenges the cost of data collection in meeting the goals for numbers of interviews [55] and eventually the quality of resulting statistics [55, 56]. We also faced such kind of issues in this survey research. Because of some vague answers, non-responsiveness, general uncertainty and the limited data of questionnaires, it is important to assess how uncertain and reliable the CVIs are.

### Conclusion

This paper introduces the bootstrapping technique into CVI sensitivity analysis and considered a part of the underlying uncertainty which is replicable for any bottom up level vulnerability assessments. Index development involves different steps such as indicator selection, variable transformation, weighting, aggregation and plausible subjectivity on selection [25]. So, as to address these issues the composite index should be tested using uncertainty analysis to add transparency to the index construction process and explore the robustness of composite index design [8, 9]. The future research may concentrate on such refinement of index composition and construction method to improve the reliability and accuracy of the index results.

### Additional file

**Additional file 1: Table A1.** Bootstrapped mean index values for the sub-indicators under the major components. **Table A2.** Dimensions, major components and sub-indicators of the CVI. Adapted from [36]. (PDF 196 kb)

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**Competing interests**

The authors declare that they have no competing interests.

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## Chapter 5

Funk, C., Raghavan Sathyan, A., Winker, P. and Breuer, L. 2018. Changing Climate - Changing Livelihood: Smallholder's Perceptions and Adaption Strategies, *The Journal of Environmental Management* (Submitted).

## **Changing Climate - Changing Livelihood: Smallholder's Perceptions and Adaption Strategies**

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### **Abstract**

Smallholder farmers in the tropics are the most susceptible to climate change while they are responsible for a large share of the world's food production. The low resource use efficiency, resource scarcity and the overdependence on natural resources for a living make them highly vulnerable to climate-induced shocks. The selection of effective adaptation strategies is one of the key challenges for smallholders to reduce their vulnerability. Farmers' perception of changing climatic parameters and their decision leading to the selection of adaptation strategies are closely interconnected. Thus, in this study, we analyze how the perceived climate change affects the adaptation strategy decision process among smallholders in three watersheds of southern India. The study employs data collected from 215 household surveys using a binary logistic model. We find that farmers perceive a substantial rise in temperature and an increase in perceived erratic monsoon occurrence. There exists a considerable variation for the three regions when it comes to the actual use of adaptation strategies. The households use various adaptation methods such as information communication technology, crop and farm diversification, social networking through cooperatives, soil and water conservation measures simultaneously. Results of the binary regression model reveal that the age of the household head, education, gender, household size, household assets, livestock, poverty status, farm size, and extension services significantly influence the choices of adaptation measures used to cope with climate change.

**Keywords:** Smallholders, watershed, climate change, perception, adaptation strategy

## **1. Introduction**

Climate change is one of the most important challenges of our time. This holds especially true for most of the developing countries in the tropics and subtropics as they are expected to be hit hardest by climate change (Burney et al., 2014; Hertel et al., 2010). Potential negative implications, among other things, are a decline in agricultural production (Frank et al., 2012), no access to safe water, increased livelihood insecurity, and a downward spiral in human development dimensions (Parry et al., 2007).

Moreover, most tropical countries own a large share of poor smallholder farmers (Harvey et al., 2014), which according to the World Bank (2003), can be defined as those with a low asset base which are operating less than 2 hectares of cropland. Of the world's more than 570 million farms, at least 90% are estimated to be run by an individual, small group of individuals or households (Lowder et al., 2016). In total, around 2.5 billion of the 3 billion people living in rural areas are relying on farming as their main source of income (FAO, 2013) and 84% of them are smallholders (Lowder et al., 2016). This is particularly problematic as their limited resources prevent them from coping with climate-induced shocks (Frank et al., 2012; Harvey et al., 2014) which in turn adds to their vulnerability (Jarvis et al., 2011).

The phenomenon of smallholder farming is especially pronounced in Asia, where India ranks second with a total of 78% of the farmers' population relying on smallholder farms. A majority of these farmers live in rainfed areas characterized by rainfall variability, temperature fluctuations and frequent droughts. As a consequence, millions of these farmers will be affected by immediate hardship and hunger as they are less able to make adequate decisions about when to sow, what to grow, and how to time inputs (National Intelligence Council, 2009). However, these impacts are locally specific and hard to predict (Morton, 2007). As climate change impacts are increasingly observed and felt by smallholder farmers (Amare et al., 2017; Yila et al., 2013), there is an urgent need to identify approaches and strategies which enhance the adaptive capacity of farmers, their households and communities (Frank et al., 2012; Harvey et al., 2014). Thus, it is necessary to understand how farmers perceive various climatic changes and how this leads to the selection of strategies and ultimately to the adaptation decision.

There exists a large number of studies that deal with climate change perception (Uddin et al., 2017; Mamba et al., 2015; Udmale et al., 2014; Juana et al., 2013; Banerjee, 2015), determinants of adaptation strategies (Banerjee, 2015; Benson et al., 2015; Burney et al., 2014; Bryan et al., 2009; Gbetibouo, 2009; Mamba et al., 2015; Ndamani et al., 2016; Yila et al., 2013) and barriers in adoption of adaptation strategies across various countries among farmers (Alemayehu et al., 2017). Yet, little is known about smallholder farmers and their perception and adaptation strategies in rainfed tropics.

The adaptation is a complex process with interconnected factors and actors, which includes interaction with the environment, resources and institutions (Adger, 2006). To get into this process, farmers should first perceive climate change and variability and then identify the adaptation measures (Maddison, 2007). Perception is the process of receiving external stimuli and converting them into psychological responsiveness based on the past and present situation (van den Ban et al., 1996). In a climate vulnerability scenario, farmers perceive specific weather parameters such as the onset of monsoon, increase in temperature, intense summer, or the unpredictability of seasons. The distribution, periodicity and effectiveness of rain fall and temperature fluctuations affect the farmers' decision to grow a crop and thus, the success of farming. Various studies across North India and dry areas of Tamil Nadu recorded the farmers' perception of declining rainfall, the erratic onset of monsoon, increasing intense rainfall, increasing heat intensity (Banerjee, 2015; Kelkar et al., 2008) and increasing dry spells (Varadan et al., 2014).

Without adaptation, it is difficult to survive with farming especially for small holders who depend solely on farming and natural resources for their livelihood. Thus, 'adaptation in agriculture is rather the norm than the exception' (Rosenzweig et al., 2007). Previous studies show that farmers adapt according to agricultural systems, location (Rosenzweig et al., 2007) and the perceived changing climatic conditions (Mamba et al., 2015; Uddin et al., 2017). At the same time, the access to technologies, support from institutions, local and community involvement (Banerjee, 2015) are vital towards the process of adaptation.

Available studies indicate that farmers adapt to the existing climate change situation in different ways, such as by selecting different crops and varieties (Dhanya et al., 2016; Hassan et al., 2008; Ndambiri et al., 2013), adjusting sowing and planting dates (Deressa et al., 2009; Mengistu, 2011; Ravi Shankar et al., 2013), shifting in cropping patterns (Banerjee, 2015), introducing livestock (Ndambiri et al., 2013; Yila et al., 2013), improving water management

practices (Banerjee, 2015; Burney et al., 2014), adapting soil conservation measure (Deressa et al., 2009), or migrating to less vulnerable regions (Ravi Shankar et al., 2013).

The main research studies undertaken in India include farmers' perception of climate change and adaptation strategies in the semi-arid tropics of South India (Dhanya et al., 2016), and impacts of climate change in the semi-arid tropics of Maharashtra and Andhra Pradesh (Banerjee, 2015). Banerjee (2015) also studied the adoption decisions of farmers specifically in improved water management and perceived capacity across villages in Maharashtra and Andhra Pradesh. Studies on perceptions of climate change and adaptation strategies in the semi-arid India reveal the importance and limited availability of local specific adaptation strategies (Banerjee, 2015; Dhanya et al., 2016) and policies with respect to farmers' concerns and responses regarding climate variability. Such kind of studies can assist policy makers, donors and researchers to better understand the situation and thus, lead to efforts to reduce the adverse effects and vulnerability due to climate change. However, limited information is available in this regard, especially at the watershed level in India.

Our research fills the gap in the existing literature by investigating not only how households perceive climate change but also by determining the main drivers that influence households' choices of adaptation measures for the specific case of Watershed Development Programs (WDP) in Kerala, India. WDPs have been initiated by the government of India for enhancing the potential of ecosystem resources and the socio-economic situation of the community in semi-arid regions. Watershed development can be seen as a multi-sectorial intervention that is specifically designed to reduce the risk associated with rainfed farming which could act as a tool for disaster management (Eriksen et al., 2007; Kerr, 2007). This study is based on three watersheds where WDPs have been implemented. We use data from previous work that focused on the establishment of a Climate Vulnerability Index for Rainfed Tropical Agriculture  $CVI^{RFT}$  (X, X, X). The  $CVI^{RFT}$  is based on data collected through household surveys, and is used to compare the climate vulnerability of three different watershed communities in Kerala, India. The index provides an overall picture of the levels of vulnerability, but an in-depth analysis of the stressors and promoting factors to adaptation measures is beyond the  $CVI^{RFT}$ . We, therefore, focus this study on the micro-level, specifically on how smallholder households perceive climate change and what the main drivers or determinants are that influence the households' choices of adaptation measure. Thus, we analyse the probability of adopting different climate change adaptation strategies

used by smallholder farmers to cope with perceived climate change by binary logistic regression modelling.

This paper is organized as follows. Section 2 gives a brief overview of the underlying concepts, the study area, the collected data, the empirical approach and the used explanatory variables for our regression model. Section 3 provides a description of the adaptation strategies and discusses our model results. The concluding remarks and policy implications are presented in section 4.

## **2. Methodology**

### *2.1 Description of the study area*

Kerala is the long strip of land located in the southwest tip of India with the Arabian Sea in the west and the Western Ghats mountains in the east. The state is divided into three geographical distinct regions: the eastern highlands (600 m and above), the central midlands (300-600 m) and the western low lands (below 300 m). The state ranks the highest in India with regard to the human development index with a high literacy (93%) and high health indicators along with rapid urbanization (Government of Kerala, 2016). The unique feature of farming in Kerala is that it is based on homesteads, a system for the production of subsistence crops for his family by the farmer – who may or may not opt for any additional production of crops (Soemarwoto, 1987). This includes a large number of food crops, plantation trees, fruit plants, vegetables and tuber crops grown with livestock, mainly for the purpose of satisfying the farmers' basic needs 63% of the total cultivated area is under cash crops like cashew, rubber, pepper coconut, cardamom, tea and coffee while 10% is under food crops like rice and pulses (Government of Kerala, 2017). Around 16% of the total cropped area is under irrigation (Government of Kerala, 2017).

In Kerala, the land reforms of the 1960s gave title ownerships to 1.5 million tenants. The land reforms inhibited free capital formation in the agricultural sector and restricted the scope of large-scale farming. The successive divisions of the joint families, through the subdivision of the inherited land, led to the emergence of a large number of small and marginal holdings (Mahesh, 2010). As a result, the agrarian structure of Kerala is dominated by the large-scale presence of marginal holdings (99%) which cultivate 77% of the total farming area (Government of Kerala, 2014). In addition, 94% of these marginal holdings are of an average size of 0.16 Ha. The agricultural income per hectare in the state during the year is too low for

the farm families to subsist on. Thus, the alarming number of smallholders in Kerala and the high dependency on monsoon and natural resources reduce the ability and coping efforts to adapt to socio-economic and environmental adversities.

Kerala has a tropical monsoon climate with the highest annual rainfall rates of 3,000 mm in India. It is known as the 'Gateway of summer monsoon' over India (Krishnakumar et al., 2009). Spatial and temporal variations in monsoon rainfall make the state extremely vulnerable to climate change (Nair et al., 2014). There has been a significant decrease of annual rainfall together with a decrease in the southwest monsoon (Krishnakumar et al., 2009; Nair et al., 2014; Thomas et al., 2016; Government of Kerala, 2014) and an increase in the northeast monsoon (Guhathakurta et al., 2008). Highest temperatures up to 40°C and above are recorded from March to April. A wide range of thermosensitive crops is grown all over the state like for instance cardamom, coffee, tea, cocoa and black pepper which makes the cropping pattern in Kerala highly vulnerable to any change in climatic condition (Krishnakumar et al., 2009). In recent years, the state faces a deterioration of natural resources, increased number of landslides, severe forest and biodiversity degradation, decrease in river water quality, conversion of paddy lands, higher water scarcity and a decrease in productivity which is accelerated by climate change impacts. Moreover, 40% of the total cropped area is prone to soil erosion. Recently, the state has suffered from its worst monsoon flooding in a century with around 400 deaths and a displacement of around one million people.

### *2.2 Data Base and Empirical Model Development*

We use data collected from 215 household interviews between August and November 2015. Out of these households, 70 households were located in Adakkaputhur and Akkiyampadam, and 75 households in Eswaramangalam watersheds, all located in Kerala. The full survey and the data collected is described by X. In short, we collected quantitative data for 59 indicators, ten major components and three dimensions of vulnerability. The interview schedule consisted of three broad parts: (i) basic information about the households, (ii) information on adaptive capacity, adaptation strategies and sensitivity and (iii) perception on natural disasters and climate variability.

We use a binary logistic model to analyze the determinants that influence the choice of adaptation measures applied by the households in the three different study areas. We follow the assumption that a farmer needs to realize a change in climatic conditions first and

perceive that this change will increase the risk of a loss in crop production or represents a threat to their well-being (Bryan et al., 2009; Kato et al., 2011). Consequently, we assume further that farm households will implement climate change adaptation strategies if this leads to an increase in their expected net farm benefits or to a reduction in the risk of crop production (Abid et al., 2015). Suppose now the following model:

$$y_{i,j}^* = X_{i,j}\beta_j + \varepsilon_{i,j} \quad (1)$$

where  $y_{i,j}^*$  is a latent variable for household  $i$  which is adapting strategy  $j$ .  $X_{i,j}$  denotes a matrix of  $k$  exogenous explanatory variables that influences a household's perception of adaptation to climate change which are summarized in Table 3.  $\beta_j$  is a vector of coefficients (including a constant) of the binary regression model and  $\varepsilon_{i,j}$  the corresponding error term for model  $j$ , which has a mean of zero and a standardized logistic distribution with a variance of  $\pi^2/3$ . We do not observe the net benefit of adapting directly, but rather  $y_{i,j}$ , which takes on values of 0 or 1 according to the following rule:

$$y_{i,j} = \begin{cases} 1 & \text{if } y_{i,j}^* > 0 \\ 0 & \text{if } y_{i,j}^* \leq 0 \end{cases} \quad (2)$$

Thus, the conditional probability that  $y_{i,j}$  equals one is

$$\begin{aligned} \mathit{prob}(y_{i,j} = 1|x) &= \mathit{prob}(y_{i,j}^* > 0|x) \\ &= \mathit{prob}(\varepsilon_{i,j} < X_{i,j}\beta_j|x) \\ &= \frac{\exp(X_{i,j}\beta_j)}{1 + \exp(X_{i,j}\beta_j)} \\ &= \Lambda(X_{i,j}\beta_j) \end{aligned} \quad (3)$$

where  $\Lambda(\cdot)$  is the cumulative distribution function of the logistic distribution. One of the limitations of the logit approach is that only the signs and the significance of the coefficients reported in the resulting regression can be interpreted directly in a meaningful way. However, we can compute the marginal effects for continuous variables from the coefficients by taking the derivative of the probability with respect to one element  $k$  of  $X$

$$\frac{\partial E(y_{i,j})}{\partial X_k} = \frac{\exp(X_{i,j}\beta_j)}{(1 + \exp(X_{i,j}\beta_j))^2} \beta_k \quad (4)$$

Thus, the marginal effect varies with the values of  $X$ . One could report the marginal effects either for the sample mean of the data or as the mean of the marginal effects over all observations. As most of the literature focuses on reporting marginal effects rather than odds ratios, we also report marginal effects for reasons of comparison in the Appendix in Tables A.1 and A.2. In addition, reporting marginal effects for dummy variables is not appropriate as the derivative with respect to a small change does not apply to the change of state for a dummy variable (Greene, 2012). In such a situation, the comparison of groups would be more appropriate. Nevertheless, the logit approach allows for another common way of interpreting the coefficients, which is used in this work. We will interpret the coefficients in terms of marginal effects on the odds ratio rather than on the probability. Using  $p = \frac{\exp(X_{i,j}\beta_j)}{1 + \exp(X_{i,j}\beta_j)}$  we can calculate the odds ratio as

$$\begin{aligned} \frac{p}{1-p} &= \exp(X_{i,j}\beta_j) \\ \rightarrow \ln \frac{p}{1-p} &= X_{i,j}\beta_j \end{aligned} \quad (5)$$

where  $\frac{p}{1-p}$  measures the probability that  $y_{i,j} = 1$  relative to the probability that  $y_{i,j} = 0$ . This allows for an intuitive interpretation of the logit model as the log-odds ratio is linear in the regressors.

Many studies have empirically investigated the factors influencing the adaptation to perceived climate change (Alauddin et al., 2014; Arunrat et al., 2017; Deressa et al., 2009; Gbetibouo, 2009; Hassan et al., 2008; Hisali et al., 2011; Seo et al., 2008; Ndamani et al., 2016) using a binomial or a multinomial logit approach. While most of the literature focuses on the multinomial approach, we find this approach to be inappropriate for our case. First of all, most of our surveyed households adopted more than one adaptation strategy simultaneously, such that the multinomial logit approach is not feasible as the choices are assumed to be mutually exclusive. In addition, we follow Abid et al. (2015) and Bryan et al. (2013) and do not combine similar adaptation measures into self-defined categories as these

might prohibit a meaningful analysis and interpretation of the adaptation strategies. Based on these reasons, we stay with the bivariate logit model to examine the factors that influence a households' decision of adopting a specific adaptation strategy.

We are interested in validating our empirical models first, before we discuss our results in more detail. Therefore, all of our estimations will be examined by testing the overall significance of our approaches and their goodness of fit. In addition, we use the receiver operating characteristics curve (ROC curve) and predictions to check the accuracy of our models.

In order to validate our model, we have to use a general hypotheses test as the logit approach is a non-linear regression. We decided to use the Likelihood-ratio test to check the overall significance of our models. Thereby, our null hypotheses are that all parameters excluding the constant are equal to zero. We test the model against a restricted version which only includes a constant. This test follows an asymptotic Chi-squared distribution with degrees of freedom equal to the difference between the number of parameters to be estimated in the two models.

Moreover, we evaluate our models by using ROC-curves. A ROC-curve allows for a graphical inspection of our model performance as it plots the fraction of correctly classified adapting households versus the incorrectly classified households which are in fact not adapting to climate change. Thus, a ROC curve illustrates the tradeoff between the sensitivity (true positive rate) and 1-specificity (false positive rate) as the threshold ( $c$ ) is varied from 1 to 0. There are two corner points that are of interest. First, for  $c = 1$  all households are predicted to be adapting to climate change, so all of the households effectively adopting are correctly specified while on the other hand all households that are in fact not adopting are incorrectly specified. Thus, the ROC-curve takes on the value (0,100). Similarly, the ROC-curve takes the value (100,0) for  $c = 0$ . Thus, if a model has no predictive ability, the ROC-curve shrinks to a straight line combining these two points (Cameron et al., 2005) Therefore, the more area there is under the ROC-curve, the better is the predictive ability of our model.

While one could compute the ROC-curves for the in-sample predictability, we decided to evaluate the performance of our model by computing out of sample predictions. Therefore, we split our dataset randomly into two groups. While we use two-thirds of the full data set as a training set to estimate our logit models, we retain the remaining third for testing the out-of-sample performance. This allows us to compute confidence intervals for the ROC-curves and the area under the curve (AUC) using bootstrap replications.

### 2.3 Choice of Explanatory Variables

The choice of explanatory variables is based on data availability and on an extensive literature review. The explanatory variables used for this study are summarized in Table 1.

We use

- household characteristics such as age of the household head, education of the household head, gender of the household head and household size;
- monetary aspects using the farm income, livestock ownership, household assets and poverty status;
- physical characteristics of the farm like the farm size and well ownership; the use of extension services;
- climate change awareness measured by a perceived decrease in rainy days, soil erosion, a rise in temperature and water depletion.

In addition, we use region fixed effects to control for any institutional and climatic differences as well as any other unobservable differences between the three regions.

*Age of household head* can be used as a proxy for farming experience. We find mixed evidence in the literature about the sign and the size of the effect of age on the use of adaptation measures. While several studies find at least partially a significant negative relationship with age (Deressa et al., 2009; Hassan et al., 2008; Jiri et al., 2017), others report that age positively influences the decision to adapt to climate change (Hassan et al., 2008; Maddison, 2007; Nhemachena et al., 2014). Some studies even detected no significant relationship at all (Esham et al., 2013; Di Falco et al., 2012). Hence, one could argue that an older and thus more experienced farmer is more likely to adapt their farming behaviour to cope with the change in climatic conditions but as she or he gets older, a farmer might also be more likely to get more risk-averse and less flexible than younger farmers. Based on these findings one could draw the conclusion that the relationship between age and adaptation measures is non-linear. Thus, we add the quadratic form of the age of the household head in our regression. Nevertheless, we expect the sign to be inconclusive.

*Education of household head* is hypothesized to be positively correlated with the adaptation of new agricultural technologies and the adaptation to climate change. A well-educated farmer is expected to have a better knowledge and to have more information about the climate change. Thus, she or he might be able to use this knowledge and to react to the

perceived change by using improved farming methods. We find this to be the conventional wisdom in the literature as e.g. Abid et al. (2015) Anley et al. (2007), Bryan et al. (2013), Deressa et al. (2009), Dolisca et al. (2006) and Hassan et al. (2008) support this argument by finding a positive and significant relationship.

*Gender of household head* influences the decision to adapt to climate change. Nhemachena et al. (2014) argue that female-headed households are more likely to use adaptation methods, as they are more involved in the agricultural work and, thus, are more experienced in farming management than men. In addition, e.g. Bayard et al. (2007) and Dolisca et al. (2006) have supporting evidence for this argument by finding a positive relationship between female-headed households and adaptation. Nevertheless, there exists also evidence that male-headed households are more likely to get information about new technologies and farming practices (Deressa et al., 2009) and have a positive influence on the adaptation process (Hassan et al., 2008; Hisali et al., 2011). Again, there exists mixed evidence, as e.g. Bryan et al. (2013), Di Falco et al. (2012) and Ndamani et al. (2016) find no influence between the gender of a household head and the adaptation to climate change.

*Household size* impacts the adaptation process. As argued by Deressa et al. (2009) and Gbetibouo (2009) one could see this from two different angles. First of all, the household size can be seen as a proxy for the labor endowment which should be positively related to adaptation as it increases the available workforce. Hence, larger households are labor intensive and have a higher adaptation capability (Jiri et al., 2017). On the other hand, a larger family might be forced to shift some family members to off-farm activities in order to increase their income and thus, to decrease the consumption pressure imposed by a larger family size. However, empirical findings seem to support the first reasoning.

*Farm income, livestock, household assets and poverty status* are considered to represent different aspects of wealth. While the farm income tells us something about the fact if a household is solely dependent on farming to pay for their living, livestock and household assets can be seen as accumulated wealth. It is hypothesized that a higher amount of wealth and financial wellbeing are positively related to use of adaptation measures (Jiri et al., 2017; Knowler et al., 2007). Households with a higher income have lesser incentives to adapt as they exhibit an optimum level of farming compared to the low income group (Jiri et al., 2017), for which the sole dependency on farming and high levels of poverty increases their

vulnerability (Panda, 2017). In addition, we use the poverty status of a household in order to cover a wide range of different wealth aspects that we cannot explicitly control for otherwise.

*Farm size* measures the total land size held by a household in acres and can be seen as a proxy for wealth (Abid et al., 2015). In addition, Alauddin et al. (2014), Chengappa et al. (2017) and Gbetibouo (2009) argue that households with a larger farm size are more likely to adopt inventions earlier than smaller farms as adaptation processes typically involve large transaction and information costs. We follow this argument and hypothesize a positive relationship between adaptation to climate change and farm size.

*Well ownership* allows to control for an adequate supply of water. If a household does not have enough water for irrigation of their crops, we hypothesize that they are more likely to engage in an adaptation process.

Table 1 – Description of the explanatory and control variables.

<b>Explanatory Variable</b>	<b>Mean</b>	<b>Standard Deviation</b>	<b>Description</b>	<b>Expected Sign</b>
Age of household head	54.7163	13.0701	Continuous	(+) / (-)
Age of household head squared	3164.6977	1462.8538	Continuous	(+) / (-)
Education of household head	2.5674	1.4122	0 if no schooling, 1 if primary school, middle school or secondary school, 2 if High school, Graduate or Postgraduate	(+)
Gender of household head	0.7953	0.4034	Dummy, takes the value 1 if male and 0 if otherwise	(+) / (-)
Household size	4.0000	1.5004	Continuous	(+)
Farm income as only source of income (Far income)	0.0837	0.2770	Dummy, takes the value 1 if yes and 0 if otherwise	(+)
Household assets	6.3488	1.5323	Continuous	(+)
Livestock ownership	0.4884	0.4999	Dummy, takes the value 1 if yes and 0 if otherwise	(+)
Household poverty status	0.5767	0.4941	Dummy, takes the value 1 if	(+)

			above and 0 if otherwise	
Farm size in hectare	0.2858	0.4536	Continuous	(+)
Well ownership	0.0651	0.2467	Dummy, takes the value 1 if well is owned and 0 if otherwise	(-)
Extension service	0.0930	0.2905	Dummy, takes the value 1 if received and 0 if otherwise	
Rainy days	0.4419	0.4978	0 if negligible or low, 1 if medium, high or if very high	(+)
Soil erosion	0.5023	0.5012	0 = Non detectable, 1 = moderate or high	(+)
Temp rise	0.8556	0.3521	0 if negligible or low, 1 if medium, high or very high	(+)
Water depletion	0.9442	0.2301	0 if irregular scarcity or no problem with water availability, 1 if seasonal depletion, considerable depletion or almost depleted	(+)

*Extension services* influence the adaptation decision. They provide assistance and information about the climate change which is required to make an adaptation decision (Deressa et al., 2009). Various studies have found a positive relationship between provided extension services and the adoption behavior of households (Deressa et al., 2009; Gbetibouo, 2009; Maddison, 2007; Nhemachena et al., 2014).

We use different *control variables* for our estimation approach. Consequently, climate change awareness is a very important factor to determine the adaptation strategies. As we stated in Section 2.2, we assume that a household needs to realize a change in climatic conditions first before adapting their behavior. Therefore, we explicitly control for the climate change awareness using the variables *Rainy days*, *Soil erosion*, *Temp rise* and *Water depletion*. Thereby, we measure the perceived existence of a substantial decrease in rainy days, the presence of soil erosion, the possible depletion of water and a considerable rise in the temperature over the past few years. Especially, the soil fertility has been found to be

positively correlated to the decision of using soil conservation methods (Di Falco et al., 2012; Gbetibouo, 2009). In addition, awareness of changes in temperature and precipitation are important for the adaptation decision (Deressa et al., 2009; Maddison, 2007; Nhemachena et al., 2014). We expect that a farmer who is aware of a change in the climatic condition will use adaptation strategies to reduce a possible loss in well-being. Additionally, we control for aspects that are specific for the three watersheds by controlling for the different regions/watersheds by using dummy variables.

### **3. Results and Discussion**

#### *3.1 Perception of and Adaptation Strategies to Climate Change*

We are interested in the adaptation measures used by farmers in response to perceived climate change. Nevertheless, there exists a distinct difference between perceiving climate change and the actual use of adaptation measures in their farming process. Our descriptive findings are in line with the assumptions we made for our empirical approach. Table 2 summarizes the results if a household perceives climate change based on five questions:

1. Did the household perceive a considerable rise in temperature over the past few years?
2. Did the household perceive a substantial increase in hot months?
3. Did the household perceive erratic rainfall during the last years?
4. Did the household perceive an increase in rainfall?
5. Did the household notice a substantial decrease in rainy days?

While the results are somewhat heterogeneous between the five questions and the three regions, we nevertheless conclude, that a vast majority of households exist that perceive at least a medium to high change in either of the categories. For example, a considerable rise in the temperature, an increase of hot months and an increase in rainfall have been recognized by more than 97% of the survey participants. At the same time, low to medium level of erratic rainfall was perceived by 87.5% of the households, while almost 90% recognized a substantial decrease in rainy days.

Farmers perceived a medium to high level of ‘considerable rise in temperature’ and ‘increase in hot months’. Similar results were reported in Bundi district of Rajasthan (Dhaka et al., 2010) and Maharashtra and Andhra Pradesh (Banerjee, 2015; Ravi Shankar et al., 2013). It is notable that the perceptions of the farmers were similar in different parts of the world, e.g. for

Ethiopia (Mengistu, 2011) and South Africa (Bryan et al., 2013), irrespective of place and season.

More than 66% of the households opined a medium to high level of perception in the ‘increase in rainfall’ parameter and 87% had experienced a low to medium level of ‘erratic monsoon’ incidences. Other studies demonstrate similar results, e.g. farmers in Andhra Pradesh discerned a decrease in rainfall in general, while at the same time facing heavy, irregular and unpredictable rains (Banerjee, 2015; Mengistu, 2011; Ravi Shankar et al., 2013).

Now, the question is how households can react if they recognize that the climatic conditions have changed over time. There exists a broad variety of possible adaptation measures used by households to cope with this perceived climate change. Below et al. (2010) reviewed adaptation strategies to climate change and found 104 different relevant practices covering the data from 17 studies and more than 16 countries in Africa, America, Europa and Asia. A major part of the literature, which examines adaptation strategies and perceived climate change, is focused on countries in Africa (Bryan et al., 2013; Deressa et al., 2009; Gbetibouo, 2009; Hassan et al., 2008; Hisali et al., 2011; Ndamani et al., 2016). The most common adaptation strategies include, among others, changing the crop variety to more drought and heat tolerant crops, changing the planting dates, irrigation, the planting of shade trees (agroforestry), soil and water conservation, changing crop types and crop diversification.

Table 2 – Perception of climate change by the households

<b>Watersheds</b>	<b>Level of perception</b>	<b>Considerable rise in temp</b>	<b>Increase in hot months</b>	<b>Erratic rainfall</b>	<b>Increase in rainfall</b>	<b>Decrease in rainy days</b>
Adakkaputhur	Negligible	0.0%	0.0%	18.6%	0.0%	24.3%
	Low	37.1%	41.4%	61.4%	21.4%	58.6%
	Medium	58.6%	54.3%	12.9%	60.0%	14.3%
	High	4.3%	2.9%	5.7%	15.7%	1.4%
	Very High	0.0%	0.0%	0.0%	0.0%	0.0%
Akkiyampadam	Negligible	0.0%	7.1%	0.0%	0.0%	0.0%
	Low	2.9%	0.0%	8.6%	0.0%	8.6%
	Medium	94.3%	92.9%	91.4%	8.6%	91.4%

	High	0.0%	0.0%	0.0%	91.4%	0.0%
	Very High	2.9%	0.0%	0.0%	0.0%	0.0%
Eswaramangalam	Negligible	1.3%	1.3%	4.0%	5.3%	8.0%
	Low	0.0%	1.3%	72.0%	72.0%	66.7%
	Medium	2.7%	1.3%	14.7%	12.0%	10.7%
	High	96.0%	92.0%	9.3%	10.7%	14.7%
	Very High	0.0%	4.0%	0.0%	0.0%	0.0%
Total	Negligible	1.4%	2.8%	7.4%	1.9%	10.7%
	Low	13.0%	14.0%	48.0%	32.1%	45.1%
	Medium	50.7%	48.9%	39.5%	27.0%	38.6%
	High	34.9%	33.0%	5.1%	39.1%	5.6%
	Very High	0.0%	1.4%	0.0%	0.0%	0.0%

However, - to the best of our knowledge - we are the first to examine the relationship between perceived climate change and adaptation strategies specific for the rainfed smallholders at watershed level in India. This is why (unlike in the micro level studies mentioned above for Africa) we find different adaptation measures used more frequently in our study. Table 3 summarizes the ten most often named strategies.

Information communication technology facilitates public awareness and efficiency in communication particularly in changing climatic parameters and adaptation to climate change (Aleke et al., 2016). Thereby, the households depend mainly on the internet and mobile phones for climate related information. Livestock introduction and crop diversification in farming reduce the sensitivity of the households towards extreme events, drought and erratic monsoon by providing an ensured additional source of income (Ndambiri et al., 2013; Yila et al., 2013). In our case, most of the households introduced poultry, goat, rabbit or cattle to their farming system. Cooperatives and self-group activities enhance the collection action, spread the risk among the members and render support to the household in terms of cash or inputs on minimal interest rate. Furthermore, stone pitched contour bunds and moisture conservation pits are mechanical measures constructed in the slope regions which help to

reduce the soil erosion and run off as well as increase the infiltration of rain water deeper in to the soil.

First of all, there exists a considerable variation for the three regions when it comes to the actual use of adaptation strategies. For instance, *Irrigation* is used quite often in Adakkaputhur and Akkiyampadam while this strategy is not reported by the respondents in Eswaramangalam at all. This is somewhat surprising given that the vast majority of households perceive a high rise in temperature and a high increase in hot months in the Eswaramangalam watershed. This might be one of the reasons, why the Eswaramangalam watershed is focusing more on crop diversification than the other two. In addition, there seems to be a general tendency that the Akkiyampadam watershed is focusing more attention on the adaptation strategies that involve a social dimension. As a result, information communication technology, cooperatives and self-help groups are far more important than in the Adakkaputhur and Eswaramangalam watersheds. Given that we find for the Adakkaputhur and Akkiyampadam watershed a majority of households that perceive a low to medium change in all the five categories (Table 3), it is not surprising that we identify a higher diversification of adaptation strategies that are simultaneously used by the households. That is why in the Adakkaputhur watershed six (and in the Akkiyampadam five) different strategies are used by at least 30% of the households while there are only three adaptation strategies used in the Eswaramangalam watershed. Thus, our household survey results reveal that, in general, the households are using various adaptation methods simultaneously.

Table 3 – Households adaptation strategies

Adaptation strategies	Adakkaputhur	Akkiyampadam	Eswaramangalam	Average
1. Information communication technology	88.6%	91.4%	53.3%	77.2%
2. Crop diversification	65.7%	62.9%	86.7%	72.1%
3. Cooperatives	17.1%	80.0%	38.7%	45.1%
4. Irrigation	61.4%	57.1%	0.0%	38.6%
5. Livestock introduction	47.1%	11.4%	13.3%	23.7%
6. Self-help groups	8.6%	52.9%	9.3%	23.3%
7. Stone pitched contour bund	32.9%	4.3%	1.3%	12.6%

8. Moisture conservation pit	35.7%	1.4%	0.0%	12.1%
9. Farming system shift	1.4%	17.1%	12.0%	10.2%
10. Crop loans	7.1%	10.0%	12.0%	9.8%

### 3.2 Model Significance and Goodness of fit

Table 4 summarizes the results for the model significance tests and the goodness of fit. The results indicate that we can reject our null hypotheses that none of the considered factors has any influence on the outcome variable for all the estimated models on a one percent level. Furthermore, we calculated the goodness of fit by using the McFadden R-squared. The value for the pseudo R-squared range from 0.29 to 0.57 indicating good fits as compared to the null model using only a constant as regressor. In addition, we measure the in-sample model correctness for the estimated models. These are computed by using an optimal threshold for the predictions of our logit models. Thereby, the optimal threshold varies between 0.32 and 0.55 for the different models. However, similar results have been obtained by using a cutoff value of 0.5. We measure the accuracy of our models by comparing the predicted values of our models with the actual responses given by the households. If a predicted value is above the threshold, it is considered as 1 (e.g., a household adopts a technology), otherwise, the prediction will be considered as 0 (e.g., a household does not adopt). The model correctness then reflects the proportion of correctly estimated positive and negative events out of the total number of events, here 215. Thus, all our models are able to predict with a precision of more than 80% if a household does or does not adapt to climate change.

Table 4 – Model significance and goodness of fit

Model	Chi-squared	P-value	Log Likelihood	AIC	McFadden R-squared	Model correctness (%)
Information communication technology	90.10	0.00	-70.347	180.695	0.39	85.1
Crop diversification	59.62	0.00	-97.488	234.976	0.23	82.3
Cooperatives	106.04	0.00	-94.980	229.960	0.36	82.8
Irrigation	157.48	0.00	-64.652	169.303	0.55	86.5

Livestock introduction	125.22	0.00	-55.174	150.348	0.53	94.0
Self-help groups	85.38	0.00	-73.913	187.825	0.37	85.1
Stone pitched contour bund	62.08	0.00	-50.210	140.420	0.38	90.7
Moisture conservation pit	81.04	0.00	-38.768	117.535	0.51	93.5
Farming system shift	43.74	0.00	-49.114	138.228	0.31	92.1
Crop loans	56.85	0.00	-40.361	120.723	0.41	94.0

Moreover, we evaluate our models by using ROC-curves, which are plotted for the ten different logit models in Figure 1. The blue shaded areas represent the 95% confidence interval for the ROC-curves estimated by using 2,000 bootstrap replications. We also depict the confidence interval for the AUC. The results indicate that models (a) - (h) show a good out-of-sample performance with mean values for the AUC well above 75%, while models (i) and (j) seem to be less suited for out-of-sample predictions. One reason for this is that the adaptation strategies *Farming system shift* and *Crop loans* have been used only by a small percentage of households. Thus, it is not surprising, that the confidence bands for these two models are wider as compared to the other eight models used. Given the low AUCs and confidence bands including the 50%, leads us to conclude that the latter two models are inadequate for our further analysis.

### 3.3 Impact of explanatory variables

We are interested in quantifying the impact of the explanatory variables that affect a farmers' choice of adaptation methods. Table 5 summarizes the regression results of the eight remaining adaptation measures. Here, we use odds ratios, which allow for a simple and intuitive interpretation of the coefficients. The following sub-sections describe the results for our various explanatory variables on the probability of adopting the respective adaptation strategy.

#### 3.3.1 Age of household head

The odds ratio for the *Age of the household head* is in most cases smaller than one, which indicates a negative relationship for most of the adaptation strategies. Nevertheless, we find only two significant values. Thus, the *Age of the household head* significantly decreases the

odds of using *Cooperatives* and *Irrigation* as adaptation measures. In addition, these effects seem to increase with age. This is not in line with our expectation that the sign of the relationship between the age of the household head and the adaptation strategies is inconclusive.

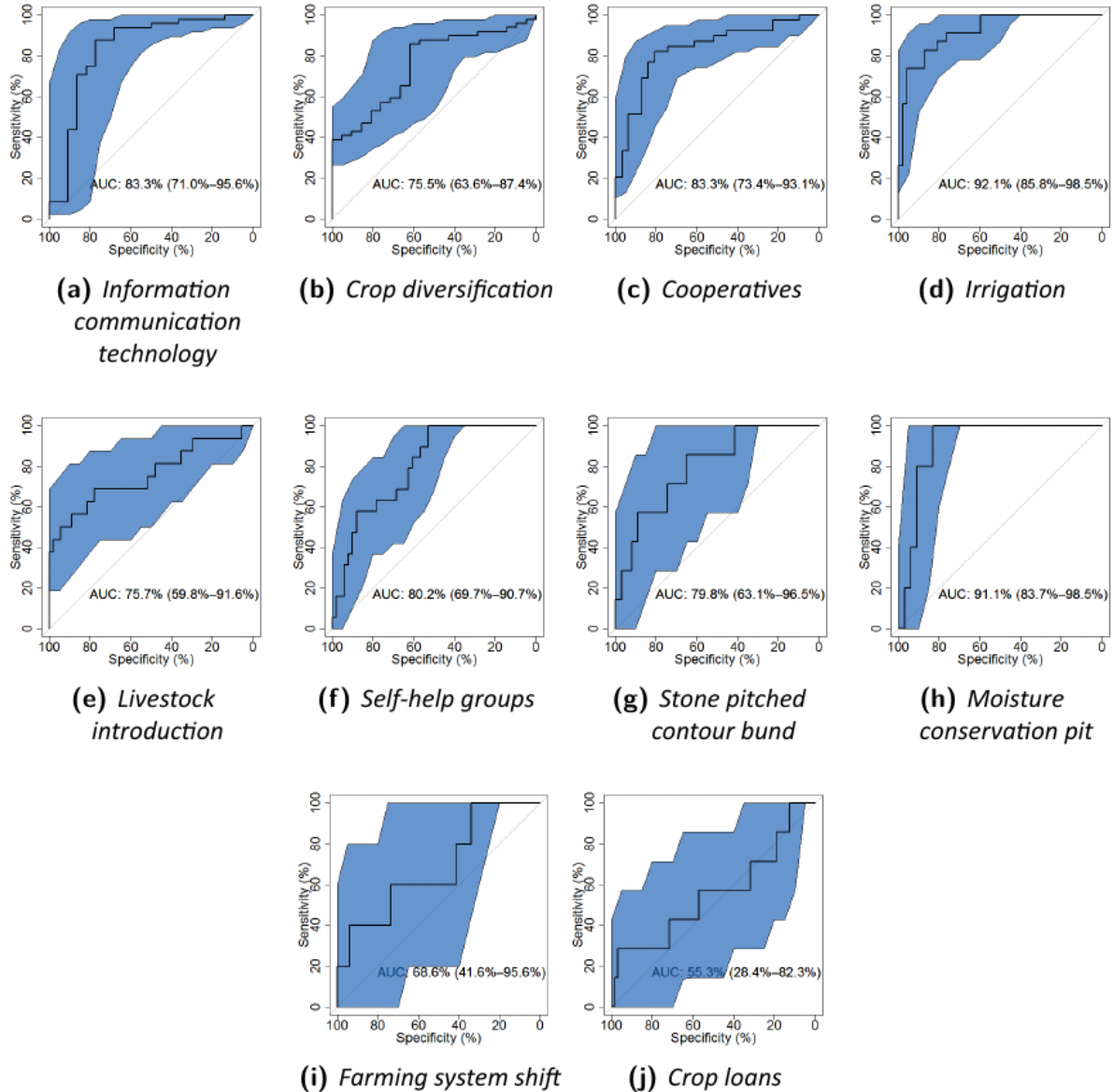


Figure 1 – ROC-plots for out-of-sample predictions. The graphs have been computed using the R package pROC by Robin et al. (2011).

### 3.3.2. Education of household head

We expect a well-educated farmer to be more aware of climate change and the usefulness of adaptation measures. However, we solely find a significantly positive relationship for the use of *Cooperatives* as an adaptation strategy. Having a household head with a primary, middle

or secondary school degree increases the odds by 200% as compared to a household head with no or a primary school degree. In addition, the odds are almost 10 times greater for a household head with a high school or university degree than for the ones in the base category.

### 3.3.3. Gender of household head

Our results suggest that the odds for a male-headed household to use *Information communication technologies* are almost 7.2 times greater than for female-headed households. This is in line with the findings in Deressa et al. (2009) that male-headed households are more likely to engage in new technologies and farming practices. Moreover, we find the opposite relationship for the use of *Self-help groups* and *Stone pitched contour bund* as adaptation strategies. Here, male-headed households are almost 66% (78%) less likely to use *Self-help groups* (*Stone pitched contour bund*) than female-headed households. A similar result has been found by Dolisca et al. (2006) that women's participation in social activities and attendance of meetings are more likely.

### 3.3.4 Household size

An odds-ratio greater than one for the household size indicates a positive relationship between the household size and the probability of adaptation to climate change. We find that increasing the household size by one person leads to a 44% increase in the odds of using *Livestock introduction* and a 35% increase in the use of *Self-help groups*. This is in line with our expectations that the household size and thus the labor endowment is positively related to the adaptation process. Nevertheless, we also find that the use of *Irrigation* decreases by 25% in this situation.

### 3.3.5 Different aspects of wealth

We use income, livestock, household assets and the poverty status to measure different aspects of wealth. While we find no significant relationship between the farm's income as the only source of a household's income, the latter three measures of wealth seem to be of great importance for the use of adaptation measures. We find a significantly positive relationship between livestock ownership and *Cooperatives* and *Livestock introduction*. Thus, a household is over 250% more likely to engage in *Cooperatives* if it owns livestock. Furthermore, the odds of introducing further livestock as an adaptation strategy are 85 times greater for a household already owning livestock. This might be due to the fact that these households already have prior experience with the challenges of animal husbandry.

Moreover, we find a mostly positive relationship between household assets and various adaptation strategies. Thus, the odds of using *Information communication technology*, *Crop diversification*, *Irrigation* or *Stone pitched contour bund* as adaptation strategies increase significantly with the household assets / the accumulated wealth. This meets our expectations. But, we also find a negative relationship for the use of *Livestock introduction*. Here, households are 46% less likely, with respect to odds, to introduce *Livestock* to cope with climate change.

In addition, we find that households that are above the poverty status are 170% more likely to use *Information communication technology* as strategy and have 7 times greater odds to use *Moisture conservation pits* compared to households that are considered to be poor. The opposite is true for the involvement in *Self-help groups*. Here, households above the poverty level are more than 66% less likely to make use of this adaptation strategy to face climate change.

### 3.3.6 Farm size in hectare

The farm size of a household might be seen as a proxy for wealth, which makes it easier for a family to adapt to climate change, as these are often associated with high transaction costs. We find a significantly positive relationship between the farm size and the engagement in *Cooperatives*. Thus, increasing the farm size by one hectare increases the odds of using *Cooperatives* by a factor of three.

### 3.3.7 Well ownership

Not owning a well indicates an inadequate supply of ground water and is considered to be positively associated with the use of adaptation measures. Nevertheless, we do not find a significant relationship of owning a well on the use of such measures.

Table 5 – Regression results – Odds ratios

	<b>Information communication technology</b>	<b>Crop diversification</b>	<b>Cooperatives</b>	<b>Irrigation</b>	<b>Livestock introduction</b>	<b>Self-help groups</b>	<b>Stone pitched contour bund</b>	<b>Moisture conservation pits</b>
Age	0.902	0.975	0.771**	0.706**	0.905	0.997	1.087	1.276
	z = -0.743	z = -0.235	z = -2.267	z = -2.247	z = -0.606	z = -0.026	z = 0.390	z = 0.831
Age^2	1.001	1.001	1.002**	1.003**	1.001	1.000	0.999	0.998
	z = 0.702	z = 0.546	z = 2.123	z = 2.184	z = 0.459	z = -0.347	z = -0.331	z = -0.838
Education1	0.909	1.942	3.025**	1.566	0.692	1.281	1.104	0.978
	z = -0.167	z = 1.355	z = 2.134	z = 0.711	z = -0.575	z = 0.410	z = 0.136	z = -0.025
Education2	3.604	4.131	9.771***	2.153	0.212	0.399	0.00000	7.761
	z = 1.147	z = 1.392	z = 2.748	z = 0.537	z = -1.026	z = -0.806	z = -0.013	z = 1.222
Gender	7.155***	1.651	1.665	1.402	0.734	0.339*	0.220*	0.541
	z = 3.438	z = 0.998	z = 1.023	z = 0.456	z = -0.451	z = -1.725	z = -1.856	z = -0.558
Household size	0.855	1.038	1.222	0.747*	1.443*	1.349*	1.215	1.508
	z = -0.863	z = 0.264	z = 1.352	z = -1.768	z = 1.845	z = 1.823	z = 1.006	z = 1.558
Farm Income	1.989	2.972	1.978	0.879	1.143	0.942	0.840	0.921
	z = 0.665	z = 1.206	z = 0.956	z = -0.140	z = 0.154	z = -0.054	z = -0.202	z = -0.089
Household assets	1.751***	1.848***	1.061	2.678***	0.542**	0.797	1.928**	1.185
	z = 2.777	z = 3.214	z = 0.368	z = 3.389	z = -2.380	z = -1.081	z = 2.077	z = 0.445
Livestock	2.109	1.259	3.585***	1.076	85.446***	2.009	0.719	0.700
	z = 1.495	z = 0.610	z = 3.097	z = 0.151	z = 5.464	z = 1.558	z = -0.572	z = -0.514
Poverty status	2.709*	1.318	0.570	1.896	0.642	0.338**	1.986	8.081**

	$z = 1.941$	$z = 0.687$	$z = -1.316$	$z = 1.281$	$z = -0.797$	$z = -2.171$	$z = 1.024$	$z = 2.529$
Farm size	0.822	1.154	3.188**	0.710	2.055	0.851	0.874	0.905
	$z = -0.288$	$z = 0.237$	$z = 2.269$	$z = -0.648$	$z = 1.405$	$z = -0.347$	$z = -0.246$	$z = -0.125$
Well ownership	0.178	1.340	0.223	2.231	0.594	0.951	0.424	1.142
	$z = -1.633$	$z = 0.373$	$z = -1.151$	$z = 0.972$	$z = -0.423$	$z = -0.038$	$z = -1.027$	$z = 0.152$
Extension service	2.400	1.512	1.984	13.627**	0.509	6.594**	2.112	2.796
	$z = 0.916$	$z = 0.544$	$z = 1.028$	$z = 2.205$	$z = -0.634$	$z = 2.423$	$z = 1.083$	$z = 1.488$
Rainy days	5.255***	0.463	1.778	1.134	0.189**	1.872	0.342	0.221
	$z = 2.790$	$z = -1.565$	$z = 1.209$	$z = 0.176$	$z = -1.990$	$z = 1.001$	$z = -1.310$	$z = -1.490$
Soil erosion	0.300	1.700	0.933	4.228**	1.570	3.172**	1.914	1.513
	$z = -1.643$	$z = 0.997$	$z = -0.124$	$z = 2.194$	$z = 0.559$	$z = 2.109$	$z = 0.618$	$z = 0.283$
Temp rise	0.130**	0.827	0.684	1.371	0.763	2.284	0.912	1.163
	$z = -2.107$	$z = -0.323$	$z = -0.559$	$z = 0.483$	$z = -0.343$	$z = 0.989$	$z = -0.148$	$z = 0.221$
Water depletion	1.236	1.987	0.599	4.183	0.594	1.615	3.526	7.236
	$z = 0.215$	$z = 0.704$	$z = -0.638$	$z = 1.202$	$z = -0.396$	$z = 0.355$	$z = 0.935$	$z = 1.407$
Akkiyampadam	0.491	4.120**	17.481***	3.208	0.039***	16.144***	0.314	0.030**
	$z = -0.752$	$z = 1.996$	$z = 3.735$	$z = 1.260$	$z = -2.757$	$z = 3.203$	$z = -0.981$	$z = -2.131$
Eswaramangalam	0.031***	8.295***	3.103	0.000	0.052***	1.459	0.011***	0.000
	$z = -3.610$	$z = 2.830$	$z = 1.594$	$z = -0.014$	$z = -2.703$	$z = 0.448$	$z = -2.756$	$z = -0.011$
Constant	10.005	0.002*	26.470	2.420	138.065	0.091	0.0001	0.00000
	$z = 0.576$	$z = -1.883$	$z = 0.971$	$z = 0.208$	$z = 1.024$	$z = -0.622$	$z = -1.301$	$z = -1.402$

Note: \*  $p < 0.1$ ; \*\*  $p < 0.05$ ; \*\*\*  $p < 0.01$

### 3.3.8 Extension Services

The use of extension services is hypothesized to have a positive relationship with the use of adaptation strategies (Jiri et al., 2017). We find a positive relationship between extension services and the use of *Irrigation* and *Self-help groups* as adaptation measures. A household's odds to use *Irrigation* are almost 12.5 times higher than for households that are not provided with extension services. In addition, the odds for using *Self-help groups* is 6.5 times higher when the household is provided with extension services. Thus, we can conclude that extension services that provide households with assistance and information about the climate change are very important for the use of adaptation strategies.

## 4. Conclusion and policy implications

Climate change is expected to have a severe impact on the life of farmers in the region of Kerala, India in the near future. Already today, one can observe a substantial spatial and temporal variation in monsoon rainfall (Nikhil Raj et al., 2012) combined with an increase in short term droughts (Thomas et al., 2016). Hence, our study aims at investigating not only how households perceive climate change, but also to observe, which measures are used and what the main drivers are that influence households' choices of adopting such measures for the case of rainfed watershed areas in Kerala, India.

We find that a vast majority of the households in the three study areas perceive at least a medium to high level of rise in average temperature and an increase in hot months. In addition, we find that an increase in rainfall has been recognized by almost everyone (>98%) of the survey participants over all three regions. However, the three examined watersheds differ considerably in terms of the quantity and the selection of implemented adaptation strategy used by the farmers to cope with the perceived climate change.

Our study also reveals that there are various factors that significantly affect the adaptation strategies used by the households. For instance, more experienced farmers are less likely to seek social assistance and are also less likely to use irrigation methods. In addition, male-headed households are found to be more engaged in using new technologies and farming practices while women's participation in social activities and attendance of meetings are more likely. Furthermore, education, farm size and owning livestock can be seen as three important factors for a household to engage in cooperatives. Thus, we conclude that farmers in the WDPs are well aware of the fact that the climatic conditions are changing and

measures should be and partially have been undertaken to overcome the potential negative effects.

Some of the determinants of adaptation strategies are institutional in nature as for example the educational status and extension services. First of all, extension services are an effective tool in educating farmers and providing them with valuable information about adaptation strategies and on how to implement those using practical applications. Thus, expansion of extension services could significantly affect the rate of adopting the strategies to cope with the climate change especially among the poorest households.

Another concern is the socio-economic status of the households with an emphasis on wealth assets. Our results strongly support this statement as we find a mostly positive relationship between household assets and various adaptation strategies. Furthermore, it is widely accepted in the literature that the poorest ones are the least equipped when it comes to dealing with long-term climate change in order to maintain their current livelihood (Bryan et al., 2013; Hahn et al., 2009; Jiri et al., 2017). By contrast, households with high level of assets are innovative and keen in accessing information related to weather and climatic parameters, social networking institutions such as cooperatives and self-help groups as well as new and modern technologies for irrigation and soil and water conservation.

We conclude that the services rendered by the WDPs are not sufficient for an effective adaptation process by the part of the population that has no or only limited access to them. Vertical and horizontal integration of the institutions, as well as effective public-private partnerships coupled with community involvement, are necessary for collaborating adaptation processes at different levels of households. Even though WDPs aim particularly on natural resource management and production system enhancement, a very few households adopted soil and water conservation measures such as Stone pitched contour bund and Moisture conservation pits, Livestock introduction and Diversification of existing farming practices. Moreover, a closer look at the indigenous adaptation strategies is necessary for facilitating the adoption process and future location specific research developments. Future research may also concentrate on an in depth qualitative analysis into the barriers of adoption processes in rainfed agriculture areas in the tropics.

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## **Conflicts of Interest**

The authors declare no conflict of interest.

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## Appendix

Table A1 – Regression results – Marginal effects evaluated at the sample means

	Information communication technology	Crop diversification	Cooperatives	Irrigation	Livestock introduction	Self-help groups	Stone pitched contour bund	Moisture conservation pits
Age	-0.010	-0.004	<b>-0.064**</b>	-0.0002	-0.005	-0.0003	0.001	0.00002
	t = -0.743	t = -0.235	t = -2.254	t = -0.002	t = -0.613	t = -0.026	t = 0.008	t = 0.002
Age^2	0.0001	0.0001	<b>0.001**</b>	0.00000	0.00004	-0.00004	-0.00000	-0.00000
	t = 0.701	t = 0.547	t = 2.112	t = 0.002	t = 0.464	t = -0.351	t = -0.008	t = -0.002
Education1	-0.009	0.115	<b>0.259**</b>	0.0003	-0.022	0.023	0.001	-0.00000
	t = -0.170	t = 1.270	t = 2.315	t = 0.002	t = -0.531	t = 0.421	t = 0.008	t = -0.002
Education2	<b>0.083*</b>	<b>0.160**</b>	<b>0.473***</b>	0.001	<b>-0.052*</b>	-0.067	<b>-0.038*</b>	0.0004
	t = 1.708	t = 2.146	t = 4.267	t = 0.002	t = -1.683	t = -1.098	t = -1.907	t = 0.002
Gender	<b>0.291***</b>	0.088	0.122	0.0002	-0.019	-0.134	-0.020	-0.00005
	t = 2.693	t = 0.929	t = 1.063	t = 0.002	t = -0.411	t = -1.461	t = -0.009	t = -0.002
Household size	-0.015	0.006	0.049	-0.0002	<b>0.020*</b>	<b>0.029*</b>	0.002	0.00003
	t = -0.863	t = 0.264	t = 1.351	t = -0.002	t = 1.795	t = 1.838	t = 0.008	t = 0.002
Farm Income	0.053	<b>0.132*</b>	0.169	-0.0001	0.008	-0.006	-0.001	-0.00001
	t = 0.839	t = 1.696	t = 0.982	t = -0.002	t = 0.146	t = -0.055	t = -0.008	t = -0.002
Household assets	<b>0.054***</b>	<b>0.099***</b>	0.015	0.001	<b>-0.034**</b>	-0.022	0.005	0.00001
	t = 2.712	t = 3.317	t = 0.368	t = 0.002	t = -2.203	t = -1.086	t = 0.008	t = 0.002

Livestock	0.072	0.037	<b>0.306***</b>	0.00005	<b>0.370***</b>	0.068	-0.003	-0.00002
	t = 1.496	t = 0.610	t = 3.304	t = 0.002	t = 5.067	t = 1.532	t = -0.008	t = -0.002
Poverty status	<b>0.103*</b>	0.045	-0.138	0.0004	-0.025	<b>-0.114**</b>	0.005	0.0001
	t = 1.792	t = 0.677	t = -1.328	t = 0.002	t = -0.744	t = -2.041	t = 0.008	t = 0.002
Farm size	-0.019	0.023	<b>0.286**</b>	-0.0002	0.040	-0.015	-0.001	-0.00001
	t = -0.286	t = 0.238	t = 2.256	t = -0.002	t = 1.354	t = -0.345	t = -0.008	t = -0.002
Well ownership	-0.279	0.044	-0.303*	0.001	-0.024	-0.005	-0.005	0.00001
	t = -1.205	t = 0.404	t = -1.656	t = 0.002	t = -0.514	t = -0.039	t = -0.008	t = 0.002
Extension service	0.064	0.060	0.170	0.006	-0.030	0.309*	0.008	0.0001
	t = 1.226	t = 0.610	t = 1.055	t = 0.002	t = -0.819	t = 1.880	t = 0.008	t = 0.002
Rainy days	<b>0.155***</b>	-0.128	0.142	0.0001	<b>-0.091*</b>	0.063	-0.008	-0.0001
	t = 2.652	t = -1.537	t = 1.222	t = 0.002	t = -1.812	t = 0.974	t = -0.008	t = -0.002
Soil erosion	-0.118	0.086	-0.017	0.001	0.025	0.113*	0.005	0.00003
	t = -1.568	t = 0.994	t = -0.124	t = 0.002	t = 0.549	t = 1.937	t = 0.008	t = 0.002
Temp rise	<b>-0.118***</b>	-0.029	-0.094	0.0002	-0.016	0.064	-0.001	0.00001
	t = -3.130	t = -0.337	t = -0.559	t = 0.002	t = -0.314	t = 1.262	t = -0.008	t = 0.002
Water depletion	0.022	0.131	-0.128	0.001	-0.035	0.039	0.006	0.0001
	t = 0.200	t = 0.617	t = -0.644	t = 0.002	t = -0.326	t = 0.426	t = 0.008	t = 0.002
Akkiyampadam	-0.076	<b>0.198**</b>	<b>0.607***</b>	0.001	<b>-0.145**</b>	<b>0.395***</b>	-0.008	-0.0002
	t = -0.676	t = 2.320	t = 5.342	t = 0.002	t = -2.278	t = 2.585	t = -0.008	t = -0.002
Eswaramangalam	<b>-0.499***</b>	<b>0.287***</b>	<b>0.276*</b>	<b>-0.609***</b>	<b>-0.139**</b>	0.038	-0.036	-0.072
	t = -3.222	t = 3.365	t = 1.673	t = -7.470	t = -2.188	t = 0.424	t = -0.009	t = -1.371

Note: \* p<0.1; \*\* p<0.05; \*\*\* p<0.01

Table A2 – Regression results – Marginal effects evaluated at the mean values over all observations

	Information communication technology	Crop diversification	Cooperatives	Irrigation	Livestock introduction	Self-help groups	Stone pitched contour bund	Moisture conservation pits
Age	-0.011	-0.004	<b>-0.037**</b>	<b>-0.034**</b>	-0.008	-0.0004	0.006	0.014
	t = -0.735	t = -0.235	t = -2.107	t = -2.017	t = -0.601	t = -0.026	t = 0.389	t = 0.813
Age^2	0.0001	0.0001	<b>0.0003**</b>	<b>0.0003**</b>	0.0001	-0.00005	-0.00004	-0.0001
	t = 0.695	t = 0.543	t = 1.989	t = 1.971	t = 0.458	t = -0.346	t = -0.330	t = -0.819
Education1	-0.010	0.103	<b>0.156**</b>	0.045	-0.030	0.027	0.007	-0.001
	t = -0.168	t = 1.328	t = 2.276	t = 0.702	t = -0.561	t = 0.413	t = 0.137	t = -0.025
Education2	0.114	<b>0.173*</b>	<b>0.323***</b>	0.073	-0.102	-0.090	<b>-0.135***</b>	0.122
	t = 1.400	t = 1.850	t = 3.265	t = 0.563	t = -1.222	t = -0.919	t = -6.290	t = 1.289
Gender	<b>0.240***</b>	0.077	0.072	0.034	-0.025	<b>-0.121*</b>	<b>-0.125*</b>	-0.037
	t = 3.263	t = 0.973	t = 1.045	t = 0.449	t = -0.440	t = -1.747	t = -1.803	t = -0.552
Household size	-0.016	0.006	0.029	<b>-0.029*</b>	<b>0.029*</b>	<b>0.033*</b>	0.014	0.024
	t = -0.849	t = 0.264	t = 1.315	t = -1.650	t = 1.701	t = 1.716	t = 0.982	t = 1.445
Farm Income	0.065	0.140	0.100	-0.013	0.011	-0.006	-0.012	-0.005
	t = 0.731	t = 1.473	t = 0.954	t = -0.140	t = 0.152	t = -0.054	t = -0.208	t = -0.089
Household assets	<b>0.057**</b>	<b>0.091***</b>	0.008	<b>0.097***</b>	<b>-0.048**</b>	-0.025	<b>0.048*</b>	0.010
	t = 2.406	t = 2.810	t = 0.367	t = 2.736	t = -2.065	t = -1.059	t = 1.877	t = 0.443
Livestock	0.074	0.034	<b>0.184***</b>	0.007	<b>0.377***</b>	0.076	-0.024	-0.021
	t = 1.567	t = 0.612	t = 3.330	t = 0.151	t = 8.639	t = 1.596	t = -0.576	t = -0.513

Poverty status	<b>0.106*</b>	0.042	-0.080	0.068	-0.035	<b>-0.116**</b>	0.048	<b>0.118***</b>
	t = 1.927	t = 0.680	t = -1.337	t = 1.222	t = -0.789	t = -2.305	t = 1.073	t = 3.069
Farm size	-0.020	0.021	<b>0.166**</b>	-0.034	0.057	-0.018	-0.010	-0.006
	t = -0.287	t = 0.237	t = 2.106	t = -0.642	t = 1.328	t = -0.346	t = -0.245	t = -0.125
Well ownership	-0.199	0.042	-0.196	0.078	-0.039	-0.005	-0.055	0.008
	t = -1.555	t = 0.387	t = -1.337	t = 1.009	t = -0.450	t = -0.039	t = -1.191	t = 0.151
Extension service	0.082	0.059	0.099	<b>0.216***</b>	-0.049	<b>0.226**</b>	0.061	0.064
	t = 1.034	t = 0.575	t = 1.039	t = 3.423	t = -0.693	t = 2.465	t = 0.987	t = 1.424
Rainy days	<b>0.172***</b>	-0.116	0.089	0.012	-0.139**	0.071	-0.077	-0.085*
	t = 2.898	t = -1.571	t = 1.151	t = 0.176	t = -2.035	t = 0.978	t = -1.354	t = -1.651
Soil erosion	<b>-0.117*</b>	0.078	-0.010	<b>0.148**</b>	0.036	<b>0.126**</b>	0.045	0.023
	t = -1.800	t = 1.009	t = -0.123	t = 2.272	t = 0.544	t = 2.170	t = 0.664	t = 0.293
Temp rise	<b>-0.169***</b>	-0.028	-0.055	0.031	-0.022	0.083	-0.007	0.009
	t = -2.971	t = -0.329	t = -0.562	t = 0.483	t = -0.333	t = 1.097	t = -0.147	t = 0.223
Water depletion	0.022	0.109	-0.075	0.141	-0.044	0.049	0.072	<b>0.091**</b>
	t = 0.210	t = 0.671	t = -0.633	t = 1.278	t = -0.374	t = 0.377	t = 1.271	t = 2.124
Akkiyampadam	-0.074	<b>0.180**</b>	<b>0.473***</b>	0.110	<b>-0.251***</b>	<b>0.371***</b>	-0.079	<b>-0.165***</b>
	t = -0.757	t = 2.475	t = 4.656	t = 1.367	t = -3.523	t = 3.190	t = -1.068	t = -2.792
Eswaramangalam	<b>-0.432***</b>	<b>0.282***</b>	<b>0.153*</b>	<b>-0.553***</b>	<b>-0.226***</b>	0.041	<b>-0.218***</b>	<b>-0.230***</b>
	t = -3.850	t = 3.512	t = 1.749	t = -10.935	t = -3.393	t = 0.454	t = -3.611	t = -2.848

Note: \* p<0.1; \*\* p<0.05; \*\*\* p<0.01

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