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Faculty of Tropical AgriSciences

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Analysis of factors influencing the adaptation behaviour of small-scale farmers towards a climate change in India

BACHELOR'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled "Analysis of factors influencing the adaptation behaviour of small-scale farmers towards a climate change in India" independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague date

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Barbora Mikešová

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Abstract

Droughts, expected to occur more frequently in India due to climate change, can immediately threaten the food security and nutrition of small-scale farmers who depend on agriculture for their livelihood. Limited resources, technologies, and information make these farmers particularly vulnerable to drought impacts. Addressing climate change effects on agriculture and supporting small-scale farmers' resilience is crucial for food security in India. In addition to environmental challenges, sustainable agricultural practices are essential to achieve improved agricultural productivity and food security for smallholder farmers in India. Crop diversification, conservation agriculture and agroforestry are among the most promoted and widely adopted practice. Given the vast area of India categorizing chosen states into different vulnerability levels based on a vulnerability index allows for the identification of the most vulnerable regions and facilitates the analysis of study outcomes. To gain a deeper understanding of Indian farmers' behaviour in adoption to climate change, in proposed framework the capacity to participate is captured as an interplay of intrinsic and extrinsic factors that influence their participation objectives, decision outcomes, and potential for future reinforcement or reversal. Among Indian quantitative studies focusing on the analysis of factors influencing smallholder farming behaviour over the past 15 years. Farmers' education and experience in farming, use of extension services and access to irrigation were the most commonly influential.

Key words: smallholder farmers, agricultural practises, environmental sustainability, socioeconomic factors

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List of the abbreviations used in the thesis

CSA	Climate Smart Agriculture
FAO	Food and Agricultural Organisation
GDP	Gross Domestic Product
MGNREGS	Mahatma Gandhi National Rural Employment Guarantee Scheme
NGO	Non-Governmental Organisations
RCP	Representative Concentration Pathways
SRI	System of Rice Intensification
UNFCCC	United Nations Framework Convention on Climate Change
WORLP	Western Orissa Rural Livelihood Project

1. Introduction

Climate change has resulted in severe impacts on livelihoods and socio-economic development globally, particularly in the global south, where agricultural production is significantly affected (Angom et al. 2021). The situation is further aggravated for smallholder farming communities in rural areas, whose primary source of income is agriculture. Climate is one of the main components that influence agriculture production in India, and the incidence of climate-related disasters is on the rise, making farmers more vulnerable. The impacts of climate change are often witnessed as floods, recurrent droughts, heat waves and temperature extremes, as well as pest resurgences and development of resistance to available pesticides by pest (Angom et al. 2021).

In India, it has caused an increase in temperatures and shifts in monsoon patterns, which negatively impact the livelihoods and food security of smallholder agricultural communities (Srinivasa Rao et al. 2016). Agricultural productivity is most likely impacted by extreme climate events, making successful and efficient adaptation critical. Vulnerability to climate change is essentially a function of exposure, sensitivity, and adaptive capacity (Majra & Gur 2009). The adaptation depends on timely recognition of the need, the incentive, and the ability to adapt. Identifying the need for adaptation requires farmers to perceive and realize actual climate changes and alter traditional farming practices to maximize returns in each new environment (Bryan et al. 2009).

Maintaining soil fertility and higher food productivity in the face of environmental challenges is key to improving food security (Srinivasa Rao et al. 2016). Jha (2021) emphasizes the critical role of adopting sustainable agroecological practices that are environmentally friendly, maintain soil fertility and are suitable for adaptation to climate change. Common practices include conservation agriculture, agroforestry, and combinations of these practices that promote agricultural yields and soil conservation (Knowler & Bradshaw 2007).

The interplay of intrinsic and extrinsic factors determines the participation objectives of an individual and the outcomes of the decision to participate, as well as whether the participation decision will be reinforced or reversed in the future (Wojewska et al. 2021). For example, socio-economic factors such as farming experience, education, household size or the extent of institutional support.

The thesis seeks to contribute to the understanding of the complex interactions between climate change and small-scale farmers in India.

2. Aims of the Thesis

The main objective of this thesis is to analyse the factors influencing the behavioural patterns of smallholder farmers to climate change in India. Most often India has to face climate hazards like droughts, floods and to some extent extreme temperatures. All these phenomena have a negative impact on agriculture.

Specific objectives:

- To identify the main factors that influence the adaptation behaviour of small-scale farmers.
- To explore the existing climate adaptation strategies and practices adopted by small-scale farmers in India.
- To analyse the socio-economic factors that hinder or facilitate the adoption of climate adaptation practices by small-scale farmers in India. This analysis will consider policy interventions and support measures aimed at promoting climate-smart agriculture among small-scale farmers in India.
- To provide recommendations for improving the climate resilience and sustainability of small-scale farming systems in India and enhancing the livelihoods of rural communities in the face of climate change.

3. Methodology

The bachelor thesis is based on secondary data. Secondary data collection was done through available scientific sources, mainly from a scientific database of Thomson Reuters Web of Sciences, Science Direct, EBSCO etc.

Key word used for research: smallholder farmers, agricultural practises, environmental sustainability, socioeconomic factors.

4. Literature Review

4.1. Agriculture sector India

4.1.1. Agriculture sector

Agriculture in India plays a vital role in the country's economy and employment prospects. High population density in rural areas, where over 70 % of the population resides, has led to agriculture employing almost half of the total workforce, as it is the primary source of income for rural citizens (Chatterjee & Rajkumar 2015). This is making India still mostly agrarian based economy. Despite contributing only 16.8% to the Gross Domestic Product (GDP) according to food and agricultural organisation (FAO) 2021. Therefore, the substantial portion of the population engaged in agriculture influences the fate of other economic sectors through farm incomes (Jayaraman & Murari 2014).

Approximately 85 % of the farmers are small-holders or marginal with having less than two acres of land (Jayaraman & Murari 2014). Majority of small-scale farmers have limited technical and financial access, many of them suffering from poverty. The government is the only entity that can provide ongoing support and enhance the agriculture sector to address the challenges faced by small-scale farmers and ensure its continued growth and contribution to the economy.

India also possesses the second largest agricultural land area, with a diverse range of 20 agro-climatic zones, making it highly susceptible to climatic factors. Like many other developing countries, India is significantly impacted by the consequences of climate change and natural hazards, with one the most prominent factor being the unpredictability of the monsoon season, upon which the agricultural system is heavily dependent.

4.1.2. Crop and livestock production

India is self-sufficient in food production, being one of the largest producers of food crops in the world. Increasing food grain production from 50 million tonnes in 1950s to 250 million tonnes in 2014 to meet the demands of its rapidly growing population (FAO 2016).

India leads the world in pulse production, accounting for 25 % of global production, and is also the largest consumer (27 % of world consumption) and importer (14 %) of pulses. It ranks second globally in rice, wheat, sugarcane, cotton and groundnut production, as well as being the second-largest fruit and vegetable producer, with a share of 10.9 % and 8.6 % of the world's total fruit and vegetable production, respectively (FAO 2016). Other important commodities being spices (such as chili, turmeric, and cardamom), jute, tea and coffee and cashew (FAO 2016). Normal estimates (average of 2015-16 to 2019-20) of area of major crops in India are shown in Figure 1.

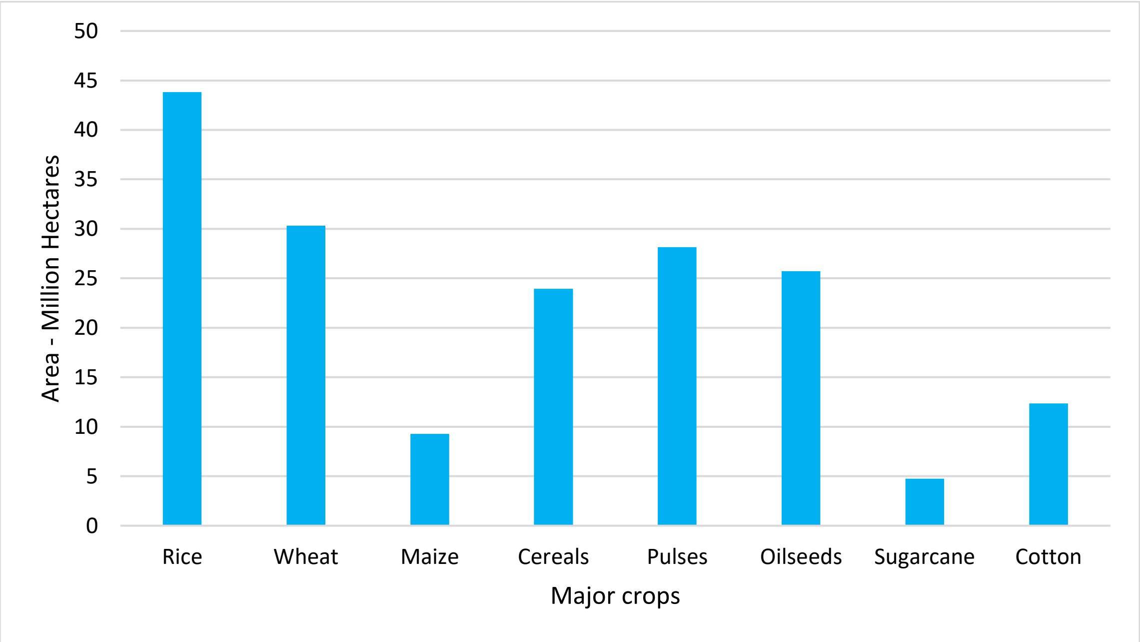

Figure 1. Normal Estimates (Average of 2015-16 to 2019-20) of Area of Major Crops in India

Source: Directorate of Economics & Statistics, DA&FW (2021)

The livestock sector plays crucial role particularly for livelihood of rural poor with marginal or no land at all and women. Providing constant income that is resilient to other factors such as seasonality or shocks during crop failure (Ali 2007). It is environmentally friendly and boosts household health and nutrition. India has a large population of livestock and poultry, including 303.76 million bovines, 74.26 million sheep, and 148.89 million goats (Panda 2021). The country is also the largest producer of milk in the world, with milk production reaching 209.96 million tonnes in 2020-21. Poultry production has advanced with technological interventions, resulting in egg production of 122.05 billion and meat production of 8.80 million tonnes according to FAO in 2020-2021. Livestock population in India (1951-2019) is shown in Figure 2.

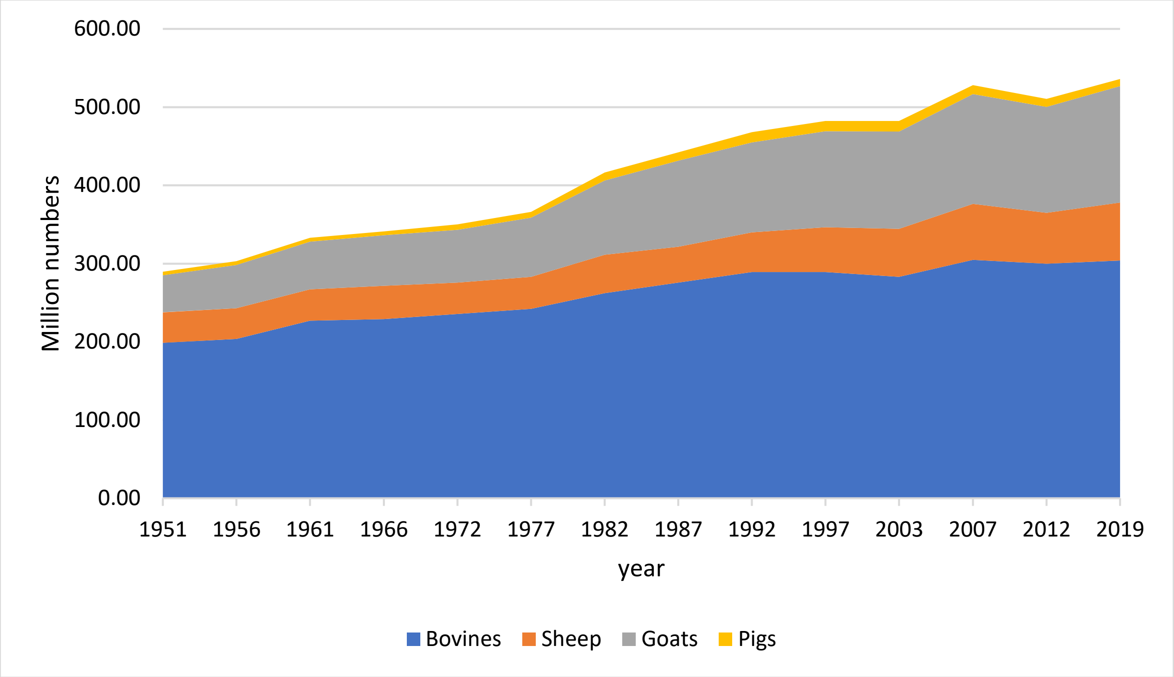

Figure 2. Livestock Population in India

Source: Livestock Census, Department of Animal Husbandry and Dairying (2021)

4.1.3. Categories of farmers

There are three main categories of farmers in India, defined by the area cultivated by each farmer. Number of operational holdings in percentage is shown in Figure 3.

1) Small and Marginal Farmers: These are farmers who own less than 2 hectares (5 acres) of land. They constitute the majority of farmers in India, accounting for more than 85 % of all operational holdings or farms. Small and marginal farmers often face challenges such as limited access to credit, low productivity, and poor market linkages (Härri et al. 2020).
2) Medium Farmers: These are farmers who own 2 to 10 hectares (5 to 25 acres) of land. They constitute around 12 % of all operational holdings in India. Medium farmers often have better access to credit and inputs and can adopt more advanced farming practices (Mahendra Dev 2012).
3) Large Farmers who own more than 10 hectares (25 acres) of land. They constitute less than 1% of all operational holdings in India but control a significant share of agricultural land and production. Large farmers often use modern farming techniques, machinery, and have good market linkages (GoI 2012).

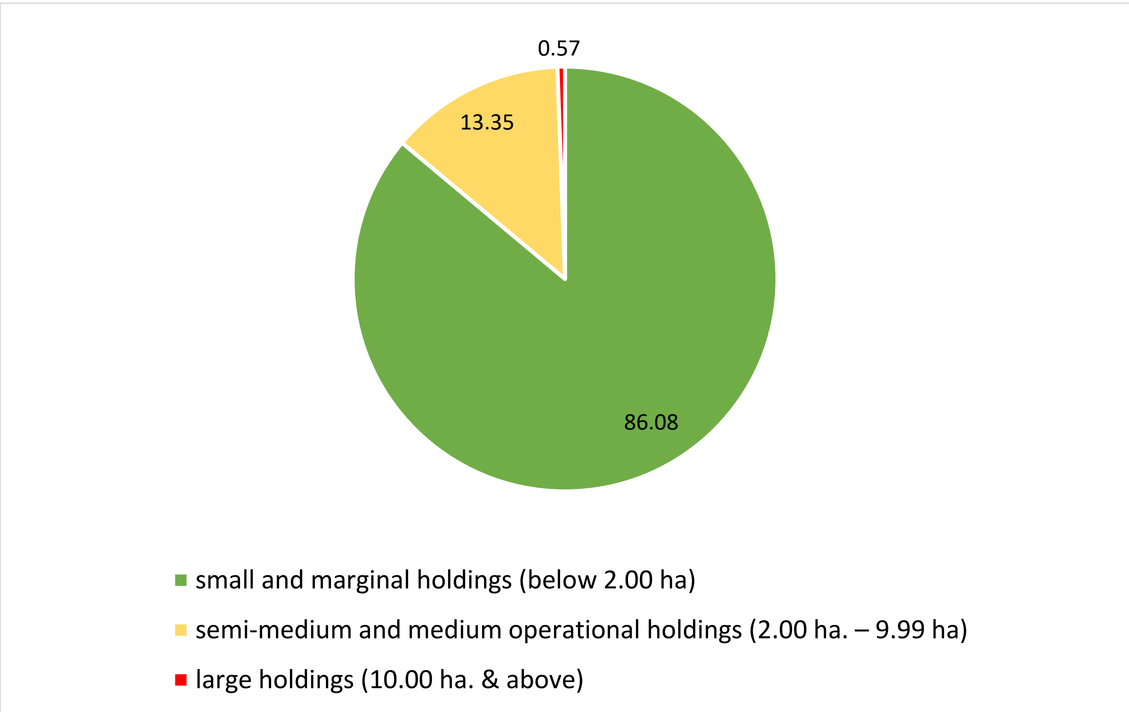

Figure 3. Number of operational holdings in percentage

Source: India Report on Agriculture Census 2015-16 (2017)

4.1.4. Land inequality

The trend of declining farm sizes in India is highlighted by data from the Agricultural Census, which reveals a reduction from an average of 2.3 hectares in 1970-71 to 1.37 hectares in 2000-01. A majority of Indian farmers are small and marginal, with around 99 million of the 121 million agricultural holdings in India in 2000-01 falling into this category. However, despite accounting for over 80 % of total farm households, their share in operated area is only 44 %, indicating significant land inequalities (Mahendra Dev 2012). In fact, data for 2005-06 shows that the share of small and marginal farmers in land holdings was as high as 83 % (Prasanna 2011). The average size of holdings has also decreased from 2.3 hectares to 1.33 hectares, with 63 % of land holdings belonging to marginal farmers with less than one hectare. This issue is further compounded by the variation in the average size of marginal holdings across states, ranging from 0.14 hectares in Kerala to 0.63 hectares in Punjab, and emphasizes the need for policy interventions to address land inequality in India's agricultural sector (Mahendra Dev 2012).

4.1.5. Impact of land fragmentation on small-scale farmers in India

In India, over 80% of farmers are considered small or marginal due to land fragmentation, a legacy of British colonialism. The British government primarily collected revenue through land tax, and the systems for tax collection varied across the country, with three types of land tenure systems: Zamindari, Raiyatwari, and Mahalwari (Sebby 2010). Even after Indian independence, they continued to have a significant impact on villages (Jha et al. 2005).

Zamindari, in particular, has resulted in highly inequitable patterns of land holdings, with few landowners holding most of the cultivatable land in many of the river valleys. While the Indian Constitution granted powers to different states to enact land redistribution measures, these measures, combined with acts of succession from one generation to the next, have reduced the size of land holdings and led to the fragmentation of land holdings of farmers (Jha et al. 2005). Studies have demonstrated that land fragmentation has a significant adverse effect on land productivity, leading to inefficient use of resources in agriculture and increasing costs (Jha et al. 2005).

This issue is further compounded by the inefficient use of resources in agriculture, such as the 25 times more water/tonne of output used to irrigate cotton in India than in Egypt (Jha et al. 2005). Therefore, addressing the issue of land fragmentation in India is important to promote sustainable agricultural practices and improve the livelihoods of small-scale farmers.

4.1.6. Men and women

Women play significant role in Indian agriculture with ongoing rise in number of female workers. Due to migration of men to non-farm activities in effort to support family needs. Number of total women workforces involved in farm as well as non-farm activities is 55 % (Kumar et al. 2020). Regardless the growing importance of women in agriculture their work is still treated as extension of their household responsibilities. Women face restricted access to credit and government subsidies due to a lack of ownership of assets, which is influenced by social norms, discrimination, and violence (FAO 2018). This lack of formal recognition prevents women from participating in government programs, such as loan eligibility, leading to vulnerability and insecurity. These social barriers also prevent women in adaptation to climate change (Dang et al. 2019). Employment in agriculture (1991-2019) is shown in Figure 4.

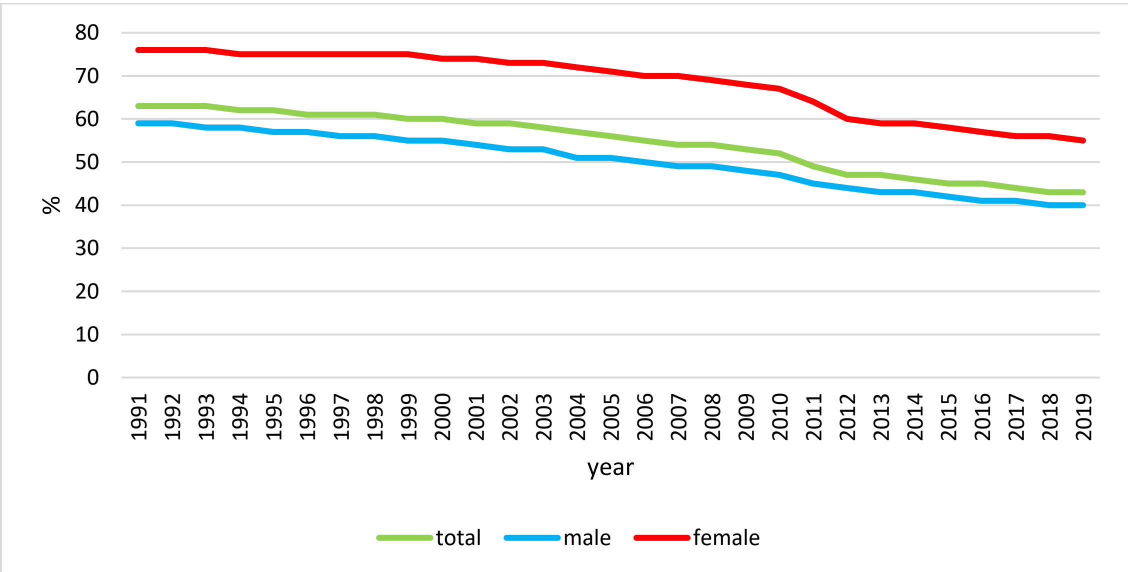

Figure 4. Employment in agriculture (1991-2019)

Source: International Labour Organization ILO (2021)

4.1.7. Poverty and malnutrition

Despite efforts to reduce poverty and improve nutrition in the country, many small-scale farmers still struggle to access nutritious food and adequate healthcare. Climate change can exacerbate these challenges, making it even more difficult for farmers to adapt and thrive.

According to FAO while achieving food sufficiency in production, India still accounts for a quarter of the world's hungry people and home to over 190 million undernourished people. The depth of poverty varies significantly across India, since it is such a diverse and large country. Thanks to continuing effort to reduce poverty, the incidence of poverty is now fixed at about 30 %. Anaemia continues to affect 50 percent of women including pregnant women and 60 percent of children in the country (FAO 2018).

4.1.8. Main problems of agriculture

Variance in agricultural growth has an impact on farm incomes as well as farmers' ability to take credit for investing in their land holdings (Deshpande 2017). Key issues affecting agricultural productivity include.

The decreasing sizes of agricultural land holdings. The trend towards decreasing sizes of agricultural land holdings in India has been a major challenge to agricultural productivity.

Continued dependence on the monsoon The system is heavily dependent on south-west monsoon (June to September), which is critical for more than half of the food production around the year (Singh et al. 2019). High dependence on rainfall for irrigation, small and fragmented land holdings and limited technical and financial resource base makes Indian farm households highly susceptible to weather abnormalities (Jain et al. 2015a).

Inadequate access to irrigation is critical to ensure crop productivity in India, but farmers often face challenges in accessing irrigation facilities (Rao et al. 2015).

Imbalanced use of soil nutrients resulting in loss of fertility of soil. Maintaining soil fertility is crucial for sustaining agricultural productivity. However, using soil nutrients in an unbalanced manner can result in the depletion of soil fertility in the long run (Chinthalu et al. 2020). The concentration of soil organic carbon is typically low in tropical regions, which is a significant contributing factor to their low soil fertility and productivity (Rao et al. 2015).

Uneven access to modern technology in different parts of the country. Modern technology can help improve agricultural productivity by enabling farmers to make better decisions around crop selection, irrigation, and soil management (APEC 2017).

Lack of access to formal agricultural credit. Access to formal agricultural credit is essential for farmers to invest in inputs like seeds, fertilizers, and irrigation (Deshpande 2017). Limited procurement of food grains by government agencies. The government of India procures food grains from farmers at minimum support prices to ensure a minimum income for farmers. However, the procurement system is limited in its coverage and scope. Expanding the procurement system to cover more crops and regions can help ensure remunerative prices for farmers (Deshpande 2017).

Failure to provide remunerative prices to farmers. Ensuring remunerative prices for farmers is critical to sustain agricultural productivity. One way to achieve this is by promoting private investment in agricultural marketing and infrastructure (Deshpande 2017).

Some of the recommendations made by comities over the years are bringing in agricultural land leasing laws, shifting to micro-irrigation techniques to improve efficiency of water use, improving access to quality seeds by engaging with the private sector finally introducing a national agricultural market to allow the trading of agricultural produce online (Deshpande 2017).

4.2. Climate Change and Agriculture: Perceptions and Adaptation

4.2.1. Climate change

Climate change is an urgent and intensifying global issue that is affecting countries and communities worldwide. The UNFCCC defines climate change as: *"a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods"* (UNFCCC 2009).

It is confirmed that in low- income, agriculture-dependent, tropical countries the farmers will be the most effected by climate change due to the lack of coping equipment (Mendelsohn et al. 2006). The relationship between climate change and agriculture is a complex and interdependent one (Vermeulen et al. 2012). Agriculture and land use changes, as well as the food system, are significant contributors of greenhouse gas emissions that contribute to climate change. Conversely, climate change has far-reaching impacts on agriculture, affecting everything from crop yields to water availability and soil health (Tripathi & Mishra 2017). The interplay between these two systems underscores the need for a comprehensive approach to addressing the challenges posed by climate change in the agricultural sector.

The variability in temperature and rainfall, as well as the increased intensity of extreme weather events such as droughts and floods, resulting from climate change, can disrupt agro-ecosystems, ultimately leading to decreased yields and income loss for farmers (Singh et al. 2018). Although farmers may not be aware of climate change as a long-term phenomenon, they often recognize changes in rainfall patterns and temperature and employ coping mechanisms or adaptive strategies at the farm or household level (Schneider et al. 2000; Tripathi & Mishra 2017). While these coping mechanisms can provide short-term solutions for weather-induced stresses in agriculture, it is crucial to implement sustainable adaptation strategies to achieve climate resilience in agriculture.

4.2.2. Adaptation to climate change

Farmers react to climate change by implementing adaptation measures that aim to mitigate the adverse impacts of climate change (Smit & Pilifosova 2005). Adaptation to climate change encompasses ecological, social, and economic adjustments and responses to climatic conditions and their effects. The capacity of farmers to adapt to climate change is significantly influenced by the level of awareness about climate change in their communities. Adaptation involves a series of actions or decisions taken by farmers to mitigate losses or derive benefits from climate change (Tseng et al. 2011). These actions can include water harvesting, early and deep planting, planting of cover crops, application of mulch to conserve moisture, planting of drought-tolerant and early-maturing crops, alley farming, and enterprise diversification etc (Selvaraju et al. 2006).

Adapting to the effects of climate change can occur at various levels of government. However, it is crucial to prioritize local adaptation efforts as local actors are better equipped to comprehend the severity of climate change (UNFCCC 2009). The adaptation process involves two steps: first, perceiving the impact of climate change and associated risks, and then taking steps to mitigate its adverse effects. The ability to perceive climate change accurately depends on the level of education and experience of an individual, which can influence their access to information. Perception is a cognitive process that involves interpreting sensory information. However, even if people perceive climate change accurately, they may not respond effectively due to constraints such as a lack of resources, information, or because of their personal beliefs (Tripathi & Mishra 2017).

Adapting agriculture to climate change is a significant challenge, particularly for marginalized and smallholder farmers who have lower levels of education and limited adaptive capacity. Therefore, it is essential to understand the accuracy of people's perception of climate change and how it motivates adaptation (McCarthy 2001). Incentivized and policy-driven adaptation strategies may be necessary to offset the losses from climate change (Tripathi & Mishra 2017).

4.3. Challenges of Environmental Sustainability

4.3.1. Soil degradation

Soil degradation is the deterioration of soil quality caused by natural events like floods, earthquakes, and wildfires, as well as human activities such as deforestation, improper agricultural practices, industrial waste mismanagement, over-grazing, and urbanization. Inappropriate farming practices include excessive tillage, use of heavy machinery, overuse of fertilizers and pesticides, poor irrigation, and inadequate crop rotation. India's soil degradation is driven by social factors such as land shortage, economic pressure on land, poverty, and population growth (Bhattacharyya et al. 2015).

Since the Green Revolution of the 1960s, the focus of India's agricultural policy has been to maximize crop yields through intensive use of high-yielding varieties, chemical fertilizers, and pesticides. However, this approach has resulted in the degradation of natural resources, particularly in rainfed areas (Rao et al. 2015). The most significant constraint on agricultural productivity is the degradation of soil, which has been caused by various factors such as erosion, salinization, and soil acidification. According to estimates, the total degraded area in India is 120.7 million hectares, of which 86.3 % is arable land. Water erosion is the most common type of soil degradation, affecting 60.7 % of the degraded land area, while wind erosion affects 10.3 % (Maji 2007). Furthermore, soils in rainfed areas are excluded from receiving benefits from chemical fertilizers and lack support for locally validated fertility-enhancing practices. The decline in soil productivity is mainly due to the accelerated erosion of topsoil, which has resulted in the loss of fertile surface soil and soil organic carbon (Maji et al. 2010). Other causes of soil degradation include the rapid depletion of soil organic matter, salt accumulation, and contamination with heavy metals. Soil compaction, surface crusting, and a decline in soil structure are also contributing factors to the reduction in agronomic productivity (Bhattacharyya et al. 2015). Thus, addressing soil degradation in India is crucial for sustainable agricultural development and the preservation of natural resources.

4.3.2. Water Scarcity

India has 18% of the world's population and 4 % of the world's fresh water, with 80 % of that water being utilised for irrigation in agriculture (Roy et al. 2022). Inadequate storage procedures, insufficient infrastructure, and poor water management have created a situation in which only 18–20 % of water is actually utilised (Das et al. 2018). India receives 1183 mm of annual rainfall, with the monsoon season accounting for 75 % of that total four-month period of monsoon precipitation (Das et al. 2018). India's 90 % crop production is constituted by the production of rice, wheat and sugarcane, which are the most water-consuming crop (Abraham et al. 2014).

Despite being a country with a prominent river system, namely the Ganga Perennial River, India heavily relies on fertile land and proper nutrition to support agricultural production. However, the country's vast size, rapid population growth, and increasing demands have led to groundwater exploitation and the looming threat of drought in several states (Rao et al. 2016). Climate change, population pressure, and migration have also contributed to the vulnerability of usable water sources due to insufficient supply (Sugden et al. 2014). Groundwater recharge primarily occurs through rainfall, and the process is augmented by surface water bodies, irrigated crops, and canals in India (Tushaar Shah 2007). The majority of groundwater removal takes place in higher unconfined aquifers, which also serve as the continuous recharge zones and the primary source of replenishable groundwater resources (Prasad & Rao 2018).

4.3.3. Droughts and floods

Drought and floods are among the most common events that threaten agricultural production (FAO 2021). Compared to droughts, floods typically occur over smaller locales in association with heavy precipitation and stream flows on shorter timescales (Mujumdar et al. 2020). In contrast to other natural perils, drought exerts a persistent and intensifying grip over time, leading to a gradual but profound degradation of affected area (Sam et al. 2017). Droughts, when combined with socioeconomic factors or conflict, have caused some of the most serious famines in history.

The long-term impacts of drought are prompting the need for proactive measures such as anticipatory and mitigatory actions. Severe heat conditions can lead to crop and livestock stress, resulting in decreased yields. Moreover, drought is intricately linked to the occurrence of pest and disease outbreaks (FAO 2021). The hydroclimatic extremes of droughts and floods are inherent characteristics of the monsoonal landscape in India. Since the mid-1990s, India has been experiencing prolonged and widespread droughts in consecutive years, with increased frequency in recent time (Mujumdar et al. 2020). According to the World Bank, India ranks as the second-most severely drought-affected country in Asia, following China. The impact of droughts in India has been significant, with over one billion people affected and 4.25 million fatalities recorded between 1900 and 2015 (Sam et al. 2017).

4.4. Overview of agroecological practices suitable for adaptation to climate change

4.4.1. Conservation agriculture

Conservation agriculture has become a prominent strategy for promoting resource conservation and agricultural sustainability. This approach holds considerable potential for enhancing crop productivity, optimizing resource use efficiency, and mitigating the impacts of extreme weather events. In recent years, conservation agriculture has gained increasing attention in South Asia, particularly for cereal systems facing production challenges (Sapkota et al. 2015). This strategy emphasizes minimal soil disturbance and permanent soil cover combined with appropriate crop rotation. Various components of conservation agriculture have been promoted to increase crop growth and productivity, reduce production costs, and improve resource use efficiency (Jat et al. 2018). One such component is zero-tillage, which is increasingly being adopted by farmers to lower production costs and increase profits (Erenstein et al. 2012). Overall, the primary goal of conservation agriculture is to achieve agricultural stability through the judicious use of external inputs and the preservation of high yielding and profitable systems.

4.4.2. Crop diversification

The adoption of crop diversification as a stress-relieving option for economic growth in the farming community is significant. In India, crop diversification is commonly perceived as a shift from less profitable traditional crops to more profitable ones. The practice of crop diversification, particularly in dryland areas, can decrease the risk of crop failures resulting from recurring droughts. Crop diversification offers several advantages, including increased income for small-scale farmers, reduced risk of price fluctuations and climatic variability, better balance in food demand, higher production of quality fodder for livestock, and conservation of natural resources (Khanam et al. 2018). Moreover, crop diversification minimizes environmental pollution, decreases the dependence on off-farm inputs, and enhances community food security (Khanam et al. 2018). In conclusion, crop diversification is a crop-selection strategy that enables farmers to cultivate a wide variety of crops in a limited area, leading to increased production-related activities and reduced risks (Neogi & Ghosh 2022). Through diversified crop rotations, integration of cover crops, green manures, and species mixtures, functional biodiversity is added to cropping systems, improving resource-use efficiency, promoting ecosystem services, and reducing negative environmental impact (Kremen et al. 2012).

4.4.3. Agroforestry

Agroforestry is a land management system that intentionally incorporates woody perennials such as trees, shrubs, palms, and bamboo alongside annual crops and/or animals in a spatial arrangement or temporal sequence. This system and its associated technologies have the potential to fulfil the demand for fuel, fodder, timber, medicine, and other non-woody forest products while simultaneously increasing green cover, alleviating pressure on forests, and reducing greenhouse gas emissions (Jinger et al. 2023). It is essential that the various components of agroforestry systems interact both ecologically and economically for optimal results (Somarriba 1992). Furthermore, agroforestry provides a practical solution for mitigating the hazards brought on by weather anomalies, managing soil erosion, and ensuring long-term sustainable output. A recent report from the Central Agroforestry Research Institute in Jhansi indicates that there is a 26.3mha area under agroforestry in India (Arunachalam et al. 2021).

4.4.4. Use of stress-tolerant, climate-smart varieties and new crops

Development of stress tolerant crop varieties with higher yield potential and resistant to multiple abiotic (drought, heat, flood, salinity) and biotic (pest and diseases) stresses is the key to reduce the adverse impacts of climatic risks (Pathak 2023). In drought-prone areas of India, farmers use drought-adapted crops such as sorghum and also adjust their production practices as a mechanism to spread risk such as staggered planting (Satapathy 2011). The introduction of short duration and improved varieties in pigeon pea, soybean, wheat, and sorghum in India helped to improve yield by 75 %, 15%, 27 %, and 91 %, respectively (Medhi 2018). Similarly, adopting heat-/moisture-tolerant seed varieties can address the problem of excess heat or moisture (Aryal et al. 2020). A large proportion of rice growing areas in India such as Uttar Pradesh (8 %), Bihar and West Bengal (40 %), and Odisha (27 %) suffer from submergence due to flood (Aryal et al. 2020). Farmers use leguminous crops, mostly red grams, mung bean, and peanuts, to supplement nitrogen to the soil which is lost due to soil erosion or excess flooding (Aryal et al. 2020).

4.4.5. Water management

An alternative approach to adapting agriculture to water stress is through integrated water management, which involves utilizing waste and marginal water for agriculture. In addition, traditional methods such as water harvesting, which involves collecting rainwater, can also help manage irrigation water deficit across seasons (Satapathy 2011). Laser land levelling is another popular method for enhancing water-use efficiency in irrigated rice-wheat systems in India (Jat et al. 2014). By using a micro-irrigation system, which includes sprinkler and drip methods, up to 84 % of water can be saved, depending on the location and crops under micro-irrigation (Kumar et al. 2016). The System of Rice Intensification (SRI) is a set of crop, soil, and water management practices that involve transplanting single seedlings and intermittently irrigating to maintain moist but aerated rice fields. Compared to the flooded system, SRI has been reported to increase crop yield by over 10 % while using 25-47 % less water in India. By reducing production costs and increasing yield, SRI can enhance farmers' adaptive capacity and increase their income (Aryal et al. 2020).

4.5. Analysis of smallholder farmers' behaviour and vulnerability to climate change in India: a review of quantitative studies and vulnerability index

A review of Indian quantitative studies analysing factors influencing smallholder farmers' behaviour and adaptation to climate change over the last 15 years

Table 1 shows an overview of Indian quantitative studies that have focused on analysing the factors influencing smallholder farmers' behaviour and adaptation to climate change over the last fifteen years. Studies were conducted all over India majority of them on the south-eastern region of the country (Bahinipati & Venkatachalam 2015; Jha & Gupta 2021; Kakumanu et al. 2016; Kumar et al. 2011; Panda et al. 2013; Patnaik et al. 2019).

Most significant and studied factors influencing farmers adaptation were education (Kawadia & Tiwari 2017a; Kumar et al. 2011; Panda et al. 2013; Patnaik et al. 2019), access to institutional support (Bahinipati & Venkatachalam 2015; Jha & Gupta 2021; Kumar et al. 2011; Panda et al. 2013; Patnaik et al. 2019), and access to irrigation (Jain et al. 2015a; Panda et al. 2013; Patil et al. 2019; Patnaik et al. 2019). Undeniably, income plays a crucial role, and higher farm income, in particular has been shown to increase the likelihood of measures such as soil conservation, changing planting dates, and crop variety diversification (Bahinipati & Venkatachalam 2015; Kawadia & Tiwari 2017a; Khatri-Chhetri et al. 2017). In contrast, higher non-farm income has been linked to the choice of planting trees, irrigation, and changing planting dates (Jha & Gupta 2021; Kumar et al. 2011). However, an increase in non-agricultural income may lead to a reduced concern about the risk of crop loss, which may discourage farmers from adopting adaptive strategies (Patil et al. 2019).

The data analysed relate mainly to data collected during the agricultural years 2013-2014 (Kakumanu et al. 2016; Kawadia & Tiwari 2017a; Khatri-Chhetri et al. 2017; Patil et al. 2019; Patnaik et al. 2019).

Table 1. A review of Indian quantitative studies analysing factors influencing smallholder farmers' behaviour and adaptation to climate change over the last 15 years

Study	Number of Respondents	Location	Year of data collection	Main factors influencing adaptation
Bahinipati & Venkatachalam 2015	285 households	Northern Odisha	2010-2011	▪ Access to agricultural extension, per capita income, received crop loss compensation.
Jain et al. 2015	779 farmers	Gujarat	2010-2011	▪ Assets, access to irrigation, risk aversion
Jha et al. 2021	700 households	Bihar	2016-2017	▪ Perception of climate change, socioeconomic characteristics of farm households, and institutional support
Kakumanu et al. 2016	513 households	Andhra Pradesh	2013	▪ Farm size, household size, access to market for sales, experience in farming
Kawadia et al. 2017	470 farmers	Madhya Pradesh	2014-2015	▪ Education, joint family-based living, income
Khatri-Chhetri et al. 2017	480 farmers	Rajasthan	2013-2014	▪ Climatic conditions and perceived risks, willingness to pay for sustainable technologies, socio-economic and location-specific variables
Kumar et al. 2011	600 farmers	Tamil Nadu	2008-2009	▪ Availability and awareness of credit, education, non-farm income sources
Panda et al., 2013	183 households	Eastern Odisha	2010	▪ Access to insurance and irrigation, education and climate information
Patil et al., 2019	333 farmers	Karnataka	2013-2015	▪ Access to groundwater, socio-economic status, crop choices, lack of incentives to conserve water
Patnaik et al., 2019	549 households	Western Odisha	2014	▪ Education, access to credit, previous experience of droughts

4.5.1. Exploring state-level vulnerability index: assessing exposure, sensitivity, and adaptation

The selected studies have been categorized into different vulnerability levels, ranging from high to low vulnerability, based on the vulnerability index presented in the study conducted by Shukla (2017). In the study vulnerability index was measured based on 3 climatic parameters exposure, sensitivity, and adaptive capacity. Changes in mean maximum and minimum temperatures as well as variation in precipitation constitute the indicators for calculating future exposure index which is based on RCPs short for Representative Concentration Pathways (Shukla et al. 2017). Sensitivity index is measured using ecological and demographic indicators. In India high sensitivity index is mostly found in arid and semi-arid regions of Deccan plateau and Eastern Ghats and some in some part of northern and eastern plains lying in subhumid ecosystem. Finally adaptive capacity as the ability of a district to accommodate modifications induced by climate change. Adaptive capacity exhibits a negative relation with vulnerability, i.e., higher values of adaptive capacity reduce vulnerability (Shukla et al. 2017).

Table 2. Exploring state-level vulnerability: assessing exposure, sensitivity, and adaptation (2017)

Study	**Location**	Exposure	Sensitivity	Adaptation capacity	**Vulnerability**
Bahinipati & Venkatachalam 2015	Northern Odisha	very low	low	very high	low
Jain et al. 2015a	Gujarat	very high	very high	low	high
Jha & Gupta 2021	Bihar	low	high	low	moderate
Kakumanu et al. 2016	Andhra Pradesh	low	very high	very high	low
Kawadia & Tiwari 2017a	Madhya Pradesh	very high	moderate	low	high
Khatri-Chhetri et al. 2017	Rajasthan	very high	low	high	very high
Kumar et al. 2011	Tamil Nadu	moderate	moderate	very high	very low
Panda et al. 2013	Eastern Odisha	very low	low	very high	low
Patil et al. 2019	Karnataka	high	moderate	high	very low
Patnaik et al. 2019	Western Odisha	very low	low	very high	low

Gujarat, Madhya Pradesh, and Rajasthan are among the most vulnerable states due to their high exposure and sensitivity, combined with low adaptation capacity. If measures are not taken, these states are likely to face greater number of challenges compared to the other studied states. Bihar has a moderate vulnerability index, possibly due to significant differences between its northern and southern regions. The north of Bihar has a more favourable climate and fertile soil, while the south is more drought-prone and has less fertile soil. Andhra Pradesh, Karnataka, and Tamil Nadu have a low vulnerability index mainly because of their high capacity to adapt to external stress caused by climate change. Odisha, which has a very low exposure index, is also showing low vulnerability. Level of vulnerability could indicate the outcomes of studies and should be considered.

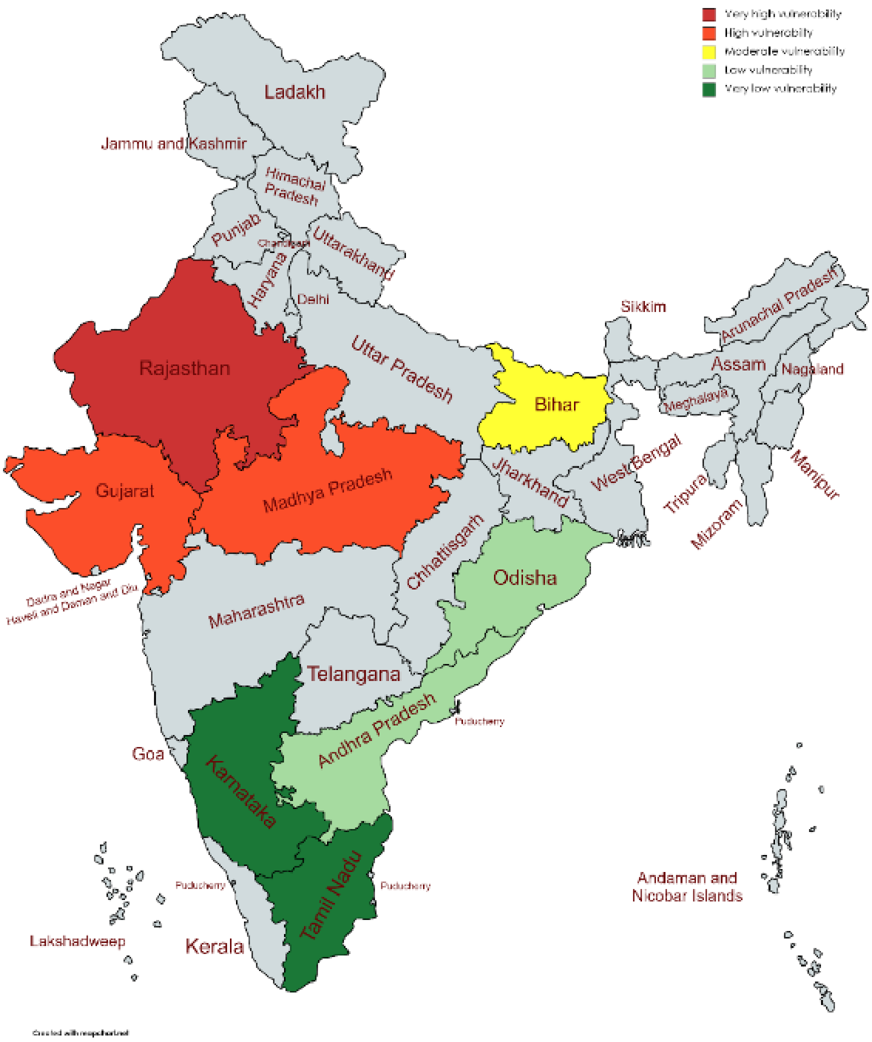

Figure 5. Study area map showing categories of vulnerability in each state

Source: author (2023)

4.6. Review of quantitative studies focusing on analysis of factors influencing smallholder farmer behaviour and their adaptation to climate change over the last 15 years

4.6.1. Factors influencing adaptation behaviour of small-scale farmers in India

Several factors influence the behaviour of smallholder farmers and their adaptation to climate change. In the study proposed framework from Wojewska (2021) was used. Farmers' decisions on adoptions of their adaptation strategies depend on two sets of variables, namely intrinsic and extrinsic factors (Fahad et al. 2023). In the proposed framework the capacity to participate is captured as an interplay of intrinsic and extrinsic factors which determine the participation objectives of an individual and the outcomes of the decision to participate, as well as whether the participation decision will be reinforced or reversed in the future (Wojewska et al. 2021). Extrinsic factors that stand for external forces affecting farmers' adaptive strategies to climate change and intrinsic factors that represents for farmers' cognitive and demographic characteristics (Fahad et al. 2023). Extrinsic factors shape knowledge and attitudes. The three categories of extrinsic factors are: institutional support, farm access, and climate variability and extremes (Wojewska et al. 2021). Institutional support includes formal and informal credit and development programmes. Farm access includes market, insurance, and irrigation access. Finally, climate variability and extremes include drought, floods and cyclones. Intrinsic factors are divided into two categories. First is farmers perception of climate change and whether the farmer experienced climate related impacts and second are socio-economic factors such as farming experience, gender, education, income, household size, farm size, migration (Fahad et al. 2023).

Table 3 lists out the independent variables taken by the studies in the regression models. Intrinsic variables related to climatic aberrations are used as prime explanatory variables to identify whether farmers are adapting to climate change and climate sensitive options (Bahinipati & Patnaik 2022), five studies considered effects of perception (Jain et al. 2015b; Jha & Gupta 202; Kawadia & Tiwari2017b; Kumar et al. 2011; Panda et al. 2013) and six experience (Bahinipati & Venkatachalam 2015; Jha & Gupta 2021; Kakumanu et al. 2016; Kumar et al. 2011; Panda et al. 2013; Patnaik et al. 2019). All studies consider at least one variable from the socio-economic factors. The indicators mostly used are farming experience, education, income and household size. Extrinsic institutional support explanatory variables being credit and development support if used they are used together (Bahinipati & Venkatachalam 2015; Jain et al. 2015a; Kakumanu et al. 2016; Kawadia & Tiwari 2017b; Kumar et al. 2011; Patnaik et al. 2019). Most used variable in farm access is access to insurance. Last extrinsic factors are climate extremes with drought being used in all studies except for (Jain et al. 2015a).

Table 3. List of independent variables considered in the papers

Study	Bahinipati & Venkatachalam 2015	Jain et al. 2015	Jha et al. 2021	Kakumanu et al. 2016	Kawadia et al. 2017	Khatri-Chhetri et al. 2017	Kumar et al. 2011	Panda et al., 2013	Patil et al., 2019	Patnaik et al., 2019
Intrinsic factors										
Climate change awareness										
Perception	N	Y	Y	N	Y	N	Y	Y	N	N
Experienced	Y	N	Y	Y	N	N	Y	Y	N	Y
Socio-economic factors										
Farming experience	Y	N	Y	Y	Y	Y	Y	Y	N	N
Gender	N	N	Y	Y	N	Y	N	N	N	N
Education	Y	N	Y	Y	Y	N	Y	Y	Y	Y
Income	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Household size	Y	N	Y	Y	N	N	Y	Y	Y	Y
Farm size	Y	N	Y	Y	Y	N	Y	Y	Y	Y
Migration	Y	N	Y	Y	N	N	N	Y	Y	Y

Extrinsic factors										
Institutional support										
Formal and informal credit	Y	Y	N	Y	Y	N	Y	Y	N	Y
Development programmes	Y	Y	N	Y	Y	N	Y	Y	N	Y
Farm access										
Market	N	N	N	Y	N	Y	N	N	N	N
Insurance	Y	N	N	Y	N	Y	Y	Y	N	N
Irrigation	N	Y	N	Y	N	Y	N	Y	Y	N
Climate variability and extremes										
Drought	Y	N	Y	Y	Y	Y	Y	Y	Y	Y
Floods	Y	N	Y	N	Y	N	Y	N	N	N
Cyclones	Y	N	N	N	N	N	Y	N	N	Y

Note: Y = yes, if the independent variables were considered by the studies in the regression models, if otherwise no = N

4.6.2. Key factors affecting small-scale farmers' climate change adaptation in India based on the proposed framework: insights from analysed studies

In order to illustrate the interdependence of various factors, each study was analysed individually. The key factor identified is the perception of climate change, which is determined by past experiences. For farmers to accurately perceive the impact of climatic variations, they must be sufficiently educated. Education was found to have a positive impact in every study. However, in some cases, despite the correct perception of climate change, farmers were unable to adapt due to other constraints such as a lack of adequate income (Bahinipati & Venkatachalam 2015; Kumar et al. 2011).

Income diversification through non-farm sources had a positive impact on the adoption of climate change adaptation measures, except for one study where it was noted that resource sustainability may not be a concern in areas with non-farm diversification opportunities (Patil et al. 2019). In Karnataka, farmers with many non-farm opportunities opted to leave agriculture entirely, which could be attributed to the low vulnerability index of the region. This could be due to higher rates of urbanization, which offer more livelihood options.

Institutional support, such as government incentives or non-governmental organisations (NGO) assistance, also plays an important role in adaptation. Providing compensation for crop losses and insurance gives farmers more resources to adapt and avoid falling into poverty. Governmental financial support creates a greater willingness to accept climate-smart practices (Khatri-Chhetri et al. 2017). Water scarcity plays a significant role in most regions, with access to irrigation being a common problem. Providing good access to irrigation has a positive impact on adaptation.

Due to the diversity of climate extremes and its impact on agriculture, Odisha was the most frequently studied state (Bahinipati & Venkatachalam 2015; Panda et al. 2013; Patnaik et al. 2019). Odisha is frequently affected by various climate extremes, such as cyclones and floods. In response, farmers take various adaptation measures to minimize the negative economic impact of these extreme events. Interestingly, one factor observed in studies from Odisha was that infant mortality was a significant driver for engaging in agricultural adaptation.

Agricultural adaptation practises include shortening or lengthening of growing seasons, changing planting dates, altering land under cultivation, and increase/decrease the use of irrigation, mixed paddy cropping, pest and disease management, water harvesting, mixed crop-livestock farming.

Self-adjustment strategies of risk management adopted by the farmers is loan from friends and relatives, bank loan, moneylenders, government relief, agricultural insurance, cooperative banks lease/sale of land.

All other factors not mentioned in the insights of analysed studies are not statistically significant in regression models.

4.6.3. Insights from analysed studies

Bahinipati's study (2015) focus on climate adaptation practices among farmers in Northern Odisha. Study found that the utilization of salt and flood-resistant indigenous/traditional paddy seeds was the most effective adaptation technique. Socio-economic factors such as household size and per capita income also played a significant role in adaptation practices. Access to agricultural extension, formal and informal credit, the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS), and compensation for crop loss were highlighted as important factors. The study was conducted in disaster-prone districts and accounted for all climatic extremes.

Jain's research (2015) analyse the perceptions of farmers regarding delayed monsoons in Gujarat. The study finds that various factors, including assets, access to irrigation, weather perceptions, and risk aversion, significantly impact decision-making processes. Specifically, farmers with less secure financial status tend to opt for sustainable measures, such as crop switching, while wealthier farmers tend to prioritize increased irrigation as their preferred strategy. The study highlights the importance of better access to credit as a key factor for improving irrigation, which can ultimately lead to more effective monsoon adaptation practices.

Jha's study (2021) is defying farmers perceptions and experiences in Bihar. The study highlights the role of socio-economic factors, particularly farmers' experiences, and reveals that younger farmers are more inclined to adopt adaptation strategies than their older counterparts. The migration of household members provides income guarantees, enabling farmers to undertake the risk of adapting to new strategies. This phenomenon is also linked to the size of the household, as larger households can send more members to non-climate-sensitive occupations. Moreover, group-based adaptation approaches that strengthen social networks have a positive impact on farmers' adaptation efforts.

Kakumanu (2016) investigated the adoption of farm technology**.** In dryland systems of Andhra Pradesh farm technology is climate change adaptation strategy. The study identified several significant variables affecting technology adoption, with the experience of drought being the most prominent factor. Other significant variables included farm size, household size, farming experience, and access to the market in relation to proximity to the market. The study also highlighted the importance of institutional support, particularly in the provision of credit and crop insurance. Specifically, farmers in Andhra Pradesh exhibited a greater tendency to invest in supplemental irrigation, which underscores the critical role of infrastructure development. This finding was associated with the challenges posed by drought and untimely rainfall, and the need to implement improved production practices.

Kawadia (2017) examine farmers' perceptions of climate change in Madhya Pradesh. The study solely focused on perception and found that farmers demonstrated accurate perceptions of changes in temperature and precipitation, as well as an awareness of extreme climate-related events. The study also noted that better perception was associated with education, as farmers with higher levels of education were able to effectively manage resources, crop cycles, and rainwater availability, resulting in increased income and a greater ability to opt for enhanced irrigation and farm mechanization. Overall, the study emphasizes the crucial role of education in shaping farmers' perceptions of climate change.

Khatri-Chherti (2017) focus on the prioritization of climate-smart agriculture (CSA) and analyzed use of CSA technologies by farmers, as well as the factors affecting their willingness to adapt to CSA. The study revealed that farmers' preferences for CSA technologies varied based on several factors, including age, gender, landholding size, income level, farming system, and location. These findings underscore the need for a well-considered and balanced policy response that can address the specific demand for CSA technology among different social groups and in different geographic locations. Furthermore, the study suggests that farmers tend to favour risk mitigation technologies such as crop insurance, agro-advisories, and rainwater harvesting, which may benefit from government support.

Kumar (2011) investigated farmers' perceptions of crop insurance as a risk management strategy in Tamil Nadu. The study identified education as the most crucial factor, as educated farmers possessed more knowledge about the workings of crop insurance. The findings of the study indicated that factors such as farm size, non-farm income, presence of risk in farming, household size, and affordability of insurance had a significant and positive impact on the adoption of crop insurance.

Panda (2013) in the western region of Odisha determined that risk-taking ability was a significant contributing factor in agricultural adaptation, specifically through access to irrigation water and crop insurance. Surprisingly, no significant effects were observed for educational level, climate information, or farming experience. Furthermore, access to credit was not deemed a crucial factor for adaptation since it enabled rice farmers to continue cultivating rice rather than switching to cotton, thus avoiding the need to reduce their reliance on rainwater. Households located in areas with greater resources, access to information and finance, are likely better positioned to engage in adaptation compared to those without these advantages.

Patil's study (2019) examines the potential for improving agricultural productivity through adaptive capacity. Despite widespread recognition of the negative impacts of climate change, which have been predominantly manifested in the form of droughts in the region, farmers with sufficient resources tend to prioritize drilling deeper for groundwater over adopting sustainable agricultural practices. In the state of Karnataka, urbanization has created alternative non-farm employment opportunities, leading small or financially disadvantaged farmers to opt out of agriculture altogether.

Patnaik (2019) in coastal Odisha identifies education, access to credit, and prior experience of droughts as significant determinants of farm-level adaptation measures. The study highlights the importance of promoting livelihood security through targeted interventions, which can improve access to formal institutions such as credit facilities, thereby positively influencing adaptation decisions. Additionally, development programs like MGNREGS and WORLP are found to have a positive impact on adaptation measures.

5. Conclusions

The aim of this research was to examine the factors that affect the behaviour of smallholder farmers towards climate change in India. Smallholder farmers play a critical role in implementing adaptation measures on the ground, and their attitudes towards adaptation are a crucial determinant of the success or failure of these strategies. Given the prevalence of drought and food insecurity in the country, it is imperative that local smallholder farmers embrace adaptation strategies and shift their unfavourable attitudes towards agro-ecological practices suitable for adaptation.

Based on the findings of this study, it can be concluded that several factors influence the adaptation behaviour of small-scale farmers towards climate change in India. These factors include socio-economic characteristics, access to information, knowledge and awareness of climate change, availability of resources, institutional support, and perceived benefits of adaptation practices.

The study revealed that the socio-economic characteristics of smallholder farmers, such as farming experience, education, and income level, influence their attitudes towards adaptation. Additionally, access to information and knowledge about climate change is crucial in promoting the adoption of adaptation strategies. The study also highlighted the importance of institutional support in providing farmers with the necessary resources and information to implement adaptation practices.

Furthermore, the study emphasized the need for a shift in attitudes towards agro-ecological practices suitable for adaptation, such as conservation agriculture and agroforestry. These practices offer several benefits, including increased soil fertility, water retention, and crop productivity.

6. Recommendation

The study highlights the importance of complementing farm-level adaptation options with non-climate sensitive local livelihood opportunities to ensure income guarantee. Moreover, the study emphasizes the significant role of socioeconomic characteristics of farm households in farmers' adaptation. Therefore, policies and programs need to encourage and strengthen social networks through group-based adaptation approaches. It is essential to maintain robust linkages between climate risk reduction and capacity building through community participation and institutional development.

The farming activities in the study area are complex due to resource availability and climatic conditions. To account for the risk associated with each technology identified for adoption by farmers, it is crucial to create more awareness through appropriate and affordable training programs. Such programs should explain the technologies and help farmers adopt them faster. Examining the possibilities of convergence with government or private sector programs that focus on technology-related issues should also be sought.

The major policy implications of this study are that investment in farmers' education is important to increase their income sustainably. Such steps will help farmers perceive climate change more accurately. Improving farmers' perception by means of these measures would be a decisive step in ensuring food security in the region in the context of climate change.

Policies and programs aimed at promoting Climate-Smart Agriculture (CSA) technologies should focus on site-specific technologies that are relevant to the local farmers. Adaptation policies need to emphasize the crucial role of providing information about available CSA technologies and creating financial resources to enable farmers to adopt various CSA technologies relevant to their location.

In rural India, developmental interventions enhance the likelihood of adopting various farm-level adaptation options to climate change. Such interventions promote access to formal institutions like credit availability, which is a crucial determinant of adaptation decisions.

The study recommends scaling up such developmental interventions to extend the adoption of various farm-level adaptation mechanisms. This would help avoid potential adverse impacts of climate change in the foreseeable future, particularly in rural India.

Extension professionals can play a significant role in enhancing farmers' decision-making in the light of changing climate parameters. The most important purpose of extension today is to empower farmers so that their voices can be heard, and they can play a major role in deciding how to mitigate and adapt to changing climate.

7. References

Abraham B et al. 2014. The system of crop intensification: reports from the field on improving agricultural production, food security, and resilience to climate change for multiple crops. Agriculture & Food Security **3**:4.

Ali J. 2007. Livestock sector development and implications for rural poverty alleviation in India. Livestock Research for Rural Development **19**: 1-15.

Angom J, Viswanathan PK, Ramesh M V. 2021. The dynamics of climate change adaptation in India: A review of climate smart agricultural practices among smallholder farmers in Aravalli district, Gujarat, India. Current Research in Environmental Sustainability **3**:100039.

APEC. 2017. The Role of Digital Payments in Sustainable Agriculture and Food Security. Available from www.betterthancash.org. (accessed April 4, 2023).

Arunachalam A, Sundaram S, Handa AK. 2021. Administering agroforestry at the district level. Current Science **121**:473–474.

Aryal JP, Sapkota TB, Khurana R, Khatri-Chhetri A, Rahut DB, Jat ML. 2020. Climate change and agriculture in South Asia: adaptation options in smallholder production systems. Environment, Development and Sustainability **22**:5045–5075.

Panda P, India government, 2021. Agricultural Statistics at a Glance 2021.

Bahinipati CS, Patnaik U. 2022. What Motivates Farm-Level Adaptation in India? A Systematic Review. Climate Change and Community Resilience. 49-68.

Bahinipati CS, Venkatachalam L. 2015. What drives farmers to adopt farm-level adaptation practices to climate extremes: Empirical evidence from Odisha, India. International Journal of Disaster Risk Reduction **14**:347–356.

Bhattacharyya R et al. 2015. Soil degradation in India: Challenges and potential solutions. Sustainability **7**: 3528-3570.

Bryan E, Deressa TT, Gbetibouo GA, Ringler C. 2009. Adaptation to climate change in Ethiopia and South Africa: options and constraints. Environmental Science & Policy **12**:413–426.

Chatterjee RN, Rajkumar U. 2015. An Overview Of Poultry Production In India. Page Anim. Hlth.

Chinthalu V, G. Hegde N, Supekar A. 2020. Study of Challenges Faced by Farmers Related to Irrigation Water for Increasing Crop Production. Asian Journal of Advances in Agricultural Research:1–6. Sciencedomain International.

Dang H Le, Li E, Nuberg I, Bruwer J. 2019. Factors influencing the adaptation of farmers in response to climate change: a review. Climate and Development **11**:765-774.

Das S, Maity PK, Das R. 2018. Remedial Measures for Saline Water Ingression in Coastal Aquifers of South West Bengal in India. MOJ Ecology & Environmental Sciences **3**.

Deshpande. 2017. State of Agriculture in India.

Erenstein O, Sayre K, Wall P, Hellin J, Dixon J. 2012. Conservation Agriculture in Maize- and Wheat-Based Systems in the (Sub)tropics: Lessons from Adaptation Initiatives in South Asia, Mexico, and Southern Africa. Journal of Sustainable Agriculture **36**:180–206.

Fahad S, Nguyen-Anh T, To-The N, Nguyen-Thi-Lan H, Nassani AA, Haffar M. 2023. A study evaluating the extrinsic and intrinsic determinants of farmers' adoption of climate change adaptation strategies: A novel approach for improving farmers' health. One Health **16**.

FAO. 2016. India country programming framework.

FAO. 2018. Country Programming Framework. Available from www.fao.org/publications/card/en/c/I9066EN/ (accessed March 18, 2023).

FAO. 2021. The impact of disasters and crises on agriculture and food security.

GoI. 2012. India Rural Development Report 2012|13.

Härri A, Levänen J, Koistinen K. 2020. Marginalized small-scale farmers as actors in just circular-economy transitions: Exploring opportunities to circulate crop residue as raw material in India. Sustainability (Switzerland) **12**:1–18.

Jain M, Naeem S, Orlove B, Modi V, DeFries RS. 2015a. Understanding the causes and consequences of differential decision-making in adaptation research: Adapting to a delayed monsoon onset in Gujarat, India. Global Environmental Change **31**:98–109.

Jain M, Naeem S, Orlove B, Modi V, DeFries RS. 2015b. Understanding the causes and consequences of differential decision-making in adaptation research: Adapting to a delayed monsoon onset in Gujarat, India. Global Environmental Change **31**:98–109.

Jat ML, Singh Y, Gill G, Sidhu HS, Aryal JP, Stirling C, Gerard B. 2014. Laser-Assisted Precision Land Leveling Impacts in Irrigated Intensive Production Systems of South Asia. Advances in soil science, 323-352.

Jat RD, Jat HS, Nanwal RK, Yadav AK, Bana A, Choudhary KM, Kakraliya SK, Sutaliya JM, Sapkota TB, Jat ML. 2018. Conservation agriculture and precision nutrient management practices in maize-wheat system: Effects on crop and water productivity and economic profitability. Field Crops Research **222**:111–120.

Jayaraman T, Murari K. 2014. Climate Change and Agriculture: Current and Future Trends, and Implications for India. Review of Agrarian Studies, 4(2369-2021-077).

Jha CK, Gupta V. 2021. Farmer's perception and factors determining the adaptation decisions to cope with climate change: An evidence from rural India. Environmental and Sustainability Indicators **10**.

Jha R, Nagarajan HK, Prasanna ASARC S, Ncaer R, Delhi N. 2005. Land Fragmentation and its Implications for Productivity: Evidence from Southern India Land Fragmentation and its Implications for Productivity.

Jinger D et al. 2023. Degraded land rehabilitation through agroforestry in India: Achievements, current understanding, and future prospectives. Front. Ecol. Evol **11**: 69.

Kakumanu KR, Kuppanan P, Ranganathan CR, Shalander K, Amare H. 2016. Assessment of risk premium in farm technology adoption as a climate change adaptation strategy in the dryland systems of India. International Journal of Climate Change Strategies and Management **8**:689–717.

Kawadia G, Tiwari E. 2017a. Farmers' perception of climate change in Madhya Pradesh. Area Development and Policy **2**:192–207.

Kawadia G, Tiwari E. 2017b. Farmers' perception of climate change in Madhya Pradesh. Area Development and Policy **2**:192–207.

Khanam R, Bhaduri D, Nayak AK. 2018. Crop diversification: an important way-out for doubling farmers' income. Indian Farming **68**: 31-34.

Khatri-Chhetri A, Aggarwal PK, Joshi PK, Vyas S. 2017. Farmers' prioritization of climate-smart agriculture (CSA) technologies. Agricultural Systems **151**:184–191.

Knowler D, Bradshaw B. 2007. Farmers' adoption of conservation agriculture: A review and synthesis of recent research. Food Policy **32**:25–48.

Kremen C, Iles A, Bacon C. 2012. Diversified farming systems: An agroecological, systems-based alternative to modern industrial agriculture. Ecology and Society **17**.

Kumar M, Sharma B, Singh OP. 2016. Water Saving and Yield Enhancing Micro-irrigation Technologies: How Far Can They Contribute to Water Productivity in Indian Agriculture? Available from www.oznet.ksu.edu/sdi/News/Whatisnew.htm. (accessed March 30, 2023).

Kumar R, Agrawal K, Vijayshankar PS, Vasavi AR. 2020. State Of Rural And Agrarian India Report 2020 Rethinking Productivity and Populism Through Alternative Approaches Published by Graphics and Design by Kanikka Sersia.

Kumar S, Venkatram R, Suresh Kumar D, Barah BC, Ranganathan CR, Venkatram R, Gurunathan S, Thirumoorthy S. 2011. An Analysis of Farmers' Perception and Awareness towards Crop Insurance as a Tool for Risk Management in Tamil Nadu. Page Agricultural Economics Research Review. Available from www.researchgate.net/publication/227365124 (accessed March 30, 2023).

Mahendra Dev S. 2012. Small Farmers in India: Challenges and Opportunities Small Farmers in India: Challenges and Opportunities Small Farmers in India: Challenges and Opportunities 1. Available from www.igidr.ac.in/pdf/publication/WP-2012-014.pdf (accessed April 2, 2023).

Maji AK. 2007. Assessment of degraded and wastelands of India. Journal of the Indian Society of Soil Science **55**:427–435.

Maji AK, Reddy GPO, Sarkar D. 2010. Degraded and Wastelands of India, Status and Spatial Distribution.

Majra J, Gur A. 2009. Climate change and health: Why should India be concerned? Indian Journal of Occupational and Environmental Medicine **13**:11.

McCarthy JJ (Ed.). 2001. climate change 2001: impacts, adaptation, and vulnerability.

Mendelsohn R, Dinar A, Williams L. 2006. The distributional impact of climate change on rich and poor countries. Environment and Development Economics **11**:159–178.

Mujumdar M et al. 2020. Droughts and Floods. Assessment of Climate Change over the Indian Region. Springer Singapore, Singapore.

Neogi S, Ghosh BK. 2022. Evaluation of Crop Diversification on Indian Farming Practices: A Panel Regression Approach. Sustainability **14**.

Panda A, Sharma U, Ninan KN, Patt A. 2013. Adaptive capacity contributing to improved agricultural productivity at the household level: Empirical findings highlighting the importance of crop insurance. Global Environmental Change **23**:782–790.

Pathak H. 2023. Impact, adaptation, and mitigation of climate change in Indian agriculture. Environmental Monitoring and Assessment **195**.

Patil VS, Thomas BK, Lele S, Eswar M, Srinivasan V. 2019. Adapting or Chasing Water? Crop Choice and Farmers' Responses to Water Stress in Peri-Urban Bangalore, India. Irrigation and Drainage **68**:140–151.

Patnaik U, Das PK, Bahinipati CS. 2019. Development interventions, adaptation decisions and farmers' well-being: evidence from drought-prone households in rural India. Climate and Development **11**:302–318.

Prasad YS, Rao BV. 2018. Groundwater depletion and groundwater balance studies of Kandivalasa River Sub Basin, Vizianagaram District, Andhra Pradesh, India. Groundwater for Sustainable Development **6**:71–78.

Prasanna L. 2011. Ex-Ante impact assessment of BT Brinjal View project intellectual property rights and competition interaction in Indian rice seed sector, emerging scenario, implications for enhancing quality seed use View project. Available from www.researchgate.net/publication/282577801 (accessed March 25, 2023).

Rao CS, Lal R, Prasad JVNS, Gopinath KA, Singh R, Jakkula VS, Sahrawat KL, Venkateswarlu B, Sikka AK, Virmani SM. 2015. Potential and challenges of rainfed farming in India. Advances in Agronomy **133**:113–181.

Rao T, Jain V, Jain A. 2016. Visiting a "frail elderly": A review on model of care and treatment strategies. Journal of Mahatma Gandhi Institute of Medical Sciences **21**:101.

Roy P, Pal SC, Chakrabortty R, Chowdhuri I, Saha A, Shit M. 2022. Climate change and groundwater overdraft impacts on agricultural drought in India: Vulnerability assessment, food security measures and policy recommendation. Science of the Total Environment **849**.

Medhi, S., Islam, M., Barua, U., Sarma, M., Das, M., Syiemlieh, E., Bordoloi, P., & Mukhim, B. (2018). Impact of Climate Resilient Practices under NICRA Project in Ri Bhoi District of Meghalaya. Economic Affairs **63**: 653–664.

Sam AS, Kumar R, Kächele H, Müller K. 2017. Quantifying household vulnerability triggered by drought: evidence from rural India. Climate and Development **9**:618–633.

Sapkota TB, Jat ML, Aryal JP, Jat RK, Khatri-Chhetri A. 2015. Climate change adaptation, greenhouse gas mitigation and economic profitability of conservation agriculture: Some examples from cereal systems of Indo-Gangetic Plains. Journal of Integrative Agriculture **14**:1524–1533.

Satapathy S, Porsche I, Kunkel N, Manasfi N, Kalisch A. 2011. Adaptation to Climate Change with a Focus on Rural Areas and India. Environment, Development and Sustainability **22**:5045–5075.

Schneider SH, Easterling WE, Mearns LO. 2000. Adaptation: sensitivity to natural variability, agent assumptions and dynamic climate changes. Climatic Change **45**:203–221.

Sebby K. 2010. The Green Revolution of the 1960's and Its Impact on Small The Green Revolution of the 1960's and Its Impact on Small Farmers in India Farmers in India. Available from https://digitalcommons.unl.edu/envstudtheses.

Selvaraju et al. 2006. Livelihood adaptation to climate variability and change in drought-prone areas of Bangladesh. Developing institutions and options. Rome : Asian Disaster Preparedness Center, Food and Agriculture Organization of the United Nations

Shukla R, Chakraborty A, Joshi PK. 2017. Vulnerability of agro-ecological zones in India under the earth system climate model scenarios. Mitigation and Adaptation Strategies for Global Change **22**:399–425.

Singh NP, Anand B, Khan MA. 2018. Micro-level perception to climate change and adaptation issues: A prelude to mainstreaming climate adaptation into developmental landscape in India. Natural Hazards **92**:1287–1304.

Singh NP, Anand B, Singh S, Khan A. 2019. Mainstreaming climate adaptation in Indian rural developmental agenda: A micro-macro convergence. Climate Risk Management **24**: 30-41

Smit B, Pilifosova O. 2005. Adaptation to Climate Change in the Context of Sustainable Development and Equity. Sustainable Development **8**: 9.

Somarriba E. 1992. Revisiting the past: an essay on agroforestry definition. Agroforestry Systems **19**:233–240.

Srinivasa Rao C, Gopinath KA, Prasad JVNS, Prasannakumar, Singh AK. 2016. Climate Resilient Villages for Sustainable Food Security in Tropical India: Concept, Process, Technologies, Institutions, and Impacts. Advances in Agronomy **140**: 101-214.

Sugden F, de Silva S, Clement F, Maskey-Amatya N, Ramesh V, Philip A, Bharati L. 2014. A framework to understand gender and structural vulnerability to climate change in the Ganges River Basin: lessons from Bangladesh, India and Nepal. Colombo, Sri Lanka.

Tripathi A, Mishra AK. 2017. Knowledge and passive adaptation to climate change: An example from Indian farmers. Climate Risk Management **16**:195–207.

Tseng ML, Wu WW, Lee CF. 2011. Knowledge Management Strategies in Linguistic Preferences Sustainable Investment View project Knowledge Management Strategies in Linguistic Preferences. Page Journal of Asia Pacific Business Innovation & Technology Management. Available from www.researchgate.net/publication/267805144 (accessed April 5, 2023).

Tushaar Shah TS. 2007. The groundwater economy of South Asia: an assessment of size, significance and socio-ecological impacts. Pages 7–36 The agricultural groundwater revolution: opportunities and threats to development. CABI, UK.

UNFCCC. 2009. UNFCCC. (2009). Report of the Conference of the Parties on its fifteenth session, held in Copenhagen from 7 to 19 December 2009; Part Two: Decisions Adopted by the Conference of the Parties.

Vermeulen SJ, Campbell BM, Ingram JSI. 2012. Climate Change and Food Systems. Annual Review of Environment and Resources **37**:195–222.

Wojewska AN, Singh C, Hansen CP. 2021. A policy tool for monitoring and evaluation of participation in adaptation projects. Climate Risk Management **33**.