ESSAYS ON THE ADOPTION AND IMPACT OF CLIMATE SMART AGRICULTURE PRACTICES: INSIGHTS FROM RURAL FARMERS OF ODISHA

Thesis

Submitted in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

by

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DECLARATION

By the Ph.D. Research Scholar

I hereby declare that the Thesis entitled **"Essays on the Adoption and Impact of Climate Smart Agriculture Practices: Insights from Rural Farmers of Odisha"**, which is being submitted to the National Institute of Technology Karnataka, Surathkal in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy** in Economics is a bonafide report of the research work carried out by me. The material contained in this Research Synopsis has not been submitted to any University or Institution for the award of any degree.

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CERTIFICATE

This is to certify that the Research Thesis entitled "**ESSAYS ON THE ADOPTION AND IMPACT OF CLIMATE SMART AGRICULTURAL PRACTICES: INSIGHTS FROM RURAL FARMERS OF ODISHA**" submitted by **Purna Chandra Tanti (Register Number: 177133SM006)** as the record of the research work carried out by him, is accepted as the Research Thesis submission in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy**.

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(Signature with Date and Seal)

DEDICATION

To My Mother Mrs. Saibani Tanti,
Father Mr. Ghasi Ram Tanti and Family

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ABSTRACT

Climate change endangers rural livelihoods by negatively impacting agricultural production through reduced crop yields, harvest loss, and increasing production costs. Odisha agriculture depends on rainfall and remains vulnerable to rising temperatures and uncertain precipitation. Climate-smart agricultural (CSA) practices have been advanced as a possible solution to adopt and mitigate climate change issues. This study addresses three objectives correlated with adopting Climate Smart Agriculture practices.

The first objective is to evaluate the factors determining agricultural machinery. It examines the effect of agricultural machinery adoption on net agricultural income, household income, and household consumption adoption among rural farmers in India. The study draws on India Human Development Survey (IHDS) data of 10,000 households spread over 28 states of India to derive the extent of mechanization for each state in India. Concerning the multivariate probit model, climate change events and shocks induce farmers to adopt farm mechanization. The other significant drivers of agricultural mechanization include access to institutional credit, availability of extension services, and landholding size. ESR model revealed that adopting machineries has increased net agricultural income by 31%, household income by 19%, and food consumption by 5%. Given these demonstrable positive effects of mechanization in agriculture

Administering a structured questionnaire survey among the 494 rural farming households of an eastern Indian state, namely Odisha, the first objective explores the key determinants of CSA adoption. The investigation will focus on one coastal district and two inland districts. In order to adapt to these weather anomalies, the respondents have implemented various CSA practices, including rescheduling planting, crop rotation, crop diversification, soil conservation, drought-resistant seeds, and agroforestry. This study uses a multivariate probit model to investigate the primary factors that influence the decision to implement CSA practices. According to the findings, perceptions of climate change, availability of extension services, and electricity for irrigation are the most important factors in adopting CSA practices. The sub-objective of this section focuses on the gender aspects of the adoption of CSA practices. The FGDs were undertaken in ten study area villages to understand the gender dimension of CSA adoption in the study area.

The third objective is to examine the impacts of CSA practices on the productivity and income of the farmers. The current study is based on the cross-sectional household survey data collected from three climate-vulnerable districts in the semi-arid regions of Odisha, namely, Balangir, Kendrapara and Mayurbhanj. The impact of CSA practices' adoption on income and productivity was analyzed using propensity score matching (PSM) and two stage least square method(2SLS). Two instruments were used to remove self-selection bias and endogeneity, i.e., distance to extension and percentage of multiple adapters in a village. Both models show the positive and significant impact of adoption on the productivity and income of the farmers. There are few policy ramifications of these findings. Adopting CSA practices requires the farmer's involvement and communication with other farmers. Effective farmer-to-farmer extension programmes enhance adoption, productivity, and income. If we want to see more widespread adoption of CSA methods, we must see more frequent extension interaction and a more conveniently located extension office.

Keywords: Climate Smart Agriculture, Agricultural Extension, Perception to Climate Change, Access to energy, Multi-Variate Probit Model, Impact Evaluation, Odisha, India

ABBREVIATIONS

2SLS	Two-Stage Least Squares Regression
AFOLU	Agriculture, Forestry, and Other Land Use
ATE	Average Treatment Effect
ATMA	Agricultural Technology Management Agency
ATT	Average Treatment Effect on the Treated
ATU	Average Treatment Effect on the Untreated
CCAFS	Climate Change, Agriculture, and Food Security
CGIAR	International Agricultural Research
CH_4	Methane
CO_2	Carbon Dioxide
COP	Conference of the Parties
CSA	Climate Smart Agriculture
CSO	Civil Society Organizations
CSV	Climate-Smart Villages
DBT	Direct Bank Transfer
ESR	Endogenous Switching Regression
FAO	Food & Agriculture Organization
FFS	Farmers' Field Schools
FGD	Focus Group Discussion
GDP	Gross Domestic Product
GGCMI	Global Gridded Crop Model Intercomparison
GHG	Green House Gas
GMT	Global Mean Temperature

GOI	Government of India
GtCO2	One billion tons of Carbon Dioxide
HDI	Human Development Index
ICT	Information and communication technologies
IFFRI	International Food Policy Research Institute
IHDS	Human Development Survey
INM	Integrated Nutrient Management
IPCC	Intergovernmental Panel on Climate Change
IV	Instrumental Variables
KCC	Kisan Credit Card
KVK	Krishi Vigyan Kendra
LLL	Land Laser Levelling
MSD	Minimum Soil Disturbance
MVPM	Multivariate Probit Model
N2O	Nitrous Oxide
NABARD	National Bank for Agriculture and Rural Development
NAFCC	National Adoption Fund for Climate Change
NAFCC	National Adoption Fund for Climate Change
NAPCC	National Action Plan on Climate Change
NIE	National Implementing Entity
NMSA	National Mission for Sustainable Agriculture
NRM	Natural resource management
OLS	Ordinary least squares
PACS	Primary Agriculture Cooperative Societies
PPP	Probability Proportional to Population
PSM	Propensity score Matching

RCPs	Representative Concentration Pathways
SDG	Sustainable Development Goal
SHG	Self Help Group
SI	Sustainable Intensification
SLCP	Short-lived climate pollutant
THS	Tractor Hiring Service
UNFCCC	United Nations Framework Convention on Climate Change
UNO	United Nations Organization
°C	Degree
US$	US Dollar

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CHAPTER 1

INTRODUCTION AND BACKGROUND TO THE STUDY

1.1 Background of the Study

The exponential growth of the world's population poses a significant problem to the current world. Third-world countries face multiple challenges due to the population explosion (Cropper and Griffiths, 1994; Alexandratos, 2005). Asian and African countries have the adverse impact of population explosion in multiple sectors (Maja and Ayano, 2021). Population growth over the years has been increasing the demand for food to feed the growing (Van et al., 2021). Eradicating extreme poverty and hunger is one of UNO's two important millennium goals (Anger, 2010; FAO, 2011). Many constructive steps have been taken to eradicate poverty and malnutrition, yet these are significant issues in most countries. Nutritious food is required to enhance the all-round development of a human being. Sustainable Development Goal 2 aims to achieve "zero hunger". SDG2 aims to strengthen food security, for which a country needs to produce more agricultural outputs (Gil et al., 2019). However, agricultural production is under threat due to unprecedented climate change issues.

Modern climate change is caused by changes in atmospheric composition caused by humans (Karl and Trenberth, 2003). Climate change is increasing the mean global temperature, and decreasing the precipitation, which has inversely led to decreases in seasonal and perennial snow and ice extent, heat waves, droughts, floods, and sea level rise, which seems purely anthropogenic (Pathak et al., 2014). Air pollution, sickness, extreme weather events, forced displacement, mental health strains, increased hunger, and poor nutrition are all consequences of climate change (Kim et al., 2014). In the agricultural sector, climate change is causing less production, high emission of Greenhouse Gases (GHG), agricultural land degradation and health hazards among farmers (Mbow et al., 2017; McMichael et al., 2007).

Agricultural production requires many stages, including land preparation, planting seeds, irrigation, applying pesticides and fertilizers, harvesting, transporting input and output, and drying. All these stages of operation are managed by human labour and by machines. The level of mechanization is categorized by looking at the intensity of use. There are three levels of farm mechanization: non-mechanized farming, semi-mechanized farming, and fully mechanized (Zhou et al., 2022). The agriculture sector is transforming from labour-intensive production to mechanical-intensive production methods. Rural farm labourers migrate to urban areas for livelihoods, creating a labour shortage in the rural agricultural labour market. Due to agricultural intensification and labour shortage, rural wages have increased (Diao et al., 2012; Uchikawa, 2022). Drudgery in the agricultural sector is also a challenge for farmers. Engagement of excess labour farmers than requirement will increase the farmers' production cost (Singh et al., 2006). There is a shift in agricultural operations where human and animal-powered operations are decreasing, and on the contrary, biofuels and clean energy-operated machinery are increasing. Over the past year, less animal power has been used, and more tractors, power tillers, diesel engines, and electric motors have been bought to ease the cultivation process. Farm power has evolved from animate to mechanical and electrical sources over time. The study by Tiwari et al. (2019) reflects the decrease in animate power sources from 93% in 1960 to 12% in 2011. Most likely, mechanization's mechanical and electrical power has increased from 7% to 87.4% in the same time frame in India.

Further, climate change and its current challenges, which led to erratic rainfall and a steady temperature rise, have negatively affected farm production by widely creating uncertain outcomes for farming communities. Farm machinery plays a big part in climate change adoption strategies. Machinery used in farming enables farmers to cultivate multiple crops in multiple seasons in a year, saves labour time, reduces production cost through precise and timely use of inputs, and so forth, which enhances farm productivity (Benin, 2015; Hatibu, 2013; Pingali, 2007; Sims and Kenzle, 2006). Biggs and Justice (2015) observed that the green revolution was about high-yielding varieties and small machines helping in land preparation, fertilization, and harvesting. Moreover, certain adoption practices, such as conservation agriculture, a basket of three specific practices, namely minimum tillage, crop residue retention, and crop rotation, require appropriate machines to implement (Jaleta et al., 2016; Jena, 2019). Especially small machines such as seeders, chisel ploughs, hand-operated weeders, and manual sprayers help adopt some climate adoption practices. Hence, agricultural machinery adoption is a part of the broader climate adoption strategy.

The benefits of farm mechanization in agriculture have been well articulated in Hatibu (2013) and Pingali (2007). The adoption of mechanical technologies boosted agricultural yields and reduced crop production unit costs in Asian countries. Semi and full-farm mechanization has a positive impact on productivity. Full farm mechanization has higher productivity than semi-mechanization (Zhou and Ma, 2022).

In 2010, the Food & Agriculture Organization (FAO) introduced a concept called Climate Smart Agriculture (CSA) to address the impacts of climate change on the agricultural production system. CSA can be viewed as a new wine in an old bottle because it combines conventional practises that allow farmers to adapt to climate change and mitigate its effects. Farmers can mitigate the negative effects of climate change on agricultural production by implementing a bundle of CSA practises. CSA aims to increase sustainable food production, adapt to climate change, and reduce greenhouse gas emissions. Farmers adopt various adoption strategies under CSA, including rainwater harvesting, drip irrigation, crop rotation, minimum tillage, and leaving crop residues. CSA aims to develop flexible food production systems that can provide sufficient food and increase income security despite the challenges of climate change. The three objectives of CSA practices are promoting sustainable agriculture, ensuring food security, and controlling GHG emissions.

External and internal factors enable farmers to adopt climate-resilient agricultural practices. External factors help to rebuild farmers' capacity to enhance their adaptive skills. Access to extension services, such as training (Zakaria et al., 2020), farm field schools (Osumba et al., 2021), and demonstrations, make farmers aware and knowledgeable about the adoption of CSA practices (Mgendi et al., 2022; Makate et al., 2019). This not only enhances their adaptive capacity but also contributes to more sustainable farming practices in the future. Farmers who receive credit from public and private banks and cooperative societies are better equipped to adopt climate-resilient practices (Kangogo et al., 2021). Providing subsidies in the form of machinery and seeds also encourages farmers to adopt CSApractices. Such subsidies can be particularly beneficial for marginal farmers struggling to finance the transition from conventional to improved agricultural practices (Ouédraogo et al., 2019). The availability of affordable energy sources and proximity to energy supply near farm fields can facilitate the use of farm power-oriented machinery, including micro-irrigation, sprinkler irrigation, drip irrigation, and other small and large agricultural machinery (Das et al.,2022). Farmers with access to clean energy sources enable better irrigation and are more likely to adopt sustainable agricultural practices, such as crop diversification and crop rotation.

Farmers' adoption of CSA practices is influenced by various internal factors, including landholding size, asset ownership, savings, and income from secondary occupations (Deressa et al., 2011; Aryal et al., 2018). These economic factors are critical determinants of farmers' capacity to invest in more sustainable agricultural practices. They provide the necessary financial resources to cover the costs of inputs and equipment needed for CSA adoption. However, other household characteristics, such as age (Khatri-Chhetri et al., 2019), gender, experience in farming activities, the number of family members, and the level of education, also play a significant role in farmers' adoption decisions.

CSA adoption is influenced positively by factors such as education level, age, family size, income streams, economic assets, familiarity with climate change, local knowledge, and good physical farming conditions among farmers (Mashi., 2022). The farmers who are more aware of CSA are likely to practice it. Policymakers and development practitioners can better support adopting CSA practices if they have a deeper understanding of these factors and how they interact.

CSA practices benefit private and public entities by increasing the farmers' productivity and income. They also maintain food security and eradicate poverty among rural farmers (Habtewold et al., 2021). As a public benefit, CSA tends to mitigate climate change in the environment by reducing the release of greenhouse gas emissions (Branca et al., 2011; Pretty, 2008). Many studies have found the triple-win concept of CSA adoption: production, mitigation and income in developing and developed countries. (Makate et al., 2017, Xiong et al., 2014, Challinor et al., 2014; Mungai et al., 2016; Lan et al., 2018). CSA practices are sustainable practices which enhance yield and income (Wekesa et al., 2018, Makate et al., 2018; Ali et al., 2018). It presents significant prospects for boosting food security, and dietary diversity, impacts per capita consumption positively and increases the household members' nutrition level and income by raising agricultural productivity (Makate et al., 2019; Mujeyi et al., 2021; Martey et al. 2020; Issahaku and Abdulai, 2020; Shahzad and Abdulai, 2021). It has negative marginal abatement costs, suggesting mutually beneficial effects between enhancing livelihoods and mitigating climate change by reducing GHG emissions (Branca et al., 2021). The conservation agriculture techniques include reduced tillage, cover cropping, intercropping, increased soil carbon sequestration, and reduced atmospheric carbon dioxide (Israel et al., 2020).

1.2 Climate Change and Agriculture: Evidence, Impact and Adoption

Climate change has been a significant policy and political debate topic, with international summits like the United Nations Climate Summit, United Nations Conferences on Sustainable Development and the Conference of the Parties (COP). The issue of climate change is a global problem that affects the entire world, not just in terms of the factors contributing to it but also in terms of the consequences resulting from it. The Intergovernmental Panel on Climate Change (IPCC) was set up to get a global governmental agreement on such a complex, multi-sectoral, uncertain and political problem as climate change 1988. IPCC made an evolutionary impact on examining climate science, impacts, and response strategies (Agrawala,1998).

According to World Meteorological Organization, "Climate is the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period ranging from months to thousands or millions of years." The variables are typically averaged over 30 years, considered the classical period. The relevant climate-related data typically includes surface variables like temperature, precipitation, and wind."

The United Nations Framework Convention on Climate Change (UNFCCC) has defined the meaning of climate change in Article 1. According to UNFCCC, "Climate change is 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 periods".

The fourth assessment report of the IPCC (2007) has identified the primary causes of climate change, which include natural factors such as changes in ocean currents, solar activity, volcanic eruptions, and other similar phenomena. Climate change has resulted in several consequences, including increased global average air and ocean temperatures, widespread snow and ice melting, and rising global sea levels. Over the last 50 years, human activities, especially the use of fossil fuels and alterations in land use, have had the most significant impact on the observed warming, making them the primary cause of this climate change (IPCC, 2007).

Fig. 1.1 shows the dynamics of global warming due to an increase in greenhouse gas emissions. About two-thirds of the solar energy that reaches Earth is absorbed by the surface and atmosphere, while the rest is reflected in space as radiation. The Earth's radiation is absorbed by the atmosphere and re-radiated back to Earth, creating the greenhouse effect, similar to the glass walls of a greenhouse, which trap heat and raise the temperature inside.

Figure 1.2 shows the historical global temperature time series data from 1840 to 2006. Treut et al. (2007) show the time series studies extracted from multiple scientific publications. The graph shows an increasing global temperature trend continuously after 1980.

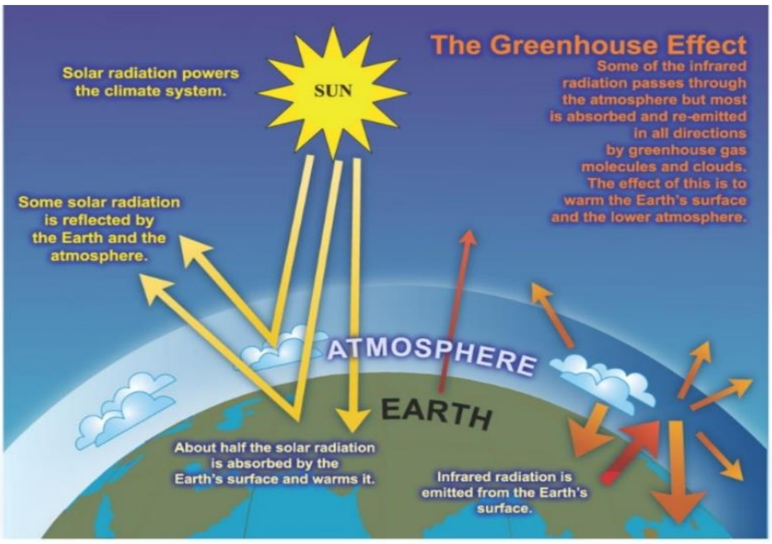


Figure 1.1 An idealized model of the natural greenhouse effect (Source: IPCC,2013)

IPCC (2013) acknowledges that The Earth's temperature is getting warmer, and there is no doubt about it. This warming trend has been unprecedented in many ways since the 1950s. The air and oceans are getting warmer, snow and ice are decreasing, and the sea level is rising. Fig 1.3 (a) shows the globally averaged combined land and ocean surface temperature anomaly. The report says that the surface of the Earth has been getting progressively warmer over the last three decades, with each decade being warmer than the previous one, going back to 1850. Between 1983 and 2012, the 30-year period was likely the warmest in the Northern Hemisphere compared to any other 30-year period. Fig 1.3(b) shows that the global mean sea level rose by 0.19 [0.17 to 0.21] m from 1901–2010. The sea level that increased during the mid-19th century is larger than the mean rate of sea rise during the previous millennia. Due to anthropogenic activities, the release and concentration of greenhouse gases have increased

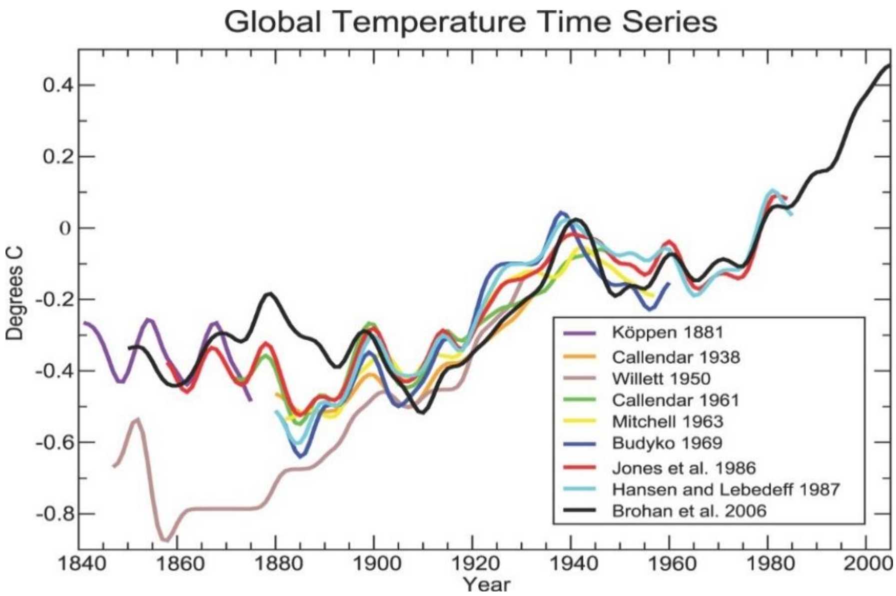


Figure 1.2 *Published records of global temperature time series. (Source IPCC,2013)*

since the pre-industrial revolution era, between 2000 and 2010, the greatest levels of emissions ever recorded were reached. Carbon dioxide, methane, and nitrous oxide concentrations in the atmosphere have reached unprecedented levels. Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) concentrations have increased by 40%, 150%, and 20%, respectively, as shown in Fig. 1.3(c). Fig. 1.3 (d) demonstrates that GHG emissions have increased in all sectors, with the exception of agriculture, forestry, and other land uses. In 2010, the energy sector produced 35% of GHG emissions, 24%

(net emissions) by agriculture, forestry, and other land use (AFOLU), 21% by industry, 14% by transportation, and 6.5% by the construction sector.

IPCC (2019) special report on Climate Change and Land recognizes the degradation and desertification of land in many regions. According to the report, since the pre-industrial period, the Earth's land surface temperature has risen twice as much as the global average temperature. This increase in land surface air temperature is causing more frequent and intense extreme events such as droughts, heat waves, and other climate-related disasters. These extreme events adversely impact food security and ecosystems, exacerbating land degradation and desertification. The current level of global warming has increased the risk of dryland water scarcity, vegetation loss, coastal degradation, soil erosion, and low crop yield decline.

In general, climate change could affect agriculture in several ways, some are mentioned here below:

• Reduced productivity, both in terms of quality and quantity, is a consequence of it.
• It causes individuals to resort to pesticides, chemical fertilizers, and irrigation methods that can have negative impacts due to the scarcity of groundwater and rainfall.
• Soil drainage, erosion, and decreased crop variety are all results of this phenomenon.

The IPCC's projections of the impacts of climate change in the future are founded on emission trajectories. These trajectories depict the direction of emissions, showing how agriculture will be the most vulnerable to climate change. One useful approach to confront climate change in the agricultural sector is to focus on adoption and mitigation. Doing so can produce food more sustainably without harming biodiversity (FAO, 2010).

1.3 Climate Change and Agriculture in India

India is the second most populous country globally, with a population of 1.3 billion and has the seventh largest land area in the world at 3.288 million square kilometres. It has a diverse ecosystem due to its range of climates, from humid and dry tropical in the south to temperate alpine in the north. Agriculture contributes 23% to India's Gross Domestic Product (GDP) (FAO,2010). While the green revolution has led to

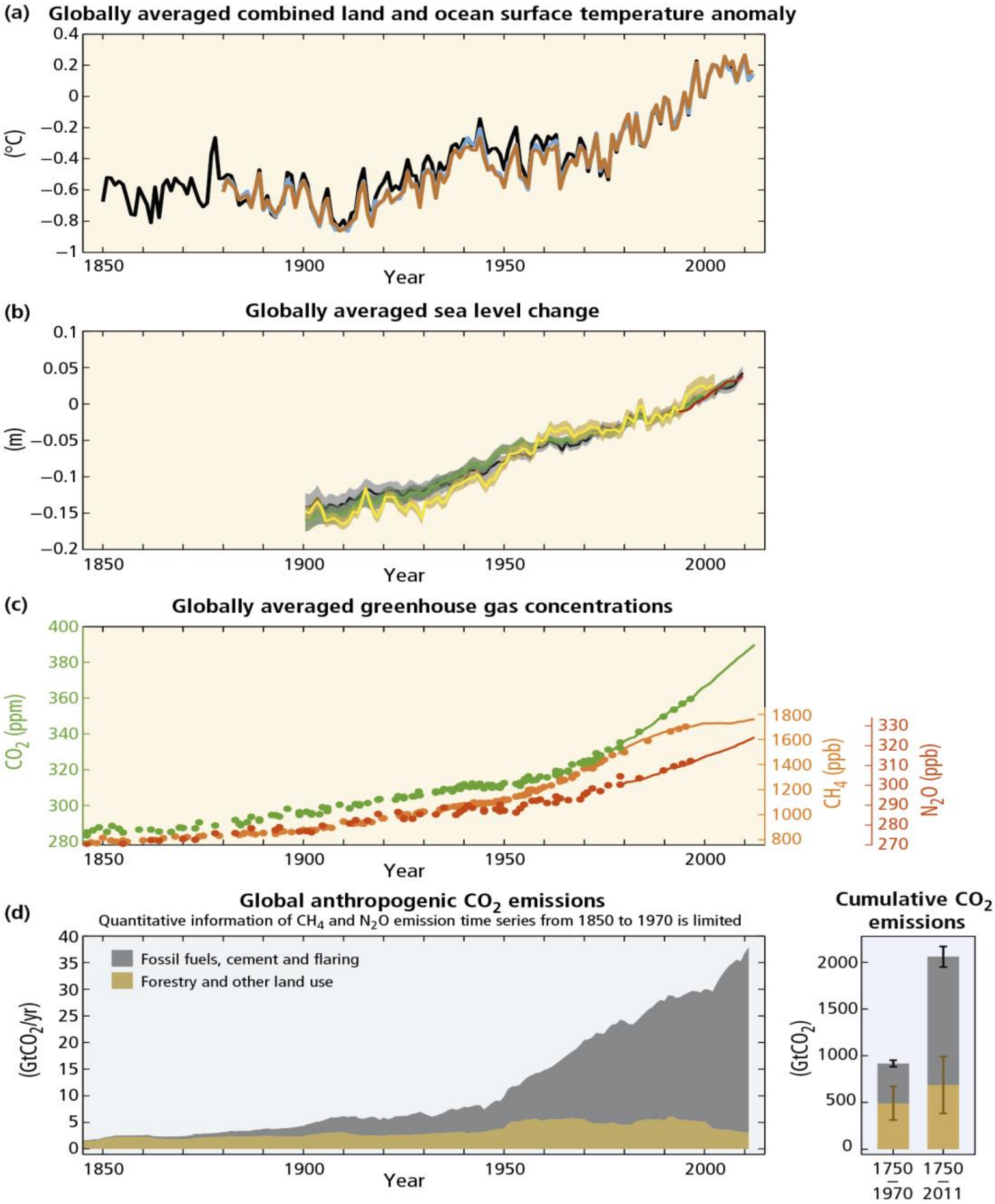


Fig. 1.3 (a-d): Climate Change Scenario Over the Year (*Source: IPCC, 2013*)

technological advances in the agricultural sector, food security remains a concern. Studies highlight temperature as a significant factor in climate change. Recent studies show climate trends have adversely affected the Indian continent (Burney and Ramanathan, 2014). The calculations of Jayaraman and Murari (2014), using the data from the Indian Metrological Department, show the average temperature of India rose from 0.6°C to 0.8°C from 1850–2010. Figure 1.4 shows the variation in the average annual temperature from the 30-year standard from 1960 to 1999. The trend shows an increase in the mean temperature over the period. In India, the projected increase in temperature for the future is greater in winter, followed by summer, monsoon, and post-monsoon seasons. According to the Representative Concentration Pathway (RCP) 8.5 emission scenario, rare cold and heat wave events will likely increase by the end of the twenty-first century in India (Basha et al., 2017).

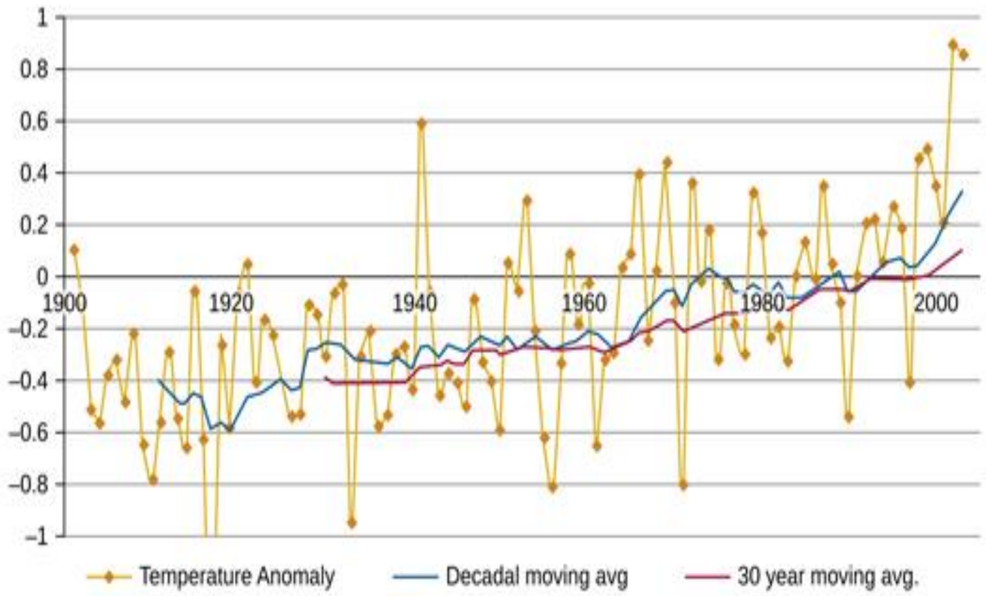


Figure 1.4 Change in mean temperatures, India, 1900-2009 (*Source: Jayaraman and Murari, 2014)*

Agriculture is one of the primary sectors which plays a crucial role in India's overall economic and social well-being. But the decrease in GDP and employment over the year shows the agriculture and allied sectors are also facing the most vulnerability due to climate change (Mall et al., 2006). Food security is directly or indirectly impacted by climate change. Due to the population explosion, food scarcity is growing, which may create severe food insecurity in the nation (Ahmad and Alam, 2018). Due to climate change, food security has been considered the most prominent challenge in India. Climate change has affected the irrigated rice yields by about 10% in most coastal districts (Abeysingha et al., 2016). Abeysingha and others (2016) analyzed the rainfall and temperature change during rice and wheat growing periods and found that climate change had a negative impact on crop production. A sectoral and regional analysis prepared by the Ministry of Forest and Environment indicates that the daily extremes in surface air temperature may intensify in the 2030s. The spatial pattern of the change in the lowest daily minimum and highest maximum temperature will alarm a warming of 1^0 to 4^o C towards the 2030s. A detailed review of the impact of climate change on the agriculture sector of India has been discussed in Chapter 2.

1.4 Climate Smart Agriculture

The Food and Agriculture Organization (FAO) coined a new term, "Climate-Smart Agriculture", at the Hague Conference on Agriculture, Food Security and Climate Change in 2010. FAO has introduced the CSA concept to address three objectives "to increase productivity in agriculture, promote adaption to climate change and to mitigate the climate change." National food security and development goals will be achieved through CSA practices. The CSA approach guides implementing environmentally friendly and resilient practices in agri-food systems. FAO (2013) advocates that by adopting CSA, it is possible to work towards achieving global goals such as the SDGs and the Paris Agreement, which focuses on addressing climate change and promoting sustainability.

FAO, (2010) has defined the three broad objectives of CSA:

1. To increase crop productivity, farm income, and food security.
2. To adopt climate-resilient agricultural practices at multiple levels of agricultural production.
3. To mitigate the environment by reducing greenhouse gas emissions from the agriculture sector (Lipper et al., 2010).

FAO has produced a sourcebook that provides the most extensive advice on climate-smart agriculture. This sourcebook includes a range of practical strategies and techniques that form the basis of climate-smart agriculture (FAO, 2013). The sourcebook elaborates on the concept of CSA and demonstrates its potential, makes it uniform, and has limitations. The sourcebook encompasses various modules that look into topics such as climate-smart agriculture, forestry, and fisheries, landscape management for climate-smart agricultural ecosystems, water management, soil management for CSA, energy, conservation, and sustainable use of genetic resources for food and agriculture. Additionally, it covers crop production systems, climate-smart forestry, climate-smart fisheries and aquaculture, sustainable and inclusive food value chains, financing climate-smart agriculture, and disaster risk reduction.

In recent times, there has been a significant increase in the attention given to climate-smart agriculture (CSA). The various stakeholders on this Earth, such as international organizations, national governments, farmers, civil society organizations (CSOs), the private sector, the research community and at the root level, the farmers, have taken steps to implement CSA initiatives (Dinesh et al., 2015).

The farmers, researchers, civil society, private sectors and policymakers coordinate to promote CSA through four main action areas: 1) Identifying the core issues of climate change; 2) Promoting climate and agriculture policy convergence; 3) Increasing the local institution's activeness; and 4) Interlink the climate and agriculture financing. CSA doesn't follow "business-as-usual" approaches; it follows flexible, context-specific solutions backed by suitable innovative policy and financing actions (Lipper et al., 2014). The author is concerned that adopting CSA by the most vulnerable groups, including smallholder producers and poor and marginalized communities, should be prioritized by identifying the barriers to adoption. There is a need for appropriate policies and planning to be developed that take into account the specific agroecological production systems present in different regions.

Dinesh et al. (2015) reviewed and analyzed 19 case studies on CSA . The author found that all of them have contributed towards the sustainable production of food, increased productivity, enhancement of food security, and increased farm incomes and development. The other co-benefits of adopting CSA are employment generation, health and nutritional benefits, and infrastructure development. The studies also showed that CSA adoption positively impacts gender and social inequalities.

Campbell et al. (2014) have connected CSA and Sustainable Intensification (SI) and found that these two practices complement each other. SI and CSA are closely interlinked practices that emphasize achieving the adaptation and mitigation goal.

FAO has advocated the Landscape approach to the CSA. FAO (2012) states, "Landscape approach refers to a set of concepts, tools, methods and approaches deployed in landscapes to achieve multiple economic, social, environmental objectives through processes that recognize, reconcile and synergize interests, attitudes and attitudes and actions of multiple actors". Adopting a landscape approach incorporating land-use planning makes it possible to mitigate conflicts arising from resource utilization and tackle the dangers facing biodiversity-rich ecosystems such as forest areas and wetlands (Scherr et al., 2012). Furthermore, implementing such an approach can aid in restoring crucial ecosystem functions and services. This method can produce advantageous and lasting implications for populations encountering unpredictable and extreme weather events. (IPCC, 2014; FAO, 2015).

FAO has prescribed a set of climate-smart crop production practices and technologies that focuses on adopting specific climatic hazards and practices that simultaneously reduce production risks and vulnerabilities (FAO, 2017). The practices include genetically modified improved seed varieties that tolerate extreme droughts and floods. The other practices are integrated pest management, improved water use and management, sustainable soil and land management, and sustainable mechanization, which enable it to face climate distress.

In particular, FAO has prescribed the following CSA adoptions, including the use of stress-tolerant seeds, crop diversification, crop rotation, crop residues management, soil mulching, agro-forestry, integrated nutrient management, rainwater harvesting, in-situ water conservation, minimizing mechanical soil disturbance or no-tillage, sustainable agricultural mechanization, integrated crop-livestock systems, deficit irrigation, precision water applications, high-efficiency pumps and improving drainage (FAO, 2013; FAO, 2017).

Disaster risk reduction measures have the potential to aid CSA in achieving its goals, especially in terms of enhancing the Adoption of climate change and strengthening the capacity of agricultural communities and ecosystems to cope with climate variations and shifts. Effective disaster risk reduction policies, programs, and practices can be useful tools to promote and expand CSA (Mitchell et al.,2010). Azadi et al. (2021) proposed a five-component framework that includes farmers predicting key incidents, quantifying the impact of incidents, identifying farmers' coping methods, assessing farmers' livelihood resources during a crisis, and adopting to climate incidents.

1.5 Adaptation vs Adoption

IPCC (2001) states, "Adaptation is the adjustment process to actual or expected climate and its effects. Adoption seeks to moderate or avoid harm or exploit beneficial opportunities in human systems. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects" (IPCC, 2001).

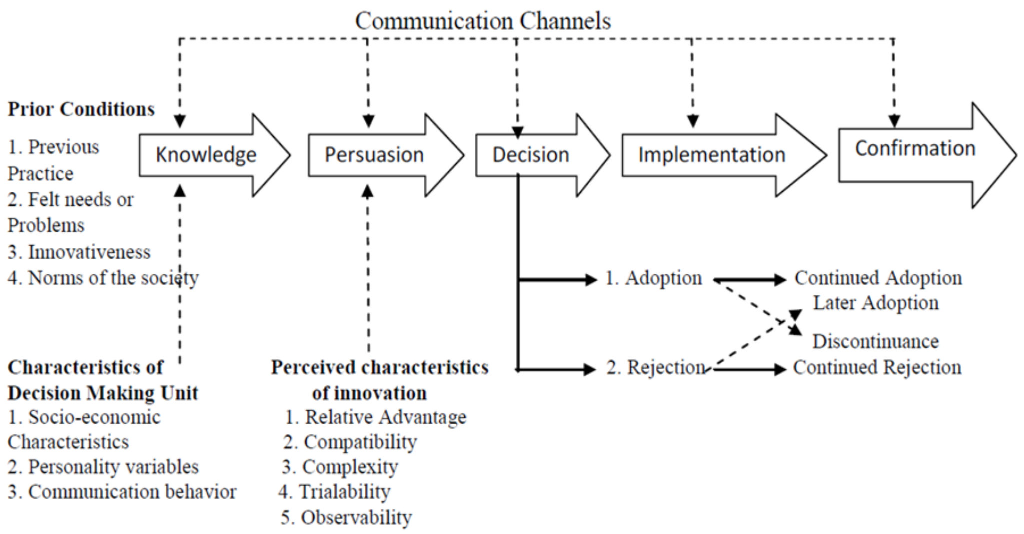
Adger et al. (2005) define "Adaptation as anything that reduces the risks associated with climate change, and vulnerability to climate change impacts, in both the short- and long-term, for both the direct beneficiary of the adoption and the wider society without compromising economic, social, and environmental sustainability."

According to the IFFRI (2007), "Adaptation is the process of improving society's ability to cope with changes in climatic conditions across time scales, from short term (e.g., seasonal to annual) to the long term (e.g., decades to centuries)."

Zilberman et al. (2012) state, "Adaptation is a change in practice or technology used by economic agents or a community, has a long intellectual history."

Adoption is typically assessed through a discrete choice analysis, where individuals are presented with options and must choose one. This analysis may also involve a continuous indicator measuring the degree or extent of adoption. For example, in a study of new technology adoption, the discrete choice might involve selecting whether or not to adopt the technology. At the same time, the continuous indicator could measure how much the individual uses the technology once they have adopted it (Zilberman et al., 2012).

Rogers (1962) divided the adoption decision into five stages: awareness, interest, evaluation, trial, and adoption. These decisions are influenced by the learning, understanding and judgment associated with adoption. Roger's innovation-decision model passes through five stages, shown in Figure (1.5). These processes include knowledge, persuasion, decision, implementation, and confirmation. Individuals in the knowledge stage are exposed to new concepts and develop understanding. In the persuasion stage, the individual either persuades others or is open to persuasion. In the decision stage, the individual decides whether to adopt or reject the new idea. In the implementation stage, the individual implements the decision made in the previous stage. In the confirmation stage, the individual continues questioning the knowledge of



the decision (Rogers, 1983).

Figure 1.5 Roger's innovation-decision model (Source: Rogers, 1983)

A growing body of research on adoption signifies that adopting various conservation agriculture practices helps build a climate-resilient system. According to Knowler and Bradshaw (2007), adopting low or no-tillage practices improves soil conditions and sequesters carbon in developed and developing countries. Adopting water-saving technologies, such as drip irrigation, can enhance the effectiveness of resource usage and potentially result in increased crop yield. This approach may also result in lower water intensity in some cases and consistently reduces drainage (Schoengold and

Zilberman, 2007). Access to financial incentives has a significantly positive effect on adopting conservation practices (Linn, 2008).

Adoption can be distinguished between micro and macro levels. Micro Adoption involves selecting discrete strategies, such as adopting existing technologies, migration, or changes in input use. Macro Adoption is measured by aggregate behaviour and involves policy rule changes at the village, country, or global level. The literature on adoption vs adoption emphasizes decisions taken by the farmers for a particular practice or technology. 'Adoption' focuses on new technologies, whereas 'adoption' focuses on existing ones (Feder et al., 1985).

1.6 Climate Smart Agriculture in India

The Indian government launched the National Action Plan on Climate Change (NAPCC) in 2008 intending to address climate change challenges on a national scale while ensuring the country's continuing development. The strategy is divided into eight major missions that focus on minimizing and adapting to the consequences of climate change in various fields (GOI, 2008).

The National Adoption Fund for Climate Change (NAFCC) was established in August 2015 to assist Indian states and union territories that are particularly vulnerable to the detrimental effects of climate change. Its major goal is to finance the costs of climate change adaptation through the National Implementing Entity (NIE). NABARD (National Bank for Agriculture and Rural Development) is the National Implementing Entity (NIE) to undertake adoption initiatives under the NAFCC. In 2014-15, the National Mission for Sustainable Agriculture (NMSA) was launched to enhance agricultural productivity, sustainability, profitability, and climate resilience. Improving farming practices, the variety of seeds, animal and fish culture, water usage efficiency, pest management, agricultural insurance, nutrient management, credit support, access to markets, access to information, and livelihood diversification are all significant adaptation approaches undertaken by NMSA.

International Agricultural Research (CGIAR), a Research Program on Climate Change, Agriculture, and Food Security (CCAFS), has been partnering with national programs to collaborate with rural communities in developing Climate-Smart Villages (CSVs). These villages are examples of local initiatives that ensure food security, encourage Adoption and enhance resilience against climate-related challenges.

CCAFS has comprehensively approached sustainable agriculture development in the Climate Smart Villages. Table (1.1) shows India's comprehensive approaches to CSA practices.

Table 1.1: Climate-Smart Village Approach by CCAFS

(Source: Ghosh et al., 2019)

	CSA Approach	Adoption Practices
1	Weather-smart activities	ICT-based agro-advisories, stress-tolerant crops, index-based insurance, weather forecasts
2	Water-smart practices	Crop diversification, laser land levelling, water conservation, resilient water management practices, direct-seeded rice, rainwater harvesting, drip irrigation, raised bed planting, alternate wetting and drying in rice.
3	Carbon-smart practices	Diversified land-use systems, conservation tillage, Agro-forestry, livestock and manure management, and residue management
4	Nitrogen-smart practices	Site-specific nutrient management, residue management and legume catch-cropping, leaf-colour charts, precision fertilizer application, hand-held crop sensors
5	Energy-smart technologies	Biogas systems, fuel-efficient agricultural machinery, minimum tillage, solar energy irrigation
6	Knowledge-smart activities	Enhancement of CSA capacity, cross-site farmer visits, farmer-to-farmer learning, seed packets of adopted varieties, market and off-farm risk management system, and community seed and fodder banks

1.7 Statement of the Problem

The food system is under significant stress due to the growing population and climate change. It is necessary to increase agriculture productivity and adopt resilient climate practices to address societal challenges such as climate change and food sustainability. Migration led to labor shortage, and higher cost is a significant bottleneck for smallholder farmers in rural areas. Adopting agricultural technologies is crucial to improving crop yield and addressing labour shortage issues (Burney et al., 2010). However, farm mechanization requires higher capital investment, which constrains small-scale farmers around the globe (Aryal et al., 2019). This creates a need to understand the patterns and determinants of adopting farm machinery among rural households. Researchers in the past have identified the determinants of mechanization at a regional or smaller spatial scale. Still, there is a need to do the same at a broader scale using large-scale household data from India. The current study has addressed this gap and undertook a comprehensive assessment of the determinants of the agricultural mechanization process in India using household data collected across all the states of the country.

Further Previous studies show that India's mechanization rate has grown by 10% between 1960 and 2011(Tiwari et al., 2019). Over this period, the use of animal power sources in agriculture declined gradually from 93% in 1960 to 12% in 2011. The country's tractors, power tillers, diesel engines, and electric motors have replaced it. Hence, there is a need for a systematic evaluation of the impact of mechanization on agricultural productivity and farm incomes in India. Most existing studies have observed a positive contribution of mechanized farming to farm production and household income. However, there is little evidence of the impact of agricultural machinery on household consumption and food security. This is one of the few studies that systematically examine the nationally representative data of India to assess the impact of machinery adoption in agriculture on household income and food security.

The agriculture and allied sector remain a crucial contributor to Odisha's economy, accounting for 18.9% of the state's Gross Value Added (GVA) in the 2018-19 fiscal year. It is also a primary source of livelihood for a large proportion of the population, particularly women. Based on the latest estimates for 2017-18, nearly half of the state's working population (48.8%) is engaged in agriculture. Moreover, the sector's output is essential for agro-based industries, highlighting its significance in Odisha's economy (Odisha Economic Survey, 2018). Of the cultivated land of Odisha, about 59 % is irrigated, and the rest is yet to be irrigated. Thus, around 40 per cent of cultivable lands are still rain-fed, where weather plays a major role.

Due to climate change, catastrophic weather events like floods and droughts are becoming commonplace, greatly increasing the unpredictability of agricultural output in Odisha. Agricultural activities are extremely dependent on rainfed and enormously vulnerable to climate change. There have been disaster declarations for Orissa in 95 of the last 105 years (Panda et al., 2017). Odisha is at risk from climate change in its northern coastal area and western district, especially in Balangir and Kendrapara (Patnaik et al., 2013). Floods have occurred in the state for 50 years, droughts for 32, and cyclones for 11 years. Twenty-nine of these cyclones were catastrophic. On the Orissa coast, the frequency of cyclones has increased. In 1999, the state was devastated by two major cyclones in close succession. The second lasted three days and caused devastation in 14 coastal districts. Approximately 15 million individuals were impacted. Two million tonnes of rice crop were destroyed, as well as 17000 square km of agricultural area.

Most of the climatic and control variables greatly influence net income from the State's agricultural production. It has been found that the Optimum level of temperature and rainfall are required to increase the net revenue from the agricultural production of Odisha. They have suggested implementing agriculture with sustainable development.

Odisha is one of the vulnerable states in India, having socio-economic and bio-physical vulnerability (Sam et., 2020). The State of Odisha faces multiple natural hazards throughout the year. A series of natural disasters have plagued the state. The eastern part of the state is highly suspectable to cyclones and floods (Sahoo et al., 2018). The eastern coastal region is also prone to sea erosion and soil salinization. Due to the lack of drainage facilities in this region, flash flood affects agriculture adversely. The western part of Odisha is highly susceptible to drought and heat waves (Panda, 2016). Due to scarcity and the delay of monsoon rainfall, western Odisha farmers often face crop losses (Sahoo and Rath, 2023). The state exhibits a low socio-economic status. The state exhibits low per capita consumption expenditures, limited access to education and household amenities, high poverty rates, suboptimal health outcomes, low levels of female literacy, and inadequate financial inclusion. Odisha ranks 31st in Human Development Index (HDI) out of 35 states and Indian territories (Government of India, 2011). Due to socio-economic and climate vulnerability, the agriculture practices in the state are primitive and less technologically adaptable (Mishra et al., 2016).

One of the major issues with rice production, particularly in the rain-fed lowland areas of Odisha, is flash floods that wash away rice plants for 10–15 days. The paddy crop fails due to irregular rainfall and delayed southwest monsoon in the inland districts of Odisha. However, the farmers of Odisha are changing the nature of agricultural production. They are switching from conventional farming to CSA practices to cope with climate change. Farmers of Odisha are gradually adopting a basket of CSA practices such as rescheduling planting, crop rotation, crop diversification, drought-resistant seeds and smart soil practices (Sahu and Mishra, 2013).

No significant micro studies have captured the impact of the adoption of CSA practices in the vulnerable regions of Odisha. It has been proposed in many empirical studies that researchers should investigate the difference in income and yield that exists between small-scale farmers who adopt CSA practices and those who do not adopt them. This could provide information about the benefits derived from taking steps to adapt to climate change.

The study of agriculture must consider gender a significant factor since women play a vital role in agricultural production. In Odisha, due to the absence of non-agricultural sources of income, male members of the family migrate to other states in search of work. This situation leads to female members taking on a more prominent role in the family's agricultural activities. Therefore, it is important to investigate how women can adopt CSA practices without a male head in the family.

Government plays a vital role in agriculture. The government has different programs and policies to mitigate climate change, but these plans are not implemented properly due to some barriers. There is a need to analyze the effectiveness of government policies towards CSA. The financial aspect is crucial for adopting CSA. In Odisha, farmers face difficulties accessing proper credit facilities, highlighting the need to investigate the challenges they encounter in obtaining credit from financial institutions. Since most farmers in Odisha live below the poverty line, financing is crucial to their ability to adopt CSA practices. Therefore, identifying relevant sources that can provide adequate financing and incentives for farmers to engage in CSA is necessary.

This study aims to address the limitations of earlier research and fill the gaps in previous studies. More micro research is needed to identify the determinants of the adoption of CSA to deal with such distressing situations. Adoption estimates are often challenging due to the high diversity of CSA methods across contexts, particularly among resource-poor countries. This study will investigate the difference in income and yield between small-scale farmers who adopt CSA practices. Analyzing the determined adoption of farm mechanization and its impact on food security and income will help develop effective policy mechanisms to deal with natural disasters in advance.

1.8 Objectives of the Study

A research gap has been identified upon conducting a thorough review of relevant literature, as outlined in Chapter 2. To address this gap, three specific research objectives have been established. The primary objective of the research was to fill the gaps in knowledge identified through an extensive investigation of the existing literature. This study has a broad focus on the issue of climate change, examining the factors that are associated with the adoption of farm mechanization and community-supported agriculture practices. The study also seeks to evaluate the impact of these practices on the food security, yield, and income of rural farmers.

Specifically, the study has undertaken the following three objectives:

1. To identify the key determinants of adopting agricultural mechanization and its impact on farmers' income and food security among rural farmers in India.
2. To investigate the role of key factors determining the adaptability of CSA technologies in rural Odisha.
    2.1 To investigate the gender issues in adopting and monitoring CSA practices.
3. To examine the impacts of adopting CSA practices on the productivity and income of the farmers.

1.9 Chapter Scheme of the Thesis

The thesis intends to contribute to the body of literature regarding adopting CSA, farm mechanization and its impact on agriculture income, yield and food security. The whole thesis is structured into six chapters.

Chapter 1.

The primary emphasis of Chapter 1 is on the introductory aspect of the study. The present chapter provides an overview of the Background of the Study, the Statement of the Problem, and the Objectives of the Study.

Chapter 2.

The second chapter contains the literature review that examines prior empirical studies and various techniques for quantifying the impact of adoption practices. The chapter reviews the impact of climate change on agriculture, factors influencing CSA adoption in India, the role of gender issues in implementing and monitoring CSA practices, drivers to adopt farm mechanization, the impact of farm mechanization, and various CSA practices.

Chapter 3.

Chapter 3, titled "Determinants of Farm Machinery Adoption and Effect on Household Income and Food Security: in India", focuses on the extensive analysis of the adoption of farm mechanization drawn from National Household Data-IHDS. This chapter has subsections: Introduction, The Materials and Method section, which describes the Data Source, Model Selection and Variable Description. The first part of the chapter focuses on the determinants of the adoption of farm mechanization. The second part focuses on the impact of farm mechanization on income and consumption expenditure.

Chapter 4.

Chapter 4, " Adoption of Climate-Smart Technologies in Agriculture: Evidence from An Eastern Indian State,". The chapter has subsections: Introduction, Materials and Method, Results, Discussion and Conclusion and Policy Implication. This chapter also has a subsection on "Essay on the gender issues in adopting and monitoring CSA practices. The main objective of this chapter is to explore the factors that determine the adoption of various CSA practices. This chapter also explores the gender issues that persist while adopting CSA practices.

Chapter 5.

Chapter 5, entitled "Essay on the Impact of CSA on Farm Income and Productivity", The sections in this chapter discuss the two econometrics methods, "Propensity Score Matching" and the "Two-stage Least Square Method". The other sections discuss the result on the impact of CSA practices on income and productivity, followed by a discussion and conclusion.

Chapter 6.

Chapter 6 includes a discussion, a summary of findings, a conclusion, a policy recommendation, limitations, and future research suggestions.

CHAPTER 2

Literature Review

2.1 Introduction

The agriculture sector is experiencing significant effects of climate change, including more unpredictable weather patterns and a rise in extreme weather events. These effects will worsen in the next decade (FAO, 2013). Human activity is considered to have caused a 1.0°C rise in global temperatures since pre-industrial levels, with a likely range of 0.8°C to 1.2°C. If global warming continues at its current rate, temperatures will rise by 1.5°C between 2030 and 2052 (IPCC, 2018). The IPCC-2014 report states that the era from the 1800s to the present has undergone the most significant warming compared to any other period (Pachauri et al., 2014). Climate change variations include an increase in average temperatures across the land and ocean areas (high confidence), more frequent occurrences of extreme heat in many inhabited regions (high confidence), higher levels of intense precipitation in some regions (medium confidence), and a greater likelihood of droughts and insufficient rainfall in certain areas (medium confidence) (IPCC, 2018). Climate change is likely to raise the risks to people's health, livelihoods, food security, water supply, human security, and economic growth with a 1.5°C global temperature rise. These risks are expected to worsen with a 2°C rise. (O'Brien et al., 2007). According to projections based on the current mitigation goals submitted by countries under the Paris Agreement, global greenhouse gas emissions in 2030 are expected to range between 52 and 58 $GtCO_2$ equivalent per year.

The developing countries are most vulnerable to extremes of climate change, extreme weather events and disasters adversely affecting the agricultural sector (Anwar et al., 2013). The impact of climate change on agriculture is unpredictable. The ultimate effect depends on climate factors and extreme occurrences, including drought and flooding. Food protection is highly fragile, as the world's population is rising exponentially, and climate change adversely affects agricultural operations, from sowing to harvesting. Adoption is a potential method of addressing current climate change. Climate adoption is highly defined in context because it depends on the target area and sector, the climate, the atmosphere, and social adoption. Adoption refers to modifications of different systems, ecologically, socially, and economically, in response to natural, anticipated, actual climatic changes, effects, or impacts. According to Burton (1999), Adoption is the process through which individuals take action to mitigate the harmful consequences of climate change while simultaneously zutilizing the opportunities provided by the environment.

This chapter is divided into numerous sections, each of which critically evaluates studies examining the relationship between climate change and its effects on agriculture. The chapter also investigates the adoption of farm zmechanization to support sustainable farming methods and discusses the impacts of climate change on the Indian agricultural sector. It also looks into how to farm zmechanization affects farmers' livelihoods and food security.

Furthermore, the chapter explores the adoption patterns of climate-smart agricultural (CSA) practices in India and identifies the determinants influencing adoption. The chapter also discusses adopting CSA practices (CSAPs) and their relationship to gender roles. Finally, the chapter evaluates the impact of CSA on farmers' welfare, including its effects on yield and income.

2.2 Empirical Literature on the Impact of Climate Change on Agriculture

Anwar et al. (2013) found that extreme weather events and disasters adversely affect the agricultural sector of developing countries. The impact of climate change on agriculture is unpredictable and ultimately depends on various climatic factors and extreme occurrences, including droughts and floods. The impact of climate change has been categorized into two aspects: the bio-physical aspect and the socio-economic aspect (Anwar et al., 2013). As this study does not primarily focus on the impact of climate change on agriculture, the literature review has been done on the general impact of climate change on agriculture around the globe and in India. The impact of climate change literature shows two broad types of impact assessment models: "general equilibrium models" and "partial equilibrium models." However, this literature survey will be reported chronologically on the historical climate change impact studies.

Adams et al. (1990) conducted a study to investigate the potential impact of climate change and increased CO_2 on agriculture in the US. Using the predictions of global climate models (GCMs), they found that changes in temperature and precipitation could lead to decreased yields of wheat, maize, and soybean and increased water requirements for crops. Nordhaus (1993) estimated the economic effect of doubling atmospheric carbon dioxide and climate change on world agriculture. Changes in domestic yields affect the prices of agricultural commodities, and changes in global consumption and production affect economic well-being. Kaiser et al. (1993) zanalyzed climate change's potential economic and agronomic effects. Moderate warming had a positive impact on crop yield; extreme warming had a negative impact on yield. The increase in global mean temperature and impacts were not consistent across sectors. Some sectors exhibited increasing adverse impacts with increasing global mean temperature (GMT), particularly coastal resources, biodiversity, and possibly marine ecosystem productivity (Hitz and Smith, 2004).

Rosenzweig and Hillel (1995) examined the effects of climate change on global food production and agriculture. Physical impacts of climate change could negatively impact crop yields, pest and disease pressure, and soil fertility (Antle, 1995). The physical impact of climate change could lead to the hindrance of economic development of the region. Climate change has adverse economic and social impacts, including food security concerns and decreased agricultural productivity (Mendelsohn and Tiwari, 2000).

Rosenzweig et al. (2001) found that changes in temperature, precipitation, and extreme weather events are likely to have significant implications for food production and the prevalence and severity of plant diseases and pest outbreaks in developing countries. Mendelsohn (2008), in an insightful review of the potential effects of climate change on agricultural production in developing countries, concluded that tropical and subtropical agriculture in developing countries is more climate-sensitive than temperate agriculture. Kumar and Parikh (2001) examined the socio-economic impact of climate change on Indian agriculture. Climate change-induced yield shocks on India's GDP could result in a 1.8 to 3.4% decline, with the reduction in agricultural GDP being the major contributing factor. Kumar and Parikh (2001) examined the sensitivity of Indian agriculture to these physical impacts. A 2^0 C increase in temperature and a 7% increase in precipitation could result in an estimated loss of about 8.4% of the total net revenue. Guiteras (2009) study assessed the impact of stochastic inter-annual weather fluctuations on agricultural productivity over 40 years.

The study revealed that the anticipated climate change during 2010–2039 is expected to decrease by 4.5–9% in the yields of significant crops. Nelson et al. (2009) used a global economic, crop simulation, and hydrological models to assess climate change. They projected that, by 2050, the yields of major crops in developing countries could decline by as much as 10%, leading to significant food price increases and reductions in food security. Lobell et al. (2012) assessed the impact of extreme heat on wheat production by using nine years of satellite measurements of wheat grown in northern India. They found that temperatures during the grain-filling stage of wheat growth exceeded a certain threshold and that the wheat plants died prematurely, resulting in lower yields. Gupta et al. (2017) examined the impact of climate change on wheat production in India. Rising temperatures and air pollution have contributed to a decline in wheat yields in India. Higher temperatures during the wheat growing season have reduced yields, with the negative impact being more pronounced in regions with high levels of air pollution. Abeysingha et al. (2016) examined the impact of climate change on rice and wheat production in the Gomti River basin of India. The study found that the temperatures and changes in precipitation patterns could lead to lower crop yields, with the negative impact being more pronounced for rice than wheat. Mishra et al. (2016) investigated the impact of climate change on agricultural production in Odisha, a state in eastern India. The Ricardian analysis shows higher temperatures during the growing season and increased rainfall variability are associated with lower farm-level net revenue of paddy.

Bangladesh, India, and Pakistan are experiencing more frequent and severe flooding between 0 and 2°C global mean temperature changes (Mirza, 2011).

Bandara and Cai (2014) examined the potential impacts of climate change on food crop productivity, food prices, and food security in South Asia, namely Bangladesh, India, Nepal, Pakistan, and Sri Lanka. Wheeler and Braun (2013) reviewed the aspects of climate change and food security. The effect of climate change on crop productivity could have a negative impact on progress towards ending world hunger, with potential consequences for food availability.

2.3 The Empirical Literature on the Adoption of CSA Practices and its Determinants

According to Smit et al. (1999), "adoption" is a process that pertains to all climate-sensitive fields, including forestry, agriculture, water management, coastal protection, public health, and disaster mitigation. Adoption is modifying something or altering one's conduct to suit a new purpose or circumstance. Adoption of climate change entails many measures to lessen susceptibility to diverse climatic extremes. Adoption of climate change is highly context-specific because it is contingent on the target region's climatic, environmental, social, and political conditions and industry. Fankhauser et al. (1999) have discussed various adoption strategies to address climate change. They suggested long-term weather-sensitive capital investments, sustainable development practices, coastal development plans, and drought contingency plans that should be revised to incorporate climate change considerations. CSA refers to a set of agricultural practices that promote food security in the context of climate change. This strategy incorporates climate change into sustainable agricultural practices to make agriculture more resilient to climate variability and lessen its contribution to global warming (FAO, 2010).

The following group of studies in Table 1 shows the adoption of CSA practices around the globe and in India. By reviewing empirical papers on the determinants of CSA adoption, they were classified into six broad categories: 1) access to extension services; 2) socioeconomic characteristics; 3) experience or perception of climate change and shocks; 4) attitude and behaviour towards risk; 5) farm characteristics; and 6) other factors.

Table 2.1 Adoption of CSA Practices over the Years

Studies	Adoption Strategies	Countries
Deressa et al., 2009	Agroforestry, soil conservation, changing crop varieties, planting dates, and irrigation methods.	Ethiopia
Bryan et al., 2009	Change in crop varieties, agroforestry, soil conservation, changing planting dates, and irrigation.	Ethiopia
Mensah et al., 2012	Crop diversification, planting of short-duration varieties seeds, changes in crop species, reducing farm size, change in planting date, and finding off-farm jobs.	Ghana
Jim et al., 2012	Hybrid seeds, High Yielding Variety seeds, row planting and seedling, levelling (land preparation), leaf colour chart (LCC), shallow tube wells, surface water pumps, postharvest management, and farm mechanization.	Philippines
Tambo et al., 2013	Mixed cropping, early maturity varieties seeds, change in crop varieties, change in planting dates, water conservation, shift to non-farm work, planting of trees/shading for animals.	Nigeria
Sarker et al., 2013	Direct seeded rice, short-duration rice varieties, change in planting dates, change in harvesting dates, agroforestry, change in crop varieties, cultivation of Nitrogen enabled crops such as pulses.	Bangladesh
Bryan et al., 2013	Rescheduling planting dates, change in crop type, crop diversifying, supplementing livestock feeds, change in fertilizer application, soil and water conservation practices	Kenya
Tessema et al., 2013	Early planting, tree planting, terracing, micro irrigation, and water harvesting.	Ethiopia
Abid et al., 2015	Change in crop variety, rescheduling planting dates, agroforestry, soil conservation, change in fertilizer, irrigation, and crop diversification.	Pakistan

Belay et al., 2017	Crop diversification, planting date adjustment, soil and water conservation, integrating crops with livestock, and agroforestry.	Ethiopia
Elum et al., 2017	DRS seeds, integrated pest management, change in planting date, diversified and relocated crop insurance.	South Africa
Tripathi et al., 2017b	Crop diversification, agroforestry, and increasing use of groundwater for irrigation.	India
Alam et al., 2017	Change in planting time, crop rotation, paddy-pulses, agroforestry, cultivating HYV rice varieties, integrated farming.	Bangladesh
Kumar et al., 2018	Maize diversification, direct seeded rice, aerobic rice cultivation, zero tillage, early harvest, and increased soil carbon (carbon sequestration).	India
Swami et al., 2020	Crop diversification, drought-resistant crops (DRC), planting/ harvesting date (PHD) change, drip irrigation, and crop insurance.	India
S. Singh, 2020	Improved irrigation facilities, change in cropping pattern, switch to non-farm occupation, use of early maturing varieties, and use of less water-consuming crops.	India
Funk et al., 2020	Information and communication technology (ICT), crop diversification, improved irrigation, and integrated farming.	India
Bahinipati and Venkatachalam, 2015	Crop diversification, changes in crop varieties, altering crop calendar and land holidays, soil conservation, pest and diseases management.	India

Ward and Makhija, 2018	Change in crop varieties.	India
Singh et al., 2018c	Water conservation techniques, use of crop varieties of suitable duration, crop insurance and participation in non-farm activities.	India
Singh et al., 2018a	Changes in cropping practices, rescheduling planting, growing crops requiring less water, and buying crop insurance.	India
Panda, 2013	Water conservation, reducing water use, shift to cotton from rice, change in planting dates, reducing cropping area, diversifying crop varieties, diversifying income, and early maturity variety seeds.	India
Khatri-Chhetri et al., 2017	Rainwater harvesting, laser land levelling, furrow irrigated bed planting, drip irrigation, cover crops method, zero tillage/minimum tillage, site-specific integrated nutrient management, green manuring, leaf colour chart, intercropping with legumes, agroforestry, concentrate feeding for livestock, fodder management, integrated pest management, and weather-based crop agro-advisory.	India
Banerjee, 2014	Crop diversification, rainwater harvesting, check dams, farm pond, and natural resource management.	India
Kattumuri et al., 2017	Irrigation provisioning, a shift in cropping patterns, mixed-cropping, agroforestry, diversified livestock holdings, leaving croplands fallow, selling assets such as livestock and trees, and migration.	India

Tripathi and Mishra, 2017a	Short-duration varieties, change in sowing and harvesting timing, inter-cropping, cropping pattern change, irrigation investment, and agroforestry.	India
Tripathi and Mishra, 2017b	Crop diversification, agroforestry, and increased groundwater for irrigation.	India
Aggarwal et al., 2019	Dug well, tube well, rainwater harvesting, drip irrigation, sprinkler irrigation, farmyard manure, vermicompost, residue incorporation, broad bed furrow, minimum tillage, use of improved seeds, crop diversification, green manuring, gully control structure, legume integration and mulching.	India
Swami and Parthasarathy, 2020	Change in planting/harvesting date (PHD), crop diversification, short-duration crops (SDC), drought-resistant crops (DRC), and micro irrigation.	India
Singh, 2020	Drought tolerant crop varieties, early maturing seed varieties.	India

2.4 Determinants of Adoption of CSA practices

2.4.1 Access to Extension Services

Access to extension services means farmers can get help from the government, non-government organizations, and other groups to undertake adoption in their farming activities. Access to extension services is the backbone of farmer adoption. Institutional factors cover the extension support on crop and livestock production, access to information on climate change, and access to credit enhancement (Deressa et al., 2009; Alauddin et al., 2014). Access to extension support from government sources empowers farmers with knowledge and awareness, and farmers get extension support to adopt more proactively than those who do not (Sardar et al., 2021; Abid et al., 2015). The agricultural extension helps farmers by providing them access to training and workshops and spreading the word about how good the CSA measures are. Institutions are very important for giving farmers the information and knowledge they need to take care of the soil, deal with low fertility and dryland soils, and make the best use of rainwater storage to deal with the lack of water in the region. Farmers with solid linkages, regular interaction with extension agents, and easy access to extension services in the study area could help adopt CSA practices. It was found that poor farmers depended a lot on government help, extension services, and information about climate change to decide how to farm. Households with access to food aid, farm support, a radio, a toilet, and electricity, as well as those with fertile soil, modern tools and equipment, informal sources of credit, and information about climate change, were better able to adopt climate change (Bryan et al., 2009). Hassan and Nhemachena (2008) identified a range of extension factors that influence farmers' decisions; the significant factors that determine the adoption decision are access to resources, institutional factors, technology and farm assets (labour, land, and capital), access to markets, and extension and credit services, which critically persuade farmers to adopt climate change activities. Marenya and Barrett (2007) found that factors such as access to credit, generation of off-farm income, and membership in social groups positively impacted the adoption of improved Natural resource management (NRM) practices. Deressa et al. (2009)

found that farmers were more likely to adapt well to climate change if they had access to credit and extension services, had larger farms, had more education, and had more social capital.

Government and non-government organizations help farmers find ways to make money outside of farming so they can have more than one source of income and keep farming even when the weather is unpredictable. Off-farm livelihood generation could help farmers to adopt climate-resilient agricultural practices (Gbetibouo, 2009). Community assets, such as access to government technical services during droughts, the concentration of continuous residential areas, and the number of lateral canals, also affect adoption in drought-prone areas (Alauddin et al., 2014; Yang-jie et al., 2014).

According to Muller and Shackleton (2013), a significant obstacle for farmers in adapting to climate change is the need for more access to information about climate change and the various options available for adoption. Access to market information, weather forecasting information, and agricultural activity information positively impacts CSA adoption (Ng'ang'a et al., 2012; Elum et al., 2017). The likelihood of a change in the crop calendar as a means of adoption increases when farmers have access to information about temperature and rainfall (Deressa et al., 2009). Informal, formal, endogenous, and externally initiated institutions are interdependent and equally important in adoption and innovation. Connectivity and interaction between these institutions can benefit the adoption process (Rodima-Taylor et al., 2012; Abid et al., 2015).

Through communities of practice, formal institutions play a crucial role in building place-based capacity for strategies to deal with climate change and adapt to it in agriculture. These institutions help farmers learn how to change on their own. Adoption practices can be improved if there are good links between formal and informal institutions that work on climate change and if they share information. Public and private institutions play a big part in helping people to adopt CSA. Better connections between government agencies and beneficiaries can improve how policies are made and carried out, making it easier for smallholders to adopt. If adoption policies are made by the central government alone, without the help of local governments, it could mean that farmers do not get the most out of them (Islam et al., 2017; Mubaya et al., 2017; Ampaire et al., 2017; Khanal et al., 2019).

Ojo et al. (2020) expounded that credit availability is a significant factor in adoption. The source of credit and the distance from the source of credit are significant determinants of adoption. Tessema et al. (2013) said that making people in rural areas more aware of credit options can help them adapt to climate change. Makate et al. (2019) state that it takes money and institutional support to implement adoption measures that can lessen the bad effects of climate change. Other studies assert that access to credit from formal and non-formal institutions could enhance the adoption of CSA practices (Tessema et al., 2013; Adenle et al., 2015; Balew et al., 2014; Swami and Parthasarathy, 2020).

Adenle et al. (2015) found that agricultural innovation systems will be one of the most important ways for developing countries to fight climate change. Policy and institutional change are vital. Many developing countries spend only a small amount of their money on research and development of technologies that could help them deal with the effects of climate change on agricultural production and adapt to them. Weak infrastructure, limited research capacity, a lack of credit facilities, and an inability to share technology make it harder to use innovation to solve the problems caused by climate change.

Plaxedes and Mafongoya (2017) used a qualitative method to learn about institutional and structural issues and the role of institutions and institutional arrangements in helping people adapt locally. In the local-level adoption strategy, they have found three ways to change: both public and private institutions in the study areas play a big part in making adoption easier; there is a clear difference between the functions of public, private, and civic institutions; institutions and informal arrangements between institutions help people to adopt together.

Jain et al. (2015) found that infrastructural development, such as access to irrigation and willingness to take risks, enhances the adoption decision. Farmers with more resources and irrigation access used more irrigation-related adoption strategies. Farmers who were poorer and had less reliable access to irrigation were more likely to change the planting date as the farming strategy during water scarcity.

Distance between extension offices and markets significantly impacts the adoption of CSA practices. The closer the distance, the higher the adoption rate. Mazhar (2021) and Aryal et al. (2018)) found a significant negative association between the distance from the market and the adoption of CSA practices. When the distance to the market is shorter, it is probable that farmers will implement various agricultural practices such as crop diversification, stress-tolerant varieties, laser land levelling, minimum tillage, and site-specific nutrient management. According to Jena's (2021) research, the proximity to the primary market, village market, and agricultural extension office positively impacted the adoption of minimum tillage.

2.4.2 Socio-economic Characteristics

The socioeconomic characteristics include the following subgroups: household demographic characteristics such as age, gender, household size, farming experience, caste, education level of the household, and family members. The economic characteristics include the asset accumulation and income of the farmer. The secondary occupation and income of the household also come under the category of the economic status of the farmers. Migration and the remittances received from it fall under the economic livelihood activities of the farmer. A series of studies advocate the significant impact of socioeconomic factors on farmers' adoption decisions for CSA.

The age of the household and farming experience have contrasting effects on the adaptive decision. The literature argues that the older the farmer, the more experience he has. The longer the farming experience, the more likely farmers are to take adaptive measures because farmers with vast experience could have extensive observation-based knowledge of climate change and adoption (Deressa et al., 2009). A higher age group of household heads had adopted agroforestry and irrigation-related adoption practices. The study by Khatri-Chhetri et al. (2017) showed a statistically significant and positive correlation between the age of the household head and the implementation of integrated nutrient management, pest management, laser land levelling, and crop insurance practices. Hassan and Nhemachena (2008) found that experienced farmers are more likely to adapt to climate change. Another group of studies argues that the older the heads of household, the more conservative they will be. So, there is a negative relationship between age and the adoption of climate change (Shiferaw and Holden, 1998). Farmers who have been farming for a long time have gained local knowledge that helps them deal with problems better than younger farmers. This has resulted in their preferring to use traditional knowledge rather than embrace modern techniques (Nyong et al., 2007; Maguza-Tembo et al., 2017).

Gender plays a major role in adopting CSA practices (Ngigi et al., 2017; Asfaw and Admassie, 2004). In a household, the adoption of CSA strategies differs between the female and male heads. Women are more likely to adopt crop-related strategies, while men are likelier to adopt livestock-related strategies. Gender-differentiated group-based adoption interventions are advocated. Male groups comprise a mix of genders, while female groups comprise only female members. This difference in composition affects perception and belief systems. Implementing gender-based interventions in groups can help both genders adapt more efficiently (Ngigi et al., 2017). Male farmers are more prone to taking risks, adopting new technologies and adapting their farming methods than their female counterparts (Asfaw and Admassie, 2004). Meher et al. (2016) say that women farmers cannot use better farming methods because they do not have enough access to information, land, and other resources. However, in some regions, an opposing perspective suggests that women are more likely to take on adaptive measures because they are actively and intensively involved in farming practices (Jost et al., 2016; Nhemachena and Hassan, 2007).

Adger et al. (2003) explored the issue of climate change adoption in developing countries. The authors pointed out that as compared to developed countries, developing countries have lesser money and weaker infrastructure, making it harder for the latter to adopt new ideas. Smit and Pilifosova (2003) explored the relationship between climate change adoption, sustainable development, and equity. They argue that socioeconomic characteristics are important in enhancing the community's and household's adaptive capacity. The weak adaptive capacity is due to a lack of proper economic resources. Uddin et al. (2014) and Abid et al. (2015) found that primary and off-farm income are crucial factors affecting farmers' adoption of climate change. Burnham et al. (2017) say that a farmer's ability to adapt can be boosted by having a higher income and having done it before.

Broadly, the studies of Deressa et al. (2009), Tadesse et al. (2009), Gbetibouo (2009), Abid et al. (2015), Bahinipati (2015), Swami and Parthasarathy (2020), Elum et al. (2017), and Mertz et al. (2009) reported that household factors such as the level of education of the household head, household size, land size, ownership of tube wells, the gender of the head of the household, the age of the farmer, and the property of the household are the major factors that affect how well they can adapt to climate change. Marenya and Barrett (2007) found that household characteristics such as age, gender, education level, and farm size had a mixed or negative impact on adapting to climate change.

Education promotes CSA. Educated farmers will learn about new technologies and share them to practice resilience to climate change. Farmer's view of climate change improves with education. This shows that educated farmers comprehend climate change better and use innovative communication methods to acquire knowledge (Abid et al., 2019). Deressa et al. (2009; 2011) found that educated farmers had adopted soil conservation and changing planting dates. Meher et al. (2016) found that education levels positively impact the adoption of crop rotation. Other studies support the positive effect of adoption on CSA practices (Kakumanu et al., 2016; Kumar et al., 2011; Maddison, 2007).

The social category is one of the covariates in adopting climate change. In Indian society, the social structure plays a critical role, especially in accessing information and facilities. Caste is one of the social capitals that affect the inequality of public spheres in rural communities of Southern Asia (Aryal et al., 2012; Holden et al., 2013; Aryal et al., 2018). There are four categories of caste present in society. Among them, those who belong to the bottom of the hierarchy are not able to access information and opportunities (Birthal et al., 2015). The lower rung in the caste system hierarchy, especially the scheduled tribes and scheduled castes, is less adaptive than the higher castes (Yamano et al., 2015). Farmers from the general caste group are likely to adopt more than others. Khatri-Chettri (2017) found that the general caste farmers were not interested in adopting weather-based crop agro-advisories and crop insurance. The probability of the general caste group adopting CSAPs is higher than the likelihood of the backward and scheduled caste groups adopting them. Farmers who are categorized under the general caste group have a higher tendency to adopt stress-tolerant seeds and site-specific nutrient management. However, they are less inclined to adopt minimum tillage (Aryal et al., 2017). A greater proportion of households not belonging to the SC/ST category identified early maturity and disease resistance as significant characteristics. SC/ST households gave a high rank to lodging tolerance, whereas resistance to pests received a higher ranking from households belonging to other castes (Krishna and Veettil, 2022).

Inter-state and intra-state migration are important in determining the adoption of CSA practices. The head of the household or other family members relocates to seek better income opportunities. The money they send back home as remittances helps improve the household's ability to adjust to changing circumstances (Bahinipati et al., 2021). Migrating households have a comparative advantage over non-migrating households regarding adaptive capacity (Jha et al., 2018).

2.4.3 Experience/Perception of Climate Change

Scholars have argued that adopting climate change in third-world countries would largely depend on the experiences that local communities have had in dealing with climate-related risks in the past (Adger et al., 2003). The increase in temperature and decrease in precipitation affect the adoption behaviour of a farmer (Deressa et al., 2011). Some studies show the perception of climate change positively and significantly impacted the adoption of CSA practices (Dhanya and Ramachandran, 2015).

Gbetibouo (2009) found that farmers in Limpopo Basin are aware of the changes in temperature, rainfall, and weather patterns and have identified climate change as the cause of these changes. Accordingly, farmers modified their planted crops, increased the planation of green plants that survive in dry conditions, adjusted water use, and protected the soil.

Jain et al. (2015) stated that farmers' adoption choices depended on their perception of the weather and their willingness to take risks. Farmers who perceive temperature increase and rainfall decrease tend to adopt adoption practices more positively than others (Gandure et al., 2013; Tambo et al., 2013). Farmers who experience increased pests and diseases are more likely to adopt adoption measures (Banerjee, 2014).

Bryan et al. (2009) found that the perception of an increase in temperature and rainfall significantly affected adopting measures to deal with climate change.

Tadesse et al. (2009) and Mertz et al. (2009) have studied and found that people in the rural Sahel know about climate change and are trying to find ways to adapt. Abid et al. (2015) evaluated that most farm households are aware of climate change and are changing their farming methods. Due to climate change, 58% of farm households have changed their way of farming according to their climatic condition.

Adger et al. (2003) pointed out that developing countries face multiple challenges in adopting compared to developed countries due to their limited resources and weaker infrastructure. The climate change vulnerable sections, such as farmers, fishermen, coastal residents, and urban dwellers, would be self-directed and aided by their social connections and available resources to adapt to climate change in agriculture. Farmers who had experienced a drought in the last five years positively impacted the adoption decision (Bryan et al., 2009).

Mathura et al. (2022) found that farmers' perceptions of rising temperatures and decreasing rainfall amounts were consistent with meteorological data. The empirical result also shows farmers adopted crop and farm diversification, agroforestry, mixed farming, intensified irrigation, planting rotation, soil moisture conservation, and cultivating short-season varieties and drought-tolerant crops with the change in the climate.

Climate change is due to human and natural activities. A farmer cannot take an adoptive action if farmers fails to grasp the idea of anthropogenic climate change and its detrimental effects on agriculture. Farmers have witnessed weather events such as droughts and floods more reliably than others (Li et al., 2017). Perceived risk is the core concept of reacting to climate change. Risk perception leads to the belief in "adverse effects for valued objects." The relationship between perceived risk and public response to climate change has been consistent regarding the importance and predictive strength (Arbuckle et al., 2015).

Traditional knowledge among the farmers influences the perception of climate change (Boillat et al., 2013). The perception of climate change and the scientific evidence on climate change has been consistent. Indigenous patterns of understanding climate change phenomena appear constant among indigenous farmers. They have used their indigenous awareness to embrace climate change (Mekonnen et al., 2018).

2.4.4 Attitude and Behaviour Towards Risk

Grothmann and Patt (2005) examined the role of human cognition in individual adoption of climate change. The individual experience is drawn from their perception of risk, social norms, and access to and availability of information and resources that influence the adoption of climate change.

Jim et al. (2012) found that capacity-enhancement activities and profit-oriented behaviour positively impacted farmers' adoption of certified seed technology and integrated crop management practices.

Truelove et al. (2015) found that drought risk perceptions, efficacy beliefs, village identification, perceived descriptive norms, social networks, cultural values, and psychological factors such as risk perception and self-efficacy had a major role in the adoption of sustainable agriculture. Farmers who thought the risk of the drought was high were not expected to do anything to protect themselves unless they felt like they could handle the threat. Farmers who thought the risk of the drought was low were not expected to do anything to protect themselves, no matter how good they were.

Li et al. (2017) found that the main drivers of farmers' adoption behaviour are financial motives and managerial considerations. Farmers who aim to increase profits and sales, acquire farm ownership, manage larger land areas, possess innovative personalities, access information from socio-agricultural networks and are more likely to adopt adaptive measures.

According to Burnham et al. (2017), having a higher income and previous adoption experiences can increase a farmer's perceived self-efficacy. The availability of farm labour is also a factor that contributes to perceived self-efficacy, an important determinant of adoption.

Azadi et al. (2019) found a complicated link between farmers' adoption behaviours and their overall beliefs about climate change, including how they see risks, how far away they are from the problem, how much they trust it, and how important the risk is to them. Climate risk perception, trust, and psychological distance drove farmers' adoption behaviours more effectively. Farmers had a sound awareness of climate change activities and associated risks, and this understanding of risk led to the trial of the adoption option. When farmers experience climate change and perceive it as a "problem," their willingness to take action is activated (Arbuckle et al., 2015).

2.4.5 Farm Characteristics

The farm plays a major role in facilitating the adoption of CSA practices. The farm characteristics that most studies have mentioned are the location of the land, size of the land, rainfed/irrigated land, soil quality, soil characteristics, availability of irrigation, availability of input, and availability of farm power. Farmers with a large piece of land are likely to adopt CSA. The large land holdings trigger farmers to invest in improved technology (Rajendran et al., 2016;). A few studies reported mixed results about the connection between land holding size and the adoption of CSA practices. The studies by Kafle, 2011; Pongvinyoo et al., 2014; Kunzekweguta et al., 2017; Xie et al., 2015; Luu et al., 2020 signify the positive correlation between the size of the land holdings and the adoption of CSA practices. However, other studies Digal and Placencia, 2019; Okon and Idiong, 2016; Suneeporn et al., 2020 establish a negative relation between the land holding size and the adoption of CSA practices. Alauddin et al. (2014) and Yang-Jie et al., 2014 reported that farm infrastructure plays a key role in determining farmers' adoption strategies. Access to electricity on the farm can help a farmer adopt water-saving strategies. In contrast, lacking electricity may result in rescheduled planting and water-saving adoptions. Community assets, such as access to government technical services during droughts, the concentration of continuous residential areas, and the number of lateral canals, also affect adoption in drought-prone areas.

2.5 Impact of CSA on Income and Yield

Mendelsohn (2008) said climate change's effects are most likely to be felt in tropical and subtropical areas of underdeveloped countries. The following empirical studies find CSA adoption's impact on farmers' income, yield, and food security.

Hasan et al. (2018) found a positive impact of CSA on food security. Bangladeshi farmers on the coast have adopted several CSA methods, such as using drought-resistant seeds, salt-resistant seeds, crop types that can handle flooding, early-maturing rice, mulching, and collecting rainwater. The adopter was 32% more food secure than non-adopters in the coastal districts of Bangladesh.

The study by (Mujeyi et al., 2021) examined the socioeconomic impact of CSA in Zimbabwe. About 386 households in four Zimbabwe districts were interviewed, and an endogenous switching regression model was used to look at the results. The results indicated that adopting CSA practices such as agronomy, agroforestry, integrated nutrient management, a change in tillage practices, and crop residue management could benefit smallholder farmers regarding food security and revenue. The study also found that putting water management practices into place helped with food security and climate change in dry and wet places. Specifically, the mitigation effects of most CSA practices were found to be higher in humid areas. Overall, the study shows that adopting CSA practices can lessen the effects of climate change and help smallholder farmers in Zimbabwe get ahead financially. Branca et al. (2011) also found that sustainable land management has contributed to food security and benefits the environment through carbon sequestration. Haq et al. (2021) reported a positive correlation between the adoption of CSA and increased calorie intake in the Punjab province of Pakistan. The adoption of multiple CSA practices had a positive impact on food diversity and nutritional intake.

CSA practices such as mulching and building trenches could boost food production, biodiversity, and biocontrol. Intercropping maize and beans with wide inter-row spacing boosted Tanzanian farmers' production and annual income (Tripathi et al., 2022). An agent-based model investigated by Bazzana et al. (2022) shows the impact of CSA adoption on food security. CSAs can boost rural well-being for farm households via access to cash, strong social networks, and integrated food markets. Mango et al. (2018) showed that CSA practices, like small-scale irrigated farming, greatly impacted agricultural revenue and net income. Improved varieties of seeds, drought-tolerant maize, and conservation agriculture have significantly and positively impacted productivity and income. Joint CSA adoption and multiple adoption practices positively affect productivity and income and negatively impact poverty more than those for single adopters among smallholder farmers (Makate et al., 2019b).

In a recent systematic review, Mizik (2021) examines how CSA might affect small farmers. Water management and crop rotation practices have been widely used to increase crop productivity. The review also found that CSA positively and directly impacts productivity and the environment. The use of heat- and water-tolerant maize varieties and pest- and disease-resistant bean varieties, conservation tillage, mulching, agroforestry, crop rotation, contour ditches, stone barriers, surface water reservoirs, and drip irrigation has yielded a good financial return for Guatemalan farmers (Sain et al., 2017). Mutenje et al. (2019) analysed the cost-benefit of adopting soil conservation, crop diversification, improved maize variety seeds, and water conservation on productivity and the environment among small-scale farmers. The result shows that the combination of adoption practices has the highest economic and environmental benefits in Malawi, Mozambique, and Zambia. Branca et al. (2021) found that minimum soil disturbance (MSD) farming generates more income than tillage-based farming in Malawi and Zambia. Zerssa et al. (2021) found that, in Ethiopia, INM (integrated nutrient management), agroforestry, and water-smart adoption techniques have had multiple benefits in terms of income, productivity, carbon sequestration, reduction in GHG emissions, and resilience to climate change.

Sardar et al. (2021) interviewed 420 farmers across three agroecological zones in Punjab, Pakistan. Their study controlled the endogeneity issue using a two-stage least squares estimation technique and estimated the impact of multiple CSA practices on productivity and farm income. Farmers who adopted multiple CSA measures reported an increase in their crop productivity of 32% and 44% kg/ha, as well as an increase in their farm revenue of 45% and 48% USD per hectare, compared to farmers who did not adopt the strategies for either cotton–wheat or rice–wheat crops.

Shahzad and Abdulai (2021) employed the use of marginal treatment effects (MTE) to examine the varied impacts of CSA practices on food security and poverty reduction in Pakistan. The research found that adopting CSA practices improved food security by providing more dietary diversity and helped reduce poverty among households.

Agbenyo et al. (2022) used the ESR (endogenous switching regression) model to evaluate the dynamics of the impact of CSA practices on farmers' income in Ghana. Adopting smart irrigation techniques, crop insurance, and organic fertilizers positively impacts household income. Adopting these CSA practices has increased the income level of households by 8–11%. Row planting is a crop-level practice adopted by Ethiopian farmers. The PSM model shows a positive impact of row planting on the household's agricultural income and food security (Fentie and Beyene, 2019).

A few researchers have shown the multidimensional impact of CSA adoption in rural areas. Habtewold (2021) indicates that the joint application of the row planting method and chemical fertilizers has a significant impact on the multidimensional poverty of farmers. Adopting these practices has significantly reduced the multidimensional poverty of a household. Awotide et al. (2022) highlighted the heterogeneous impact of CSA practices on household poverty among the farmers of Mali. They have used the instrumental variable quantile treatment effects model and found that the welfare impact of CSA practices has a heterogeneous effect on the various sections of society. Specifically, in the bottom tail of the distribution, the poorest community of farmers gets the highest benefit from adopting CSA practices.

There are very few impact evaluation studies in India. Most studies conducted in India found a significant impact of CSA adoption on productivity, income, and food security. Most of the studies have concentrated on the Eastern Gangetic Plain more than the other parts of the country. Gathala et al. (2022) found that adopting conservation agriculture-based sustainable intensification (CASI) has increased crop production by 10%, while the demand for labour has reduced by 50%. Using water and energy smart agriculture practices efficiently has enhanced productivity by 19% and 26%, respectively. By following this method, the cost of production has decreased by 22%. This CASI adoption also mitigated the emission of CO_2 equivalent by 10–17% (Pal et al., 2022). Adopting land laser levelling (LLL) has increased water efficiency, productivity, and agricultural income in drought-prone areas of India. Sustainable intensification of CSAPs has ensured income and food security for the farmers of semi-arid regions of India (Pal and Kapoor, 2020). CSAPs have a positive impact on the social capital of the farmers. Adopting CSAPs has reduced out-migration by 21% and reduced the knowledge gap between males and females in Bihar, India (Agarwal et al., 2022).

Hasan (2018) addressed the impact of CSA practised on coastal farmers in southern Bangladesh and investigated the factors that influence household food security. The study area covers seventeen distinct types of CSA practices that the farmers have adopted. The result shows 32% were classified as food secure, 51% were identified as experiencing mild to moderate food insecurity, and the remaining 17% were found to be severely food insecure. The study found a significant positive correlation between adopting CSA practices and household food security, as measured by per capita annual food expenditure.

The study conducted by Khanal et al. (2018) examined the impact of CSA on farm yields. The present study employs a simultaneous equations model to examine the distinct impacts of adoption on individuals who have adopted a particular CSA practice and those who have not. The use of an endogenous switching regression model addresses the issue of selectivity bias. The adoption of CSA strategies has been observed to result in a significant enhancement in rice yield.

FAO (2010) has advocated the concept of CSA. The objectives are to increase agricultural productivity, support equitable farm income increases, increase food security, and mitigate climate change. Many empirical studies have attempted to provide evidence on various factors that trigger the adoption of climate change. The socio-demographic variables and institutional factors determine the adoption of climate change among farmers (Bryan et al., 2009; Tripathi and Mishra, 2017). Education of the household head, farm experience, household size, land size, tenancy status, access to market information, weather forecasting information, and agricultural extension positively impact the adoption of CSA practices (Khanal et al., 2018). The institutional factors such as government extension services, training, access to multimedia, access to credit, access to subsidies, direct transfer of cash, distance to the input market, and crop insurance positively impact the adoption of CSA practices (Bryan et al., 2013).

The perception of climate change significantly affects adoption practices (Swami and Parthasarathy, 2020). Access to the farm's electricity helps a farmer adopt water adoption strategies. The lack of electricity makes a farmer adopt water-saving adoptions and reschedule planting (Yang-jie et al., 2014).

Modern farm mechanization provides a profitable substitute for farm labour (Richards and Martin, 2019). Farm mechanization largely depends on the socio-economic and institutional background (Bryan et al., 2009). However, the adoption decision is also influenced by geophysical and institutional factors, such as the size of the landholdings, the topography of the land, the availability of credit facilities, agricultural extension service, and per-hectare profitability (Wossen et al., 2017). Agricultural mechanization is also influenced by regional differences, landholdings, extension services, cooperative membership, and access to credit (Jena, 2019; Sarkar, 2020).

Mechanization helps increase the productivity and income of individual farmers and benefits a community by mitigating the effects of climate change on the environment (Branca et al., 2011; Pretty, 2008). Over the years, many studies in developing and developed countries established the triple win of CSA practices such as production, mitigation, and adoption (Lan et al., 2018). These practices have proved sustainable and environmentally friendly, increasing yield, farm income, resource efficiency, and fewer inputs (Makate et al., 2018).

In India, a lack of studies discovered the impact of CSA on the productivity and welfare of households. Khatri-Chettri et al. (2016) have found the significant impact of CSA adoption on total production costs and yield in therice–wheat system in the Indo-Gangetic Plain of India. The adoption of land laser levelling (LLL) technology has increased 12–16% in rice yield and net income in Karnataka (Pal et al., 2021). Lopez-Ridaura et al. (2018) pointed out that adopting CSA practices is good for India's food security. Choudhary et al. (2022) found a significant and positive impact of soil and water conservation measures (SWCMs) on farm productivity and income in a semi-arid region of central India. Kumar et al. (2020) assessed the impact of soil and water conservation practices on farm productivity and risk exposure in the semi-arid tropics of India. They found that soil and water conservation practices improved crop revenue and reduced variability. Interestingly, the study shows that soil fertility reduces the chances of downside risk, i.e., crop failure. CSA practices improve the utility of the land, promise crop yields, and strengthen the economic, social, and societal perspectives, which can strengthen sustainable production-consumption patterns (Qureshi et al., 2022).

2.6 Factors Affecting the Adoption of Sustainable Farm Mechanization

The food system is under significant stress due to the growing population and increased demand for the industrial food system. Additionally, malnutrition and climate change have amplified the threat, causing instability in food prices. Though several poverty eradication programmes worldwide have been implemented, malnutrition is still a significant global challenge (Global Nutrition Report, 2018; Prosekov and Ivanova, 2018). Furthermore, climate change's current challenges, which led to erratic rainfall and a steady temperature rise, have negatively affected farm production by creating widely uncertain outcomes for farming communities. Farm machinery plays a big part in climate change adoption strategies. Machinery used in farming enables farmers to cultivate multiple crops in multiple seasons in a year, saves labour time, reduces production cost through precise and timely use of inputs, and so forth, which enhances farm productivity (Benin, 2015; Hatibu, 2013; Pingali, 2007; Sims and Kenzle, 2006). As Biggs and Justice (2015) observed, the green revolution was not just about high-yielding varieties but also about small machines helping in land preparation, fertilization, and harvesting.

Furthermore, certain adoption practices, such as conservation agriculture, a basket of three specific practices, namely minimum tillage, crop residue retention, and crop rotation, require appropriate machines to implement (Jaleta et al., 2016; Jena, 2019). Especially small machines such as seeders, chisel ploughs, hand-operated weeders, and manual sprayers help in the adoption of some climate adoption practices. Hence, agricultural machinery adaptation is a part of the broader climate adoption strategy. The climate-sensitive livelihoods are migrating to diversify incomes and risk transition due to increased extreme climate events (Maharjan et al., 2020). It is necessary to increase agriculture productivity and adopt resilient climate practices to address societal challenges such as climate change and malnutrition. Migration-led labour shortage and higher costs are significant bottlenecks for smallholder farmers in rural areas (Dhiman and Dhiman, 2015).

There is a dramatic increase in agricultural productivity, as well as a transition away from agricultural practices that were more labour-intensive and towards agricultural practices that were more capital- and technology-intensive, such as the use of new varieties, synthetic inputs, and agricultural machinery for all agricultural operations (Paul et al. 2004, Dimitri et al. 2005, Hoppe et al. 2007, Chavas et al. 2010; Bowman and Zilberman, 2013).

The adoption theory on agricultural technology has an interdisciplinary area of study that integrates two theories: decision theory and diffusion of innovations theory. The adoption theory primarily focuses on the factors that trigger farmers' adoption and non-adoption of new technologies. The available literature can be classified into three discrete domains, specifically the paradigm of innovation diffusion, economic constraints, and adopter perception (Adesina and Zinnah, 1993; Prager and Posthumus, 2010; Ruzzante et al., 2021).

Ryan and Gross (1943) pioneered works, while Rogers (2003) contributed the innovation-diffusion paradigm. The paradigm acknowledges that information is a crucial factor that spreads innovation through society. This paradigm has been defined by the seminal work of Rogers (2003), first published in 1962. The theory focuses on the types of innovations and their diffusion rates in society. The theory has assumed that society comprises three categories of adopters: innovators, early adopters, and laggards. These categories primarily align with socio-economic, personality, and communication attributes (Rogers, 2003; Ruzzante et al., 2021).

The paradigm of economic constraints argues about the optimization of utility; disparities in resource allocation result in trends of observable adoption patterns. The works of Adesina and Zinnah (1993) and Negatu and Parikh (1999) emphasize economic factors that shape the individual decision to adopt mechanization. The paradigm is well explained by Ruzzante et al. (2021) in their meta-analysis work.

The paradigm of adopter perception suggests that the adoption behaviours of farmers are determined by their perceived needs and perceived attributes of innovation. The perception of innovation among farmers is influenced by a combination of cultural, contextual, and individual factors, which in turn impact their decisions regarding adoption. Intrinsic factors, such as knowledge, perceptions, and attitudes, and extrinsic factors, such as the characteristics of the farmer, the external environment, and innovation, influence farmers' perception and their decision to adopt technology. This paradigm is supported by the studies of Kivlin and Fliegel, 1967, Adesina and Zinnah, 1993, and Meijer et al., 2015.

Farm mechanization depends on the socio-economic and institutional background (Bryan et al., 2009; Mobarak, 2014; Panda et al., 2013) factors such as the size of the landholdings, the topography of the land, availability of credit facilities, agricultural extension service, cooperative membership, and per hectare profitability (Ouma and de Groote, 2011; Wossen et al., 2017). It is also noted that seasonal migrant workers owning agricultural land diversify their non-farm income by investing in agricultural technologies (McLeman and Smit, 2006; Sobczak-Szelc and Fekih, 2020; Ma et al., 2018; Sarkar, 2020; Jena, 2019). Large-scale farmers are first adopting farm mechanization and new technology in agriculture (Qian et al., 2016b; Suvedi et al., 2017). The studies also found higher mechanization in the multi-crop pattern compared to the mono-crop pattern (Singh 2006). According to Foster and Rosenzweig's (2010) perspective, the determination of technology choice and input allocations are based on considering both financial and non-financial returns to adoption. Factors such as self-learning, social learning, technological externalities, schooling, credit constraints, and incomplete insurance also play a role in this decision-making process.

Typical economic analysis of technology adoption's determinates has examined factors such as individual traits and resources, information adequacy, risk and uncertainty, institutional limitations, input accessibility, and infrastructure availability to explain why and how people adopt new technologies. (Koppel 1994; Foster and Rosenzweig 1996; Kohli and Singh 1997; Rogers, 2003; Uaiene, 2009; Mwang and Kariuk, 2015)

The other agricultural and development economic literature contains numerous studies on the determinants of the adoption of farm mechanization. The determinants can be classified into three distinct categories, namely, farmer characteristics (including age, gender, education level, farming experience, off-farm work, etc.), farm characteristics (such as farm size, location, soil fertility, etc.), and social facilitating conditions (e.g., subsidies, extension services, farmer organisations, etc.).

Few studies have categorized the determinants into broadly three categories social, economic and institutional (Akudugu et al., 2012; Lavison, 2013; McNamara, Wetzstein and Douce, 1991). To investigate the quantitative relationships between these factors and farmers' adoption choices, probit models, multivariable models, bivariate ordered probit models, multinomial logit models and other econometric models were used.

Dai et al. (2015) have categorized the factors that affect the adoption of water-saving farm mechanization into two categories, i.e., external and internal (Wang et al., 2010). The internal factors that affect farming households comprise different factors such as non-farm income, farm income, crop order, risk aversion, labour quantity, gender, age, education level, and social capital. The exogenous variables encompass a range of factors such as the expenses associated with water-saving technologies in agriculture, the extent of water scarcity, the expenses incurred for water usage, the nature of the water source, the size of the agricultural land, the quality of the cultivated land, the level of support provided by extension services, the challenges associated with water storage, and the issues related to the presence of harmful wildlife.

The adoption of farm mechanization depends upon the farmers' household characteristics. The household head's age influences farm machinery adoption in both directions, and the literature has reported that older farmers tend to adopt farm-operated machinery more than younger farmers. Due to old age, farmers could not do labour-intensive activities, so they preferred mechanization over manual labour during agricultural production. Older farmers tend to be more experienced and knowledgeable; accordingly, they will likely add machinery to their production activities (Mignouna et al., 2011; Kariyasa and Dewi, 2011; Asante et al., 2014; Saka et al., 2005). The studies of Barman et al. (2019), Saliou et al. (2020), Debertin et al. (1982), Khumbulani et al. (2020), Kuwornu et al. (2017), and Barman et al. (2019) reflected that age has a significantly negative impact on the adoption of farm machinery. The younger farmers are more aggressive, and they used to experiment the farming practices with agriculture mechanization. The older farmers are less likely to use the new machinery due to their old school thought of farming activities. The old farmers tend to align with the old agricultural practices, which is convenient. The ageing of the household head and rising wages will increase the demand for agricultural mechanization services in the future (Yi, 2018).

Compared to female heads, families led by men are more likely to adopt irrigation pumps and harvesters. Families headed by men are more likely to own, buy, or use farm machinery than those led by women. This could be because women are less likely to know the benefits of mechanization (Motalleb et al., 2018; Aryal et al., 2021). The male head having agriculture as the primary occupation has a higher probability of mini-tiller adoption than the female household head (Paudel et al., 2020). The prospect of adopting mechanization for the female-headed household head will remain lower even after having the same level of attributes between male-headed and female-headed households. The disaggregated study by Xiaoshi and Wanglin (2022) shows that agricultural mechanization and land productivity are positively correlated. It also shows that mechanization increases the land productivity of female-headed households more than it does for male-headed households.

The educational status of the household head determines the adoption of agricultural machinery. Educated farmers tend to adopt modern agriculture machinery more than their counterparts. Years of education articulates farmers to expand their agriculture operations by including modern machinery. Education enhances farmers' knowledge and skill in using farm machinery (Alen and Manyon, 2007; Moock, 1981; Barman et al., 2019; FAO, 2013; Nkonya et al., 1997; Abdulai, 2016; Mignouna et al., 2011; Namara et al., 2013). Few studies have reported that education till high school has a positive impact on the adoption of farm mechanization, whereas higher education obtained degrees in college and universities has a negative impact on the adoption of technology in agriculture (Daberkow and McBride, 2003). A qualified household head with a higher degree and technical education tends to work in off-farm activities and generate better income than in farm activities (Posadas, 2018). Jamison and Moock (1984) articulated that there is no significant relationship between farmer education and technical efficiency in agriculture. Spouse's education has a positive effect on the adoption of farm mechanization (Aryal et al., 2019). An educated spouse in the family could talk about the pros and cons of adopting new technology that can help increase productivity and income.

The household size determines the adoption of farm mechanization. The likelihood of adopting tractor-powered mechanization goes up with the increase in the size of the family in every case. Large family tends to change mechanized operations in agricultural activities, and they used to cultivate large size of agricultural land (Diao et al., 2014; Kirui, 2019; Onyeneke, 2017; Saliu et al., 2016; De Souza Filho et al.,1999; Abdulai et al., 2008). The studies of Aryal et al. (2019) and Khumbulani et al. (2020) reported no significant impact of family size on adopting mechanization. Kuwornu et al. (2017) reported that the size of the household has a negative impact on the intensity of farm mechanization. Larger household sizes may make some family labour available for farm-related tasks. Since mechanization is a labour-replacing activity, a larger family implies an abundance of labour; consequently, there are fewer activities for machines to mechanize, decreasing mechanization's intensity.

Farmers are also pressured to buy machines due to a fast decline in rural labour. The findings of Akram et al. (2020) imply that farming families with more family members available for farm work are less likely to own farming machinery. Family labour is cheaper than contracted labour for farmers. These farmers do not need to engage in farming machinery. If a farmer does not have family help and needs to hire outside help, investing in machines would be more beneficial to save time and money (Mottaleb et al., 2016). Due to the migration of the working population from the countryside to the towns, agricultural output has suffered from a lack of available labour. Based on their farm's available resources and the effects of technological advancement, farmers will opt for labour-saving technology like machinery to compensate for the loss of human labour (Quan and Doluschitz, 2021). Huan et al. (2022) also show that current labour migration encouraged the adoption of mechanization services, and the land size also significantly impacted the adoption of farm mechanization in China. Urban migration is attracting rural farm labour by offering high wage rates.

Farming experience has a positive impact on the adoption of farm mechanization. Farmers who have longer farming experience can know the usage of farm mechanization. Experienced farmers are likely to do farm operations innovatively; hence, they tend to adopt technology positively in agriculture. Ainembabazi and Mugisha (2014) found an inverted-U relationship between the adoption of and experience with agricultural technologies. The practical knowledge gained from farming can be advantageous during the initial phases of technology adoption. This is particularly relevant when farmers evaluate the technology's potential advantages, ultimately influencing its continued usage or abandonment in the long run.

Regarding energy sources, electricity was mostly used to power irrigation pumps. Tractors and diesel engines were also used to power machinery. Water is a very important part of farming. Many farmers still prefer to use diesel engines because there is not enough electricity, the power goes out without warning, and it costs a lot to add renewable energy sources. Using tractors and tillage farm mechanization was found to have a statistically significant positive association with alternative energy sources, including renewable energy and electricity (Akram et al., 2020).

The extent to which farm mechanisation is present in households is significantly influenced by the civilian infrastructure, particularly with regard to a farm's proximity to roads and the accessibility of alternative power sources such as renewable energy or electricity. Development projects in a region, irrigation and road infrastructure improvements, and farmers joining farm cooperatives, farming groups, and farmers' associations will make it easier for them to use new farming technologies (Aryal et al., 2020). The fixed farm mechanization, such as tube wells, is insignificant in this study (Akram et al., 2020). The same study also acknowledges that road infrastructure positively determines the adoption and possession of farm machineries such as tractors, threshers, and power tillers.

The farmers' financial status and land size positively impact the adoption and owned agricultural machinery. According to the study of Akram et al. (2020), farmers with more property and animals were more likely to own their farm equipment. But the other part of the result is more interesting: farmers who owned their land were more likely to have farm mechanization than farmers who rented their land. Also, bigger farm holdings seemed to support the ownership of more farm machinery than smaller farms. Farmers with larger holdings were likelier to use machines, while farmers with smaller holdings were less likely to use machines. This was mostly because farmers with more land were more likely to be financially stable than farmers with less land, and they were also more likely to invest in modern agricultural equipment (Barman et al., 2019). Studies (Kasenge, 1998; Gabre-Madhin and Haggblade, 2001; Ahmed, 2004; Uaiene et al., 2009; Mignouna et al., 2011) were reported and cited by Mwangi and Kariuki (2015) on the positive correlation between the land size and the adoption of farm mechanization. The empirical findings of Ma et al. (2018) suggest that having a non-farm secondary income source, having a larger farm, and receiving subsidies all positively affected the adoption of machinery. Crop sowing area, arable land area, crop variety, number of family labour, subsidies, technical assistance, and economies of scale determine the machinery adoption (Quan and Doluschitz, 2021). The land size and extension contact are positively related to adopting agriculture mechanization. The larger farms tended to interact frequently with the extension agent and are likely to adopt farm mechanization (Kuwornu et al., 2017; Anang, 2018). The larger the land size, the higher the chances of getting credit from financial institutions; otherwise, the smallholder farmer seldom gets credit from financial institutions (Ghosh, 2010). Farmers who have their land readily opt to harvest with mechanization. Farmers who own land have more flexibility in adopting technology, whereas landless smallholders must first seek the landowner's (landlord) permission to implement technological adoption (Novitasari, 2021, July).

Farmland characteristics such as the number of plots, terrain, and structure of cropland are also included because they are regarded as crucial factors influencing household decisions regarding farm mechanization (Wang, Yamauchi, and Huang, 2016; Foster and

Rosenzweig, 2017; Wang et al., 2018; Huan et al., 2022). Soil quality and the fertility of the soil also determine the adoption of farm mechanization. Good soil quality and fertility of soil encourage farmers to invest in farm mechanization (Veisi, 2012). Farmers' desire to use the tractor hiring Service (THS) was favourably and significantly influenced by their land holdings, adult female labour endowment, oxen endowment, and herbicide usage experience (Takele and Selassie, 2018). The desire of farmers in the study area to adopt the tractor service business was a sign of their wealth class, which was indicated by their ownership of oxen and other traits. Farmers who owned two or more oxen were more willing to attempt THS than farmers who owned none or just one ox.

In the case of South Asia, especially in India and China, farm mechanization is increasing among smallholder farmers (Aryal et al., 2021). Smallholder farmers are increasingly utilizing farm machinery on their small landholdings, primarily due to locally - manufactured and locally suitable equipment availability. This trend is particularly evident on small and fragmented lands, where custom hiring service centres have emerged as a popular option for farmers seeking to rent machinery without incurring the high costs associated with purchasing their equipment (Zhang et al., 2017; Sidhu et al., 2015). The availability of quality machines and spare parts in the nearest markets could help to upscale the mechanization in rural areas. Tillage machines' availability, the efficiency of operating machines, product attributes, and accessibility and price effect of mechanization products could enhance the adoption of mechanization (Nazu et al., 2022; Downey and Erickson, 1989; Owombo et al., 2012). According to Hanafie (2010), the application of postharvest technology is affected by several factors, particularly tool characteristics, ease of use, products created, and ease of access, all of which significantly impact farmers' choice of mechanization. Rural farmers had started using machinery and outsourcing to engage in labour-intensive work. The small and marginal farmers in developing countries earn off-farm income by providing rental mechanization services (Yang et al., 2014; Sims and Kienzle, 2016; Zhang et al., 2017; Huan et al., 2022; Baudron et al., 2015; Mandal, 2014, June). The custom hiring centres are increasing where the farmers could get machinery on rent; the farmers used to hire the types of machinery such as four-wheel tractors (4WT) drawn zero-till seed drills, threshers, laser-land levellers, mini-tillers, and spare parts. These hiring centres supply farm machinery to marginal and small farmers on an instalment basis without purchasing expensive agricultural machines and equipment (Biggs and Justice, 2015; Zhang et al., 2017; Aryal et al., 2015; Erenstein and Farooq, 2009).

The notion of farmers' membership in social organizations is frequently regarded as a manifestation of social capital. Social organizations deliver information regarding new agricultural technologies. Consequently, this variable may be a surrogate for awareness about innovation in certain instances (Ruzzante et al., 2021). Development of social institutions such as cooperative societies, self-help groups, and other social peer groups could enhance the betterment and development of financial support to marginal and smallholder farmers, which could help in the adoption of farm mechanization (Ghosh, 2010; Wossen et al., 2017). Membership in cooperative societies and cooperative-based payment systems could help small-scale farmers adopt conservation tillage techniques (Nazu et al., 2022). Social capital, such as interaction with peers via textual messages, phone calls, or meetings during festival outreach, helped to adopt farm machinery (Huan et al., 2022).

Off-farm income has a positive impact on the adoption of farm mechanization. Off-farm mechanization could help rural farmers to overcome the credit constraint. Due to a lack of credit availability and money, farmers could not invest in farm machinery; hence, if a household is generating non-farm income, it is likely to get a substitute for borrowed capital in rural economies. The non-farm income could help as a liquid capital to rent or purchase the farm machinery (Reardon et al., 2007; Ellis and Freeman, 2004; Diiro, 2013). However, a few labour-intensive agriculture practices had a negative relationship with off-farm income and the adoption of mechanization (Goodwin and Mishra, 2004). If a farmer has another job apart from agriculture, he is likely to adopt a tube well, pump, tractor, tillage, and thrasher (Akram et al., 2020). Framers with livestock are more likely to adopt all types of farm mechanization. Livestock rearing has a significant positive impact on the adoption of farm mechanization (Akram et al., 2020).

Perception towards new technology and farmers' involvement in evaluating the technology's suitability could uptake the adoption decision of mechanization among the farmers (Adesina and Zinnah, 1993; Karugia et al., 2004; Wandji et al., 2012). So, before the intervention of any new agricultural technology, farmers should be introduced to see the feasibility of the technology use. Farmers' perceptions of agricultural mechanization can assist policymakers, NGOs, businesses, and engineers in determining the best methods of bringing mechanization to the farmers (Amponsah et al., 2018; Taiwo and Kumi, 2015).

Farmers' willingness to embrace new technologies directly correlates to their access to extension services. Farmers can learn more about the availability, correct application, and benefits of new agricultural technologies from extension agents. An extension agent links the technology's developers (researchers) and the people who will ultimately benefit from it (end users). This reduces the total cost of doing business, especially in getting information about cutting-edge technology (Genius et al., 2010). Some studies (Mignouna et al., 2011; Karki and Siegfried, 2004; Uaiene et al., 2009; Akudugu et al., 2012) reflect the positive association between access to extension services and the adoption of mechanization. Farmers with access to extension services can take advantage of farmer field schools, where they can learn about new techniques in agriculture through hands-on instruction and observation (Abdulai and Bakang, 2011). Subsidies for heavy and light mechanization are available, and extension services can assist farmers in accessing them. Access to extension workers and farm machines was positively correlated with adoption, but problems included spare parts, trained labour, farm machine maintenance, and machine availability (Ayandiji and Olofinsao, 2015). Training and demonstration to the farmers and agricultural machine operators and credit support could help to upscale the adoption of tillage mechanization among rural farmers (Nazu et al., 2022).

Adopting new agricultural technologies, such as mechanisation, could be positively influenced by the availability of information through extension personnel and farmers' field schools (FFS). The significance of access to market and institutional services lies in accessing farmers' knowledge and information regarding agricultural mechanization. The distance to the village market is a medium for market accessibility, and the distance to extension services is a surrogate for institutional service accessibility. Adopting mechanization and distance to market and extension service are inversely related. The lower the distance higher the probability of adoption (Ahimbisibwe et al., 2020; Kassie et al., 2015; Abdulai, 2016; Aryal et al., 2019; Chowdhury et al., 2014). Few other studies (Tesfaye et al.,2014; Shikuku et al., 2017) found no significant impact of extension services on adopting new technology among farmers. Subsidization encourages the adoption of machinery. Farmers in rural areas are more likely to invest in machinery if they can get subsidized support from the government. The government could subsidize the purchase of agricultural machinery to upscale the adoption of mechanization (Quan and Doluschitz, 2021).

2.7 Impact of Farm Mechanization on Food Security and Income

The benefits of farm mechanization in agriculture have been well articulated in Hatibu (2013) and Pingali (2007). The adoption of mechanical technologies helped enhance agricultural productivity and lowered the unit cost of crop production in Asian countries. Power-intensive mechanization operations have occurred rapidly in countries such as India, Bangladesh, Nepal, and the Philippines, where high population densities and low wages persist (Pingali, 2007). Several recent studies using household survey data establish that mechanization has helped lowering input costs, increase yield, and save man-days per hectare compared to traditional farms (Rahman et al., 2011; Vortia et al., 2021; Adebayo et al., 2018; Rahut and Behera, 2016; Abid, Schneider, and Scheffran, 2016; Paudel et al., 2019; Adu-Baffour, Daum, and Birner, 2019; Ali et al., 2018; Cunguara and Darnhofer, 2011; Kassie, Shiferaw, and Muricho, 2011; Wu et al., 2010). While showing that adoption of mechanization benefits farmers on average, these studies also express concern about large heterogeneity among the smallholders that may undermine the magnitude of the impact. Wealthier farmers largely adopt it since investing in capital expenditure is a big decision which needs initial capital. The ability of small and marginal farmers to adopt machinery is constrained by inadequate access to credit facilities. Despite this heterogeneity, some studies have shown a significant poverty reduction impact of agricultural mechanization (Ali and Behera, 2016; Paudel et al., 2019). Aryal et al. (2020) have found that the land laser levelling through tractors significantly impacts yields (rice and wheat) and net returns in the rice-wheat production system in Haryana, India. Naresh et al. (2014) estimated that laser land levelling practices in the state of Uttar Pradesh in India could save irrigation water by 21% and energy by 31%, and increase the yield by 6.6, 5.4 and 10.9% in rice, wheat and sugarcane production, respectively.

Smallholder farmers have widely adopted farm mechanization services in China by substituting self-owned equipment for labour. Qing et al. (2019) showed that those who owned mechanization services could improve farm productivity and profitability via substituting labour but may not necessarily improve crop yield in China. The growth of the use of larger machinery and reducing the labour intensity of farm production have significantly improved China's potential for economies of scale (Jetté-Nantel, 2020; Zhu et al., 2022). Qui et al. (2022) show that agricultural mechanization services benefit medium farms more than small and large farms in China. Medium-sized farms are more likely to use agricultural mechanization services, and that adoption increases farm output. Land productivity is also associated with the adoption of the level of mechanization. Semi and full-farm mechanization has a positive impact on productivity. Full farm mechanization has higher productivity than semi-mechanization[1] (Zhou and Ma, 2022). Wang et al. (2015) compared China and India's productivity, land size and mechanization. They found that the operational land size has a direct and proportional relationship with crop yields in China, while the former has an inverse relationship in India. However, mechanization has a positively significant impact on yield and productivity in both China and India.

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[1] There are three levels of farm mechanization: non-mechanized farming, semi-mechanized farming, and fully mechanized farming (Ma et al., 2022). If the machines are not used at any stage of agricultural activities, it is called "no mechanization." Semi-mechanized farming refers to using machines at some stages of agricultural production. Full mechanization refers to using machines in every stage of agricultural activities (Zhou and Ma, 2022).

2.8 Role of Women in Adopting CSA Practices

The observable consequences of climate change are progressively more conspicuous in contemporary times. These include the difference in the mean temperature and precipitation levels, modifications in the magnitude, timing, and spatial spread of precipitation, a surge in the frequency of severe climate-induced events such as droughts and floods, and a rise in sea levels (IPCC, 2007). Anthropogenic climate change poses the greatest threat to developing nations. Rural farmers in developing nations are highly vulnerable to extreme events. As a result of the phenomenon of climate change, female farmers encounter a greater number of obstacles in comparison to their male counterparts. Gender disparities persist in the fight against climate change in developing countries. Women constitute 70% of the population living below the poverty line in the developing world, which amounts to 1.3 billion individuals. Women contribute to agriculture significantly and account for about 43% of the global agricultural labour force (FAO, 2011). The threats posed by global warming have not convinced policymakers of the significance of positioning women at the centre of their vision for sustainable development (Denton, 2002). Still, research into climate change's many gender-related aspects is severely lacking (MacGregor, 2010).

The presence of structural inequality and disempowerment has a detrimental impact on the capacity of women farmers to address issues related to climate change and food security effectively (Demetriades and Esplen, 2008). The phenomenon of climate change is anticipated to have a disproportionate impact on female smallholder farmers, as it is likely to perpetuate pre-existing gender disparities and amplify the socioeconomic and political hazards that these farmers encounter (Steinfield and Holt, 2020; Tantoh et al., 2021; Tschakert and Machado, 2012).

Rural women farmers are more sensitive towards climate change due to their work profile which includes childcare, gathering firewood, collecting drinking water, managing most of the household work, and also executing most of the agricultural operations as farm labour (Goh, 2012; Alfthan et al., 2011; Jost et al., 2015). The responsibility of women increases when their male counterpart migrates to another city in search of work. The exposure to climate change increases for a woman farmer when she takes responsibility for farming activities without a male (FAO, 2011). Further, the adaptive capacity is constrained by the factors such as less access to agricultural resources such as land, extension services, inputs, and mechanization. The social norms and gender roles in society are also an obstacle to the adaptive capacity of women farmers (Kakota et al., 2011; Wright and Chandani, 2014; Jost et al., 2015).

The issue of climate change presents obstacles in the efforts to sustain and enhance female smallholder farmers' agricultural and labour productivity (Murry et al., 2016). Climate change adversely impacts the socioeconomic life of women. It affects the health condition likely to increase cardiovascular and respiratory diseases (Denton, 2002). FAO (2011) has examined the impact of climate change and differential risk, focusing on the gender dimensions. The report finds a strong correlation between gender equality and climate change, particularly in rural agricultural contexts where women face restricted access to clean energy, technical support for crop irrigation, and insufficient low-cost farming inputs and credit from financial institutions. This review explores the role of women in adopting and upscaling CSA practices worldwide.

The discourse surrounding the gender aspects of climate change and food security has been a topic of discussion in the field of development literature and practice for a considerable period. The inadequate comprehension of the intersection between climate change and socioeconomic challenges faced by susceptible populations in regions prone to conflict is a current issue (Omolo, 2010). Female farmers may experience a lack of autonomy compared to their male counterparts when making significant decisions regarding improvements in agricultural practices (Murray et al., 2016). Women's labour in agriculture is subject to limitations due to their involvement in the unpaid care economy, which may fluctuate throughout their lifespan, such as before childbirth, during childcare, or while caring for older people (Peterman et al., 2010). Various studies have asserted that women smallholder farmers must have access to relevant inputs and tools to take up CSA practices

(World Bank, FAO, and IFAD, 2015). The adaptability among the women head farmers is low. It is due to financial or resource limitations in a patriarchal society dominated by men, a lack of access to information and extension services, and a greater labour demand for women head farmers (Bryan et al. 2013; Deressa et al. 2009; Jost et al., 2016). Despite efforts to promote the adoption of new labour-productivity-enhancing technologies and Community Supported Agriculturepractices, women farmers still encounter obstacles (UN-Women, 2015).

The review of the gender analysis can provide insights into the decision-making processes concerning climate-smart agricultural practices, such as intra-household bargaining and resource allocation. Various groups exist in a household, such as households headed by men or women or women residing in households headed by men (Murray et al., 2016; Ngigi et al., 2016). Generally, ideological, social, and economic dominancy and encounters exist in taking a decision which is a limitation towards the progressive adoption decision. Firstly, the review tries to explore the combination of structural factors that give rise to vulnerability, coupled with the risk posed by climate change, which contributes to widening the disparity in agricultural resources available to female farmers. Secondly, the review tries to identify gender roles in the adoption of CSA practices in developing countries.

Demetriades and Esplen (2010) described that the persistent gender inequality in society and climate change could enhance women's poverty rate more than men's. The intra-household disparity in the distribution of power and property and less access to and control over financial, material, and human resources undermines the capabilities to adapt to predicted or existing climate change issues. The statutory and customary laws prevent women from accessing their land rights, which could lead to inaccessibility to credit. The biased nature of various institutions treats men only as farmers and debars women from accessing the extension and technology in agriculture in a climate-vulnerable region. Lack of access to land rights, credit, and technology among women farmers could significantly constrain adaptation to climate change. Women also face sexual and domestic violence after climate change-induced disasters (Bartlett, 2008).

Angola (2010) conducted a case study in Namibia and tried to find the relationship between gender and climate change. The author asserted that the impact of climate change on the means of subsistence of individuals varies based on gender. This research suggests that households headed by widows or bachelors experience greater difficulty managing the risks and vulnerabilities associated with climatic variability and changes than those headed by females. The level of impact that climate change has on the environment and the extent to which women are exposed to climatic risks are major.

Ribeiro and Chaúque (2010) studied Mozambique and found that both men and women were impacted by climate change, but the degree of impact was different for both genders. Women farmers had access to resources but did not have control and property rights over them. The community had experienced consecutive droughts over the past two years, resulting in a rise in male individuals migrating to other locations in pursuit of employment opportunities. Consequently, the involvement of women in productive agricultural work has significantly escalated.

An article by Glazebrook (2011) examines the distinct influence of climate change on women residing in the northeastern region of Ghana. The argument posited by the author is that women residing in rural areas are especially susceptible to the impacts of climate change, owing to their significant dependence on agriculture as a source of sustenance and their limited access to resources and information necessary for adapting to fluctuating weather conditions.

Babugura et al. (2010) present a case study that examines the effects of climate change on gender in South Africa. The research reveals that climate change disproportionately impacts women, as they are more susceptible to its economic, social, and health consequences owing to pre-existing gender disparities. Integrating gender perspectives into climate-related policies, enhancing women's involvement in decision-making processes, and furnishing women with economic prospects in sustainable sectors help to face the climate change issue among woman farmers.

An article by Arora-Jonsson (2011) examines the different lenses employed while discussing women, gender, and climate change. The author argues that the account mentioned above fails to acknowledge women's susceptibility to the impacts of climate change and their potential to contribute to adaptive measures. The article underscores the necessity of transcending facile generalizations and adopting a more comprehensive and intersectional strategy towards climate action.

Arora-Jonsson, (2011) indicated that women are disproportionately affected by climate disasters due to their socially constructed gender roles and responsibilities and their comparatively disadvantaged economic status, particularly in developing nations. Gender disparities in Bangladesh regarding the exercise of human rights, political and economic standing, land possession, housing circumstances, susceptibility to violence, education, and health (specifically reproductive and sexual health) render women more susceptible to the effects of climate change-triggered calamities, both before and after of their occurrence.

Onta and Resurrection (2011) found the intersections of gender and caste in the context of climate change adoption. They have presented novel evidence of potential unintended consequences and opportunities and resilient practices related to gender and caste in Nepal. The interdependence and interconnectivity of various factors play a crucial role in devising effective adoption strategies, particularly in light of the escalating issue of food insecurity caused by reduced crop productivity in the face of climate change.

Goh's (2012) review finds the gender-specific effects of climate change on individuals residing in developing nations. Women and men are impacted differently. The impact of climate-related incidents on the well-being and assets of men and women varies. Climate-related shocks disproportionately impact women in comparison to men. The adverse effects of climate change on agricultural production, food security, health, water and energy resources, climate-induced migration and conflict, and climate-related natural disasters exhibit gender-based variations, leading to differential impacts on the assets and well-being of both genders.

Alston (2013) compiles research from various regions, including Australia, Canada, Africa, Asia, and Europe, to showcase the growing body of evidence indicating the significance of gender on climate change. The effects of climate change are experienced differently by women and men, both during and after a climate crisis. These experiences are influenced by various factors, including cultural norms and practises, work roles and access to resources, safety and security, and varying levels of vulnerability resulting from these factors.

Lambrou and Nelson (2013) confirm that gender plays a significant role in how farmers experience and express climate variability in their coping strategies to guarantee their livelihoods and food security. As they pursue food security, women's and men's perceptions and responses to the effects of altered climatic conditions differ significantly.

Carr and Thompson (2014) acknowledge gender and climate change adoption in rural contexts showing that men and women often perceive climate unpredictability and change differently. Evidence shows that women cultivate crops with different biophysical properties than men in rural contexts. Women also have limited decision-making and access to land and input. Women are also developing locally suitable adoptions to climate change.

Sugden et al. (2014) reported that in the context of the Eastern Gangetic Plain and agrarian stress, male out-migration is the main cause of gendered vulnerability. This has changed how to work, and resources are shared. Even though people from all walks of life move, the most vulnerable are women from poor farmers and tenant families. Women are coming up with ways to deal with the effects of climate change, building skills and plans that work well in their areas.

Alston (2015) in his book noted that women face greater vulnerability during and after a climate-induced disaster. Women are more likely to die, suffer, and face violence due to less control over resources and the inequality structure of society. Women have less access to resources that need preparedness for disaster, adoption, and mitigation.

Yadav and Lal (2018) noted women farmers' exposure to climate change. The susceptibility of women populations to climate change can be attributed to various factors such as poverty, gender inequality, insecure land rights, high dependence on agriculture, and limited access to education and information. The susceptibility is further complicated by the limited resources, societal marginalization, restricted mobility, and absence of involvement in the disaster response decision-making procedures.

Ylipaa et al. (2019) examine how men and women in Thái Bnh adapt to climate change and make a living as farmers. The study finds that male and female farmers have different rights and responsibilities. This leads to unequal opportunities and immobility for women, which makes them more vulnerable to the effects of climate change and threatens to reduce their ability to adapt to climate change. Women do not have rights or control over things they are responsible for, but they do not have rights or control over them. So, women cannot get access to and add to knowledge production to help them escape their difficult situation. They also do not have the power to participate in or change policymaking.

The study by Balikoowa et al. (2019) asserts that female-headed households are more vulnerable than male-headed households. Women enjoy fewer assets and opportunities compared to men. Women farmers usually face resource constraints when a female in the household is undertaking the headship without male members. Due to resource constraints, the adaptive capacity is decreasing among women farmers. Households headed by females exhibited less resilient livelihoods, elevating their susceptibility to the impacts of climate change. Female-headed households, primarily widowed women, also possessed a smaller amount of land.

Alhassan et al. (2018) found the vulnerability to climate change among male head and female farmers in Ghana. The vulnerability of female-headed households was found to be significantly higher in relation to their socio-demographic profile, livelihood strategies, social network, and access to water and food than male-headed households. Female-headed households exhibit greater sensitivity to climate change and variability, rendering them comparatively more vulnerable in terms of adaptive capacity when compared to male-headed households. Overall, households headed by females exhibited greater susceptibility to climate change impacts and variability than those headed by males.

Asadullah and Kambhampati (2021) assert that women's labour participation in agriculture gradually decreases in the developing world, where female farmers' participation increases. However, labour participation in agriculture has not enhanced women's lives beyond being a farmer, although female participation in agriculture has enhanced food security and women's empowerment. The formation of Women in Agriculture (WIA) farmer groups and cooperative groups has facilitated the dissemination of agricultural innovations and provided women farmers with better access to farm inputs and credit than they would have as individuals (Ogunlela and Mukhtar, 2009). However, multiple studies reveal that women lag behind men in agricultural technology adoption on climate change (Rola-Rubzen et al., 2020; Vemireddy and Choudhary, 2021).

Majumder and Shah (2017) noted, in the context of Indian agriculture and household livelihood, that women play a pivotal role in providing essential support. Despite this, their participation is often limited to the role of workers. The current availability of farm tools is primarily geared towards male farmers, leaving rural women to rely on traditional tools and methods. This has decreased efficiency, increased physical strain, increased occupational health hazards, and reduced income for these women. Theis et al. (2018) did extensive qualitative studies in Bangladesh to show women do not adopt water-level adoption irrigation pumps due to technological complexity, difficulty in operating machines due to physical requirements, and difficulty in hiring and controlling the labour force. A study by Gouse et al. (2016) shows that female farmers emphasise labour-saving technology and pest control variety of seeds. The male farmers focus on yield benefits, whereas the female farmers prioritize the taste, quality, and simplicity of cultivation.

Khatri-Chhetri et al. (2020) developed a women's CSA adoption map to determine women producers' adoption of CSA practices and the resulting impact on drudgery. Nepal's agriculture is swiftly becoming increasingly female-dominated. The Nepalese women farmers have adopted direct seeded rice (zero tillage and minimal tillage using machinery), green manuring (GM), laser land levelling (LLL), and a rice intensification system (SRI). In addition to reducing women's agricultural drudgery, these practices have increased productivity and farm income.

Hariharan et al. (2020) compared women's participation in the climate-smart village (CSV) approach and looked at how it affected gender equality in Haryana and Bihar between 2012 and 2015. Both states examined showed an increase in women working in CSVs and in women's political, social, and agricultural lives across Haryana. The economic, social, and agricultural participation of Bihar's CSVs is also improving. To some extent, promoting change in gender equality helps women in the interviewed groups develop their skills and abilities. The analysis shows the benefits of CSA interventions in the CSV approach.

Balasha et al. (2023) examined gender differences in climate change perception and how they affect farmers' adoption of sustainable practices. About 50% of women farmers preferred Indigenous climate knowledge, while 61% of men farmers said experience and exchange helped them read and predict climate trends. Male farmers used less pesticide for climate change adoption than female farmers. More women (50%) than men (32%) planted living hedges to prevent field erosion. Nnadi et al. (2023) investigated the challenges and opportunities linked to gender in the region of South-East Nigeria. The study highlights significant disparities between male and female-headed households adopting migration and livelihood diversification strategies. Women faced challenges related to inadequate farming knowledge, while male farmers encountered difficulties due to insufficient knowledge of mechanization. The female demographic exhibited lower involvement rates in training programmes and limited availability of telecommunication resources conducive to hands-on learning. Similarly, the study of Mphande et al. (2022) examined the difference between male and female-headed households and found that female farmers encountered difficulties obtaining hybrid legume seeds, inoculants, and promoting beans. One of the challenges faced by men in the soybean industry was the issue of low market prices.

Nchanji et al. (2022) show that different groups of men and women use and adopt CSA technologies for growing beans differently. Hove and Gweme (2018) found that adopting conservation farming among the women farmers of Zimbabwe enhanced food security in the region. Farmers who implemented conservation agriculture techniques while adhering to the recommended components and employing appropriate strategies experienced an enhancement in their food security during the dry season. Ge et al. (2023) examined the difference between males and females in adopting crop diversification as a CSA practice. Adopting crop diversification among male farmers depends significantly on their attitudes, subjective norms, behavioural control, and environmental knowledge. On the contrary, female farmers' adoption of crop diversification is not influenced significantly by their attitudes, subjective norms, perceived behavioural control, and environmental knowledge.

2.9 Research Gap

From the literature review, it can be concluded and summarized that agricultural productivity is impacted by climate change and variability. Due to climate change activities, the other socio-economic condition of farmers adversely impacted. The vulnerability to the agriculture sector is increasing day by day. So, most farmers are undertaking different strategies to cope with climate change.

Many studies have been conducted to assess the impact of climate change on agricultural productivity and the income of farmers. The adaptation strategies at the global level and national levels have been documented. Very few studies have been conducted to find out the adaptation strategies at the household level. Very few studies are conducted in the regionally diversified area. Most of the studies have conducted qualitative and semi-quantitative research on adopting CSA. Most studies have been conducted to find a limited number of adoption strategies. The other possible adoption strategies have been ignored. The socio-economic and physiological vulnerable areas facing the continuous threat of climate change has not been considered at full fledge. Studies have not properly articulated the role of agricultural extension institutions in upscaling CSA practises. By taking care of all these gaps, this study tries to bridge a few of the gaps and tries to differ from the other studies in the following points.

1. This study has been conducted in three different agro-climatic zones of Odisha, which have different geographical, cultural and economic statuses. The three different agroecological zones also faced several climate changes induced extreme events, such as one area being prone to drought and others being prone to cyclones and floods.
2. The studies try to bridge the gap by studying in Odisha's most underdeveloped and tribal-dominated regions. To conduct a study in such a region is a difficult task for a researcher. The research in such vulnerable areas could help look into developing vulnerable sections.
3. This study tried to determine the role of institutional and infrastructural access in upscale CSA practices among local farmers. Qualitatively and quantitatively, the study tried to find the nexus between institutions and individuals.
4. The study has observed and included many popular CSA practices ongoing in Odisha, which the other studies failed to capture.
5. This study tried to determine the impact of technology adoption on income, yield and food consumption on a national and regional scale, which the other studies have not incorporated.

CHAPTER 3

DETERMINANTS OF FARM MACHINERY ADOPTION AND EFFECT ON HOUSEHOLD INCOME AND FOOD SECURITY: IN INDIA

3.1 Introduction

The food system is under significant stress due to the growing population. Additionally, climate change has amplified the threat causing instability in food prices. The climate-sensitive livelihoods are migrating to diversify incomes and risk transition due to increased extreme climate events (Maharjan et al., 2020). It is necessary to increase agriculture productivity and adopt resilient climate practices to address societal challenges such as climate change and food sustainability. Migration led to a labor shortage, and higher cost is a significant bottleneck for smallholder farmers in rural areas (Dhiman and Dhiman, 2015). Adopting agricultural technologies is crucial to improving crop yield and addressing labour shortage issues (Burney et al., 2010; Pathak, 2015). However, farm mechanization requires higher capital investment, which constrains small-scale farmers around the globe. Further, the hiring cost of agricultural machinery has increased to 40% of the total intermediate cost in the farm sector (Aryal et al., 2019). This creates a need to understand the patterns and determinants of adopting farm machinery among rural households.

The sustainable development goals (SDGs) 1 and 2 of the United Nations have targeted eradicating poverty and hunger by 2030. Achieving these targets requires a higher than the business-as-usual level of growth in farm production (Godfray et al., 2010; Gregory and George, 2011; Ruttan, 2002; Tilman et al., 2002). Godfray et al. (2010) estimated that farm production needs to be increased by 70–100% to achieve SDGs 1 and 2.

Furthermore, climate change's current challenges, which led to erratic rainfall and a steady temperature rise, have negatively affected farm production by creating widely uncertain outcomes for farming communities. Machinery used in farming enables farmers to cultivate multiple crops in multiple seasons in a year. It also saves labour time and reduces production costs through the precise and timely use of input. Due to mechanization, farm productivity could be enhanced (Benin, 2015; Hatibu, 2013; Pingali, 2007; Sims and Kenzle, 2006) as Biggs and Justice (2015) observed that the green revolution was not just about high-yielding varieties but also about small machines helping in land preparation, fertilization, and harvesting.

Furthermore, certain adoption practices, such as conservation agriculture, a basket of three specific practices, namely minimum tillage, crop residue retention, and crop rotation, require appropriate machines to implement (Jaleta et al., 2016; Jena, 2019). Especially small machines such as seeders, chisel ploughs, hand-operated weeders, and manual sprayers help adopt some climate adoption practices. Hence, agricultural machinery adoption is a part of the broader climate adoption strategy.

Technology adoption in agriculture is slower in South Asia and Sub-Saharan Africa compared to Latin America, East Asia, and the Caribbean (Gollin et al. 2005). Jack (2013) highlighted that the market inefficiencies prevailing in these countries constrain technology adoption. Examples of these market imperfections include "missing markets" for risk, credit, or land (i.e., a lack of formal insurance providers, financial institutions, or the ability to buy, sell, own, or reliably hold onto one's land). Janvry et al. (2017) explained that the underlying production function in agriculture is only partially understood as many non-observable phenomena cloud it. A high degree of heterogeneity of conditions can yield unexpected outcomes.

Furthermore, the production function is subject to random shocks, principally in weather events with incompletely known probability distribution due to limited records or climate change. As a result of this complexity, slow diffusion of technology is expected, and hence, extension services need to find effective ways of accelerating the learning process. Foster and Rosenzweig (2010) advocated the decisions to adopt technology choice and input allocations are determined by the financial and non-financial returns to adoption, self-learning, social learning, technological externalities, schooling, credit constraints, and incomplete insurance.

Farm mechanization saves time and labour; the long-run production cost will decrease and boosts crop output and farm income (Cossar, 2019; Qian et al., 2016). Indian agriculture witnessed the sectorial transformation from traditional input choice to modern input (labour and animal draught power to energy-driven machines) (Vatsa, 2013). This led to a rapidly expanding farm machinery market with strong demand. However, the overall mechanization level in India is only 40-45%, where 42% for soil and seedbed preparation, 29% for seeding and planting, 34% for plant protection and 37% for irrigation. The level of mechanization is higher for wheat and rice crops, at around 60-70%, but less than 5% for other crops (Mehta et al., 2014). Previous studies show that India's mechanisation rate has grown by 10% between 1960 and 2011 (Tiwari et al., 2019).

Over this period, the use of animal power sources in agriculture declined gradually from 93% in 1960 to 12% in 2011. The country's tractors, power tillers, diesel engines, and electric motors replaced it. Agricultural machinery encourages small and marginal farmers to engage in sustained agricultural intensification and enhance land productivity (Kienzle et al., 2013; Mottaleb et al., 2016; Tilman et al., 2011).

Farm mechanization depends on socio-economic and institutional factors such as the size of the landholdings, the topography of the land, availability of credit facilities, agricultural extension service, cooperative membership, and per hectare profitability (Bryan et al., 2009; Panda et al., 2013; Wossen et al., 2017). Large-scale farmers are the ones who adopt farm mechanization and new technology in agriculture first (Qian et al., 2016; Suvedi et al., 2017). The studies also found a higher level of mechanization in the multi-crop pattern than in the mono-crop pattern (Singh 2006). Researchers in the past have identified the determinants of mechanization at a regional or smaller spatial scale. Still, there is a need to do the same at a broader scale using large-scale household data.

To address this gap, the current study undertook a comprehensive assessment of the determinants of the agricultural mechanization process in India. There is also need for a systematic evaluation of the impact of mechanization on agricultural productivity and farm incomes in India. Most existing studies have observed a positive contribution of mechanized farming to farm production and household income. However, there is little evidence of the impact of agricultural machinery on household consumption and food security. This is one of the few studies that systematically examine the nationally representative data of India to assess the impact of machinery adoption in agriculture on household income and food security.

Furthermore, this study uses a dataset that has reached out to most of the states in India and collects very detailed data on net agriculture income, total household income, consumption and several other indicators. The literature review shows that most studies have smaller sample sizes over a district or micro-region. The study covers a national picture; moreover, this study's calculation of net agricultural income is that all the costs and revenues during the farming seasons of the individual households in each state have been recorded. Similarly, household income and consumption account for each outcome indicator constituent.

The remaining sections of the chapter are as follows. In Section 2, the materials and methods used in this study have been elaborated. On in section 3, the results and findings are discussed. Finally, section 5 lays out the overall discussion of the findings and concluding remarks.

3.2 Materials and Methods

3.2.1 Data Source and Distribution of the Sample

This study uses the India Human Development Survey (IHDS II) data conducted in 2011-12 by the National Council of Applied Economic Research, New Delhi, and the University of Maryland. This is a nationally representative dataset consisting of multiple socio-economic indicators. The final sample size for IHDS-II is 42152 households, of which 27579 are rural and 14573 are urban dwellers. These households are spread across 33 states and union territories, 384 districts, 1420 villages, and 1042 urban blocks. The stratified sample of towns and villages within states (or groups of states) is selected using probability proportional to population (PPP). Table 1 shows the distribution of the sample across the country. We have extracted 10253 households' data from 42152 households based on two criteria. First, 21 states are purposefully selected based on the size of the states and the priority of the agriculture sector. Seven states and union territories has been excluded. Second, we have selected only the rural areas across the country.

Table 3.1: Distribution of Samples

States	**Frequency**	**Per cent**
Jammu and Kashmir	133	1.30
Himachal Pradesh	291	2.84
Punjab	312	3.04
Uttarakhand	108	1.05
Haryana	410	4.00
Rajasthan	727	7.09
Uttar Pradesh	1079	10.52
Bihar	383	3.74
Arunachal Pradesh	46	0.45
Assam	148	1.44
West Bengal	350	3.41
Jharkhand	125	1.22
Orissa	574	5.60
Chhattisgarh	574	5.60
Madhya Pradesh	1,225	11.95
Gujarat	507	4.94
Maharashtra	1125	10.97
Andhra Pradesh	559	5.45
Karnataka	1255	12.24
Kerala	102	0.99
Tamil Nadu	156	1.52
Total	10,253	100

Source: Authors' Calculations

We filtered out the data and found that Karnataka has the most (12.25 %) rural farmers, and Arunachal Pradesh has the lowest (0.45%). Uttar Pradesh, Madhya Pradesh, West Bengal, Gujarat, Odisha, Chhattisgarh, Jharkhand, and Andhra Pradesh have more rural farmers. The sampling weights used to draw the sample size from each state and UT are published by the IHDS survey team, and we use those weights in the regression models.

3.2.2 Multivariate Probit Model

Farmers in the present study adopted more than one type of mechanization, a multivariate probit model (MVPM) (relationships among identified adoptions of agricultural technology) is appropriate for assessing the determinants for the choice of small-scale farm machinery. Farmers are more likely to adopt one or more machinery; therefore, the choice of one may complement or substitute the use of other machinery. The MVPM acknowledges the joint decision to use these machines by accounting for the potential correlations of the unobserved random error term between the equations. Further, the MVPM helps us understand whether farm machinery complements or substitutes other machinery.

This is a qualitative choice model, where a farmer's decision to adopt farm machinery is discrete. To establish the relationship between farm mechanization and household characteristics - the study employs tube wells, electric pumps, diesel pumps, tractors/power tillers, mechanical threshers and seed drill machines as dependent variables. The adoption of farm mechanization is binary in response. Farmers who adopted mechanization take value 1, and others take 0. This model simultaneously analyses the influence of explanatory variables on each dependent variable (adoption of farm mechanization).

Let us assume that the i^{th} farm household (i =1, 2…N) is deciding on whether to adopt y^{th} machinery, where y denotes choice from among tube well (T), electric pump (E), diesel pump (D), tractor/power tiller (P), thresher (H) and seed drill (S). Let us assume that the benefit derived from the machinery, with or without adoption, will take U_o and U_y.

So, a farmer decides to adopt the y^{th} machinery if the net benefit of adoption is higher than without.

So $Biy^* = U^*j - Uo > 0$

Finally, the model is $B^{*}iy = X'\ iBy + \varepsilon_{ip}$ (y=T, E, D, P, H, S) ………………………… (3.1)

If we write the 1st equation into the observed binary outcome, our equation for each machine type will be:

$$Biy = \begin{cases} 1\ andif\ B^{*}iy > 0 \\ 0\ andotherwise \end{cases} \text{ (y=T, E, D, P, H, S) } \ldots\ldots(3.2)$$

The error terms jointly follow a multivariate normal distribution in the multivariate probit model with zero conditional mean and variance normalized to unity. There is a symmetric variance-covariance matrix of the error terms.

3.2.3 Endogenous Switching Regression

In a typical impact evaluation study, there is a high likelihood of selection bias if the intervention is not administered through a randomization process (Wooldridge, 2002) This bias results from economic agents self-selecting themselves into the development intervention based on a host of pre-existing factors, some of which are observable and others not. For example, whether the farmer household owns agricultural machinery and thus performs mechanized farming is not a random assignment; hence, it is not exogenous. Instead, the farmer's adoption of mechanization in farming depends on several factors. Some of these factors may be unobserved yet and may be correlated with the outcome variable we intend to assess for impact evaluation. Such omitted variables can disrupt the effective estimation of the development program's impact. Regression estimations typically would not pick up the self-selection by the observations leading up to endogeneity. This will create inaccurate standard errors and, in turn, inefficient slope coefficients.

To formalize the selection bias, let us assume that a farmer either adopts mechanized land preparation, irrigation, and harvesting, thus a package of mechanized farming practices (MFP) or follows the manual labour farming practice. Thus, the adoption of MFP happens if the expected utility of the adoption is. (U_a) is more than non-adoption (U_{na}), i.e., $U_a - U_{na} > 0$. Let A_i^* be the latent variable showing the expected utility from adopting MFP by the i^{th} farmer and is referred to as:

$$A_i^* = Z_i\alpha + \varepsilon_i \ where\ A_i = \begin{cases} 1\ if\ Z_i\alpha + \varepsilon_i > 0 \\ 0\ otherwise \end{cases} \ldots\ldots(3.3)$$

where A_i has a binary outcome taking the value 1 if a farmer adopts MFP and zero if he or she uses only manual labour; Z represents the household characteristics, landholdings, and other control variables that affect the decision to adopt or not adopt MFP, and ε is an error term normally and independently distributed with mean 0 and variance σ^2. Agricultural productivity is denoted as (Y) of household i is stated as:

$$Y_i = X_i\beta + \gamma A_i + u_i \text{ ……………………………………………………………(3.4)}$$

Xi represents the household characteristics, land holdings, extension service, and other village-level variables affecting crop productivity. γ captures the effect of MFP adoption on crop productivity. In the self-selection problem, the effect of γ might be biased, and it may happen when relatively more informed and prosperous farmers choose to follow MFP. Then the yield or the income effect is over (under) estimated. This self-selection may occur due to observable and unobservable factors correlated with the potential outcomes. The observable factors can be explicitly included in the regression model. However, the unobservable factors are far more serious and create the endogeneity bias.

The propensity score matching (PSM) method has been used to correct self-selection bias in some studies (Becerril and Abdulai, 2010; Kassie et al., 2011; Jena et al., 2012; Jena and Grote, 2017). However, PSM does not account for the unobservable variables, such as skills in crop management, motivation, etc., that may have influenced the outcome. Several studies have used the endogenous switching regression (ESR) model to deal with the unobservable bias (Jena, 2019; Jena, Stellmacher, and Grote, 2017; Jaleta et al., 2016; Jaleta, Kassie, and Erenstein, 2015; Kleemann, Abdulai, and Buss, 2014; Teklewold, Kassie, Shiferaw, and Köhlin, 2013). Hence, the current study uses the ESR model for impact evaluation.

There are two regimes in the ESR model –the primary regime consists of the households that adopt farm mechanization and those that do not adopt mechanization come under the secondary regime. The specifics of the ESR have been discussed in (Jena 2019; Jaleta et al., 2016; Kleemann et al., 2014).

The outcome of these two regimes can be expressed as follows:

$Regime\ 1: Y_{1i} = X_{1i}\beta_1 + \sigma_{1u1i}\hat{\lambda}_{1i} + u_{1i}\ if\ A_i\ 1\ (\ adoption\ of\ farm\ mechanization)$ (3.4a)

$Regime\ 2: Y_{2i} = X_{2i}\beta_2 + \sigma_{2u2i}\hat{\lambda}_{2i} + u_{2i}\ if\ A_i\ 0\ (Non\ adoption\ of\ farm\ mechanization)$ (3.4b)

where, Y_i is the outcome variable (such as net agriculture income, total income, and total consumption) by the i^{th} household under regimes 1 (Adoption) and 2 (non-adoption) and X_{ik} represents the covariates. The ratios $\hat{\lambda}_{1i} = \frac{\phi(Z_i\hat{\alpha})}{\Phi(Z_i\hat{\alpha})}$ and $\hat{\lambda}_{2i} = \frac{\phi(Z_i\hat{\alpha})}{1-\Phi(Z_i\hat{\alpha})}$ Are called the inverse Mill's ratios (IMR) estimated from the first-stage selection regression (often a Logit or Probit model). Any self-selection bias that confounds the data is corrected by including these inverse Mill's ratios in equations (3.4a) and (3.4b). Further, bootstrapping standard errors have been used to correct for heteroskedasticity arising from the regressions. σ_{1u1i} and σ_{2u2i} are the variances of the error terms from the two regimes, respectively.

The real and counterfactual scenarios for the expected conditional and average treatment effects are estimated for each of the two regimes. They are -

(a) $E[Y_{1ij}|X_{1ij}, A_{ij} = 1] = X_{1ij}\beta_1 + \sigma_{1u1i}\hat{\lambda}_{1ij}$*(Adopters with the adoption of mechanization)* (3.5a)

(b) $E[Y_{2ij}|X_{2ij}, A_{ij} = 0] = X_{2ij}\beta_2 + \sigma_{2u2i}\hat{\lambda}_{2ij}$*(Non-adopters without adoption)* (3.5b)

(c) $E[Y_{2ij}|X_{1ij}, A_{ij} = 1] = X_{1ij}\beta_2 + \sigma_{2u2i}\hat{\lambda}_{1ij}$*(Counterfactual for Adopters of Mechanization)* (3.5c)

(d) $E[Y_{1ij}|X_{2ij}, A_{ij} = 0] = X_{2ij}\beta_1 + \sigma_{1u1i}\hat{\lambda}_{2ij}$*(Counterfactual for the Non-adopters of mechanization)* (3.5d)

The 3.5(a) and 3.5(b) are the conditional expectations of the adopters and non-adopters, respectively. However, the true average treatment effect on treated (ATT) will be known by comparing the actual outcome of adopters with a counterfactual of what would have happened if they decided not to adopt mechanization. This counterfactual outcome is estimated in 3.5(c). So, the ATT is calculated as 3.5(a) – 3.5(c). Similarly, the counterfactual for non-adopters is 4(d). and the average treatment effect on untreated (ATU) is calculated as 3.5(b) – 3.5(d).

The ESR model uses exclusion restriction to identify the first-stage regression from the second stage. The exclusion restriction could be an exogenous variable used in the first-stage adoption model but not included in the second-stage outcome regression. However, in the absence of a suitable instrument for identification, the model's nonlinearity can be used as an exclusion restriction (Jaleta et al. 2016).

3.2.4 Variable Description

The dependent variables intended to focus on the adoption of farm mechanization among rural farmers in India. The adoption of tube wells, electric pumps, diesel pumps, tractors, threshers and seed drill machines has been taken to determine the determinates to adopting this machinery. For the impact analysis, the three types of machinery were investigated, such as tractors, electric pumps, and diesel pumps.

The average treatment effect is estimated using the outcome variables such as net agricultural income, total household income and food consumption. The 1996 World Food Summit in Rome stated that "food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO, 1996). Hence, there is no single way of measuring food security. Most of the empirical studies on food security, including those by Babatunde et al. (2008), Feleke, Kilmer and Gladwin (2005), Iram and Butt (2004) and Lemba (2009), concentrate on objective food security measures at the household level. These measures look at consumption (converted into calories) or expenditure data. However, we know that consumption has a large seasonal volatility, and most studies use a single-round survey that frequently focuses on the last month before the survey was run. Therefore, consumption data may systematically under or over-report the true food security scenario, depending on the year the survey was conducted. Mallick and Rafi (2010) adopted subjective food security measures to overcome this shortcoming of the food consumption method. The IHDS data we used in this study lacks subjective food availability and security measures. It has detailed information on household consumption. Hence, we have used household consumption expenditure as a proxy for the food security variable.

The explanatory variables used to identify the factors influencing the adoption of agricultural mechanization are described in Table 2 below.

Table 3.2: List of Explanatory Variables used

	Explanatory variables used in the model
Household Attributes	**Education**: Education assists farmers in gathering additional information and positively influences the farmers' adoption decisions to farm mechanisation. (Akudugu et al., 2012; Mulwa et al., 2017)
	Gender HH: The use of farm machinery is influenced by the gender of the family head. Farm mechanisation is more likely to be bought or rented by male household heads. Farm mechanisation is less common in households led by women. (De Groote and colleagues, 2018; Jena, 2019; Paudel and colleagues, 2020).
	Age of HH: The age of the Household Head exhibits a heterogeneous impact on their inclination towards the adoption of machinery (GC et al., 2019; Zampaligré and Fuchs, 2019).
	Family Size: Adoption has a mixed effect on family size. If a large family generates labour, mechanisation is less likely to adopt that family. If a large family generates more off-farm income, the family tends to adopt mechanisation. (Deressa et al., 2009)
Intuitional Factors	**Crop Insurance**: CI has a positive impact on the adoption of farm machinery

	Kisan Credit Card: Kissan Credit makes credit available to farmers; credit availability positively affects farm machinery adoption. (Fosu-Mensah et al., 2012; Opiyo et al., 2016)
	Debt: Bank, Credit Microfinance, and Fixed Deposit in Banks have a positive impact on the Adoption of Mechanisation.
	Confidence in Govt: Farmers' trust in the state and local self-government policies positively impacts machinery adoption. (Kakumanu et al., 2016)
Climatic Factors	**Climatic Shock:** Farmers regularly exposed to climatic variations are more inclined to adopt farm mechanisation.(Asrat & Simane, 2018; Bryan et al., 2013)
	Crop Failure: Previous crop failures have a positive effect on the use of agricultural tech nology.(Habtemariam et al., 2016)
Financial Factor	**Livestock Ownership, Total Landholdings, and Total Assets**: There exists a significant correlation between adoption and livestock ownership, total landholdings, and total assets of farmers. (Akudugu et al., 2012; Mponela et al., 2016; Mulwa et al., 2017; Posadas, 2018)
Social Capital and other Factors	**Membership in SHG, Saving Group and Cooperative Society:** Farmers who are members of social groups are likely to adopt farm mechanization (Wissen et al., 2017)
	Migration has a mixed impact on the Adoption of farm Mechanisation. (McLeman & Smit, 2006; Sobczak-Szelc & Fekih, 2020; Maharjan et al., 2020)
	Mobile phone: Access to mobile likely to positively affect to adopt of farm mechanization

Source: Authors own compilation from literature review

3.3 Results and Discussion

We analyzed whether the mechanization rate is higher in the states where the agricultural labour shortage is higher too. It is observed that the states such as Bihar (58%), Andhra Pradesh (49%), Madhya Pradesh (49.33%), Tamil Nadu (50%), Chhattisgarh (49%), and Odisha (45%) have a larger percentage of agricultural laborers in their total workforce (NABARD, 2021). These states have a lower level of farm mechanization (35-45%) due to smaller and more fragmented landholdings and a higher participation rate in the agricultural labour force (Tiwari et al., 2019). The states of Punjab, Haryana, and Uttar Pradesh have a lower percentage of their workforce employed in agriculture, with an average participation rate of 20-30% (NABARD, 2021). These northern states have a higher overall farm mechanization level of 70-80%, with 80-90% for rice and wheat mechanization. This is not only due to a declining agricultural workforce but also to highly productive land and government support, which may include subsidies, technological assistance, and infrastructure development (Tiwari et al., 2019). The adoption intensities of six adopted machineries are presented in Fig. 3.1 to 3.6. The figures show a high intensity of machinery adoption in the Northwestern states of India.

3.3.1. Dependent Variables

A detailed description of the variables and summary statistics used for the study is presented in Table 3.3. The study used six dependent variables: tube wells, electric pumps, diesel pumps, tractors, threshers, and seed drill machines. The use of tube wells accounts for the highest percentage (22.4%), followed by the use of electric pumps (19.4%), diesel motors (11.4%), tractors (11.4%), threshers (3.7%), and seed drill machines (3.5%). Electric pumps are widely used due to the low cost of electricity for agricultural purposes—scanty and erratic rainfall creates water stress in India. Farmers adopted tube wells driven by electric power to address the water stress. Labour scarcity in the region had driven the farmers to use seed drill machines and threshers.

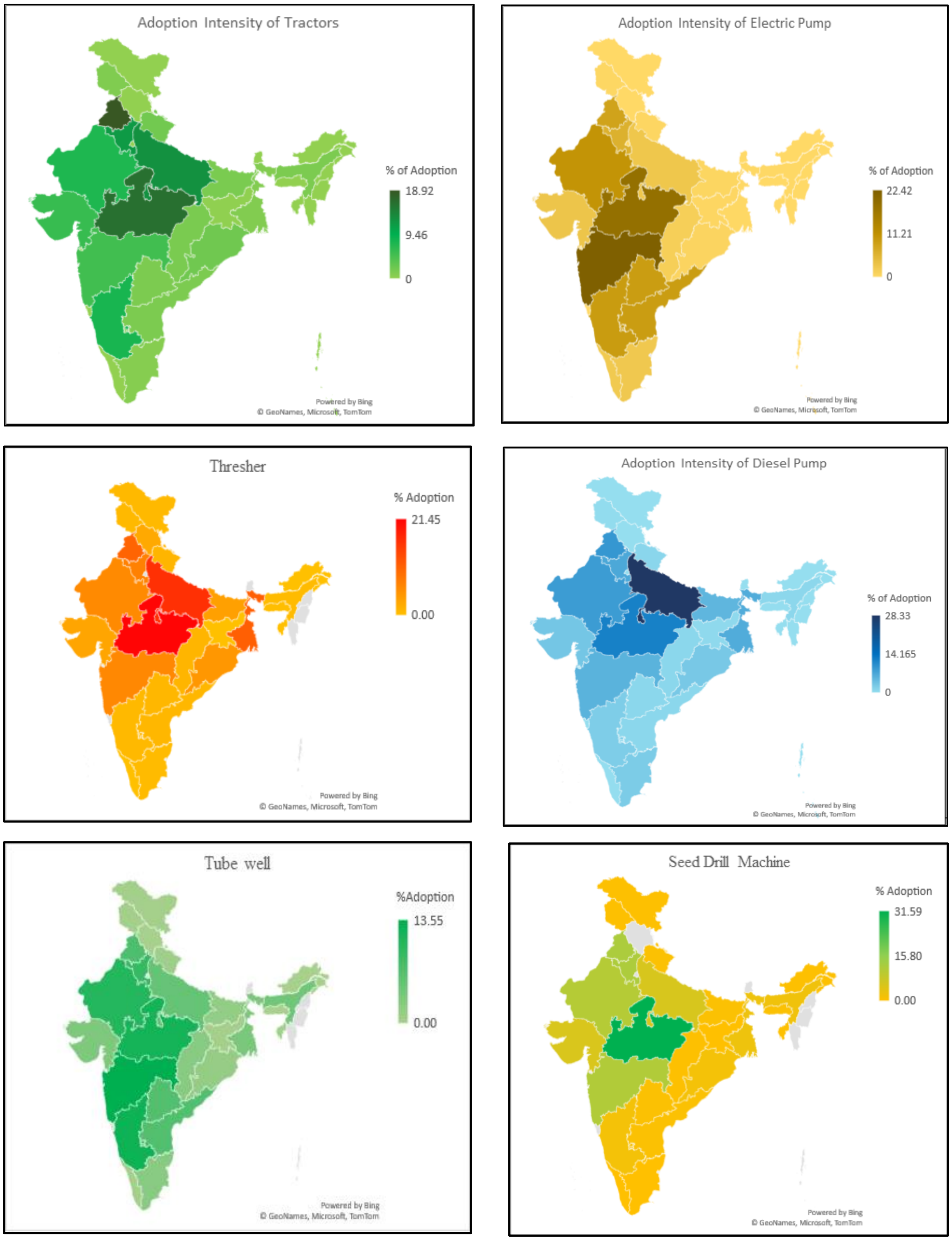


Figure (3.1-3.6) Adoption Intensity of Various Agricultural Machinery across the States

3.3.2 Independent Variables

3.3.2.1 Household Characteristics

The average size of the family was five among the sampled households. Around 85% of household heads were male. In India, the household-level farming decision was dominated by male members. The average years of schooling of the household head were five years, which shows most of the farmers had attended at least primary school. The average highest adult education was seven years. The other adult education in the family had more education than the household head.

3.3.2.2 Intuitional Factors

Farmers had purchased crop insurance from both private and government institutions. Crop insurance helps a farmer get compensation if the crops grown get damaged due to natural calamities or hazards. Around 3.5% of farmers had insurance from government institutions, and 0.7% of farmers had crop insurance from private institutions. Indian banks introduced the Kisan credit card scheme in 1998. The objective of the scheme was to provide term loans for agricultural needs. Around 14.4% of farmers had access to the Kisan Credit Card Scheme.

An efficient and flexible banking system helps farmers with better adoption. Farmers had access to loans from various financial institutions. Farmers who got loans from banks were 35.9%, and from microfinance, 10.2%. 7% of farmers had a fixed deposit in the bank to meet their future needs. Agricultural extension services are the life support for rural farmers. There are various social groups as well as government organisations that provide extension services to the farmers. A government can establish confidence among the people by providing several extension services. If a government works for farmers' upliftment, farmers repose more confidence in the government. Farmers' confidence in the government also determines their decision to opt for mechanisation. In this study, 30 % of people have shown a great deal of confidence, more than 40 % have shown only some confidence, and more than 20 % have hardly any confidence in the state and local governments.

3.3.2.3 Financial Factor

The average landholding of farmers was 3.6 acres. Framers used to cultivate more land during the Kharif season due to rainwater that supplements irrigation. The average cultivated land during the Kharif season was 3.01 acres. The average irrigated land owned by farmers was 1.78 acres, much less than the total landholdings. Livestock is an integral part of the farming system. About 80.5 % of the farmers owned livestock. Farmers used the livestock for farming operations and sold it during financial constraints. Farmers possessed an average of 13 assets. The assets include vehicles, furniture, electronic items and other tangible properties.

3.3.2.4 Climatic Factors

The climatic factors include climatic shocks and crop failures. Around 13.8% of farmers had faced regular climatic shocks such as drought, flood, cyclones and other natural hazards that negatively affected the agricultural operation. Crop failure is a regular phenomenon in India due to natural hazards. Around 39.8% of farmers had crop failures due to natural hazards and climate change during the study period.

3.3.2.5 Social Capital and Other Factors

Social capital enhances the adaptive capacity of farmers by engaging them in a participatory way. Around 21% of farmers had registered in the Self-Help Group (SHG). The government provides a low-interest loan to the SHG groups to invest in agriculture. Framers (7.8%) registered in cooperative societies to access credit at a minimum interest rate and access the organisation's subsidy benefits. Around 9.4% of farmers were doing seasonal migration to interstate or intrastate. Farmers used to do seasonal migration to access more non-farm income. 77.7% of farmers had mobile phones, which act as a medium of information exchange. Farmers get regular weather advisories and agricultural information through mobile.

Table 3.3: Descriptive Statistics of Dependent and Independent Variable

Variables	Mean	SD	Description of the variables	Expected sign
Treatment Variables				
Tractor	0.08	0.27	Dummy=1 if HH Adopted, 0 otherwise	
Electric Pump	0.24	0.43	Dummy=1 if HH Adopted, 0 otherwise	
Diesel Pump	0.14	0.34	Dummy=1 if HH Adopted, 0 otherwise	
Independent Variables				
Gender HH	0.85	0.357	1 if the gender of the household head is male,0 otherwise	+/-
Age HH	49.29	13.99	HH age (years)	-
HH Education	5.8	5.00	Household Head number of years of schooling	+
Family size	5.277	2.545	Total members of the family	+
Seasonal migration	0.094	0.292	1 if HH Seasonal Migrant, 0 otherwise	+/-
Crop insurance (Govt.)	0.035	0.186	1 if HH have Govt Crop Insurance,0 otherwise	+
Crop insurance (Pvt.)	0.007	0.088	1 if the household has Pvt. Crop Insurance,0 otherwise	+
Kisan credit card	0.144	0.352	1 if household has Kisan Credit Card,0 otherwise	+
Debt.: bank	0.359	0.479	1 if HH has debt in bank,0 otherwise	+
Credit microfinance	0.102	0.302	1 if HH is a member of credit society,0 otherwise	+
Fixed deposit in the bank	0.070	0.256	1 if HH is member, have a fixed deposit in the bank,0 otherwise	+
Member of Credit group	0.215	0.411	1 if HH is a member of SHG,0 otherwise	+
Member of cooperatives	0.078	0.268	1 if HH is a member of a cooperative society,0 otherwise	+
Confidence in state govt.	1.907	0.725	3=less confidence,2=some confidence,1=more confidence	-
Confidence on panchayat.	1.893	0.706	3=less confidence,2=some confidence,1=more confidence	-
Climatic shock	0.138	0.345	1 if faced by climatic shock flood or drought,0 otherwise	+
Crop failure	0.398	0.489	1 if HH had crop failure in past,0 otherwise	+
Owns livestock	0.805	0.395	1 if HH have livestock,0 otherwise	+
Total assets	13.10	5.779	Household assets in a number	+
Total land holdings (acre)	3.605	4.948	Total Land holdings by the farmer in the number of acres	+
irrigated land Kharif (acre)	1.789	3.666	Total Irrigated Land during Kharif Season	+

Source: Authors own calculation

3.4 Interdependency of Machine Types Used

We have calculated the pairwise correlation coefficient to measure the degree of association between various mechanisation adopted. We have reported the result of the Multi-Variate Probit Model in Table 6. The table shows the Likelihood Ratio Test of rho21 = rho31 = rho41 = rho51 = rho61 = rho32 = rho42 = rho52 = rho62 = rho43= rho53 = rho63 = rho54 = rho64 = rho65 = 0, Model $chi^2(15)$ =1699.31 and Prob > chi^2 = 0.0000. This model fits our data very well, so the null hypothesis that all regression coefficients are collectively equal to zero is rejected. We can reject the null hypothesis from t test.

Table 3.4: Pairwise correlation coefficients across machinery use and likelihood ratio test

Binary Correlation	Correlation Coefficient	Standard Errors	z-value
rho21= Electric Pumps and Tube Wells	0.492***	0.015	0.000
rho31= Diesel Pump and Tube wells	0.104***	0.021	0.000
rho41= Tractors and Tube wells	0.223***	0.025	0.000
rho51= Thresher and Tube wells	0.149***	0.029	0.000
rho61= Seed Drill Machinery and Tube wells	0.251***	0.029	0.000
rho32= Diesel Pump and Electric Pumps	-0.016	0.021	0.596
rho42= Tractors and Electric Pumps	0.097***	0.026	0.000
rho52= Thresher and Electric Pumps	0.107***	0.030	0.004
rho62= Seed Drill Machine and Electric Pumps	0.198***	0.030	0.000
rho43= Tractors and Diesel Pump	0.282***	0.026	0.000
rho53= Thresher and Diesel Pump	0.258***	0.028	0.000
rho63= Seed Drill Machinery and Diesel Pump	0.172***	0.032	0.000
rho54= Thresher and Tractors	0.553***	0.023	0.000
rho64= Seed Drill Machinery and Tractor	0.564***	0.026	0.000
rho65= Seed Drill Machine and Thresher	0.398***	0.030	0.000

a) Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho61 = rho32 = rho42 = rho52 = rho62 = rho43= rho53 = rho63 = rho54 = rho64 = rho65 = 0: Model chi2(15) = 1699.31, Prob > chi2 = 0.0000
b) Log likelihood = -15920.633, Wald chi2(150) = 3992.55
c) The numbers in rho refer to 1 = Tube Well, 2= Electric Pump, 3= Diesel Pump, 4= Tractors Tiller, 5= Thresher, 6= Seed drill
d) *Significant at 10%level; **Significant at 5% level; ***Significant at 1%

that the covariance of the error terms across equations is not correlated. The Likelihood ratio test indicates that at least one covariance of the error term is statistically significant, implying that the equations in the model are connected. Using the MVP model over univariate probit models will be more appropriate. The direction of influence for most of the independent variables is as expected. The likelihood ratio statistics (Wald chi2(150) = 3992.55) are highly significant(P=0.0000), showing that the variables explain the model sufficiently. The pairwise correlations between the error terms are statistically significant (Table 5). The positive correlation between error terms reveals an unobserved correlation between the adoption of farm machinery. Farm machines are complementary, and the negative coefficient reveals substitutability adoption decisions of farm mechanization.

Tube well positively correlates with an electric motor, diesel motor, tractor, thresher and seed drill machine. A negative correlation between the electric pump and diesel pump shows both substitutable each other. However, other potentially omitted factors may have affected all adoption decisions.

3.5 Factors Determining the Adoption of Farm Mechanization

The mean difference between adopters and non-adopters of mechanization for different household characteristics. The result indicates that the mean age of the household head of adopters is relatively lower than that of non-adopters. Where the younger generation farmers adopt farm mechanization compared to old generation farmers. Similarly, the Education level is higher among the adopters compared to the non-adopters of the mechanization. The evidence from past results retrospect that young farmers with training adopted the new agriculture machinery (Aryal *et al.*, 2019). Non-adopters resemble characteristics such as being involved in seasonal migration, limited availability of land for cultivation (less than 2 acres of land), dry land, and lack of access to various extension services and technological factors. Alternatively, adopters extensively use extension services and institutional access, demonstrating their capabilities in adopting farm machinery in day-to-day agricultural activities. Farm mechanization adopters had access to credit services. The past results also reveal that farmers who belong to cooperative societies focus on saving and credit services, allowing them to access credit and further the adoption of farm mechanization (Paudel *et al.*, 2019a).

Farmers generally follow common adoption practices, sometimes leading to a strong correlation in the empirical estimation. Table 3.4 presents the Pairwise correlation coefficient to measure the degree of association between various mechanisation farmers adopt. The pairwise correlation coefficients are tested across the residuals. We reject the null hypothesis from the result as the covariance of the error terms across equations is not correlated. The Likelihood ratio test indicates that at least one covariance of the error term is statistically significant, implying the use of the MVP model than univariate probit models. The positive correlation between error terms reveals an unobserved correlation between the adoption of farm machinery. Farm machines are sometimes complementary and substitutability based on the farmer's choice. Table 3.5 shows the factors that determines the adoption of farm mechanization.

Climate shocks act as a barrier and are also a significant indicator of the adoption of farm mechanization. Frequent climate-related disaster influence farmers to adopt modern mechanization to follow climate-resilient practices (Asrat and Simane, 2018; Bryan *et al.*, 2013). Our results indicate that climate shocks were crucial in adopting farm mechanization in the broader context. Climate shocks significantly impact adopting all types of machine use (tube wells, electric pumps, diesel pumps, thresher and seed drill machines). The positive effect of climate shock on farm mechanization was also found by Habtemariam *et al.* (2016).

Social capital is a significant indicator of the adoption of farm mechanization and well-being (Jena et al., 2017; Khosla and Jena, 2020; 2022). Farmers in social groups such as cooperative societies, SHG groups and the savings group have access to different information on agriculture extension. Farmers in the societal community are more likely to get short-term credits and input subsidies. Our result reflects that farmers' participation in the social group significantly positively impacts the adoption of tube wells and diesel machines. An insignificant relationship was found between mechanization indicators and migrant workers. However, a significant negative relationship was found between tractors and migrant workers. Previous studies recorded that migration has a mixed impact on the Adoption of farm Mechanisation (McLeman and Smit, 2006; Sobczak-Szelc and Fekih, 2020). Additionally, access to information such as mobile phones significantly affect the adoption of tube wells and electric pumps.

Institutional factors are the major determinants in behavioural adoption among developing nations. Institutions enable infrastructure development, knowledge transfer, and training which help in crop productivity (Aryal *et al.,* 2019; Justice and Biggs, 2020). Credit availability from different sources eases the financial constraint and encourages farmers to invest in capital-intensive technology in agriculture. Kisan credit card (KCC) is the forefront program in providing access to credit for farming activities. Farmers' access to KCC enhances the likelihood of adopting an electric pump, tractor and thresher. Farmers fail to invest in farm mechanization due to low yield of agriculture income and lack of credit. The benefits of loans and subsidies provided by these institutions are essential to farmers' prospect of farm machinery adoption (Wossen *et al.*, 2017). Bank loans and access to banking have a significant positive impact on adopting farm machineries such as tube wells, electric pumps, tractors and seed drill machines. Further, household heads enrolled in microfinance credit significantly impacted adoption of tube wells and seed drill machines. Crop insurance and credit availability were the major determinants of farm machinery adoption in South Africa, Nigeria, and Nepal (Fosu-Mensah *et al.,* 2012; Opiyo *et al.,* 2016). Extension activities are the important drivers of technology transfer (Kakumanu *et al.,* 2016). To measure extension services offered by the government, a proxy variable of confidence in the state government and panchayat was employed. The

Table 3.5: Multivariate Probit Model Results

Variables	Tube Well	Electric Pump	Diesel Pump	Tractors/ Tiller	Thresher	Seed Drill
HH Sex	0.061	0.111**	0.011	0.022	0.043	0.175**
	(0.044)	(0.046)	(0.050)	(0.067)	(0.078)	(0.087)
HH Age	-0.003***	-0.003**	0.002	0.000	0.000	-0.002
	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)
Years of Schooling	-0.007**	-0.007**	-0.002	-0.006	-0.000	-0.008
	(0.003)	(0.003)	(0.003)	(0.005)	(0.005)	(0.005)
Highest Adult Education	0.001	-0.005	0.010**	0.002	0.012*	0.001
	(0.004)	(0.004)	(0.004)	(0.006)	(0.007)	(0.007)
Size of Family	0.017***	-0.004	0.036***	0.049***	0.046***	0.039***
	(0.006)	(0.006)	(0.007)	(0.008)	(0.009)	(0.009)
Seasonal Migrant Work	-0.035	0.025	0.020	-0.167*	0.036	0.199**
	(0.054)	(0.056)	(0.059)	(0.097)	(0.096)	(0.092)
Crop Insurance Govt.	0.065	0.130*	-0.228**	-0.144	0.065	0.390***
	(0.074)	(0.074)	(0.092)	(0.100)	(0.109)	(0.098)
Crop Insurance Pvt.	0.294**	0.335**	-0.495**	-0.185	-0.066	0.050
	(0.154)	(0.153)	(0.200)	(0.191)	(0.205)	(0.200)
Kisan Credit Card	-0.047	0.004	0.352***	0.367***	0.426***	0.193***
	(0.044)	(0.045)	(0.048)	(0.058)	(0.066)	(0.068)
Own Mobile Phone	0.112**	0.099**	-0.005	-0.134*	-0.191**	-0.181**
	(0.045)	(0.047)	(0.050)	(0.080)	(0.083)	(0.087)
Credit from Public Bank	0.206***	0.260***	-0.021	0.134***	-0.076	0.107*
	(0.033)	(0.034)	(0.040)	(0.050)	(0.059)	(0.060)
Credit from Micro-Finance	0.095**	-0.024	-0.133*	0.075	0.037	-0.346***
	(0.054)	(0.056)	(0.070)	(0.087)	(0.097)	(0.128)
Fixed Deposit	0.202***	0.084	0.177***	-0.067	0.289***	0.154*
	(0.055)	(0.057)	(0.061)	(0.077)	(0.079)	(0.087)
Savings Group	0.067	0.293***	-0.171***	-0.419***	-0.321***	-0.278**
	(0.049)	(0.049)	(0.064)	(0.087)	(0.099)	(0.108)
Self-Help Group	-0.208***	-0.137***	-0.199***	-0.165**	0.018	-0.157*
	(0.043)	(0.044)	(0.052)	(0.069)	(0.076)	(0.087)
Co-operative Society	0.123**	0.229***	0.024	0.082	0.084	0.121

	(0.052)	(0.052)	(0.061)	(0.071)	(0.081)	(0.081)
Confidence in State Government	0.022	0.019	-0.071***	0.008	-0.025	-0.039
	(0.022)	(0.022)	(0.025)	(0.032)	(0.037)	(0.038)
Confidence in Panchayat	0.074***	0.084***	-0.008	-0.019	-0.010	0.003
	(0.022)	(0.023)	(0.025)	(0.033)	(0.037)	(0.038)
Climatic Shock	0.127***	-0.259***	0.142***	0.121*	0.010	-0.107
	(0.045)	(0.050)	(0.051)	(0.071)	(0.080)	(0.086)
Crop Failure	0.054*	0.159***	0.101***	0.026	0.115**	0.255***
	(0.033)	(0.033)	(0.037)	(0.050)	(0.057)	(0.058)
Owns Livestock	0.210***	0.156***	0.292***	0.269***	0.141*	0.548***
	(0.041)	(0.042)	(0.051)	(0.072)	(0.079)	(0.110)
Total Household Assets	0.046***	0.052***	0.016***	0.089***	0.048***	0.046***
	(0.003)	(0.004)	(0.004)	(0.005)	(0.006)	(0.006)
Total Landholding	0.032***	0.047***	-0.005	0.022**	0.020**	0.029***
	(0.008)	(0.008)	(0.010)	(0.010)	(0.010)	(0.010)
Cultivated Land (Kharif)	-0.065***	-0.086***	-0.020*	0.005	-0.010	-0.021
	(0.010)	(0.011)	(0.012)	(0.011)	(0.013)	(0.013)
Irrigated Land (Kharif)	0.095***	0.093***	0.055***	0.060***	0.046***	0.056***
	(0.006)	(0.007)	(0.007)	(0.007)	(0.008)	(0.008)
Constant	-2.046***	-2.163***	-1.972***	-3.643***	-3.139***	-3.450***
	(0.105)	(0.109)	(0.119)	(0.172)	(0.189)	(0.211)
Observations	10,227	10,227	10,227	10,227	10,227	10,227

a) Standard errors in parentheses
b) *Significant at 10% level; **Significant at 5% level; ***Significant at 1% level
c) Observations: 10,227,
d) Log likelihood = -15920.633, Wald chi2(150) = 3992.55
e) Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho61 = rho32 = rho42 = rho52 = rho62 = rho43= rho53 = rho63 = rho54 = rho64 = rho65 = 0: Model chi2(15) =1699.31, Prob > chi2

result indicated that adopting tube wells and electric pumps were strongly associated with confidence in the local government. Wealth is a crucial measure in adopting farm mechanization. Famers with higher incomes diversify into various investments like land and livestock. Therefore, we adopt the size of total landholding, livestock ownership and total assets to represent wealth. The increase in the wealth indicators was associated with a higher probability of adopting all kinds of farm mechanization. These findings are corroborated by Aryal *et al.* (2021), who found that wealth is positively associated with machinery use.

The results show that the male-headed household is likelier to adopt electric pumps and the seed drill machine than owning the tractor and thresher. This evidence is largely found in the literature, where female-headed households lack the adoption of farm mechanization – due to limited access to information and prevailing social barriers (Aryal *et al.,* 2019; Motalleb *et al.,* 2018). The age of the farmers has a significant role in the adoption and choices to enhance productivity. Farmers, over time, are more likely to adopt irrigation. However, the results from the present study show that the higher the age, the lower the likelihood of adoption of mechanization (especially - tube well and electric pumps, which are negatively significant). These differences in age and adoption vary largely in studies focusing on smaller spatial scales and nationwide studies (Aryal *et al.,* 2021). Family size has a predominantly larger influence on the adoption of mechanization; large families diversify to generate non-farm incomes, which are later invested in farm mechanization. The results reveal that family size significantly impacts the adoption of tube wells, diesel pumps, tractors, threshers and seed drill machines. Similar evidence in South Africa indicates a positive association between household size and farm mechanisation (Owombo *et al.,* 2012; Kirui, 2019). Education is an important driver of farm mechanisation. Studies in the past have evidenced a positive association between education and mechanization (Aryal *et al.*, 2021). However, the findings from the present study show that higher education among household heads negatively affected the adoption of farm mechanization. This contrasting result could be because of low-level schooling and practising the traditional methods. The average schooling of the household head is only 5 years indicates the traditional practices. Literacy is undoubtedly an indicator of change in behavioural adoption. The proxy variable of adult education in the family proved to have a significant positive effect on the adoption of farm mechanization. Households with adults having higher education levels have a higher chance of the usage of mechanization in agriculture.

3.6 Impact of Agricultural Machinery Adoption on Household Income and Food Security

3.6.1 Comparing outcome variables and key covariates between adopters and non-adopters

Tables 3.6- 3.8 compare the key factors such as household income, consumption, assets, household characteristics, and access to credit between the adopters and non-adopters of the three types of machinery considered in this study, such as tractors, electric pumps, and diesel pumps. The mean difference test results show a statistically significant difference between the adopters and non-adopters of all three types of machines regarding land ownership, possession of livestock, and other assets. Regarding household characteristics, we use the education level of the household head. It was observed that adopters of agricultural machines have a higher education level in their families compared to non-adopters.

Considering the discussion above, it may seem plausible that the adopters self-select themselves into adopting mechanized farming practices owing to their higher levels of land ownership and access to credit, the two most important inputs required for the success of mechanized farming. For this reason, we resort to ESR models for gauging the impact of farm machinery adoption on household income**.** Furthermore, the distribution of the three outcome variables, namely net agricultural income, total household income, and household consumption, shows that the few considerably richer households in the adopters and non-adopters groups skew the distribution (See Fig. 4-12). The income distribution in developing countries generally shows this pattern. Several outlier tests have been done to identify and weed out the outliers in all three outcome variables; however, the skewness in the distribution remains. The Kernel density function of these outcome variables indicates

Table 3.6: T-test of the Covariates of Tractor Adoption

	Non-Adopters		Adopters		
	Mean	Std. Dev	Mean	Std. Dev	T-test
Net Agricultural Income (‘000 Rupees)	47.41	89.07	223.49	229.31	-43.26***
Total income (‘000 Rupees)	82.24	106.50	280.82	265.09	-41.30***
Consumption expenditure (‘000 Rupees)	101.71	97.79	232.74	200.63	-31.49***
Gender	0.85	0.35	0.87	0.34	-0.97
Age	49.20	13.92	48.39	13.67	1.53
Education	5.88	4.98	5.88	5.31	-0.01
Family size	5.22	2.45	6.70	3.36	-15.41***
Seasonal Migration	0.10	0.31	0.04	0.21	5.22***
Crop insurance Govt.	0.03	0.18	0.08	0.27	-6.19***
Crop insurance Pvt.	0.01	0.08	0.02	0.01	-4.63***
Kisan credit card	0.13	0.34	0.36	0.48	-17.27***
Debit Bank	0.35	0.48	0.60	0.49	-13.77
Debt micro	0.11	0.31	0.08	0.28	1.85*
Fixed deposit	0.06	0.24	0.13	0.33	-6.55***
Member credit	0.13	0.33	0.06	0.24	5.01***
Member Cooperatives	0.07	0.26	0.16	0.37	-8.88***
Trust state govt.	1.91	0.73	1.92	0.77	-0.32
Trust panchayat	1.91	0.71	1.84	0.76	2.54**
Climatic shock	0.14	0.35	0.13	0.33	1.1
Crop loss	0.41	0.49	0.40	0.49	0.45
Livestock	0.80	0.40	0.91	0.28	-7.82***
Assets	12.40	5.45	12.97	5.78	-34.37***
Landholding	3.22	4.07	9.91	9.59	-37.07***
Irrigated land	1.45	2.60	7.12	8.43	-43.29***

*Significant at10%level; **Significant at 5% level; ***Significant at 1% level

Table 3.7: T-test of the Covariates of Diesel Pump Adoption

	Non-Adopters		Adopters		
	Mean	Std. Dev	Mean	Std. Dev	T-test
Net Agricultural Income (‘000 Rupees)	59.32	113.74	104.87	153.41	-11.87***
Total income (‘000 Rupees)	95.79	133.54	144.36	181.35	-10.76***
Consumption Expenditure (‘000 Rupees)	107.38	108.54	150.23	144.12	-11.74***
Gender	0.85	0.35	0.86	0.35	-0.46
Age	49.15	13.93	49.37	13.79	-0.48
Education	5.92	5.00	5.79	5.16	0.83
Family size	5.26	2.51	6.07	3.10	-9.70***
Seasonal Migration	0.10	0.29	0.09	0.29	0.20
Crop insurance Govt.	0.04	0.19	0.04	0.19	-0.11
Crop insurance Pvt.	0.01	0.08	0.01	0.07	0.67
Kisan credit card	0.13	0.33	0.27	0.44	-12.21***
Debit Bank	0.35	0.48	0.43	0.49	-5.13***
Debt micro	0.10	0.30	0.06	0.23	4.67***
Fixed deposit	0.06	0.25	0.11	0.31	-5.40***
Member credit	0.10	0.30	0.07	0.25	3.71***
Member Cooperatives	0.08	0.27	0.11	0.31	-3.54***
Trust state govt.	1.90	0.74	1.85	0.74	2.48**
Trust panchayat	1.91	0.72	1.86	0.74	2.23**
Climatic shock	0.13	0.34	0.15	0.36	-2.17
Crop loss	0.39	0.49	0.44	0.50	-3.25***
Livestock	0.80	0.40	0.90	0.30	-8.24
Assets	12.83	5.81	14.77	6.30	-10.34***
Landholding	3.63	4.92	4.97	6.27	-8.15***
Irrigated land	1.79	3.63	3.50	5.13	-13.86***

Table 3.8: T-test of the Covariates of Electric Pump Adoption

	Non-Adopters		Adopters		
	Mean	Std. Dev	Mean	Std. Dev	T-test
Net Agricultural Income ('000 Rupees)	50.76	102.17	121.08	164.68	-22.40***
Total income ('000 Rupees)	87.08	120.33	163.32	194.66	-20.59***
Consumption Expenditure ('000 Rupees)	106.01	107.32	158.24	147.70	-16.91***
Gender	0.86	0.35	0.88	0.33	-2.32**
Age	49.17	13.99	48.23	13.63	2.59***
Education	5.85	4.97	5.76	5.13	0.67
Family size	5.16	2.49	5.61	2.80	-6.68***
Seasonal Migration	0.10	0.30	0.07	0.06	3.50***
Crop insurance Govt.	0.03	0.17	0.07	0.25	-7.13***
Crop insurance Pvt.	0.01	0.07	0.02	0.14	-6.58***
Kisan credit card	0.15	0.36	0.22	0.42	-7.51
Debit Bank	0.37	0.48	0.53	0.50	-12.98***
Debt micro	0.10	0.31	0.10	0.31	0.01
Fixed deposit	0.05	0.22	0.11	0.31	-8.90***
Member credit	0.12	0.33	0.17	0.38	-5.08***
Member Cooperatives	0.08	0.27	0.15	0.36	-9.60***
Trust state govt.	1.92	0.73	1.95	0.74	-1.74*
Trust panchayat	1.88	0.71	1.94	0.73	-2.87***
Climatic shock	0.09	0.29	0.09	0.29	-0.04
Crop loss	0.38	0.49	0.42	0.49	-3.11***
Livestock	0.78	0.41	0.85	0.35	-6.92***
Assets	16.37	5.78	16.37	5.78	-3.37***
Landholding	3.54	4.91	5.75	6.32	-16.04***
Irrigated land	1.48	3.37	3.97	5.06	-24.29***

*Significant at10%level; **Significant at 5% level; ***Significant at 1% level

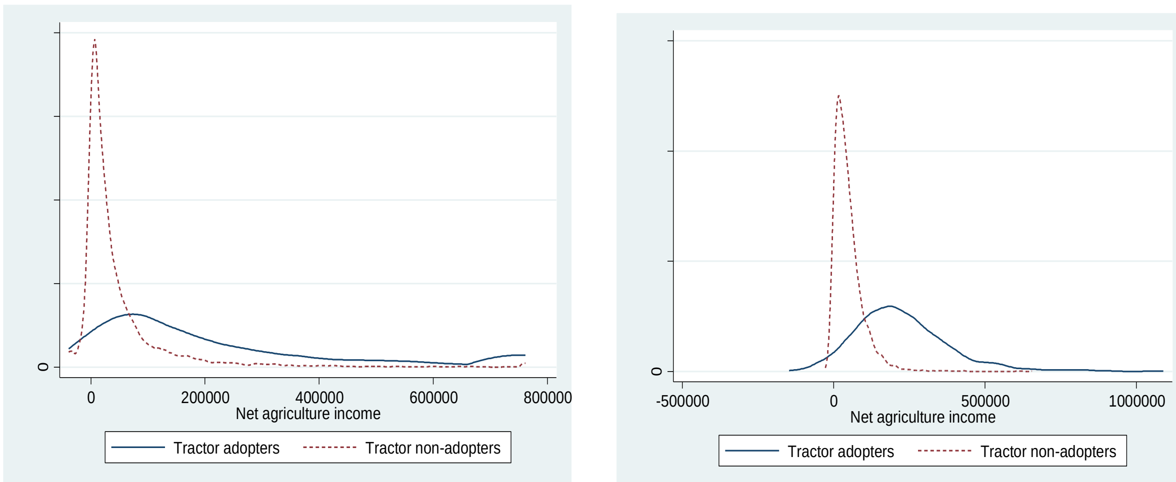


Figure 3.7(a) Before ESR estimation Figure 3.7(b) After ESR estimation

Figure 3.7: Net Agricultural Income Distribution of Adopters and Non-adopters of Tractors, before and after the ESR estimations

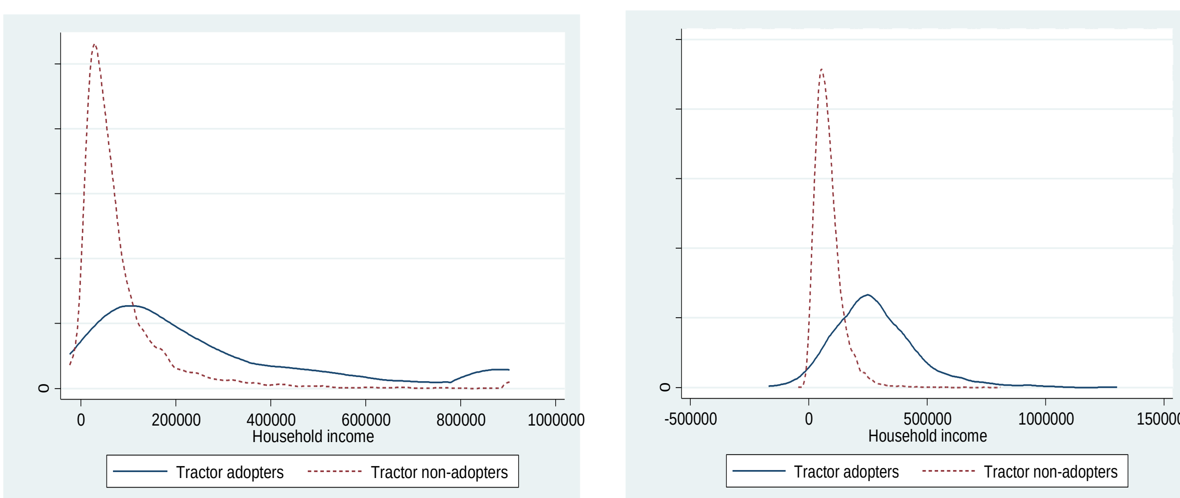


Figure 3.8(a) Before ESR estimation Figure 3.8(b) After ESR estimation

Figure 3.8: Total Household Income Distribution of Adopters and Non-adopters of Tractors, before and after the ESR estimations

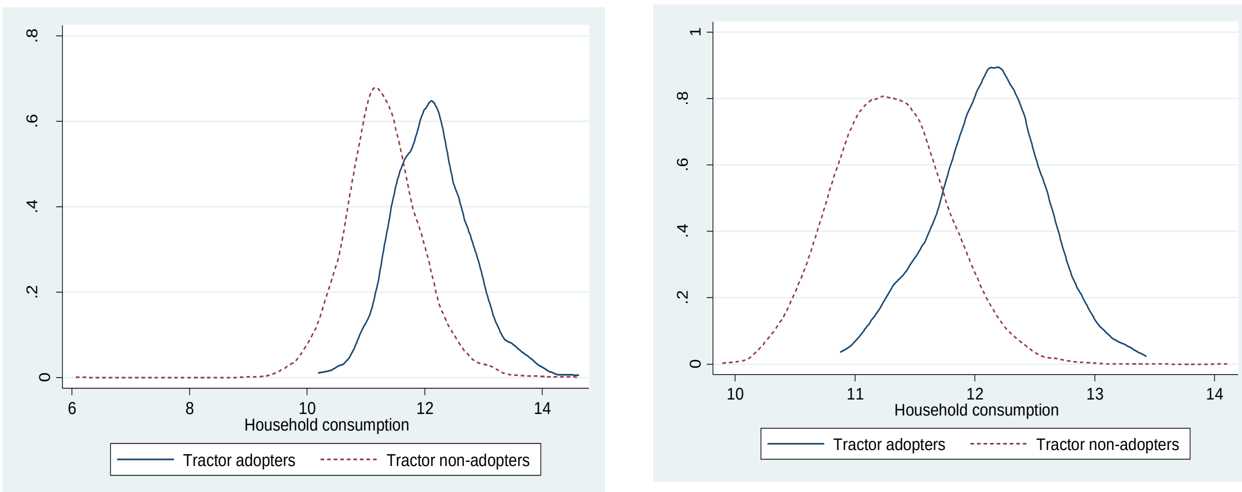


Figure 3.9(a) Before ESR estimation Figure 3.9(b) After ESR estimation

Figure 3.9: Household Consumption Distribution of Adopters and Non-adopters of Tractors, before and after the ESR estimations

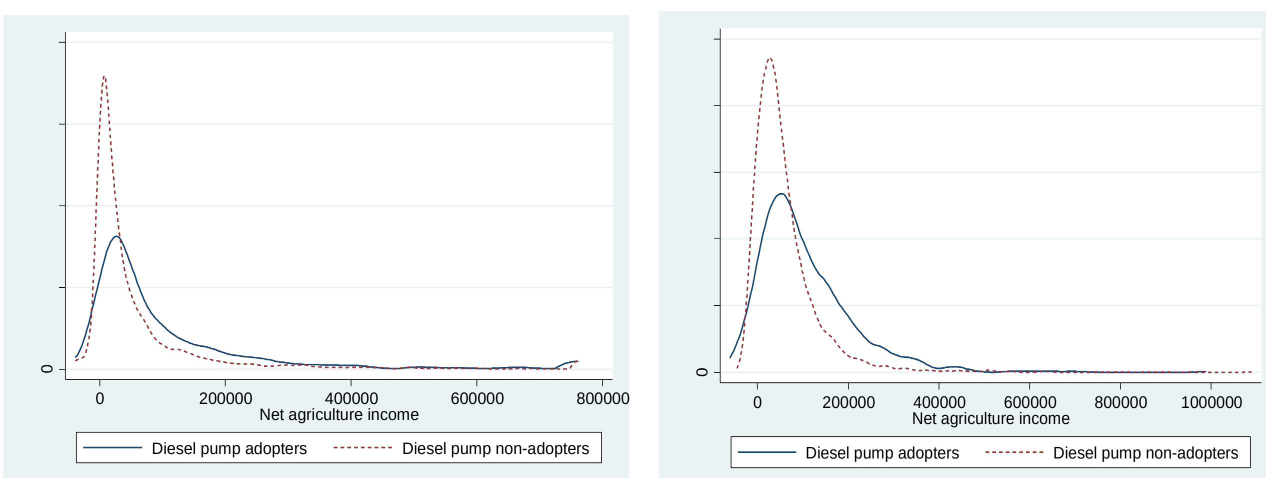
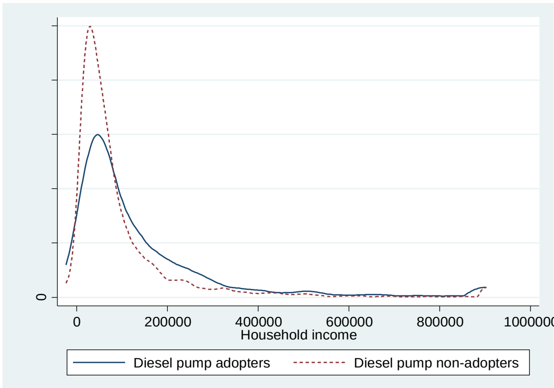


Figure 3.10(a) Before ESR estimation Figure 3.10(b) After ESR estimation

Figure 3.10: Net Agricultural Income Distribution of Adopters and Non-adopters of Diesel pump, before and after the ESR estimations



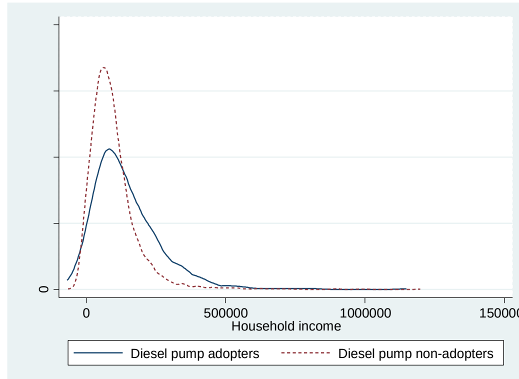
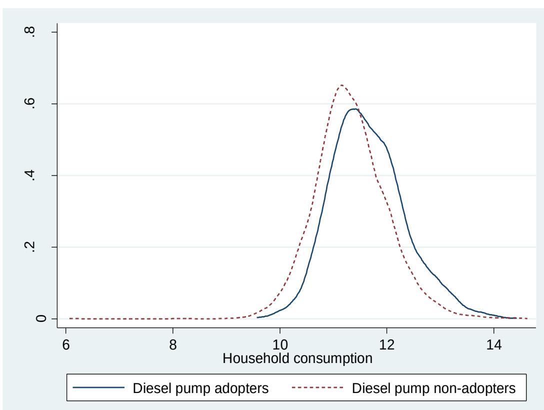


Figure 3.11(a) Before ESR estimation Figure 3.11(b) After ESR estimation

Figure 3.11: Total Household Income Distribution of Adopters and Non-adopters of Diesel pump, before and after the ESR estimations



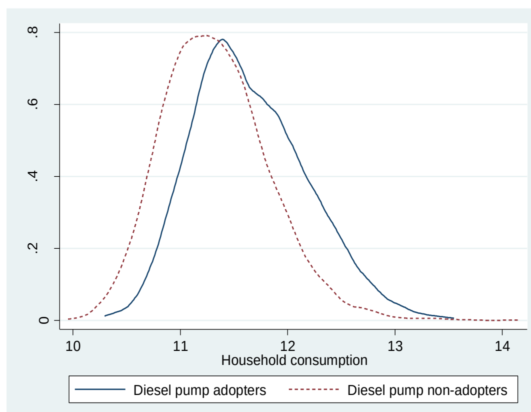


Figure 3.12(a) Before ESR estimation Figure 3.12(b) After ESR estimation

Figure 3.12: Household Consumption Distribution of Adopters and Non-adopters of Diesel Pump, before and after the ESR estimations

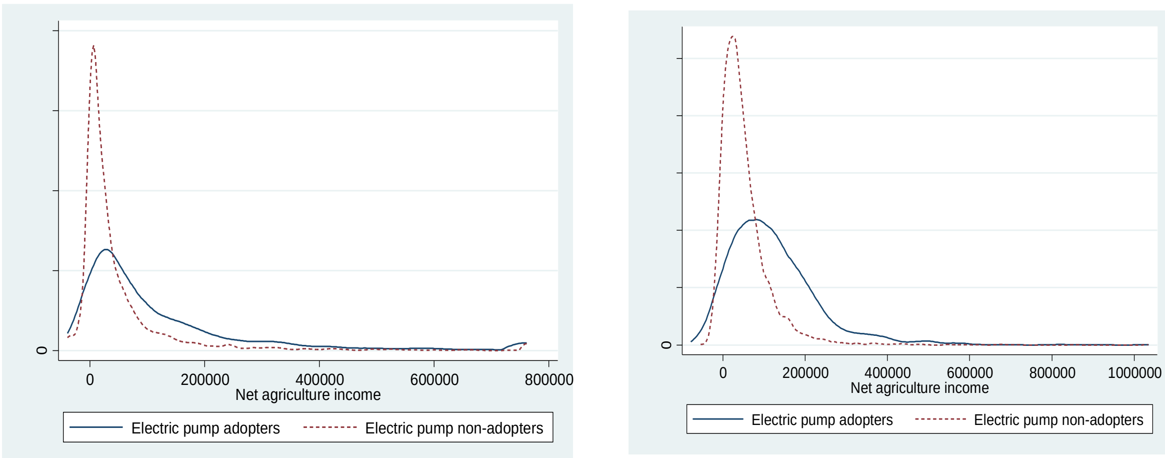


Figure 3.13(a) Before ESR estimation Figure 3.13(b) After ESR estimation

Figure 3.13: Net Agricultural Income Distribution of Adopters and Non-adopters of Electric pump, before and after the ESR estimations

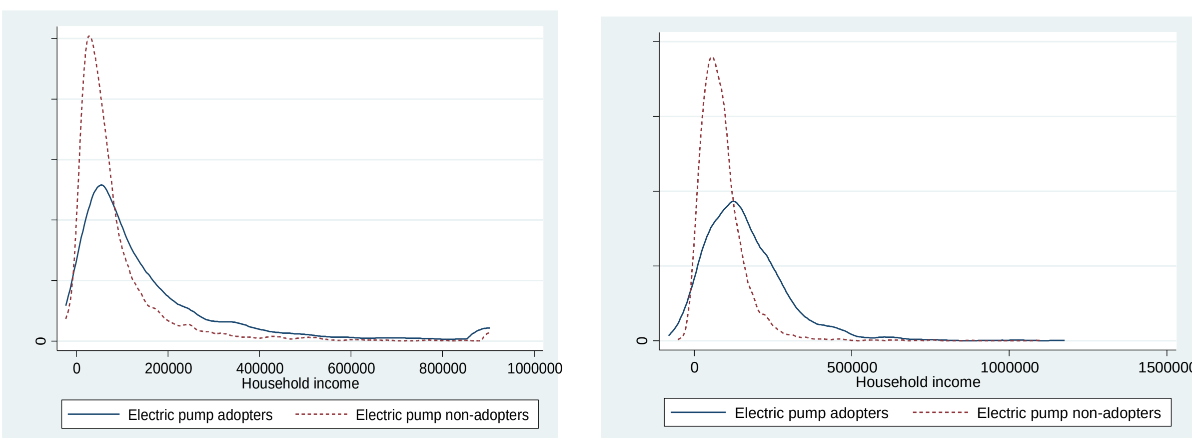
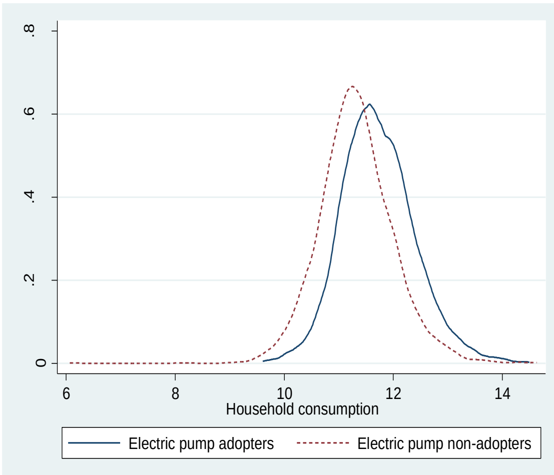


Figure 3.14(a) Before ESR estimation Figure 3.14(b) After ESR estimation

Figure 3.14: Total Household Income Distribution of Adopters and Non-adopters of Electric Pump, before and after the ESR estimations



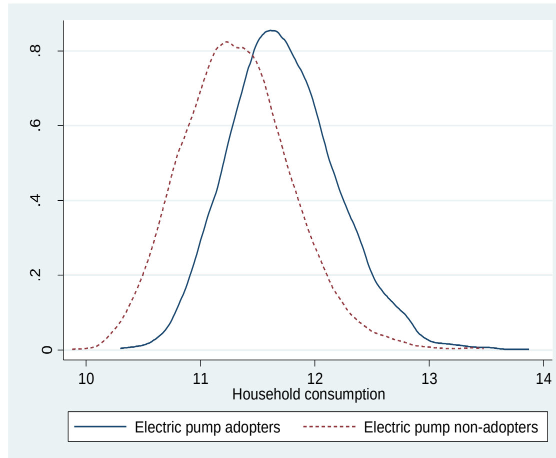


Figure 3.15(a) Before ESR estimation Figure 3.15(b) After ESR estimation

Figure 3.15: Household Consumption Distribution of Adopters and Non-adopters of Electric Pump, before and after the ESR estimations

that, on average, the adopters have higher household income and consumption levels. This finding is confirmed by the mean comparison test results shown in Tables 3.6-3.8. An interesting point to note is that in Figures 4 – 12, we have compared the Kernel densities of outcome variables between adopters and non-adopters of different types of machinery both before and after the ESR. The Figures show that the skewness that appeared before the ESR estimations have reduced significantly after it. The pattern of distributions moves towards normal distribution after the ESR because the first stage selection regression has captured some of the selection bias arising from observable and unobservable covariates.

As obtained from the ESR model, the adoption effects have been furnished in Tables 7a, 7b, and 7c. The income values have been rescaled by dividing them by 1000 to keep the coefficient values within the presentable limits. While discussing, though, we present these values in their original form. The second aspect of impact evaluation is to examine the impact of mechanization on food security; the latter is represented as the log of household consumption. There are negative incomes for some of the households. In the case of net agricultural income, at least 10% of the households have negative income, and for total household income, at least 3% have negative income. Because of the negative values in income variables, we have not done any logarithmic transformation for these variables. For the consumption variables, though, the logarithmic transformation has been done, transforming the distribution into a near-normal one. The ESR model employed to examine this question produces the average treatment effect on treated (ATT) and the average treatment effect on untreated (ATU).

3.7.2 Impact of Tilling Machinery Adoption on Income and Consumption

The tilling machinery examined in this paper is both 4-wheeler and 2-wheeler tractors. The impact of adopting these machines in agricultural production has been assessed on net agricultural income, total household income, and log consumption expenditure. The ATT and ATU results are displayed in Table 3.9a. The ATT of tractor adoption on net agricultural income is positive and statistically significant at a 1% significance level. The impact is an increase in net agricultural income by USD 3,302.39[2], which is 31% higher for adopters than their counterfactual scenario of non-adoption. The ATU, which shows the average treatment effect on non-adopters had they decided to adopt, is also positive, with an impact of USD 236.9 9, about 8%. This shows that if the non-adopters had chosen to adopt tractors, they would have gained 8% more net agricultural income.

The ATT for tractors concerning total household income is positive and statistically significant at 1% significance, with an impact of USD 2,895.24, which shows that adopters have been better off using the machinery than the counterfactual scenario by 19%. Although we also find positive ATU, it is statistically insignificant. Such findings are common where ATT has statistical significance but ATU does not (Jena et al., 2021). The food security indicator's consumption expenditure has also been enhanced due to machinery adoption. This can be observed from Table 3.9a, as the ATT and the ATU are positive and statistically significant at a 1% significance level.

[2] INR is converted to USD by using PPP exchange rate 16.161 of 2012

The second stage outcome regression results of ESR concerning the adoption of tractors for net agricultural income, total household income, and household consumption are provided in Table 3.10. The results reveal that family size is positively associated with higher incomes and consumption. A larger family can provide the required labour time in agricultural activities and, thus, reduce the hired labour cost. Since agricultural wages are rising in India, adequate family labor can increase the net agricultural income. Crop insurance from the government is linked negatively to the income variables for non-adopters. This may be because the non-adopters who lost income due to crop loss have obtained insurance from the government, but the amount could be insufficient to overcome their loss.

The variable livestock has a positive effect on the outcome variables. Livestock is reared in the plain and hilly regions for milk and meat, a source of income. An increase in landholding and the proportion of irrigated land is found to have increased both the income and consumption variables for the adopters and non-adopters. A fixed deposit in the bank increases the adopters' net agricultural income and consumption. Fixed savings may provide the households with the required avenue for investment in farming and may have contributed to higher farm incomes.

Similarly, consumption expenditures are buoyed by having a sum of savings in the bank. On the other hand, bank credit tends to reduce the net household income of the non-adopters of the tractor. The experience of climatic shock and crop loss negatively impacts income and consumption for adopters and non-adopters. Both variables have appeared with negative and statistically significant coefficients in the expected lines.

3.7.3 Impact of Irrigation Machinery Adoption on Income and Consumption

The estimated ATT and ATU for the irrigation machinery, such as diesel and electric pumps, are reported in Tables 3.9b and 3.9c, respectively. The ATT for diesel pumps is positive but not statistically significant for agricultural and household income. However, the adopters have a positive edge over the non-adopters regarding the food security indicator. In the case of ATU, the non-adopters would have received USD 737.57 more

Table 3.9: ESR results in the Adoption of different machinery

Table 3.9a: ESR results in the Adoption of tractor

Tractor Machinery Adoption					
Outcome variables	Category	Decision		Adoption Effect	Heterogeneity effect
		Adopters	Non-adopters		
Net Agricultural Income ('000 rupees)	ATT	(a) 223.49(5.66)	(c) 170.12(5.01)	53.37(7.56) ***	172.25 (3.91) ***
	ATU	(d) 51.24 (1.04)	(b) 47.41(0.51)	3.83(1.16) ***	122.71 (2.28) ***
Total Household income ('000 rupees)	ATT	(a) 280.81(6.55)	(c) 234.03(6.15)	46.79(8.99) ***	200.04 (4.89) ***
	ATU	(d)80.77(1.32)	(b) 82.24(0.63)	-1.47(1.46)	151.79 (2.80) ***
Log household Consumption	ATT	(a)12.12(0.02)	(c)11.99(0.02)	0.14(0.02) ***	0.68(0.02) ***
	ATU	(d) 11.44(0.01)	(b)11.29(0.01)	0.15(0.01) ***	0.69(0.02) ***

* Significant at 10%level; **Significant at 5% level; *** Significant at 1% level

Table 3.9b: ESR results of Adoption of Diesel pump

Diesel Pump Machinery Adoption					
Outcome variables	Category	Decision		Adoption Effect	Heterogeneity effect
		Adopters	Non-adopters		
Net Agricultural Income ('000 rupees)	ATT	(a) 104.87(3.11)	(c) 99.46(3.11)	5.40(4.40)	33.63(2.83) ***
	ATU	(d) 71.24(1.01)	(b) 59.32(.09)	11.92(1.35) ***	40.15(2.55) ***
Total Household income ('000 rupees)	ATT	(a) 144.36(3.66)	(c) 142.22(3.56)	2.14(5.10)	39.68(3.40) ***
	ATU	(d) 104.68(1.23)	(b) 95.79(1.03)	8.90 (1.60) ***	46.43(2.94) ***
Log household Consumption	ATT	(a)11.65(0.02)	(c)11.58(0.02)	0.07(0.02) ***	0.23(0.02) ***
	ATU	(d) 11.41(0.01)	(b) 11.33(0.01)	0.09(0.01) ***	0.25(0.02) ***

* Significant at 10%level; **Significant at 5% level; *** Significant at 1% level

Table 3.9c: ESR results of Adoption of Electric pump

Electric Pump Machinery Adoption					
Outcome variables (In Indian rupees)	Category	Decision		Adoption Effect	Heterogeneity effect
		Adopters	Non-adopters		
Net Agricultural Income (‘000 rupees)	ATT	(a) 121.08 (2.52)	(c) 100.80(2.06)	20.28(3.25) ***	68.75(2.37) ***
	ATU	(d) 52.33 (1.07)	(b) 50.76 (0.81)	1.56(1.34)	50.03(1.84) ***
Total Household income (‘000 rupees)	ATT	(a) 163.31(3.00)	(c) 145.29 (2.29)	18.03(3.78) ***	78.07(2.84)
	ATU	(d) 85.24(1.29)	(b) 87.07 (0.93)	-1.83(1.59)	58.21(2.09) ***
Log household Consumption	ATT	(a) 11.72(0.01)	(c)11.63(0.01)	0.09(0.02) ***	0.32(0.01) ***
	ATU	(d) 11.41(0.01)	(b) 11.32(0.01)	0.09(0.01) ***	0.31(0.01) ***

* Significant at 10%level; **Significant at 5% level; *** Significant at 1% level

Table 3.10: ESR estimates of Adoption of Tractor machinery on outcome variables

	Total income ('000 Rupees)		Net agricultural income ('000 Rupees)		Total Consumption Expenditure (log)	
	Adopter	Non-adopter	Adopter	Non-adopter	Adopter	Non-adopter
Gender	19.44	-0.29	25.61	0.74	-0.02	0.03**
	20.97	2.84	18.16	2.42	0.06	0.01
Age	-0.20	0.04	0.06	-0.02	0.001	-0.0002
	0.54	0.07	0.46	0.06	0.001	0.0004
Education	-1.80	-0.09	-1.88	-0.25	0.003	-0.0003
	1.44	0.21	1.25	0.18	0.003	0.001
Family size	8.80***	4.61***	4.34*	0.78*	0.05***	0.08***
	3.05	0.53	2.59	0.45	0.01	0.002
Seasonal Migration	-61.02***	1.79	-38.88**	-3.22	0.04	0.03*
	21.67	2.56	18.13	2.04	0.08	0.02
Crop insurance Govt.	25.60	-20.46***	5.63	-7.50	0.10	-0.01
	35.50	6.07	30.66	5.46	0.07	0.03
Crop Insurance Pvt.	46.64	-7.34	60.51	-5.69	0.07	0.001
	51.06	15.25	48.36	13.30	0.13	0.05
Kisan credit card	13.76	-6.76*	7.61	0.99	0.01	0.09***
	23.66	3.83	20.55	3.10	0.05	0.02
Debit Bank	-13.13	-6.57**	-19.07	-1.63	0.02	0.07***
	21.11	2.62	18.09	2.22	0.04	0.01
Debt micro	-15.43	-8.81***	-45.44	-9.91***	0.15**	0.04**
	32.27	3.39	27.68	2.84	0.08	0.02
Fixed Deposit	57.30**	35.26***	11.81	29.18***	0.01	0.09***
	25.72	6.09	22.74	5.40	0.05	0.02
Member credit	23.70	3.07	21.66	-0.50	0.03	0.03
	41.17	3.81	37.35	3.36	0.08	0.02

Trust state govt.	12.94	-0.02	8.15	0.59	-0.01	0.01**
	10.69	1.47	9.46	1.22	0.02	0.01
Trust panchayat	-12.35	0.42	-10.36	-0.11	-0.001	0.01
	10.72	1.47	9.60	1.24	0.02	0.01
Climatic shock	-51.73**	-1.69	-51.40**	-0.57	-0.02	0.06***
	23.90	3.03	19.87	2.58	0.06	0.02
Crop loss	-37.29**	-11.18***	-24.42	-9.66***	0.08*	0.06***
	17.69	2.04	15.40	1.77	0.04	0.01
Livestock	-42.52	-2.79	-14.56	3.76*	0.05	0.12***
	28.48	2.63	23.29	2.20	0.07	0.01
Assets	11.79***	3.38***	5.89	2.33***	0.04***	0.05***
	4.18	0.37	3.60	0.32	0.01	0.001
Landholding	6.38***	0.22	5.77***	2.02***	0.003	0.004**
	2.37	0.58	2.04	0.53	0.004	0.002
Irrigated land	7.85***	4.66***	6.74***	6.42***	0.01	0.02***
	2.13	1.05	1.90	0.99	0.004	0.003
Jammu and Kashmir	Base	Base	Base	Base	Base	Base
Punjab	-122.95	-47.71***	-97.69	0.76	-0.66***	-0.33***
	78.66	15.21	89.01	12.45	0.21	0.06
Uttarakhand	-129.06	-48.64***	-86.86	-19.85**	-1.01***	-0.74***
	89.37	12.44	98.55	10.09	0.23	0.06
Haryana	-153.49**	-25.94**	-112.99	3.78	-0.76***	-0.31***
	76.64	12.62	87.74	9.72	0.21	0.05
Rajasthan	-116.43	-34.98***	-136.56	-12.49	-0.69***	-0.45***
	79.86	10.48	87.82	8.13	0.22	0.04
Uttar Pradesh	-128.78	-65.67***	-148.06*	-26.61***	-0.63***	-0.51***
	78.39	10.26	88.51	8.01	0.22	0.04
Bihar	-161.65*	-52.62***	-164.19*	-25.03***	-0.62**	-0.54***
	88.80	10.60	94.90	8.15	0.29	0.05

Assam	-165.99**	-44.32***	-174.86*	-17.49	-1.06***	-0.58***
	81.66	13.27	90.52	10.87	0.23	0.05
West Bengal	-206.91**	-42.57***	-184.76**	-15.46*	-1.02***	-0.71***
	82.72	11.82	91.28	9.21	0.23	0.05
Orissa	-213.28***	-57.70***	-155.94*	-21.89***	-1.02***	-0.89***
	81.04	10.32	89.52	7.95	0.24	0.04
Chhattisgarh	-149.59*	-58.05***	-112.30	-26.17***	-1.26***	-0.90***
	84.22	10.13	95.30	7.97	0.24	0.05
Madhya Pradesh	-209.20***	-60.31***	-184.47**	-27.56***	-0.78***	-0.56***
	78.04	10.29	88.44	8.13	0.22	0.04
Gujarat	-141.28*	-31.45***	-95.43	10.29	-0.76***	-0.45***
	84.44	11.91	93.67	9.88	0.22	0.05
Maharashtra	-151.27	-25.33**	-134.49	4.29	-0.81***	-0.68***
	92.37	10.55	97.73	8.39	0.23	0.04
Andhra Pradesh	-172.37	-47.55***	-122.13	-28.23***	-0.42	-0.41***
	115.27	10.79	112.28	8.57	0.26	0.05
Karnataka	-107.45	-32.29***	-108.55	-18.66**	-0.55**	-0.44***
	80.97	10.54	90.84	8.28	0.22	0.04
Mills1	-3.89		-30.58		-0.19**	
	51.57		44.16		0.09	
Mills2		-158.12***		-80.13***		0.16**
		21.12		17.96		0.06
Constant	80.75	43.73***	168.96	8.41	11.77***	10.50***
	210.02	12.56	191.86	10.07	0.43	0.06
R^2	0.4599	0.303	0.4584	0.2893	0.4992	0.5128
F (36, 716)	15.23	51.44	14.68	46.43	23.6	243.18
N	753	8715	753	8715	753	8715

*Significant at10%level; **Significant at 5% level; ***Significant at 1% level

Table 3.11: ESR estimates of Adoption of Diesel Pump on Outcome variables

	Total income ('000 Rupees)		Net agricultural income ('000 Rupees)		Total Consumption Expenditure (log)	
	Adopter	Non-adopter	Adopter	Non-adopter	Adopter	Non-adopter
Gender	16.23	-3.51	12.95	-0.26	-0.06	0.03*
	14.62	3.57	11.88	2.99	0.05	0.02
Age	-0.34	0.09	-0.36	0.02	-0.0003	-0.0004
	0.29	0.09	0.24	0.07	0.001	0.0004
Education	0.10	0.02	0.28	-0.21	0.01**	-0.001
	1.28	0.26	1.06	0.23	0.004	0.001
Family size	4.73*	4.92***	0.53	1.13*	0.05***	0.08***
	2.58	0.75	2.18	0.64	0.01	0.003
Seasonal Migration	-16.41*	-1.42	-10.19	-6.47***	0.05	0.03
	9.15	2.99	7.50	2.35	0.06	0.02
Crop insurance Govt.	-36.81	-16.95**	-28.36	-10.30	0.20**	-0.01
	31.92	8.19	24.91	7.23	0.10	0.03
Crop Insurance Pvt.	39.43	45.69**	56.08	26.95	0.68***	-0.002
	101.55	21.21	88.70	17.64	0.20	0.07
Kisan credit card	30.51	-10.96**	13.97	1.60	-0.12*	0.11***
	23.95	5.52	19.69	4.81	0.06	0.02
Debit Bank	-3.98	-5.28	-11.62	-1.41	-0.02	0.06***
	18.27	3.31	15.69	2.72	0.05	0.01
Debt micro	-5.68	-5.67	-10.29	-9.40**	-0.10	0.05**
	22.73	4.41	17.88	3.71	0.07	0.02
Fixed Deposit	56.75**	22.20***	25.94	16.95***	-0.09	0.09***
	27.15	7.20	22.77	6.11	0.07	0.02
Member credit	36.32	-8.04*	15.19	-8.35**	-0.17**	0.02
	35.30	4.76	30.81	4.12	0.07	0.02

Trust state govt.	2.60	3.59*	5.75	2.39	0.06**	0.01
	7.04	1.88	5.99	1.63	0.02	0.01
Trust panchayat	-8.75	-0.65	-7.12	-1.18	-0.003	0.01
	5.70	1.88	4.89	1.60	0.02	0.01
Climatic shock	7.34	-7.67*	-10.82	-3.42	-0.19***	0.05**
	23.16	3.92	18.98	3.38	0.06	0.02
Crop loss	-22.23	-17.26***	-23.58**	-11.84***	-0.002	0.06***
	14.13	2.76	12.23	2.44	0.04	0.01
Livestock	8.08	-13.65***	0.26	-1.47	-0.23**	0.13***
	39.35	3.65	33.63	3.11	0.10	0.02
Assets	9.82**	4.69***	4.53	3.25***	0.02	0.05***
	4.34	0.45	3.69	0.40	0.01	0.002
Landholding	10.17***	3.45***	9.99***	3.79***	0.01**	0.003
	2.10	0.62	1.75	0.57	0.004	0.002
Irrigated land	3.48	9.39***	1.29	10.13***	-0.02**	0.02***
	4.68	1.11	3.93	1.01	0.01	0.003
Punjab	Base	Base	Base	Base	Base	Base
Uttarakhand	-28.66	-14.67	18.25	-36.02**	0.17	-0.36***
	96.37	16.74	87.58	15.28	0.23	0.06
Haryana	-45.01	-5.49	-5.00	-25.07*	0.28**	0.03***
	53.87	15.74	47.48	13.51	0.13	0.05
Rajasthan	-36.46	-24.72*	-43.26	-47.48***	-0.06	-0.05***
	32.58	13.49	28.09	11.55	0.09	0.04
Uttar Pradesh	-29.60	-75.18***	-60.31*	-70.75***	-0.47***	-0.10***
	39.05	12.27	31.55	10.84	0.11	0.04
Bihar	-47.14*	-52.47***	-57.97***	-64.28***	-0.24***	-0.13***
	25.67	12.81	21.05	11.10	0.08	0.04
West Bengal	-36.40	-62.98***	-75.53**	-61.52***	-0.73***	-0.30***

	43.14	13.70	33.98	12.10	0.11	0.04
Orissa	-107.20	-35.40**	-65.85	-48.23***	-0.17	-0.49***
	70.34	14.29	61.89	12.58	0.18	0.05
Madhya Pradesh	-105.85**	-48.15***	-90.30**	-60.44***	0.00	-0.17***
	45.49	13.82	39.71	12.04	0.11	0.04
Gujarat	-37.03	-36.20**	-4.78	-33.59**	-0.01	-0.05
	44.44	14.72	40.63	13.19	0.10	0.04
Maharashtra	-109.42	-18.90	-38.63	-32.84**	0.39*	-0.29***
	98.51	15.59	86.84	13.85	0.23	0.05
Karnataka	-70.72	-2.58	-20.54	-40.90***	1.58***	-0.07
	177.66	16.56	155.53	14.74	0.45	0.05
Tamil Nadu	-64.35**	-47.98***	-81.01***	-68.47***	-0.28***	-0.31***
	32.25	14.06	26.86	12.42	0.10	0.06
Mills1	57.06		-21.44		-1.21***	
	141.23		121.21		0.35	
Mills2		-141.42***		-68.27**		0.14
		37.06		33.74		0.11
Constant	-120.57	-1.94	77.85	18.77	13.19***	10.15***
	325.80	15.66	277.58	13.49	0.82	0.06
R^2	0.4611	0.4219	0.4666	0.4345	0.5808	0.5348
F (36, 716)	12.77	57.42	12.42	52.72	46.95	230.7
N	1134	7077	1134	7077	1134	7077

* Significant at 10%level; **Significant at 5% level; *** Significant at 1% level

Table 3.12: ESR estimates of Adoption of Electric Pump on Outcome variables

	Total income ('000 Rupees)		Net agricultural income ('000 Rupees)		Total Consumption Expenditure (log)	
	Adopter	Non-adopter	Adopter	Non-adopter	Adopter	Non-adopter
Gender	-9.57	1.09	-6.33	2.24	0.0001	0.03
	10.75	3.71	9.29	3.05	0.03	0.02
Age	0.28	-0.07	0.01	-0.08	0.0001	-0.0003
	0.26	0.09	0.22	0.07	0.001	0.0004
Education	0.54	-0.35	0.05	-0.35	0.002	-0.001
	0.68	0.27	0.61	0.23	0.002	0.001
Family size	6.38***	5.68***	2.53*	1.38**	0.07***	0.08***
	1.71	0.67	1.47	0.54	0.005	0.003
Seasonal Migration	-6.05	-0.11	-12.67*	-4.10*	0.10**	0.03
	8.21	3.11	6.80	2.37	0.05	0.02
Crop insurance Govt.	-21.89	-16.28*	-17.24	-8.07	-0.09**	0.02
	15.91	9.12	13.56	8.17	0.05	0.04
Crop Insurance Pvt.	10.97	1.45	4.48	5.40	-0.16	-0.07
	31.80	30.85	29.42	28.61	0.10	0.09
Kisan credit card	14.86	2.27	18.57**	4.60	0.03	0.09***
	11.39	4.26	9.42	3.60	0.03	0.02
Debit Bank	-11.49	-3.54	-15.23*	2.44	0.02	0.07***
	8.78	3.35	8.03	2.80	0.03	0.01
Debt micro	-14.18	-3.18	-28.29***	-7.87**	0.02	0.06**
	12.26	4.57	9.63	3.85	0.04	0.02
Fixed Deposit	49.04***	29.90***	27.33**	24.78***	-0.03	0.10***
	14.11	8.37	12.25	7.20	0.04	0.03
Member credit	-6.96	3.98	-9.26	0.80	-0.0003	0.04**
	10.91	4.82	9.47	4.15	0.03	0.02

Trust state govt.	3.75	1.06	5.05	0.13	0.05***	0.002
	4.82	1.80	4.17	1.51	0.02	0.01
Trust panchayat	2.08	-5.53***	-1.09	-4.44**	-0.01	-0.002
	5.55	2.02	5.04	1.75	0.02	0.01
Climatic shock	-11.50	-6.90	-5.47	-2.94	0.05	0.06**
	11.50	4.21	10.13	3.65	0.04	0.02
Crop loss	-27.17***	-13.18***	-20.50***	-9.84***	0.06**	0.08***
	7.64	2.65	6.66	2.26	0.03	0.01
Livestock	-23.94	-12.50***	-9.18	-3.37	-0.03	0.12***
	14.79	4.10	13.28	3.67	0.04	0.02
Assets	9.40***	4.75***	5.90***	3.04***	0.04***	0.06***
	1.59	0.51	1.49	0.46	0.005	0.002
Landholding	4.28***	4.45***	5.03***	4.59***	0.01***	0.002
	1.61	0.81	1.34	0.76	0.004	0.002
Irrigated land	12.15***	5.02***	9.77***	6.32***	-0.01	0.02***
	2.56	1.77	2.61	1.73	0.01	0.005
Punjab	Base	Base	Base	Base	Base	Base
Haryana	-13.53	-19.85	-8.10	-26.85*	0.04	0.06
	24.06	16.63	22.05	14.59	0.07	0.05
Rajasthan	-7.43	-51.61***	-29.08*	-61.21***	-0.18***	-0.04
	19.12	14.70	16.97	12.82	0.06	0.04
Uttar Pradesh	-34.25	-48.10***	-61.94*	-50.07***	0.26**	-0.11**
	39.99	14.97	31.97	13.33	0.11	0.05
Chhattisgarh	-105.59**	-61.45***	-91.74**	-60.93***	-0.25*	-0.51***
	40.76	15.10	38.42	13.39	0.13	0.05
Madhya Pradesh	-60.65***	-72.70***	-67.77***	-69.93***	-0.18***	-0.19***
	19.15	14.08	16.71	12.53	0.06	0.04
Gujarat	-55.00	-32.79**	-35.19	-22.19	0.05	-0.05
	36.34	16.16	33.87	14.67	0.09	0.05

Maharashtra	-31.28	-80.81***	-29.54	-70.83***	-0.34***	-0.32***
	20.14	14.76	18.33	13.45	0.06	0.04
Andhra Pradesh	-53.82**	-82.03***	-62.91***	-83.64***	-0.16**	-0.004
	21.02	14.95	18.80	13.56	0.07	0.04
Karnataka	-30.41	-45.35***	-42.36**	-60.72***	0.02	-0.05
	22.12	14.45	19.31	12.91	0.07	0.04
Kerala	115.18**	-79.15***	41.83	-74.47***	-0.15*	-0.09
	45.96	22.21	36.32	19.07	0.09	0.07
Tamil Nadu	-57.37***	-57.66***	-74.52***	-72.29***	-0.40***	-0.31***
	20.79	15.48	18.98	13.16	0.09	0.07
Mills1	10.57		-4.05		-0.37***	
	38.11		38.00		0.11	
Mills2		-55.93**		-35.19		0.03
		25.05		23.49		0.07
Constant	-63.14	38.98**	7.44	42.17***	11.05***	10.15***
	89.36	16.04	87.71	13.76	0.26	0.06
R^2	0.4595	0.3619	0.4509	0.3799	0.494	0.5124
F (36, 716)	28.51	35.55	25.68	32.53	55.28	188.07
N	1931	6099	1931	6099	1931	6099

* Significant at 10%level; **Significant at 5% level; *** Significant at 1% level

agricultural income and USD 550.70 in total household income had they adopted the machine. Similarly, positive ATU is found for food security indicators as well. The results in Table 3.8c shows that the ATT of electric pump adoption on net agricultural income is positive with an impact size of USD 1254.87, meaning that the adopters are better off by this amount compared to a state of non-adoption of the machine. Similarly, the ATT on household income is USD 1115.64. A positive and statistically significant ATT is also found for the food security indicator. The ATU that reports the benefit of adoption by the non-adopters is positive for both net agricultural and household income. So, the overall findings from Tables 3.8b and 3.8c suggest that irrigation machinery adoption has benefited adopters by increasing their incomes and consumption.

Table 3.11 presents the switching regression results for both adopters and non-adopters of diesel pumps for net agricultural income, household income, and consumption. The household size is found to be positively influencing all three outcome variables of the adopters and the non-adopters alike. Seasonal migration seems to be reducing the net agricultural income of the adopters and the household income of the non-adopters of the diesel pump. A possible reason for this is that since the migrating households may primarily depend upon hired labour for farming activities, it will increase the cost of farming and reduce the margin of agricultural income. The variable, crop insurance from the private companies, shows a positive association with the net agricultural income of the non-adopters. The household asset variables, such as total land holding and percentage of irrigated land, were positively associated with both the income and food security indicators for adopters and non-adopters. Fixed deposit savings in the bank also favourably affect all three outcome variables. As expected, the experience of climatic shock reduces household income and worsens their food security condition.

The switching regression results for adopters and non-adopters of electric pumps are provided in Table 3.12. The findings are similar to what has been observed in Tables 3.9b and 3.9c, except that the households possessing the *Kisan* credit card are the ones that obtained higher net agricultural and total household income in Table 3.11. The mills' ratio variables (mills 1 and mills 2) are statistically significant in all the outcome regressions suggesting that there was, in fact, considerable selection bias due to unobservable factors. Hence, the use of the ESR model is justified. The state dummies are used in all the regressions to capture state-specific time-invariant heterogeneity, such as differences in geographical terrains and socio-cultural habits. The coefficients of these dummy variables are shown in the Tables but are not discussed in the text

3.8 Discussion

In all the regressions, we have used the population sampling weights to account for the ratio of the samples drawn to population size in the states (provinces). Further, the number of states and sample size used in the estimation vary from one type of machinery to another, depending on the percentage of adopters of these types of machinery. We have considered those states with at least 1% or more adopters in the sample from that state, hence, dropping the non-relevant states for the respective machinery. For example, states like Arunachal Pradesh, Nagaland, and Sikkim are dropped for tractors.

The results show that access to credit positively contributes to adopting machinery. Both the access to bank credit and possession of Kisan credit cards are positive and statistically significant for all three types of machinery. Previous studies have also confirmed that access to key institutional support, such as credit facilities, has increased the adoption of agricultural technology (Ali et al., 2016; Mottaleb, Krupnik, and Erenstein, 2016; Wossen et al., 2017; Chandio et al., 2019; Paudel et al., 2019; Akram et al., 2020; Saliou et al., 2020). Furthermore, plot-specific characteristics like access to irrigation facilities and land size positively affect the adoption of these types of machinery. Irrigation facility increases the adoption of mechanized farming, as shown by the positive and significant coefficient of the variable, irrigated land. Family size is positive and statistically significant for adopting machines like tractors and electric pumps. This finding is corroborated by existing studies such as Adekunle et al. (2016), Takeshima and Bhattarai (2019), and Sarkar (2020).

Both household assets and possession of livestock variables have a positive and statistically significant influence on the adoption decision. This indicates that households with a relatively higher stock of wealth may be able to adopt the types of machinery. Farmer households with a fixed deposit in the bank are more likely to adopt mechanization. This may happen because the deposit in the bank provides them with a cushion against any default on the bank loan, they might have taken to purchase such types of machinery. Membership in a farmer cooperative is positive and statistically significant for all three types of machinery, indicating that the former acts as both an information catalyst and a peer effect. This inference is in line with the studies of Aryal et al. (2019); Paudel et al. (2019); Aweke (2013); and Ketema et al. (2016).

As expected, and hypothesized in Table 3.3, climatic stress may have induced farmers to adopt mechanized farming. The results show that the experience of climate shock-like drought, uncertain rainfall, and flood have increased the likelihood of adopting tractor and electric pumps. For example, with mechanized tilling, farmers can prepare the land and sow the seeds on short notice and similarly can harvest in a short span of time using the harvesters in the event of untimely storms and flash floods.

3.9. Conclusion and Policy Implications

India has made the transition from labour-intensive to capital-intensive agricultural production. The data at the national level suggest that the use of tube wells, electric pumps, and tractors increased during 2004-2011. The states with more fertile land and better irrigation facilities are relatively more mechanized and experience higher productivity.

The major finding from the study is that households experiencing climatic shocks at regular intervals adopt mechanized farming. Especially with the southwest monsoon in India increasingly becoming uncertain, farmers reschedule their planting dates to avoid flash floods and dry spells. Short-duration varieties of paddy and other crops are suitable for such farming. Tractors, power tillers, threshers etc., help plant and harvest in less time. So, agricultural machineries are complementary to the broader climate change adoption drive.

Although the experts have highlighted the role and significance of mechanization in the current sustainable agricultural production, there is limited research to understand the exact impacts of mechanization on agricultural income and food security in India. The current study taps a household survey conducted in all the states of India to examine the impact of agricultural mechanization on net agricultural income, household income, and food security represented by household consumption. The adoption rate of mechanized farming is still low, and its distribution is uneven in India. A higher percentage of machinery adoption is observed in the central plains and north-central regions. Since this region is situated in the Indo-Gangetic plains, they have large tracts of fertile land that may have induced the farmers in these states to adopt mechanization.

The findings from the adoption model show that access to credit through usual bank credit and *Kisan* credit cards has increased the probability of adoption. Furthermore, plot-specific characteristics like access to irrigation facilities and land size positively affect the adoption of these types of machinery. Experience of climatic shocks and crop loss triggers positive adoption decisions because farm mechanization helps farmers to adapt to climatic shocks. Being a member of a farmer cooperative was also found to be a determinant of adoption decisions in our study. This suggests that social capital has a positive influence on agricultural technology adoption.

The impact evaluation estimates show that adopting tilling implements such as tractors and power tillers has the biggest positive impact on net agricultural income, which is 31% higher than non-adopters. Similarly, the impact on household income and consumption was 19% and 5%, respectively. Adoption of other machinery, such as diesel and electric pumps too, increased income and consumption for the adopters significantly.

Even though tractors are mostly used in India's north and center plains, power tillers can be used in upland areas. In recent decades, academic and non-academic research institutions and state government leaders promoted high-yielding hybrid seeds, fertilizer, and pesticide use. Little attention was paid to popularising the adoption of small and medium-sized motorized equipment. There is a need to promote and make available smaller machines and equipment such as 2-wheeler tractors and power tillers in the fragmented landholding regions of East and North-east India. Recently, there has been a surge in small and medium-sized machines in south, east and north-eastern regions. The rental service of agricultural machines has supported this expansion in mechanization. However, there is a need to further deepen the mechanization drive in the Indian agricultural sectors. The prevalent view that mechanized farming suits only large landholding settings should change. More research should be devoted to developing scale-appropriate machines such as mini-tillers (5 to 9 horsepower) in small and fragmented landholding settings.

Appropriate policies that increase the likelihood of getting credit support from a government and non-government organization, frequent extension contacts, improved farmers' access to equipment and machinery at the right time and price, and infrastructural development like improved irrigation facilities could boost farm mechanization in the rural agricultural sector. Mechanization will accelerate if farmers can access or enroll primary agriculture cooperative societies for loans, subsidies, and training. Adoption will boost work, income, and the standard of life in India. This could improve agricultural activities when livestock with drafts and labor is scarce.

Our research has various policy ramifications that could expedite the mechanisation of agriculture in India. Small and marginal farmers face difficulty availing of mechanization due to inadequate financial capital and lack of access to credit, forcing them to take informal credit to mechanise their farming. However, informal credit often ends up with less attractive net profit due to its inherent high-interest rates. Appropriate insurance mechanisms encouraging small and marginal farmers to follow mechanized farming should be the priority in agricultural policymaking. Rural credit supply and financial inclusion are needed to upscale farm mechanization. Timely and easy access to low-interest loans helps to increase the adoption of farm machinery.

The findings further suggest that awareness about schemes like National Mission on Agricultural Extension and Technology (NMAET) and the Sub Mission on Agricultural Mechanization (SMAM) should increase as these policies increase farmers' trust in local government. Extension services, financial and institutional factors such as access to credit from various sources, banking services such as fixed deposits at the bank, crop insurance, and KCC positively impact farm machinery adoption. As part of the twelfth five-year plan, the Indian government has launched a mechanisation initiative to promote custom hiring centres with low-cost rental access to machinery. These customised hiring centres should be strengthened and installed in climate-vulnerable and remote geographic areas. Availability of small farm machinery, repair and maintenance services in local regions emphasized to hilly areas should be emphasized upscale farm mechanization. There is a need for training and skill development programmes for farmers regarding the updated technology adoption.

CHAPTER 4

ADOPTION OF CLIMATE-SMART TECHNOLOGIES IN AGRICULTURE: EVIDENCE FROM AN EASTERN INDIAN STATE

4.1 Introduction

The anthropogenic emission of greenhouse gasses is rising alarmingly, causing a widespread adverse impact on human and natural systems (IPCC, 2021). Representative Concentration Pathway (RCP) 4.5 scenario projected the global mean temperature to rise between 2.5° and 3 °C at the end of the 21st century from the pre-industrial baseline (IPCC, 2014). According to the latest Intergovernmental Panel on Climate Change (IPCC) report AR6 (IPCC, 2021), the emissions of greenhouse gasses from human activities are responsible for the current 1.1 °C of warming since the pre-industrial level and finds that averaged over the next 20 years, the global temperature is expected to reach or exceed 1.5 °C (IPCC, 2021). The catastrophic effects of global climate change due to the increased atmospheric concentration of greenhouse gasses have been scientifically proven (IPCC, 2022). In the last few decades, researchers have quantified the effect of climate change on the agriculture sector (Schlenker et al., 2006; Mendelsohn et al., 2008; Fisher et al., 2012; Kalli et al., 2020; Kali et al., 2022). These studies have confirmed that climate change will remain the most potent threat to agricultural systems and food security around the globe.

Several studies have established that developing countries are most vulnerable to climate change due to their lack of adaptive capacity (Mertz et al., 2009; Taraz, 2017). South Asia and Sub-Saharan Africa are the most vulnerable regions to climate change among developing countries (Banerjee et al., 2013; Eckstein et al., 2021; Aryal et al., 2021; Rahut et al., 2021a, 2021b). According to the Global Climate Risk Index (CRI), India is ranked seventh in climate vulnerability (Eckstein et al., 2021). Climate change effects continuously threaten many agricultural systems, which many field studies have confirmed (Aryal et al., 2021; Tesfaye et al., 2017; Aryal et al., 2020a, 2020c; Kalli and Jena, 2020).

Adapting to climate change in agriculture requires an integrated approach where the precise application of inputs, climate-resilient seeds, and appropriate tillage methods hold significance (Arora, 2019; Connolly-Boutin and Smit, 2016; FAO, 2011; Jena, 2019). Broadly CSA focuses on developing resilient food production systems that provide food and income security under progressive climate change and variability (Lipper et al., 2014). Sustainable agricultural systems must be developed to adapt to climate change (Arora et al., 2019; Connolly-Boutin et al., 2016; FAO, 2011; Jena et al., 2019). The Food and Agriculture Organization (FAO) of the United Nations Organization (UNO) and various agricultural scientists have been advocating an array of agricultural technologies collectively known as 'climate-smart agricultural technologies (CSA) as a solution to cope with the challenges posed by climate change (FAO, 2010). The CSA mainly intends to build a resilient food production system that ensures food and income security (Lipper et al., 2014; Vermeulen et al., 2012). Adapting to climate change is critically linked to knowledge and awareness of local climatic conditions and socioeconomic and institutional factors. Smallholder farmers require both technical and financial support to adopt new technologies. Several studies have highlighted that one of the major bottlenecks in adopting CSA technologies in developing countries is the lack of awareness and knowledge about CSA (Aryal et al., 2018; Jena et al., 2021; Marenya et al., 2017). Farmers take action in response to their perceived risk of climate change. They may understand the local climate well and have developed indigenous sustainable adoption practices over the years (Singh et al., 2020; Srivastava et al., 2017; Tripathi et al., 2017 Adoption of climate change is highly region-specific as it depends on the target region's climatic, environmental, socio-economic, and political conditions. Smallholder farm households need technical know-how and financial support to consistently follow new technological innovations and adoption (Pingali et al., 2019; Bhatta et al., 2016).

Furthermore, an institutional perspective of CSA studies focuses on access to institutional networking, market access, and knowledge sharing (Totin et al., 2018). Dougill et al. (2017) and Pulkkinen et al. (2016) emphasized the significance of knowledge networks, communication, and capacity building in driving and enhancing CSA adoption. Institutional policy and support, including government and non-governmental agricultural extension services, credit facilities, subsidies, and awareness-raising programs, are vital components of climate adoption strategy (Mulwa et al., 2017; Raj and Garlapati, 2020; Mazhar et al., 2021; Sardar et al., 2021). Access to agricultural inputs (e.g., seed, fertiliser, labor), post-harvest facilities, market outlets, and input and output pricing drives a user's decision to adopt CSA (Maharaj et al., 2015; Harvey et al., 2014; Alem et al., 2015).

Interaction among institutions through networking and partnership, a win-win public-private collaboration of institutions, and capacity building to local communities through training, demonstrations, and peer interactions could enhance CSA adoption s (Mazhar et al., 2021; Shames et al., 2016; Pagliacci et al., 2020). The interaction between local extension officials and farmers creates a long-term communication network that enhances farmers' technical knowledge regarding CSA technologies. However, CSA is still a new concept among the extension workers and farmers in South Asia and, thus, still a challenging process to follow. Most previous studies on CSA in India focused on productivity and net returns. Though some studies focused on the factors affecting CSA adoption (Aryal et al., 2018a, 2020; Tesfaye et al., 2019), they have not explicitly examined the role of institutional factors in CSA adoption's success. The local extension officers can impart technical knowledge regarding CSA technologies, enhancing farmers' ability to adopt these technologies.

Furthermore, access to key inputs necessary to use CSA technologies would also determine the adoption rate. One such input is energy sources such as electricity and fuels. The electric and diesel pumps must follow several practices, such as crop diversification, crop rotation, and drip irrigation. This study explores the determinants of adopting CSA technologies in several districts in an Eastern Indian state, namely

Odisha. In particular, the role of perception of climate change, access to extension, and access to energy sources have been investigated. The study sites have diverse climatic conditions and, thus, provide a good basis for a scientific evaluation.

One of the biggest constraints to CSA technology adoption for the resource-poor smallholder farmers in developing countries, apart from financial and technical support, is the lack of awareness and knowledge about CSA (Aryal et al., 2020a, 2018a; Jena, 2021; Marenya et al., 2017, 2020).

Most studies on CSA adoption in India were also from the Indo-Gangetic Plains, including Bihar and Haryana (Aryal et al., 2020b; Hariharan et al., 2020; Aryal et al., 2018b; Mittal and Mehar, 2016). Many studies have observed that access to extension services is essential to support farmers required to adapt to climate change (Mazhar et al., 2021; Jha et al., 2021). The study examines the determinants of CSA adoption in Odisha, an eastern Indian state frequently marred with extreme climatic events and has experienced massive losses to human lives and livelihoods. The estimated economic damage from natural disasters has increased in Odisha over the years and their frequency. The value of life and property loss was estimated at INR 10.5 billion in the 1970s, which increased nearly seven times in the 1980s and nearly 10 times in the 1990s (Das, S. 2016). Odisha was hit by cyclone “Fani” in 2019, claiming 64 lives and causing damages worth over INR 241.8 billion. Therefore, using the primary farm household survey data from the Eastern Indian state of Odisha, this study furthers the understanding of the attitude of smallholders towards CSA adoption. The contribution of this study is two-fold- firstly, it focuses on the regions that are least researched in the Indian context. Secondly, it examines the role of the institutional dimension of climate adoption strategies such as agricultural extension, subsidies, and training by assessing the adoption of CSA practices.

4.2 Materials and Methods

This section discusses the survey design, variable description, and the econometrics method employed.

4.2.1 A Brief Introduction to Odisha

Odisha is one of the States of India. It is located between the parallels of 17.49'N and 22.34'N latitudes and meridians of 81.27'E and 87.29'E longitudes. It has a coastline on the Bay of Bengal that stretches for about 480 km. It is 1,55,707 km^2 in size, 800 km from north to south and 500 km from east to west. It is India's ninth-biggest state by land area and the eleventh-largest by population. It has 4.7% of the country's land area and 3.7% of its people (Government of Odisha, 2018). The state is divided into four physiographic zones: the Coastal Plains, the Central Table Land, the Northern Plateau, and the Eastern Ghats. North Western Plateau, North Central Plateau, North Eastern Coastal Plain, East and South Eastern Coastal Plain, North Eastern Ghat, Eastern Ghat High Land, South Eastern Ghat, Western Undulating Zone, Western Central Table Land, and Mid Central Table Land are the ten Agroclimatic Zones. According to the Population Census of 2011, approximately 83.3% of the population in Odisha resides in rural regions. Since Odisha is an agricultural state, a significant proportion of its rural labour force is employed in agricultural pursuits. The agricultural sector remains a significant means of sustenance for a considerable portion of the populace in the state. However, the Gross Value Added (GVA) derived from the agricultural and allied sectors in Odisha amounted to approximately 21.27% in 2020-21(A) and 21.38% in 2019-20 (Government of Odisha, 2021).

The total population of Odisha is 419.74 lakh, out of which the total number of agriculture workers (Cultivator+ Agricultural Labor) is 108.44 lakh. 41.04 lakh total cultivator and 7.29 female cultivators contributes a significant portion of the state agriculture. Climatic and soil conditions significantly influence the agriculture of Odisha. The state's climate is classified as tropical, featuring elevated temperatures, elevated humidity levels, moderate to high precipitation, and brief and mild winter seasons.

Table 4.1 Historical data on natural calamities in Odisha

Years	Natural Calamities	Years	Natural Calamities
1980	Severe flood, drought	2001	Severe flood, heatwaves
1981	Flood, drought, cyclone, heat waves	2002	Severe drought, heatwaves
1982	Severe flood, drought, a very severe cyclone	2003	Heat waves, flood
1983	Heat Waves, Flood	2004	Heat waves, flood
1984	Drought, severe floods, cyclones	2005	Severe heatwaves flood, drought
1985	Severe flood, cyclone	2006	Heat waves, severe flood
1986	Drought, severe floods, cyclones	2007	Heatwaves, drought
1987	Drought, severe floods, cyclones	2008	Severe heatwaves flood, drought
1988	Drought, severe heatwaves	2009	Severe drought, heatwaves, cyclones, floods
1989	Drought, cyclones, heat waves, flood	2010	Severe heatwaves, flash floods, and drought
1990	Severe flood	2011	Drought, Flood
1991	Severe Flood	2012	Drought, Flood
1992	Severe flood, drought	2013	Very severe cyclonic storm `Phailin' / Flood
1993	Drought	2014	Flood, very severe cyclonic storm 'Hudhud
1994	Severe Flood	2015	Drought, Flood & Heavy Rain
1995	Severe floods, cyclones, heatwaves	2016	Flood and heavy rain, Drought
1996	Severe drought, severe heat waves, flood	2017	Flood and heavy rain, Drought, Pest Attack, Unseasonal Rain
1997	Severe flood and drought	2018	Cyclone "Titli", drought
1998	Severe drought, Severe heatwaves, flood	2019	Cyclone "Fani and Bulbul"
1999	Super Cyclone, floods, heatwaves	2020	Cyclone "Amphan"
2000	Severe drought, heatwaves	2021	Cyclone "Jawad"

Source: Annual Report on Natural Calamities, Special Relief Commissioner (Government of Odisha), Annual reports of OSDMA (Orissa State Disaster Management Authority), (Das, 2016)

The average annual precipitation of the region is 1451.2 millimetres. Odisha is considered to be among the states that are highly susceptible to the impacts of climate change. The State is located on the country's eastern coast and is characterized by a 480 km long vulnerable coastline. As a result, the region is subject to recurring climate hazards, including cyclones and coastal erosion. Climate-induced natural calamities hit Odisha over several years (See Table 4.1).

The Kharif season is the primary cropping period, during which rice is the predominant crop cultivated in approximately two-thirds of the cultivated land. The practice of crop cultivation during the rabi season is predominantly limited to regions with access to irrigation facilities and residual moisture. The State cultivates various significant crops, including pulses such as arhar, moong, biri, and kulthi, oilseeds such as groundnut, sesamum, mustard, and niger, fibres such as jute, mesta, and cotton, sugarcane, as well as vegetables and spices. During the Kharif season, rice is the dominant crop in the cropped area, while during the rabi season, pulses occupy nearly half of the cropped area. In addition to oilseeds, a significant portion is occupied by vegetables, fibres, maize, and ragi (Government of Odisha, 2018).

4.2.2 Description of the Study Areas

The study collected data from two extreme climatic regions: inland and coastal districts of Odisha. The geographical maps of the study districts are shown in Figure 4.1. The current study covers three districts: Kendrapara, Mayurbhanj, and Balangir. The state's climate varies considerably, with droughts, floods, and cyclones being the regular climate disasters adversely affecting the regional economy. A detailed description of the study area has been discussed below.

4.2.2.1 Balangir District: Balangir District is an inland district located in the western part of Odisha. The district comes under the Western Central Tabled Land agro-climatic zone. It is between $20^{o}9'$ and $21^{o}05'$ North latitude and $82^{o}41'$ and $83^{o}42'$ East longitudes. It is bordered by the districts of Bargarh in the north, Kalahandi in the south, Subarnapur in the east, and Nuapada in the west. This region has a hot and humid climate. Droughts had struck the district more than thirteen times in the previous three decades, making it a drought hotspot. Regarding the irrigation status, around 10.9 % of the cultivated land is irrigated during the Kharif and 5 % during the Rabi seasons in this region.

The main source of rainfall in the area is the southwest monsoon. The district gets an average of 1229.47mm of rain each year, below the average rain falls. About 80% of the total rainfall happens between June and September. In the area, droughts happen quite often.

4.2.2.2. Kendrapara District: Kendrapara District is situated in the eastern region of

Odisha. The location's geographical coordinates are within the range of 86°14’ to 87°3’ east longitude and 20°21’ to 20°47’ north latitude. The Bhadrak district delineates the region under consideration to the north, the Jagatsinghapur district to the south, the Bay of Bengal to the east, and the Cuttack district to the west. The district's climate is typically hot and humid during April and May and cold during December and January. June is often when the monsoon season ends. In 2018, the district received 1885.8 mm of rain, significantly higher than average. (1556.0 m.m).

Nearly 77% of its cropped area is rainfed, while the rest, 23%, is irrigated. The Kendrapara district has seen six cyclones in the last two decades, the highest among all coastal districts of India. The district has recognized high-risk zones for sea erosion and soil salination (Maharjan, 2018). Sea erosion and salination of soil are the other high-risk climate-induced events in the district. While the high-altitude cropped land is deprived of adequate irrigation facilities, the lower-altitude land faces water lodging due to the lack of a drainage system. Paddy, black gram, green gram, sunflower, peanuts, and jute are major crops produced in the district.

4.2.2.3. Mayurbhanj: Mayurbhanj district is a land-locked district in the north-central plateau agro-climatic zone located in Northern Odisha. It lies between 85° 40' and 87° 11'

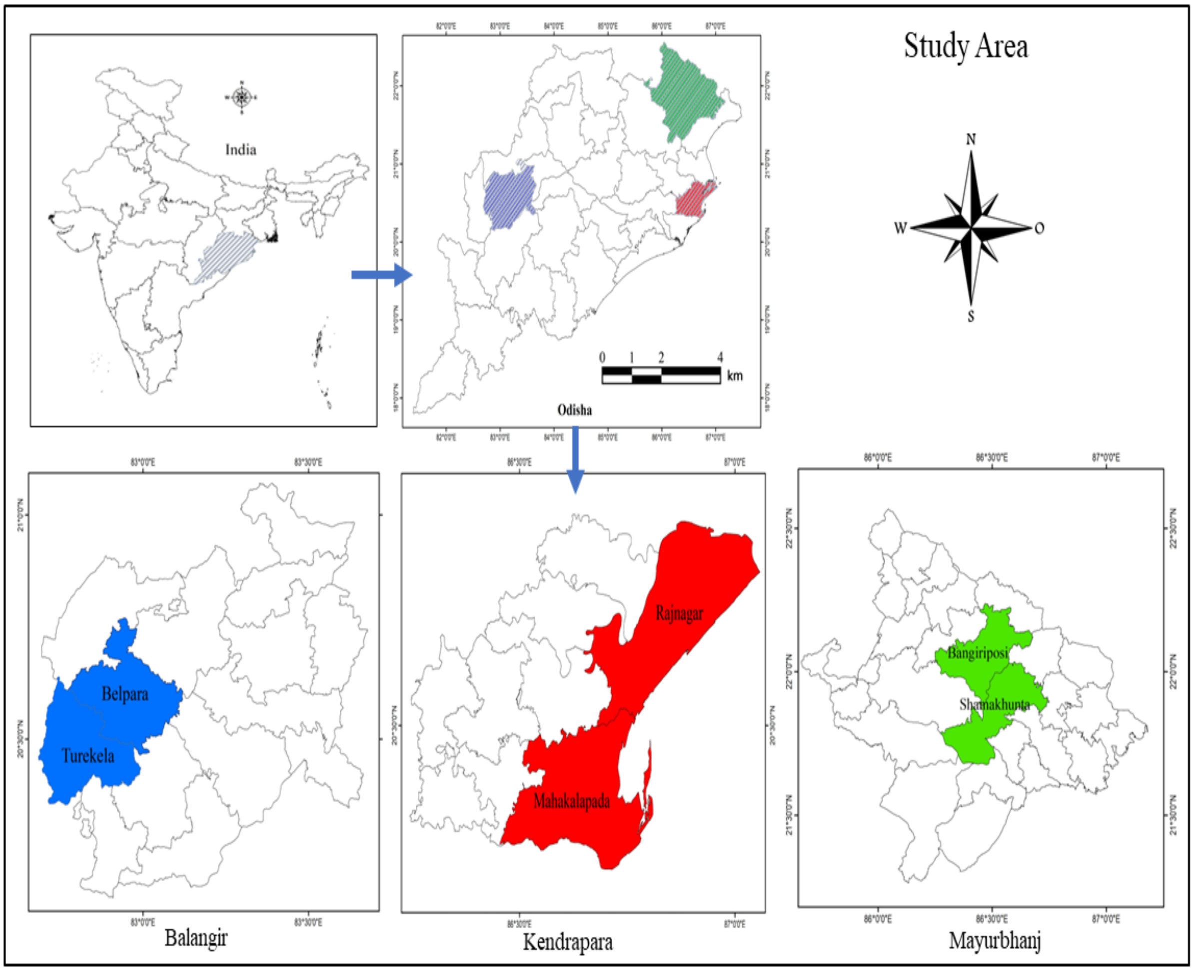


Figure 4.1. Study Area (showing the three climate-vulnerable districts as study districts)
Source: Authors' own compilation by using Arc GIS

East and latitudes 21° 16' and 22° 34' North. It is bordered by the states of West Bengal in the north, Jharkhand in the south, Balasore in the west, and Keonjhar in the east. Mayurbhanj is densely populated by tribal communities (58%) and characterized by a tropical to sub-tropical climate with hot summer spells. Most of the time, the weather in the area is hot and humid from July to September and cold from December to January. Most of the time, the monsoon rain arrives in June. In 2018, the district got 1654.3 mm of rain, less than the normal amount. (1600.6 m.m.). With 15% of the cultivable area during Kharif and 5.3% during Rabi seasons being under irrigation, the farming in the district is mostly rainfed. Paddy, pulses, and oilseeds are the main crops grown in the district.

However, due to the irregular rainfall, the area under pulses, oilseeds, and other cereals has increased, while the area under Kharif paddy has decreased.

The study area's temperature and rainfall trends are presented in Figures 4.3 and 4.4. The analysis reveals an increasing trend in the annual average temperature from 1982 to 2019, with the inland district exhibiting a greater increase compared to other parts of the study area. The trend of average annual rainfall between 1988 to 2022 indicates a downward trend for the inland district of Blangir, while the rainfall trend for the other two districts remains stable. These findings suggest that climate change significantly impacts the study area, with rising temperatures and changing rainfall patterns posing significant challenges for agricultural production and water availability.

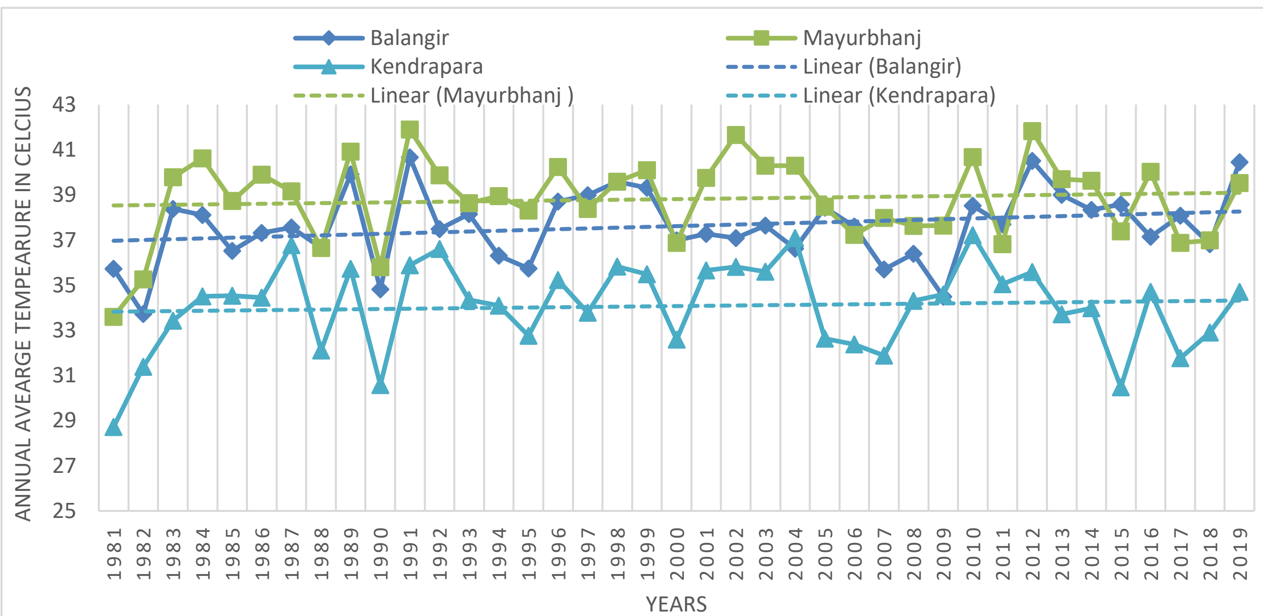


Figure 4.2 The trend of average annual temperature between 1988 to 2022 in three study districts of Odisha

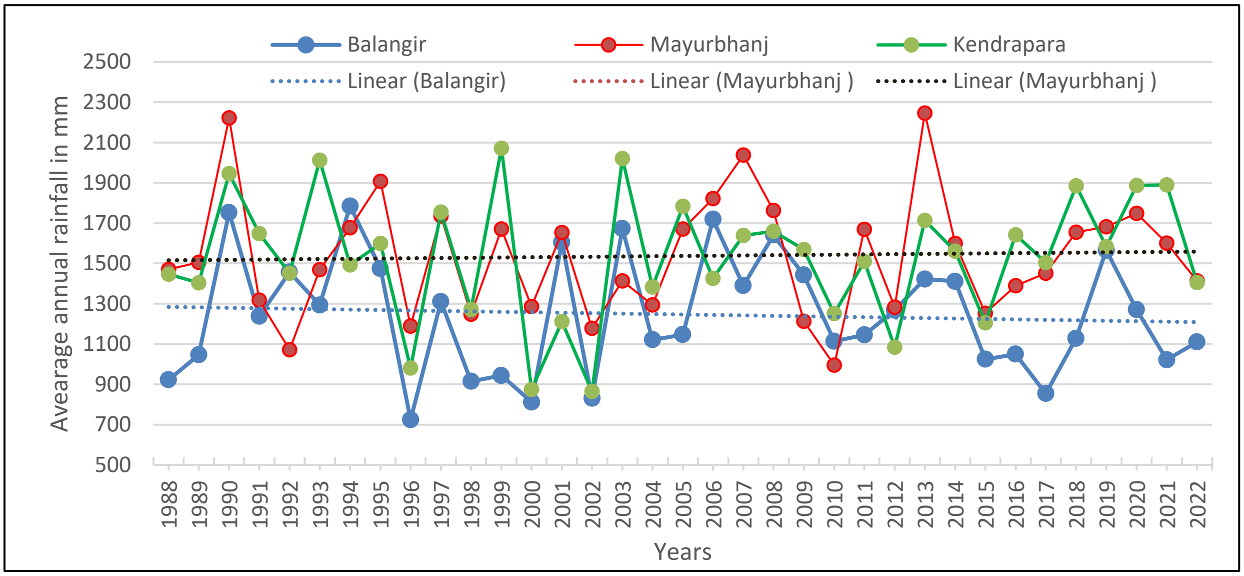


Figure 4.3 The trend of average annual rainfall between 1981 to 2019 in three study districts of Odisha

4.2.3 Determination of Sampling

The present research uses cross-sectional data from 494 rural farmers in Odisha collected in the 2019-20 production year. The sample size is determined using the statistical formula proposed by Arkin and Colton (1963).

$$n = \frac{NZ^2 * p * (1-p)}{Nd^2 + Z^2 * p(1-p)} \text{ ()}$$

where,

n = required sample size (385)

N = total number of households (4,209,660)

Z = confidence level (at 95% level Z = 1.96)

p = estimated population proportion (0.5, this maximizes the sample size)

d = error limit of 5% (0.05)

The minimum requirement of a sample size to run this study is 385, but we collected 550 household data. Eventually, after cleaning, we used 494 samples for the analysis.

4.2.4 Selection of Study Districts and Villages

The present research uses cross-sectional data from 494 rural farmers in Odisha collected in the 2019-20 production year. The sample was drawn by multistage stratified sampling. The process of study area selection has been described in Fig. The three districts belonging to two different ecosystems were chosen, enabling us to study the heterogeneous effects of climate change and different aspects of adoption patterns. In the second stage, the blocks were also chosen purposefully by looking at the vulnerability level to climate change. The various reports and advice from the agriculture officer and experts were considered in selecting the blocks. The villages were selected randomly from each block. Finally, the households were selected using a random walk method (Kersting and Wollni, 2012; WHO, 2007). This method refers to a type of random sampling wherein random numbers determine the number of paces between sample points. In which direction to move is also determined randomly by tossing a coin.

4.2.5 Data collection

The survey questionnaire was pretested and validated. The questionnaires were sent to two experts working in agriculture and resource economics and with experience in the field survey. After finalizing the questionnaire, we pretested it by undertaking a pilot survey. Pretesting the questionnaire helps increase the validity and reliability of the survey evidence. The questionnaire was comprised of a wide range of sections, i.e., general household information, information on land and cropping patterns, information on income and yield, perception of climate change, adoption of various CSA practices, access to various govt schemes including credit and subsidies, information on household assets position, input and output marketing challenges and challenges related to the adoption of CSA practices. We have also asked about the farming characteristics such as farm size, cropping pattern, production, adoption of CSA practices and its barriers. Further, various government extension services such as training, subsidies, crop insurance, and access to credit were included. To know the farmers' perception of climate change, questions on the perception of an increase in temperature, a decrease in rainfall, and an increase in drought and flood were included in the questionnaire.

The surveys were administered in the local languages (Odia, Sambalpuri) with the assistance of data enumerator staff and two friends. On average, completing each survey took between 45 minutes and one hour. On the survey sheet, the interviewees' responses were recorded. The inform consent was taken before the interview of each household.

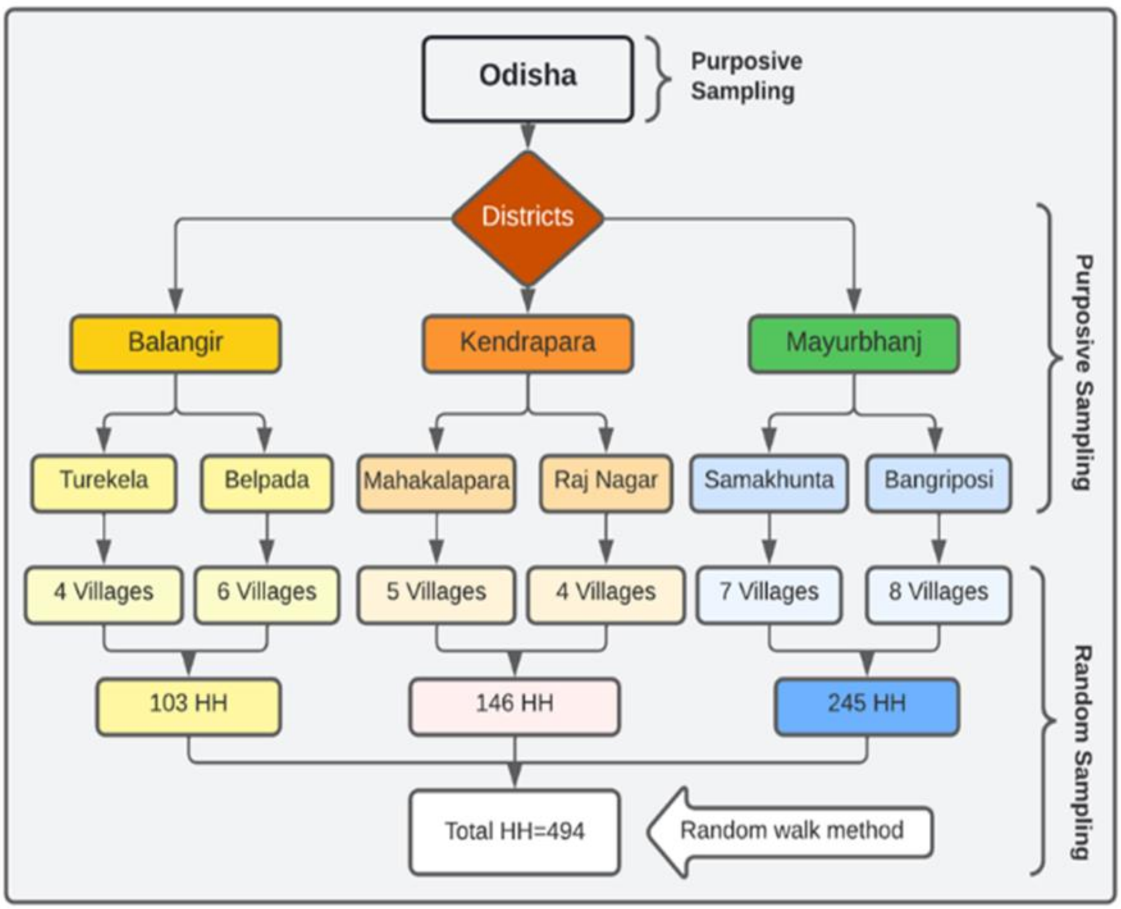


Figure.4.4 Study Design "(Source: Authors own creation)

4.3 Analytical and Econometrics Model

The determinants of CSA adoption were analysed using a Multivariate Probit Model. As a qualitative choice model, the farmer's option to adopt CSA practices is discrete. Crop diversification, drought-resistant seeds, soil conservation, rescheduling planting, crop rotation, and agroforestry have been taken as dependent variables. These six dependent variables are binary in response: the responses from farmers who adopt one of the CSA practises take value 1, and others take 0. This model simultaneously analyses the influence of explanatory variables on each dependent variable (adoption of CSA practises). It allows the unobserved and unmeasured factors (error terms) to be freely correlated (Greene, 2000). Complementarities (positive correlation) and substitutability (negative correlation) between different options may be the source of the correlations between the error terms (Belderbos et al., 2004).

The univariate logit and probit models may generate biased estimates in the multiple dependent variables model. The univariate methods assume the independence of error terms for the different adoptions of CSA practices, whereas a farmer may adopt various CSA practices. There may be a chance that one adoption could influence the decision to adopt other CSA practices, so univariate models are not appropriate enough to be used in this study. Farmers use a basket of CSA practices in farming activities to cope with the effects of climate change on agriculture (Aryal et al., 2020; Mittal and Mehar, 2016). Some practices are complementary, and some practices are substitutable with each other. This study uses multiple equations to determine the relationship between multiple dependent variables and independent variables.

Let us assume that the i^{th} farm household (i =1, 2…N) is deciding on whether to adopt j^{th} adoption strategies, where j denotes choice from among crop rotation (C_r), crop diversification (C_d), rescheduling planting (Rp), drought-resistant seeds (D_r), soil conservation (S_c) and agroforestry (A_f). Let us assume that the benefit derived from the machinery with or without adoption will take U_o and U_j, respectively.

So, a farmer decides to adopt the j^{th} CSA practice if their benefit with adoption (U_j) is higher than the benefit without adoption (U_0). Define $B_{ij}*$ as the difference between U_j and U_0; however, one of them is the actual outcome, and the other is it's counterfactual,

$B_{ij}* = U_j - U_o$.

If we write the equation into the observed binary outcome, our equation for each CSA adoption will be:

$$B_{ij} = \begin{cases} 1\ andif\ B^*_{ij} > 0 \\ 0\ andotherwise \end{cases} \boldsymbol{j} = (R_p, C_r, C_d, D_r, S_c, A_f) \ldots\ldots (4.1)$$

Finally, the multivariate model is

$$B_{ij} = X'_i\beta_j + \varepsilon_i \; (j = R_p, C_r, C_d, D_r, S_c, A_f) \ldots\ldots (4.2)$$

where $B*_{ij}$ is the latent adoption variable, X'_i is a vector of explanatory variables such as household socio-demographic characteristics, institutional factors and climatic factors, β_j is the coefficient, and ε_i is the error term. The error terms jointly follow a multivariate normal distribution in the multivariate probit model with zero conditional mean and variance normalized to one. There is an asymmetric variance-covariance matrix of the error terms.

4.3.1 Description of the Variable:

The adoption practices are identified from the pre-field visit and the farmer's field observation. Further, with consultation from Block Extension Officers, the selection of dependent variables has been fixed. We have included other adoption variables in our study; however, the popular and largely used by the local farmers are considered for the study analysis. The important CSA practices followed in the study areas are described in Table 1.

Table 4.2. Definition of the CSA practises or Dependent Variables

Adoption Strategies	As Defined in This Study
Rescheduling planting	Due to uncertainty of the onset of monsoon, farmers do alter the planting dates. It is being rescheduled to prevent the delayed commencement and irregularity of the monsoon season. Sometimes, farmers reschedule too early and sometimes late to the planting dates (Singh et al., 2018; Panda et al., 2013).
Crop rotation	Crop rotation is an agricultural technique involving the sequential cultivation of various crops in a field over time, aiming to improve soil quality and reduce pest and disease problems. This technique is widely employed in Odisha, particularly in the Balangir District. Its primary goals are to increase crop yield, maintain soil fertility, and reduce dependence on synthetic inputs. In accordance with the following sequence, the agricultural practice of crop rotation is implemented in this region. Pulses follow Paddy cultivation, then back to paddy, and subsequently followed by ginger and groundnut cultivation. (Abegunde et al., 2019).
Crop diversification	Crop diversification involves simultaneously cultivating multiple commodities on the same plot of land. Diversifying crops reduces the susceptibility of crops to pests and diseases, increases food security, and helps producers earn more money. Farmers in this region cultivate ginger and niger alongside pulses (Jha et al., 2018).

Soil Conservation	Soil conservation refers to practices that prevent soil erosion and degradation, maintain or improve soil quality, and preserve soil fertility to guarantee sustainable crop production. Farmers practise terracing, afforestation, contour bunding, earth bunding, mulching and conservation tillage in the study region. Soil conservation also involves minimizing acidification, salinization, or other chemical contaminants to reduce erosional soil loss (Lobo et al., 2017; Singh et al., 2018).
Drought-resistant seeds	Drought-resistant seeds have been bred or genetically modified to grow successfully in arid conditions. These seeds can be planted in areas with insufficient water or irrigation, and they can still develop and produce a harvest despite the lack of water. In water-scarce regions that lack irrigation areas, farmers plant drought-resistant seedlings of short-duration varieties or early maturity variety seeds (Khatri-Chhetri et al., 2016).
Agroforestry	Agroforestry is a land management technique that involves the cultivation of crops and the planting of trees and shrubs. This method is also referred to as integrated crop and forest management. The system above exhibits multifunctionality in land use and can generate diverse benefits for the environment, society, and the economy. Agroforestry is a land management system that has been shown to mitigate soil erosion and enhance soil fertility (Jhariya, 2019).

Source: Authors' preparation

Following the previous literature, the explanatory variables are constructed and given in Table 2.

Table 4.3. Explanatory Variables

Category	Variables	Expected Outcome	Sources
Institutional	Govt. extension	+	(Azadi et al., 2019; Bryan et al., 2013; Jha et al., 2021)
	Training	+	
	Farmers to farmer Extn.	+	
	Training	+	
	Machinery/ Seed subsidies	+	
	Cooperative society	+	
	Credit from a public bank	+	
Perception of climate change	Temperature is increasing	+	(Carlton et al., 2016; Funk et al., 2020)
	Rainfall is decreasing	+	
	Droughts and floods are increasing.	+	
	Experienced shocks	+	
Access to energy	Multiple/ Electricity/Kerosine /Diesel	+	(Jain et al., 2015; Ngigi et al., 2017)
Household Attributes	Age of the HH.	+/-	(Abid et al., 2015.Musafiri et al., 2022; Bryan et al., 2018; Tripathi et al., 2017)
	Education of the HH.	+	
	Years of farming	+	
	Household size	+	
	Social category	+/-	

Source: Compiled by the Author

4.4 Results and Discussion

4.4.1 Adoption of CSA

Figure 4 indicates that 74.5% of farmers used rescheduling planting, 62% practised soil conservation, 59.3% practised crop rotation, 36% adopted drought-resistant seeds, 31.2% practised crop diversification, and 10.3% followed agroforestry across the study districts.

Rescheduling planting is a practice in which the planting date varies to avoid a delayed monsoon. Farmers adjust the planting dates to avoid yield damage, lowering the water management cost. From our sample, 74.6% of farmers in the Balangir district and 70% of the Mayurbhanj district practised rescheduling planting due to the delayed Kharif season monsoons[3]. About 83% of the respondents of the Kendrapara district planted early to avoid flash floods during the harvesting season. Farmers in the upper region follow late paddy planting, whereas the farmers from the lower region move the paddy planting forward to earlier dates. We observed that the floods and cyclones affected farmers regularly, keeping the less fertile land barren during the Kharif season and cultivating it during Rabi.

Seasonal or annual crop rotation entails the switching of crops in the field. It is an essential component of CSA since it helps maintain soil health, control pests and weeds, and maintain soil organic matter. Around 59.3% of our sampled farmers followed the crop rotation across the three districts. The highest number of respondents from the Mayurbhanj district (65%) practised crop rotation, followed by Balangir (62%) and Kendrapara district (48%). The farmers from the Balangir district follow rice-vegetable, rice-oil seeds, maize-pulse or oilseeds and fibre-pulse crop rotation systems annually. At the same time, the farmers in Kendrapada follow crop sequences such as jute-rice-pulse and rice-green gram/black gram/groundnut. In the Mayurbhanj district, the rice-mustard/ linseed/Bengal gram/safflower/black gram/lentil/green gram crop rotation system is followed annually.

[3] There are two main crop seasons in Odisha namely, Kharif and Rabi seasons. While Kharif is the season of summer crops such as paddy, cotton, maize, groundnut, and sugarcane that are water-intensive, winter crops such as paddy, wheat, lentils, bengal grams, millets, peas, and potatoes are grown in the Rabi season which requires cold weather and a moderate water supply.

Around 31.3% of farmers in the study district followed crop diversification. Paddy is a dominant crop in the study districts, but paddy production and profit are not up to the mark due to climate uncertainty and market conditions.

So, along with paddy, farmers diversified to pulses, fibre and oilseed crops. It helps to reduce the risk by growing multiple crops. If one crop is damaged due to weather or pest-related shocks, the recovery could be made from another crop. Besides engaging in livestock production and fisheries, farmers grow sugarcane, oilseeds, cotton, and horticultural produce. The highest percentage of farmers (57.28%) were found to be practising crop diversification in the Balangir district, followed by Mayurbhanj (28.57%) and Kendrapara district (17.12%). Farmers of the Balangir district diversified towards pulses (urad, moong, tur, and other pulses), oilseed (groundnut) and fibre crops (cotton) along with paddy.

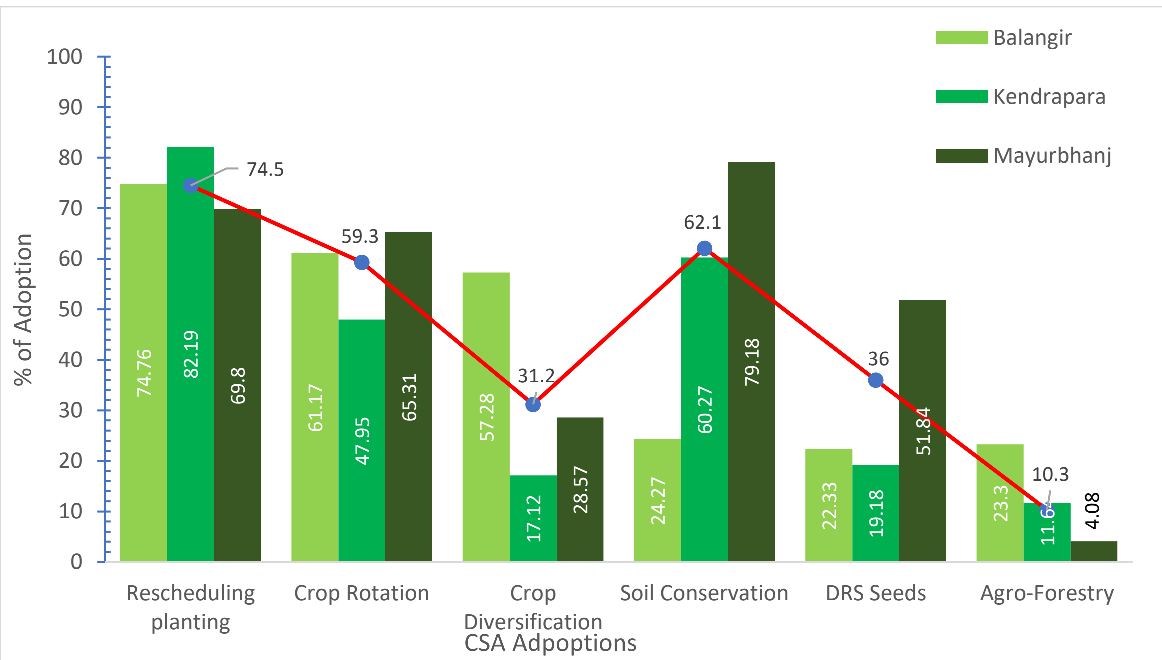


Figure 4.5 Adoption s of CSA Practices across the District

Farmers of the Mayurbhanj district followed the five most concentrated crops: paddy, black gram, horse gram, green gram and maize. The respondents adopted soil conservation measures such as gypsum application, enhancing the height of field bunds, mulching and crop rotation. The scrubs are planted, and stone bunds are constructed along the fence of the farm plots to restrict soil erosion. The highest number of farmers who adopted soil conservation are from the Mayurbhanj district, followed by Kendrapara and Balangir districts.

Farmers have used short-duration variety seeds, also known as early maturity variety seeds, to mitigate the drought condition in the study area. On average, 36% of the farmers used drought-resistant seeds. Early maturity paddy varieties, namely, Swarna sub-1, MTU-1010, Lalat and Konark, were used on the medium-altitude land, whereas Khandagiri, Heera, Kalinga-III, and Vandana varieties were adopted in high-altitude land. Paddy varieties such as Swarna, Sub-1, CR-1014, Durga, Sarala, SR-10, Sonamani and Lunishree were adopted in the low-altitude land.

About 10.3% of the respondents followed the agroforestry practices across the study districts - 23.3 % from the Balangir district, 11.64% from the Kendrapara district, and 4.08% of farmers from the Mayurbhanj district. The trees such as mango, cashew, guava, teak and eucalyptus were planted in the uplands and on the bunds and ditches. The plantation of coconut-based agroforestry is predominantly found in the coastal Kendrapara district. The plantation of Bambusa nutans tress is primarily located in the Mayurbhanj district.

4.4.2 Socio-Demographic Characteristics

Table 3 shows the descriptive statistics of the sampled households. The land size operated by the farmers in the study region is observed to be 3.41 acres on average. The farmers have, on average, 25 years of farming experience, the highest farming experience being 65 years and the lowest being 1 year. The average age of the interviewed respondents is 51 years, and the average years of schooling are seven years, which shows that the household head has attained at least upper primary school. The surveyed households rear, on average, six livestock.

There are four broad social categories of farmers in the study region. Among them, 29% are General, 44% are OBC, 7% are Scheduled Caste, and 18% are Scheduled Tribes .About 70 % of farmers responded in the affirmative that they receive climate information and government extension support from the government. Climate information includes disseminating information on expected seasonal rainfall and temperature, monsoon onset time, and predicted climate extremes like flood and drought. Agricultural extension services cover the demonstration, plant protection, soil health, and market information. Access to extension services across the districts has reflected in Figure 5. Agricultural extension sources include field officers, mobile, radio, and television. 31% of the farmers received training and demonstration from the allied state agriculture department, such as Krishi Vigyan Kendra (KVK), Agricultural Technology Management Agency (ATMA), and NGOs. Farmers engage in collaborative and participatory farming, which helps them share relevant information and technological know-how. About 52% of the farmers followed their peers and neighbours to operate agricultural activities and adoption.

The state government provides subsidies for machinery, seeds, and fertilizer. Farmers get a 50% subsidy for the tillers and 40% for the tractors in Odisha. They must purchase the machinery using their funds, after which the subsidy amount is transferred directly to their bank accounts through DBT (Direct Bank Transfer) Mode. Govt. of Odisha provides certified seeds to the farmers at a subsidized rate at the beginning of the cropping season. However, farmers are dissatisfied with mistiming the supply of subsidized seeds. Often, the subsidized seed would be in short supply when farmers needed them, and when the seeds were finally available, it would be too late as the farmers would have finished planting by purchasing them from the open market. So, the subsidy does not serve the purpose of helping needy farmers. We used machinery and seed subsidies as two explanatory variables. It has been noted that 28% of the respondents got machinery subsidies, and 40% obtained seed subsidies.

The respondents received agricultural credit from state-owned banks, cooperatives, and private banks. Around 46% of farmers obtained credit via cooperative societies, commonly known as primary agriculture cooperative societies (PACS). Nearly 24% received credit from public-owned banks such as the State Bank of India, Canara Bank. Most of the rural farmers get loans from regional rural banks such as Utkal Grameen Bank. Farmers usually get credit by using their land records as security. Farmers with larger landholdings can receive a higher credit limit for their agricultural activities. On average, farmers travel 6.2 km to the input market from their homestead and 13 km to reach the nearest agricultural extension office, the "block agriculture office." They visit the extension office to get crop advisories, access different agriculture schemes and receive training from the extension officers. Energy availability near the agricultural field helps farmers for better adoption. The lack of surface irrigation facilities and adequate rainfall makes farmers largely dependent upon the groundwater and local water bodies for irrigation. Around 17.2% of farmers use multiple energy sources, and 43% do not have any energy source for irrigation purposes. While 14% of farmers used diesel for irrigation, 22.5% of farmers have access to electricity near their agricultural fields.

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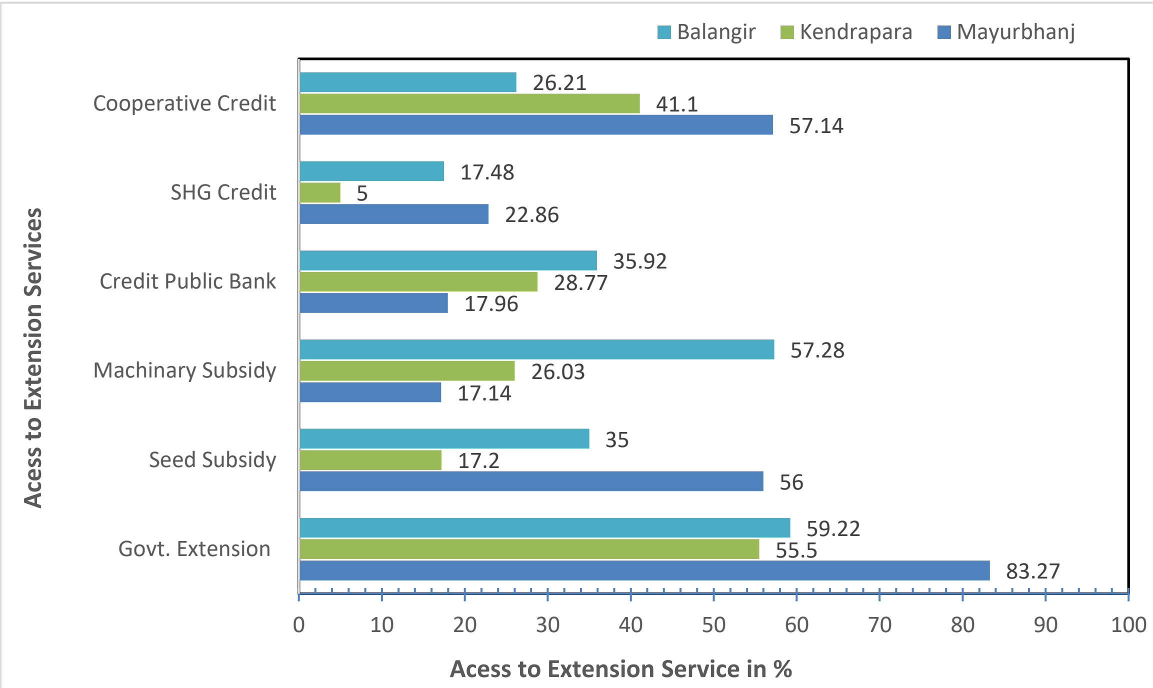

Figure 4.6 Access to extensions services (*Source* -Own calculations)

4.4.3. Perceptions of Climate Change and Climatic Shocks

Figure 6 depicts the percentages of farmers who believe that climatic factors have changed during the past 15 years. Most farmers are affected by summer temperature, winter temperature, rainfall intensity, rainfall frequency, droughts, cold waves, heat waves, and floods. About 85% noted that temperature has increased over the summer season, and 76% believed rainfall has decreased during monsoon. Because the survey location is in drought and flood-prone zones, 53 % of farmers believe droughts in their region have increased, and 41 % believe floods occur frequently. The state meteorological department sends farmers updates on climatic variability via text messages and brief phone calls.

Regarding climatic shocks in the last five years, 56% of the farmers have experienced drought, while 25.5% have experienced floods and submergence. We examined and validated whether these perceptions correlate with the meteorological data of the study districts. In the appendix, we reported Odisha's drought, flood and cyclone events in the past 20 years [Table A1]. The average temperature and rainfall data of the three districts from 1993 to 2018 are given in Figures 7 and 8.

The perception of an increase in temperature aligned with the average temperature of the Balangir district but not for Kendrapara and Mayurbhanj. The mean temperature of the Balangir district has increased in the last 20 years, whereas the mean temperature of Kendrapara and Mayurbhanj has decreased. It is confirmed that the perception of decreasing rainfall is also aligned with the monthly average rainfall data trends. Figure A.2 shows a decrease in the average rainfall from 1980 to 2017 for Balangir and Mayurbhanj districts. The perception of a decrease in rainfall is high among Balangir and Mayurbhanj farmers. The average rainfall trend for the Kendrapara district has increased over the year. The historical data of natural calamities in Table 4.1 correlates with the perception of increased drought and flood events in Odisha, but the perception of a decrease in precipitation does not match the farmer.

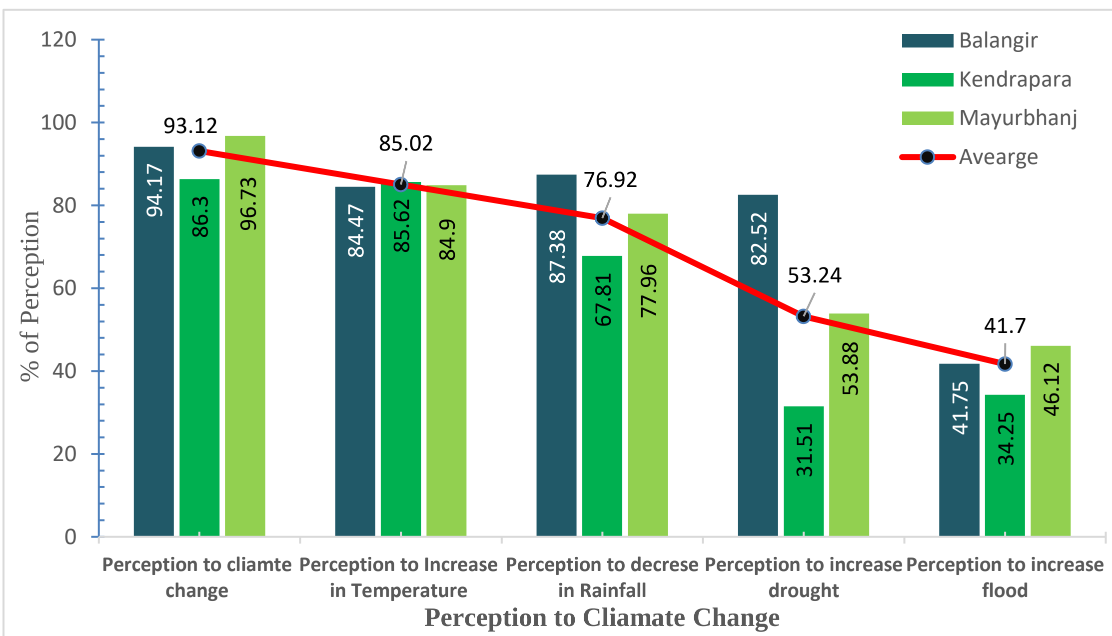

Figure 4.7 Perception of Climate change among the rural farmers

Table 4.4. Descriptive Statistics

Variable	Description	Mean	Std. Dev.	Min	Max
Rescheduling planting	Binary: 1 If the farmer is adopted, 0 otherwise.	0.745	0.436	0	1
Crop Rotation	Binary: 1 If the farmer is adopted, 0 otherwise.	0.593	0.492	0	1
Crop Diversification	Binary: 1 If the farmer is adopted, 0 otherwise.	0.312	0.464	0	1
Soil Conservation	Binary: 1 If the farmer is adopted, 0 otherwise.	0.621	0.486	0	1
DRS Seeds	Binary: 1 If the farmer is adopted, 0 otherwise.	0.360	0.481	0	1
Agroforestry	Binary: 1 If the farmer is adopted, 0 otherwise.	0.103	0.304	0	1
Land Size	Farm Land Size (in acres)	3.41	2.53	0	15
Farming experience	Continuous: in years	25.538	12.781	1	65
HH SIZE	Continuous: in Numbers	4.895	1.655	1	11
Age	Continuous: in years	50.735	11.727	18	82
SHG	Binary: 1 If the farmer is a member of SHG, 0 otherwise.	0.711	0.454	0	1
Govt. Extn	Access to Govt. Extension (Dummy, yes=1, no=0)	0.700	0.459	0	1
Farmers to Farmer Extn.	Contact with peer farmers (Dummy, yes=1, no=0)	0.522	0.500	0	1
Training	If farmer gets training (Dummy, yes=1, no=0)	0.314	0.464	0	1
Migration	If farmers migrate for work (Dummy, yes=1, no=0)	0.261	0.440	0	1
Education	Continuous: in years	7.781	5.371	0	17
Machinery Subsidies	If farmer avails machinery subsidy (Dummy, yes=1, no=0)	0.281	0.450	0	1
Seed Subsidy	If farmer avails seeds subsidy (Dummy, yes=1, no=0)	0.401	0.491	0	1
Cooperative Credit	If farmer avails credit from cooperative society (Dummy, yes=1, no=0)	0.460	0.499	0	1
Credit from Public Bank	If farmer avails credit from public banks (Dummy, yes=1, no=0)	0.249	0.433	0	1
Perception to increase in temperature	If farmers perceive to increase in temperature (Dummy, yes=1, no=0)	0.850	0.357	0	1
Perception to decrease in Rainfall	If farmers perceive to decrease in rainfall (Dummy, yes=1, no=0)	0.769	0.422	0	1

Perception to increase in drought	If farmer experiences drought (Dummy, yes=1, no=0)	0.532	0.499	0	1
Perception to increase in flood	If farmer experiences flood (Dummy, yes=1, no=0)	0.417	0.494	0	1
Experienced Drought	If farmer experiences drought (Dummy, yes=1, no=0)	0.559	0.497	0	1
Experienced Flood Shock	If farmer experiences flood (Dummy, yes=1, no=0)	0.255	0.436	0	1
Livestock	Continuous: in Numbers	6.433	9.362	0	68
Distance to Market	Continuous: in K. M	6.248	3.850	0	18
Distance to Extension Office	Continuous: in K. M.	13.09	9.197	3	42
General	If farmer belongs to General ((Dummy, yes=1, no=0)	0.18	0.38	0	1
OBC	Binary	0.381	0.486	0	1
SC	Binary	0.067	0.250	0	1
ST	Binary	0.368	0.483	0	1
Multiple Energy Source	If farmer uses multiple sources of energy in Agriculture (Dummy, yes=1, no=0)	0.172	0.378	0	1
No-access to any Energy	Binary	0.4251	0.494	0	1
Kerosine	Binary	0.038	0.193	0	1
Access to Diesel	If farmer uses diesel for irrigation (Dummy, yes=1, no=0)	0.140	0.347	0	1
Access to Electricity	If farmer uses electricity for irrigation (Dummy, yes=1, no=0)	0.225	0.418	0	1
Mayurbhanj	If farmer belongs to Mayurbhanj district ((Dummy, yes=1, no=0)	0.496	0.500	0	1
Balangir	If farmer belongs to Balangir district ((Dummy, yes=1, no=0)	0.209	0.407	0	1
Kendrapara	If farmer belongs to Kendrapara district ((Dummy, yes=1, no=0)	0.295	0.456	0	1

Total Sample:494

4.5 Determinants of CSA Adoption

The findings of the multivariate probit model are shown in **Table 4.6.** This model examined the factors influencing CSA practices: crop rotation, crop diversification, soil conservation, rescheduling planting, drought-resistant seeds, and agroforestry.

We calculated the pairwise correlation coefficient to measure the degree of association between various CSA practices. The correlation coefficient of error terms derived from the MVP model estimate is shown in **Table 4.5**. The likelihood ratio and chi-square tests reveal that the model fits our data pretty well, rejecting the null hypothesis that all regression coefficients are collectively equal to zero. The Likelihood ratio test indicates that at least one covariance of the error term is statistically significant, implying that the model equations are connected and indicate the use of the MVP model than univariate models. The likelihood ratio statistics show that the direction of influence for most independent variables is as expected, and the variables explain the model sufficiently. The positive correlation between error terms reveals a complementarity between adopting CSA practices, while the negative coefficient shows substitutability. Soil conservation is positively correlated with rescheduling planting, crop diversification and crop rotation, which indicates that these practices are adopted in conjunction. Drought-resistant seeds positively correlate with crop rotation and soil conservation. However, other potentially omitted factors may have affected all adoption decisions.

4.5.1 Perception of Climate Change and Experience of Climatic Shocks

Climatic change awareness and timely information on climate variability positively correlate with adopting CSA practices and technologies. Farmers who have access to climate and weather information become more aware and knowledgeable about the changes in rainfall and temperature. This helps them make an informed choice about how to adapt to climate change and become more resilient. The monsoon rainfall is the mainstay of Indian agriculture. The meteorological department in India predicts the onset of the monsoon. If the monsoon season is delayed, farmers constantly updated on weather reports.

Table 4.5. The Correlation Coefficient of Error Terms Obtained from the MVP Model Estimation

Binary Correlation	Correlation Coefficient	Standard Errors
rho21	-0.128	0.084
rho31	0.022	0.086
rho41	0.134	0.082
rho51	0.069	0.084
rho61	0.634***	0.118
rho32	0.274***	0.082
rho42	0.091	0.081
rho52	0.168**	0.080
rho62	0.096	0.111
rho43	-0.107	0.083
rho53	-0.110	0.087
rho63	0.0707	0.119
rho54	0.240***	0.075
rho64	0.0350	0.115
rho65	0.053	0.118

a) Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho61 = rho32 = rho42 = rho52 = rho62 = rho43= rho53 = rho63 = rho54 = rho64 = rho65 = 0: Model chi2(15) = 54.7235, Prob > chi2 = 0.0000

b) The numbers in rho refer to 1 = Rescheduling Planting, 2= Crop Rotation, 3= Crop Diversification, 4= Soil Conservation, 5= DRS Seeds, 6= Agro Forestry

c) Standard errors in parentheses, *Significant at 10%level; **Significant at 5% level; ***Significant at 1%

are more inclined to reschedule their planting dates. Farmers perceiving a decreased rainfall are also likely to adopt soil conservation and agroforestry practices. Farmers who perceive an increased temperature are more likely to adopt CSA practices. The perception of increasing temperatures significantly influences the adoption of rescheduling planting, crop rotation, soil conservation, and drought-resistant seeds. The perception of increased floods significantly impacts the adoption of rescheduling planting, crop rotation, and drought-resistant seeds. Farmers who perceive increased drought events are more likely to adopt crop diversification. They used to minimize the risk of crop damage by diversifying the crop into multiple categories. Farmers who foresee a rise in flood disasters are more prepared to adopt several CSA practices, such as rescheduling planting dates, crop rotation, drought-resistant seeds, and agroforestry. These findings align with (Nyang'au et al., 2021; Tessema et al., 2013; Hirpha et al., 2020; Deressa et al., 2011; Funk et al., 2020).

4.5.2 Access to Extensions Services

Besides crop diversification, access to government extension services significantly impacts all adoption practices. The government of India has launched a scheme, namely "Support to State Extension Programmes for Extension Reforms", in collaboration with the state government of Odisha from 2005-06. The extension support operates with different levels of institutional mechanisms such as state, district, block, and village levels. The State Level Sanctioning Committee (SLSC) was set up to approve the State Extension Work Plan (SEWP), which is part of the State Agriculture Plan (SAP). The district-level organization works to ensure the delivery of extension services to farmers and to check the overall policy direction. At the district level, an autonomous registered society called "ATMA" (Agricultural Technology Management Agency) provides farmers with direct extension support. ATMA disseminates the technologies to farmers through an institutional arrangement and participatory model. Block Technology Team comprises agriculture officers and other allied departments within the block. The Block Farmers Advisory Committee prepares the Block Action Plans (BAP) and provides necessary extension support directly to the farmers. The Farmer Friend (FF), input dealers, Village Agriculture

Workers (VAWs), and Agriculture Overseers (AOs) work at the ground level to serve as a vital link between the extension system and farmers.

The extension's support is primarily driven by mobilizing farmer groups, farmers' training, exposure visits, and conducting demonstrations. Extension support to farmers, agricultural demonstrations at the local level, low-cost publications, information exchange via printed materials, and the development of technology packages in electronic form are included.

Farmers who receive government extensions significantly impact rescheduling planting dates, crop rotation, soil conservation, drought-resistant seeds, and agroforestry. Farmer-to-farmer extension services include information sharing and collaborative engagement. The peer effect has a significant positive impact on agroforestry. Other government supports, such as subsidies and credit programs, will likely enhance the adaptive capacity to adopt CSA practices. Farmers with continued access to extension services are more likely to integrate horticultural crops with traditional grains and pulses to diversify their farm income. Our model's access to the agricultural extension variable measures how often a respondent engages with extension officers. The more interaction there is, the more probable CSA practices will be adopted. The positive impact of extension service on CSA adoption was also found in other studies (Abid et al., 2015; Khan et al., 2020; Tripathi et al., 2017).

However, heterogeneity persists in the farmers' information dissemination and extension support. Many farmers were unaware of the extension facilities that were available to them. Lack of education and awareness kept them away from access to extended support. Lack of working staff, lack of monitoring of field staff's work, delayed distribution of inputs (fertilizer, seeds), and focus on only a few progressive farmers are the barriers to accessing extension services in the study area. Farmers had reported that few influential farmers get continuous support, but the poor and marginal farmers fail to get extension support.

Agricultural input machinery subsidies significantly impact the various adoption techniques used by farmers (Amadu et al., 2020). Seed subsidies enable crop diversification, crop rotation, and the adoption of agroforestry. Suppose farmers could get seeds subsidies and seed supply from the government, which could help the likelihood of adopting crop diversification, crop rotation and agroforestry. Access to machinery subsidies has a significantly positive impact on crop diversification. Farmers who use farm machinery are likely to adopt multiple crops. Using farm machinery could save the time and labor of the farmer. Access to credit from cooperative society has a statistically significant negative effect on the adoption of rescheduling planting. The possible reason could be that access to credit from cooperative society helps farmers access irrigation during delayed monsoon. So they are less likely to reschedule planting. Distance to the input and output market doesn't significantly influence adoption activities in our study. But the distance of the extension office has a significantly negative impact on the adoption of drought-resistant seeds and rescheduling planting. A decrease in distance to the extension office will likely increase the adoption of drought-resistant seeds and rescheduling planting. Our result aligns with the study of (Aryal et al., 2020) in the Indo-Gangetic Plains of India.

Being a member of an SHG group significantly positively impacts adopting drought-resistant seeds. The SHG groups supply the seeds and fertilizers in the study area, which helps the farmer adapt. Membership in SHG allows farmers to get long-term loans, which could help them purchase drought-resistant seed varieties (Khatri-Chhetri et al., 2019). Membership in a cooperative society doesn't significantly impact adopting any practices. The possible reason could be that the credit farmers are getting spent on other household activities rather than agricultural ones.

4.5.3 Energy Use and Adoption of CSA

There is a surge in energy use in Indian agriculture. Being a rainfed system, a decrease in average rainfall over the last decade has created a water crisis in the study region and has increased the demand for higher energy use in irrigation. The use of diesel and electric pumps is rising, especially on a rental basis. Access to energy positively affects crop rotation, diversification, and agroforestry adoption. Access to multiple energy sources will likely adopt crop diversification and agroforestry among the farmers. Those who used diesel as an energy source for farming operations adopted crop rotation, crop diversification and agroforestry.

4.5.4 Other Determinants Factors

Our model includes both age and age square to identify the influence of age on the adoption of CSA practices. Age has a statistically significant positive effect on soil conservation, whereas age square negatively impacts it, meaning relatively older farmers are more likely to adopt soil conservation. Further, it shows that an increase in the household head's age would increase the probability of soil conservation.

Livestock acts as a coping financial asset for farmers during a financial emergency. They sell their animals and invest in addressing climate-related risks. A farmer that produces animals has a significant positive impact on crop rotation, crop diversification, and soil conservation. Framers with livestock could sell their livestock and generate income to diversify their production basket (Khatri-Chhetri et al., 2019).

The land size has a significantly positive impact on adopting crop rotation, crop diversification and soil conservation. Farmers who cultivate a large patch of land are likely to diversify their cropping pattern to reduce the damage due to climate-induced events. The farmers had larger landholdings that were likely to adopt agroforestry in their surplus land. The size of land holdings also determines the amount of credit a farmer can access. If land holdings are large, they are likely to get more credit from the financial institution and could invest it for multiple CSA practices (Tanti et al., 2022; Aryal et al., 2018).

Seasonal migration has a negative and significant impact on adopting soil conservation. It could be the lack of time and resources to maintain the ditches and fields to make soil conservation. There is a mixed result with India's seasonal migration and adoption decisions (Aryal et al., 2018).

4.6 Discussion

The current study shows that the household head's age, education, access to extension service, training, livestock ownership, agricultural subsidies, awareness of climate change, and use of energy in agriculture influence the adoption of climate-smart agricultural practices.

Farmers linked with government policies and programs are likelier to adopt multiple CSA practices, such as crop diversification and crop rotation. Crop diversification is quite popular in the Balangir district, where farmers cultivate multiple crops such as paddy, cotton, and vegetables. Adopting multiple crops is a risk-hedging strategy in which if climate variability adversely affects one crop, other crops can still contribute to household income. It has been understood that farmers in the Balangir district shifted to cotton from paddy after frequent droughts. Low input cost, easy procurement of cotton in the local market, the establishment of cotton mills nearby, and high selling prices have attracted the farmers to shift to cotton cultivation. It is observed that farmers do integrate farming with crop diversification in the Kendrapara district. Farmers usually construct a small pond in their fields for fish cultivation, which can help them generate off-farm income and provide water for irrigation during water stress. Farmers who receive extension services also integrate horticultural crops to diversify their farm income. Farmer's field school and government extension outreach are instrumental in higher adoption rates. Our findings align with other studies (Abid et al., 2015a; Aryal, Sapkota, Rahut, et al., 2020; Khan et al., 2020; Tripathi and Mishra, 2017) who observed the positive impact of extension service on CSA adoption.

The awareness about climate change and regular information on climate variability has a positive association with adoption. Similar results were reported by Jha et al. (2018) and Zamasiya et al. (2017). Farmers who receive regular updates from the regional meteorological centres are more likely to adopt modern practices. Other studies have also found similar results (Belay et al., 2017; Singh, 2020). Migration has a positive and significant impact on crop rotation and drought-resistant seeds. Farmers do not migrate in the *Kharif* season due to high value-added crops and more labor requirements. They migrate in the *Rabi* season to earn off-farm income in the urban centres. These findings are in line with Belay et al. (2017).

From the findings of drivers of the adoption of CSA practices, we observed that access to extension services is a key driver. Rural farmers possess traditional knowledge of several adoption practices to cope with changing weather, pest disease, water run-off, and soil contamination. However, these traditional ways of dealing with such challenges become inadequate in the face of rapid climate extremes, which have become common due to climate change. Hence, a mix of traditional and modern practices can be the solution for effectively adopting climate change. Extension service is highly effective in providing information and technical training to adopt certain CSA practices. Soil conservation practices were demonstrated by the extension officers in the study region. During our qualitative data collection regarding expert and focus group discussion, we learned that a group of farmers from each village turned up for extension meetings and field demonstration training programs. These farmers could be termed as 'progressive farmers'. During the early drives of extension meetings, these farmers showed interest in participating and became regular visitors to such extension programs. They subsequently tried to train others in the village; however, certain personality traits such as innate abilities, risk preferences, and work ethics play a role in such peer-to-peer extension dissemination.

Farmers with continued access to extension services are more likely to integrate horticultural crops with traditional grains and pulses to diversify their farm income. Access to the agricultural extension variable used in this study measures how often a respondent engages with extension officers. The frequency of extension engagement decided the adoption rate of CSA practices. Several existing studies establish the positive impact of extension services on CSA adoption (Abid et al., 2015; Khan et al., 2020; Tripathi et al., 2017).

However, large heterogeneities among the farmers' communities prevent deep penetration of CSA activities, limiting potential benefits. Technology adoption requires a threshold level of understanding among the farmers. There are rural hinterlands in the study region where farmers could not understand even very basic concepts of soil management. The government of India launched a subsidized program termed ‘soil health program’ in 2016, through which soil samples from farmers’ plots are tested, and crop selection advices are given based on the test results. From our FGDs, we learnt that about half of the farmers approached were not interested in such soil tests. Lack of primary education is still prevalent in many parts of rural India, where farmers are not inclined toward new practices. Due to rough geographical terrains, it is also difficult for extension agents to travel to these hinterlands. Extension services are ineffective due to insufficient coordination between farmers and technical staff. Especially, challenges were faced during subsidy disbursement drives wherein funds were not available when farmers needed them. Such incidents created mistrust among farmers towards the official and government schemes. Such mismanagement also created adverse selection and moral hazards. Our expert group interviews with the extension official found that the interested and serious farmers withdrew from government subsidy schemes due to a lack of timely availability of seed, fertilizer and machinery subsidies. Eventually, the wasteful and casual farmers obtained the subsidy when it finally arrived, and they spent it away on non-agricultural activities. This happens quite often in many parts of the country.

4.7 Conclusion and Policy Implication

This study explored the factors influencing farmers' adoption of CSA practices. The findings show that farm-level adoption involves multiple adoption practices. The prime adoption practices include rescheduling planting, soil conservation, crop rotation, crop diversification, drought-resistant seeds and agroforestry. We conducted questionnaire surveys with 494 rural farmers of Odisha, collecting data on their CSA adoption strategies and their key determinants to adopting CSA practices. The study's empirical findings reveal that the key determinants of adopting specific CSA technologies are: perception of climate change, extension services, and access to energy.

This study asserts that most farmers know about climate change and its adverse impact. They rely heavily on their climate projections derived from traditional knowledge, information from extension agents, and information shared within their peer network. Those respondents who have experienced climatic shocks and perceive that such events will occur in the future are more likely to adopt rescheduling planting, crop rotation, crop diversification, soil conservation, and drought-resistant seeds. The study recommends that government and extension partners prioritize awareness creation on climate change information and weather events.

The key driver for adopting CSA practices among rural farmers is access to extensions service. Crop advisory, crop management training, demonstrations, farmers' field schools, machinery subsidies, seeds subsidies, and access to formal credit helps rural farmers enhance their adaptive capacity. Furthermore, access to and availability of irrigation energy sources positively affects the farmers' adoption behaviour. Access to electricity near the farming field helps farmers adopt multiple practices as the irrigation cost becomes less. Government subsidies on electricity consumption and infrastructure at farmers' fields can boost the adoption. Crop rotation and crop diversification are the main CSA practices for farmers with access to electricity for irrigation.

The study findings also reveal the barriers to the adoption of new technologies. The first and the most frequently encountered impediment to adoption was a lack of financial resources. Agriculture credit is offered based on the size of landholdings in the formal credit market. Due to farmers' marginal landholdings, they could receive a small amount of credit from banks, which was insufficient to cover the farming operation. Additionally, the formal credit institution blocklists a few farmers for past loan defaults and nonpayment on time. Due to the higher interest rates charged by non-formal lenders, farmers hesitate to obtain credit. They stated that if they get loans from non-traditional lenders, a significant portion of the profit is spent repaying the higher interest rate.

Second, a lack of efficient extension services, coordination between farmers and technical staff, and timely subsidy disbursement creates obstacles to adopting sustainable agricultural practices. While some farmers receive weather-related information, they cannot apply it due to insufficient in-hand training. The lack of information on updated adoption technologies, training, and field demonstrations presents a barrier to CSA adoption. Several farmers feared adopting new techniques, assuming they would lose all their investments when something went wrong. The information on crop insurance schemes is not frequently disseminated. Farmers were unaware of the premiums they would have to pay and the crop insurance benefits they would receive in case of crops failed. Their lack of comprehension of the schemes' details, the insurance process's complexity, and the non-renewal of previous insurance policies contributed to their ignorance of crop insurance. It made them less confident in the adoption of new practices. Finally, underdeveloped output markets pose a key barrier to adopting CSA practices. The farmers are enthusiastic about adopting crop diversification, crop rotation, and switching to a new variety of crops; however, they withdraw from such activities due to insufficient market access and a low price for the final product. In the short run, government support may be needed to nurture the adoption goal among resource-poor farmers; however, bottom-up initiatives from the grassroots level are required to establish a climate-smart agricultural system in the long run.

Table 4.6. Multivariate Probit Model Results

Variables	Rescheduling Planting	Crop Rotation	Crop Diversification	Soil Conservation	Drought Resistances Seeds	Agroforestry
Total area cultivated	-0.019	0.083**	0.074**	0.071**	0.031	0.121
	(0.029)	(0.029)	(0. 028)	(0.030)	(0.027)	(0.037)
Farming experience	0.008	0.0003	-0.009	-0.007	-0.003	-0.005
	(0.007)	(0.006)	(0.007)	(0.006)	(0.006)	(0.009)
HH size	-0.008	-0.005	0.014	0.007	0.039	-0.060
	(0. 041)	(0.040)	(0.043)	(0.042)	(0.040)	(0.063)
Age	0.039	-0.032	0.030	0.080*	0.030	0.005
	(0.043)	(0.042)	(0. 043)	(0.042)	(0.040)	(0.582)
Age2	-0.0004	0.0003	-0.0003	-0.0006*	-0.0004	-0.00002
	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0006)
Member in SHG	0.261	-0.051	0.004	-0.199	0.303*	0.280
	(0.166)	(0.154)	(0.162)	(0.158)	(0.157)	(0.229)
Govt Extn.	0.329*	0.320**	0.078	0.380**	0.291*	0.460*
	(0.166)	(0.149)	(0.163)	(0.158)	(0.162)	(0.226)
Farmers to farmer Extn	0.260	0.265	0.128	0.178	-0.161	0.557**
	(0.205)	(0.189)	(0.201)	(0.192)	(0.191)	(0.275)
Training	0.040	-0.069	0.264	-0.116	0.046	0.018
	(0.163)	(0.153)	(0.166)	(0.163)	(0.150)	(0.230)
Migration	0.091	0.230	0.061	-0.315**	0.111	-0.030
	(0.167)	(0.151)	(0.166)	(0.155)	(0.155)	(0.220)
Education	0.006	-0.009	0.005	0.003	0.019	0.002
	(0.013)	(0.012)	(0.013)	(0.013)	(0.013)	(0.019)
Machinery subsidies	0.064	0.266	0.280*	0.108	0.161	-0.118

	(0.177)	(0.163)	(0.166)	(0.168)	(0.167)	(0.237)
Seed subsidy	-0.111	0.657***	0.538***	-0.100	0.111	0.831***
	(0.158)	(0.149)	(0.157)	(0.156)	(0.149)	(0.221)
Co-operative society	-0.270*	0.133	0.138	0.134	-0.121	0.180
	(0.155)	(0.138)	(0.152)	(0.147)	(0.142)	(0.204)
Credit from a public bank	0.275	0.194	0.144	-0.085	-0.261	-0.133
	(0.172)	(0.156)	(0.162)	(0.157)	(0.162)	(0.216)
Perception of climate change						
Increase in temperature	0.635***	0.381**	-0.394*	0.517**	0.400*	0.357
	(0.198)	(0.198)	(0.218)	(0.208)	(0.211)	(0.418)
Decrease in rainfall	0.375**	0.157	0.024	0.456***	-0.114	1.047**
	(0.178)	(0.168)	(0.183)	(0.173)	(0.173)	(0.373)
Increase in drought	0.141	-0.065	0.330**	-0.169	0.087	-0.328
	(0.157)	(0.147)	(.165)	(0.156)	(0.150)	(0.229)
Increase in flood	0.474***	0.275**	0.078	0.006	0.448***	0.508**
	(0.156)	(0.140)	0.148	(0.144)	(0.141)	(0.200)
Experienced drought	-0.288	-0.141	-0.751***	0.220	-0.143	-0.496*
	(0.159)	(0.149)	0.170	(0.154)	(0.149)	(0.237)
Experienced flood	0.511**	-0.015	-0.047	0.030	-0.070	-0.081
	(0.198)	(0.174)	0.185	(0.173)	(0.181)	(0.258)
Owns livestock	0.008	0.014*	0.019**	0.025***	0.006	0.008
	(0.008)	(0.008)	(0.008)	(0.009)	(0.007)	(0.011)
Distance to market	0.014	0.004	0.0006	0.010	0.028	-0.189
	(0.020)	(0.019)	(0.021)	(0.020)	(0.019)	(0.032)
Distance to the extension office	-0.018*	-0.002	0.008	0.006	-0.046***	-0.001
	(0.010)	(0.009)	(0.009)	(0.009)	(0.011)	(0.124)
OBC	0.053	0.033	-0.321	0.325	0.042	-0.055
	(0.233)	(0.199)	(0.219)	(0.198)	(0.211)	(0.280)

SC	-0.212	0.371	-0.014	0.039	-0.536	0.219
	(0.311)	(0.295)	(0.325)	(0.292)	(0.349)	(0.373)
ST	0.012	-0.006	-0.472	0.479**	0.131	-0.098
	(0.203)	(0.226)	(0.240)	(0.220)	(0.229)	(0.330)
Multiple energy sources	0.181	0.237	0.491**	0.064	0.299	0.541*
	(0.224)	(0.190)	(0.225)	(0.202)	(0.194)	(0.297)
Kerosine	-0.920*	-0.065	0.472	0.023	-0.191	0.318
	(0.370)	(0.351)	(0.376)	(0.436)	(0.425)	(0.583)
Access to diesel	-0.073	(0.815) ***	1.204***	-0.271	0.163	0.669**
	(0.224)	(0.222)	(0.226)	0.221	(0.207)	(0.336)
Access to electricity	0.115	0.522*	0.773***	-0.003	0.139	0.920***
	(0.203)	(0.188)	(0.201)	(0.196)	(0.187)	(0.276)
Kendrapara	0.754**	0.183	-0.009	-0.131	-0.423	1.856***
	(0.330)	(0.293)	(0.321)	(0.289)	(0.292)	(0.476)
Balangir	0.066**	0.231	1.273***	-1.601***	-0.671**	2.160***
	(0.295)	(0.261)	(0.274)	(0.268)	(0.263)	(0.383)
Constant	-2.174	-0.928	-2.160	-3.111	-1.653	-4.985
	(1.163)	1.133	(1.161)	1.145	(1.102)	(1.644)
Observations	494	494	494	494	494	494

f) Standard errors in parentheses

g) *Significant at 10% level; **Significant at 5% level; ***Significant at 1% level

h) Observations: 494

Log-likelihood = -1314.7206, Wald chi2(150) = 567.04

4.8 Role of Gender in Adopting Climate Smart Agriculture Practices and Challenges

Rural women are crucial in managing natural resources, the environment, and agriculture production. Compared to men, women face multiple challenges related to financial and resource constraints and lower access to information and extension services (Tall et al., 2014; Huyer, 2016). In the previous section, we discussed why women are less adaptive than men. However, some agricultural economists believe women are active agents in devising responses to climate change and adapting to its effects. (Denton 2002; Dankelman 2010; Huyer, 2016). Edmunds et al. (2013) believe that women's participation in advancing technology and management decisions could improve the positive outcomes of community activities and lead to gender justice. Anderson et al. (2011) argue for incorporating leadership from rural and Indigenous women to address water system infrastructure, quality, and security issues in rural regions. Female farmers have the potential to improve food security and increase their livelihood opportunities by expanding the cultivation of high-value crops (Quisumbing et al., 1996). Women engaged in agricultural activities play a crucial role in safeguarding biodiversity. The engagement of individuals in crop diversification and environmentally sustainable agricultural practices yields substantial advantages for the agricultural industry and the broader society (Nordhagen et al., 2021). Due to differences in both observable and unobservable characteristics of male- and female-headed families, there is a large gender gap in climate change adoption in agricultural households. It is suggested that closing the gap can boost female-headed families' climate change adoption by nearly 19% (Aryalet al., 2022).

The studies mentioned above provide evidence that gender plays a role in adopting climate-smart agricultural practices in various regions of the world. This study addresses the gender role in adopting CSA practices and the challenges farmers in the study district of Odisha face.

4.8.1 Methodology

The study of climate change is inherently multidisciplinary and requires collaboration across various fields within the physical and social sciences (Berrang-Ford et al., 2015). The primary aim of conducting a focus group discussion (FGD) is to gain insights and understanding on a specific topic. The utilisation of this tool enables the collaborative compilation and examination of data for various objectives, including the implementation of a specific innovation (Ndah et al., 2011), the evaluation of necessities (Tipping, 1998), and the assessment of programmes (Packer et al., 1994), among others. FGDs were considered appropriate methods for collecting high-quality data relatively quickly (Ritchie and Lewis 2003).

Qualitative data were collected in the study area through FGDs to investigate the impact of gender on the adoption of CSA among rural farmers. The FGDs aimed to gain insight into the perspectives of both males and females regarding climate change and their inclination towards embracing CSA techniques. The FGDs were conducted in 10 villages within the study area, with a participant count ranging from 12 to 15 individuals per village. The FGDs comprised household heads willing to participate and knowledgeable about the prevailing climatic conditions and associated adoption measures within their localities. The study's participants were 35- to 55-year-olds who possessed at least ten years of farming experience. To investigate perspectives on gender, distinct FGDs were held with male and female participants. The study was conducted during February and March of 2019. Participants were allowed to attend the study during their leisure time in the afternoon, specifically from 1 to 4 pm. Each FGD lasted for a duration of 60 to 90 minutes. The selection of the researcher and moderator from the same native state was made to facilitate effective communication and comprehension. Before initiating the discussion, the farmers were asked for their informed consent. The research personnel were introduced to the participants by extension agents operating within the local area. The effective communication facilitated a secure environment for the farmers to participate in the FGD and agree to be interviewed by us. The assistance of the indigenous data enumerators facilitated the discourse. The assistance of the local enumerators facilitated improved communication with the male and female members of the local community.

4.8.2 Livelihood and Food Security Issues

The districts of Balangir and Mayurbhanj have a large tribal population. Tribal populations rely on agriculture and forest resources for a living. The residents of these two districts make their living through agriculture and livestock. Male farmers, in general, choose agriculture as their primary source of income. The forest is a source of income for tribal farmers in Balangir and Mayurbhanj. Male farmers forage for wood, bamboo, and honey in the forest and sell them at a nearby market. Female farmers rely on the forest for their subsistence. Female farmers collect kendu leaf, jhuna, broomsticks, mahul, and other medicinal products from the forest. Some products, such as kendu leaf and mahul, are sold through cooperatives, while others are sold directly to customers in the nearest market. Traditionally, they relied on agriculture and forest resources for a living. However, slow agricultural growth and significant loss of forest cover (Mishra et al., 2022) have highlighted alternative employment structures that are insecure and unsustainable for these regions. The impediment to basic livelihood activities leads to distress migration and an increase in the region's poverty rate. The Balangir district continues to have a high inter-state and urban migration rate.

Farmers in Balangir complained that mechanization had reduced the hours they could engage as agricultural labourers. There are not enough Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) projects in the village to keep them employed. So, they are leaving the state and migrating to find employment elsewhere.

> *"In the Kharif season, we farm, and in the other seasons, we migrate to another place with the whole family to work in the brick industry," says one Balangir farmer. "By taking the whole family with us, we can earn more money, and after working for six months, we can return to our homeland.*

Therefore, we engage in seasonal migration as a means of income diversity," ***he added.***

Both male and female agricultural labourers participate in employment guarantee programmes such as MGNREGA. They participate in constructing village roads, ponds, and other infrastructure improvement projects within the village. A disparity in wages exists between male and female farmers in the area. A negligible disparity exists between the agricultural productivity efforts of males and females. The societal norms and patriarchal structure perpetuate a gender-based wage disparity for female farmers.

The inhabitants of Kendrapara district rely on marine-based livelihoods and non-agricultural employment opportunities. In the non-agricultural season, male farmers engage in fishing activities in both marine and freshwater bodies. Farmers who possessed boats exhibited greater resourcefulness compared to those who did not. However, some farmers work daily as fishing labourers and earn a restricted income. The alternate cohort of agriculturalists had procured rented boats to engage in piscatorial activities. Fishing served as a viable means of diversifying the livelihoods of the coastal farmers residing in the Kendrapara district. As reported, the Mahakalpara Block of Kendrapara district has experienced a growth spurt in the prawn industry. Farmers are employed as labourers in the prawn industry to support their livelihood. A small proportion of young members within households engage in inter-state migration, and they consistently provide financial support for agricultural pursuits within their families. Women engaged in agricultural activities in Kendrapara district tend to avoid leaving their residences for employment. Instead, they engage in domestic labour. Females engage in modest economic activities such as agroforestry, food preparation, aquaculture care and production, domestic poultry rearing, cultivation and selling of agricultural products from fields and homestead gardens, managing small-scale businesses, and labour in sectors other than agriculture.

The interviewed men and women reported that food security concerns their families. The climate hazards make them opt for off-farm income. Their off-farm income had to be spent on medical emergencies, fertilizers, seeds, and agricultural machine rent. However, they face food security issues due to low off-farm income and productivity during natural hazards. Due to inflation and low income, families reduce their consumption amount and change their consumption patterns. Households with low socioeconomic status experience limited availability of food resources, which increases their vulnerability to malnourishment. Child malnutrition is a prevalent health concern that increases susceptibility to mortality and morbidity related to infectious and parasitic illnesses. Access to safe water and sanitation remains fundamental for remote communities' necessities. However, the government-aided public distribution system and public health aids partially help them to recover from food insecurity.

4.8.3 Exposure to Climate Hazards and Impact on the Livelihood

The Indian Government's National Action Plan on Climate Change (NAPCC) acknowledges women as a particularly vulnerable group in climate change. The National Action Plan on Climate Change (2008: 14) specifies that ‘‘The impacts of climate change could prove particularly severe for women. With climate change, there would be increasing scarcity of water, reductions in yields of forest biomass, and increased risks to human health, with children, women and the elderly in a household becoming the most vulnerable . . . special attention should be paid to the aspects of gender.’’

The adverse impacts of climate change and natural hazards have devastated the economy of the Balangir and Kendrapara districts. The farmers in these two districts were negatively affected by the extended drought, cyclone, and flood events that the region witnessed. The FGD findings indicate that small-scale farmers of both genders have noted increased climate change-related hazards. Male and female farmers are commonly exposed to natural hazards threatening their agricultural livelihoods. The farmers in these two districts have reported experiencing significant shocks such as droughts, heat waves, typhoons, outbreaks of pests and diseases, floods, and fluctuations in crop productivity.

The women farmers of Balangir district reported that due to the drought, they failed to work in the agriculture field, making them suffer the loss of wages, creating an imbalance in their family expenditure. The women head farmer was the family's sole bread earner through agriculture, so the loss of yield due to drought made them incur financial losses and face livelihood issues. Due to drought events, women farmers had the burden of financial credit. Due to the lack of land rights, the women farmers depended on informal credit, where they were charged a heavy interest rate. So, loans from informal credit sources pushed them into more financial distress. The women farmers dependent upon the forest-based off-farm livelihood lost their way of earning. Due to drought events, forest-based products became unavailable, so the women farmers lost their livelihood. Both men and women who responded said they experienced social and health-related issues, such as disruptions in their children's education, financial difficulties, and the need to take out loans. Women described how illness outbreaks among children and household members were frequent during extreme events.

Balangir women farmers *shared how drought and water stress in the area force them to migrate with their families. They added that it was extremely difficult for a woman to migrate to different places with small children.*

The landless farmers of Balangir *stated that the drought affects them the most because if their crop is lost due to natural hazards, their landowners do not consider the loss. They demand money or product, so they must migrate to compensate for the loss and repay their share to the landowners. The landowners also do not allow the tenant to claim crop insurance.*

The farmers of Kendrapara were also facing distress due to climate change. Farmers have discussed in FGD that the lack of water management, irrigation facilities, and drainage have been hit hard due to agricultural practices. Rivers and tributaries flow into the district. However, due to a lack of proper planning, farmers cannot get water during the cultivation period, and instead, they get flash floods during harvesting.

> ***A farmer from Kendrapara said****, "Pests and diseases have increased a lot in the current period; pest attacks have become a threat to our yield. Government should assess the loss it and should give compensation."*

***Another farmer from Mahakalpara of Kendrapara said**, "The saline water and high tide is a challenge for us; I sowed paddy seeds and transplanted saplings. The hope to get good yield was destroyed due to seawater entering our fields because of a damaged saline stone bund."*

***Another farmer commented on the man-made hazard,** "The increase of prawn industries in their area and the release of toxic and chemical water into the canal, combined with farmers doing irrigation, causes damage to the agricultural field and river water as well."*

***Another farmer in Kendrapara District's Rajnagar Block stated** sea erosion was a major issue in their area. Due to rising sea levels, the sea has washed its pasture and agricultural land away. Previously, people kept milch animals for milk. People used to keep livestock because there was pastureland available. Still, due to erosion, people have reduced their livestock and milch animal keeping, and the production of milk and dairy products has been reduced. It also posed a problem for livelihood diversification.*

***According to a farmer from the coastal areas of Kendrapara District**, "the sea level is rising, extreme weather events, and changes in ocean currents have become a problem for fishing, causing a loss of livelihood."*

4.8.4 Change in the Gender Role of Farming Practices

The primary objective of this chapter is to investigate the impact of gender on the adoption of CSA practices. The probit regression model did not incorporate gender as a determinant of CSA adoption decisions because approximately 90% of the households in the sample reported a male member as the head of the household. Nevertheless, it is common for women to engage in agricultural activities within farming households. Despite patriarchal cultural practices prevalent in developing countries, women members make significant contributions to agriculture, even though they are typically not regarded as household heads. In the study area, it was observed that predominantly male members assume the role of the head of the family. A female member heads a mere 10% of households, and even in such cases, women do not exercise full autonomy as household heads. The male members of the family assume financial authority. The Government of Odisha has implemented a policy to allocate 30% of women farmers' seats in agricultural training programmes. However, extension officers have reported that women's participation in these programmes is infrequent due to the male-dominated societal structure and the responsibility of household chores. Male members attend the training programmes on behalf of the female farmers.

Based on the findings of the FGDs and field observation, it has been noted that male and female farmers assume distinct roles throughout all phases of agricultural activities. The influence of gender in a farming operation is supported by factors such as the farmers' income, education, and social background. Farmers with greater wealth and larger landholdings tend to employ male and female labourers in agricultural activities. Farmers from the general caste do not involve female members in agricultural activities. Instead, they alter the farming patterns of both male and female members by engaging women from other communities as agricultural labourers. Both male and female farmers from the SC
Table 4.7 displays the gender roles associated with various agricultural operations, ranging from tillage to harvesting. Typically, male farmers are responsible for performing land preparation tasks. According to female farmers, tillage is typically carried out by their male counterparts. However, they have not attempted to undertake this task due to the challenges associated with operating machinery without proper training and support. The perception among female farmers that tillage is a practice primarily reserved for male farmers can be attributed to inadequate training and prevailing social norms.

Table 4.7: Diversity of Agriculture Operation across Gender in Odisha

Source: Authors' observation in the field

Agriculture Operations	Male Farmers	Female Farmers	Both
Land preparation (Tillage)	✓		
Seedbed preparation			✓
Marketing seeds and fertilizer	✓		
Apply fertilizer as a basal dose	✓		
Uprooting of seedling		✓	
Transporting seedlings to the main plot			✓
Sowing/transplanting	✓	✓	
Fertilizer as a top dressing	✓		
Inter-culture/ Beushening			✓
Weeding		✓	
Irrigation	✓		
Watching crop	✓		
Harvesting		✓	✓
Threshing			✓
Bagging, storing, transporting			✓
Marketing			✓
Major activities and decisions were taken for agriculture operations.	✓		

Typically, male head farmers hire only male farmers for this activity. Both males and females carry out seedbed preparation. The task of tillage is done independently, while female head farmers enlist the assistance of other farmers. Male farmers typically cultivate paddy crops using suboptimal seeds,

while male and female farmers cultivate non-paddy crops, including vegetables, fruits, and cash crops. The male farmers in the family purchase inputs such as seeds, fertilizers, and machinery. Due to the distance factor, the women farmers could not access the input stores, so they took help from the male farmers to purchase inputs.

Female farmers engage in three primary agricultural activities. Female farmers typically engage in activities such as uprooting seedlings, transplanting, weeding, and harvesting crops. Mostly male farmers carry out the agricultural activities mentioned above in the Kendrapara district. During the FGD, it was reported that female farmers engage in these activities in exchange for daily wages or labour exchange. In rural regions, labour scarcity necessitates households to exchange labour to expedite agricultural operations. According to the farmers, their primary tasks involve the application of fertilizers, irrigation of the land, managing diseases and pests, and protecting crops from wild animals. Currently, farmers are utilizing various types of machinery for agricultural practices. Post-harvesting management is crucial for farmers to avoid post-harvest losses. The women farmers help to clean the threshed paddy and other vegetable crops. The male farmers package the harvested crops and store them in a proper place. Both male and female farmers engaged in marketing. If the yield is more, the male farmers take the responsibility to sell the crop, whereas if the quantity and distance to the market are less, the women farmers also take it to the market. The tribal women farmers sell small products in the local market. They sell the product as retail marketing, where consumers directly buy products from them.

An interesting observation is that transplanting and harvesting were regarded as celebratory occasions among women residing in rural areas. During this period, individuals perceive an opportunity to engage with other female peers, facilitating discussions and exchanging views on diverse topics. Tribal women farmers have been observed to perform a unique song ritual during their transplanting period. According to a female farmer, engaging in agricultural work provides relief and enjoyment, reducing their burden.

> ***According to a Village Extension Officer****, "female farmers are equally capable as male farmers, and in fact, they exhibit greater dedication towards their work. During extension meetings, female farmers listen attentively to the information provided and apply it to their agricultural practices. Notwithstanding, the female farmers' limited exposure to technological advancements and educational opportunities, coupled with language barriers, restricts their ability to embrace innovative agricultural technologies. Conversely, their male counterparts enjoy greater exposure to alternative sources of information. Consequently, individuals attempt to take advantage of different methods of adoption."*

The present study reports that the female farmers hailing from the Balangir district exhibited knowledge of crop diversification and its advantages. The individuals encourage their partners to engage in the cultivation of both cotton and paddy crops to mitigate the potential for crop failure. Likewise, female farmers hailing from Kendrapara engage in integrated farming practices. The local population participates in agricultural activities such as livestock husbandry, fisheries, and cultivating horticultural crops and paddy.

Women farmers reported that they are more interested in seed selection and storage. They have practised exchanging seeds with their neighbours, using local varieties, and storing seeds in proper containers. They advocated that these practices helped them to maintain crop diversity and reduce the risk of crop failure due to extreme weather events.

Farmers, both men and women, agreed that it was easier to take care of livestock in fields during disasters and droughts. Backyard chickens and goats can be used as security against droughts and storms. They are also cheaper and require less labour. During natural hazards, crops do not grow, and it is easy to get cash by selling livestock at local markets.

The women expressed satisfaction with being part of a social group, specifically a Self-Help Group (SHG), which facilitates their access to agricultural credit, subsidies, and training. Periodically, they were given opportunities to engage in field exposure visits to observe and acquire knowledge on innovative farming practices in the context of climate change. Social groups facilitate the adoption of CSA practices systematically, thereby empowering individuals to do so. The female farmers within a social collective have implemented organic farming techniques. The female farmers have devised their methods of producing vermicompost and organic manure to improve the soil quality. Female farmers engaged in seed purification before transplantation within the rural community. In addition, they bought substantial machinery, including a tractor, and launched a rental service for fellow farmers, thereby generating supplementary income.

4.8.5 Barriers to the Adoption of CSA among Women Farmers of Odisha

The issue of land ownership presents a significant obstacle to the adoption of CSA practices among rural women of Odisha. The land records officially bear the names of male individuals. A large percentage of male individuals migrate to different states to diversify their means of livelihood. Without a male head, the wife encounters significant challenges accessing extension services. Women farmers who lack official possession of land face challenges in obtaining loans from financial institutions, which results in their reliance on local money lenders who charge high-interest rates.

Moreover, the physical accessibility to the market is limited among female farmers in Odisha. The inability of female farmers to access long-distance markets can be attributed to entrenched social constraints. The limited availability of access deprives them of ample opportunities to vend their produce at a justifiable cost. The limitations mentioned above impede their ability to obtain inputs from remote markets, even if they are readily available. Tribal women can traverse great distances to sell their crops, particularly vegetables, at the marketplace.

Female farmers comprise a substantial segment of the labour force in Odisha, serving as agricultural workers. Female workers receive lower wages than their male counterparts, allegedly due to the assumption that they cannot operate large-scale equipment. In certain instances, male and female farmers engage in equivalent agricultural tasks; however, male farm labourers receive higher wages than their female counterparts. Male farmers are predominantly engaged in the activities of ploughing and tilling. After the initial stage of agricultural production, female farmers engage in various farming activities, including but not limited to planting, sowing, weeding, harvesting, and post-harvest processing. The disparity in wages between male and female agricultural workers serves as a hindrance for women seeking to enter the agricultural sector.

Based on the findings of the FGDs, it was noted that among the households sampled, in a majority (72%) of the cases, male members were responsible for making significant decisions about farming activities. In contrast, female members were responsible for decision-making in only 8% of the households. In comparison, in the remaining 20% of the households, both male and female members shared the responsibility of making major decisions related to agricultural activities. Gender-based disparities exist in members' perspectives, with males prioritizing higher income generation and females prioritizing food balance and security.

Women's "monthly sickness" (menstrual or period pains) makes them physically weak, which affects their farming plans and times. Men in the house do not understand this problem. Women can only farm in the late afternoons and evenings because they have to care for their homes, while men can farm in the mornings and during the day. When preparing the land, women said they have less energy than men, so they only plant, weed, harvest, and sell their crops. Social stratification and restriction in patriarchal society imply that women farmers are not allowed to be exposed to work among the higher classes in society.

4.9 Conclusion

This sub-chapter explains the multidimensional effects of climate change on male and female farmers in climate-induced vulnerable areas of Odisha. The FGD in the study area reflected the qualitative understanding of climate change, adoption and barrier nexus across gender in rural Odisha. The discussion with male and female farmers revealed the livelihood impact due to climate change. Climate-induced hazards and poor socioeconomic status, including the study district's farmers, made the community vulnerable. Both male and female farmers were facing prolonged droughts, frequent floods, and pest and disease attacks were the major factors in the loss of livelihood among the rural farmers of Odisha. The discussion established that climate change, rural migration, and financial distress were interconnected. Female head farmers were more vulnerable than males due to gender inequality, credit constraint, lack of access to resources, and social restrictions.

Further, this chapter shows the gender roles in the execution of agricultural activities. The patriarchy-dominated agricultural sector gives freedom to male farmers to take the major decisions of farming activities. Female head farmers could not take the proper decision without male support. With proper support from peer farmers, the government, and the family, women farmers could adopt CSA practices more intensively than men. Women farmers in Odisha face several obstacles, including a lack of access to land, credit, and technology. Despite the social, economic, and environmental challenges, the rural women farmers adopted climate-resilient agricultural practices to increase productivity and adapt to climate change. They have used climate-resilient agricultural practices such as drought resistance seed, agroforestry, conservation agriculture, and off-farm livelihood diversification.

Policymakers should consider a gender-inclusive analysis and identify the fundamental vulnerabilities of women producers. Focusing on marginal women smallholder producers, including enhancing agricultural livelihood opportunities, is essential. Incentives, public safety networks, subsidies, and compensation schemes should be coordinated. The government should promote women farmers by providing them with financial incentives and all ground-level extension support. Help should be extended to women farmers to enable them to incorporate cutting-edge agricultural technology into their practices.

CHAPTER 5

IMPACT OF CSA PRACTICES ON HOUSEHOLD INCOME AND AGRICULTURAL YIELD

5.1 Introduction

From 2016 to 2021, natural disasters such as cyclones, flash floods, floods and landslides resulted in crop damage on more than 36 million hectares of land, causing financial losses of around $3.75 billion for farmers in India. The annual damages caused by river flooding in the country are expected to increase by about 49% if the temperature increases by 1.5°C. In comparison, the damage caused by cyclones is projected to increase by 5.7% (The Hindu, 2022). So, at this highly vulnerable stage, climate-smart agricultural (CSA) practices have the potential to increase productivity, strengthen resilience to climatic shocks and reduce greenhouse gas emissions (FAO 2011). CSA emphasizes food and income security in the era of advancing climate change and variability by developing resilient agricultural production systems (Vermeulen et al., 2012; Lipper et al., 2014).

CSA practices benefit private and public entities by increasing the farmers' productivity and income. They also maintain food security and eradicate poverty among rural farmers. As a public benefit, CSA tends to mitigate climate change in the environment by reducing the release of greenhouse gas emissions (Branca et al., 2011; Pretty, 2008). Many studies have established the triple-win nature of CSA adoption: production, mitigation and income in developing and developed countries (Makate et al., 2017; Xiong et al., 2014; Challinor et al., 2014; Mungai et al., 2016; Lan et al., 2018). CSA practises have been sustainable and environment-friendly and have enhanced yield and income (Wekesa et al., 2018; Makate et al., 2018; Ali et al., 2018).

In India, a limited number of research studies have examined the effects of CSA on the well-being of households. These studies have found that implementing practices such as improved crop varieties, laser land levelling, and zero tillage can lead to an overall increase in production in the rice-wheat system in the Indo-Gangetic plain region of the country.

The adoption of these CSA practices has a significant impact on the reduction of the cost of production (Khatri-Chhetri et al., 2016). Conservation agriculture (CA) and improved livestock husbandry have improved food security for large and medium-scale farmers in Bihar, India (Lopez-Ridaura et al., 2018). Measures to conserve soil and water have positively affected farm productivity and income in the semi-arid region of Bundelkhand in central India (Choudhary et al., 2022). Soil smart practices such as regular soil bund reduce the chances of downside risk, i.e., crop failure (Kumar et al., 2020). Adopting crop-smart and water-smart strategies meets several objectives of the SDGs (Qureshi et al., 2022).

Due to climate change, catastrophic weather events such as floods and droughts are becoming commonplace, greatly increasing the unpredictability of agricultural output in Odisha (Mishra et al., 2016). Due to regular shocks in agriculture, crop loss, poor harvests and unpaid bank credit, a few farmers have even committed suicide in Odisha (Mohanty et al., 2019; Pattanayak and Mallick, 2016). One of the major issues with rice production, particularly in the rain-fed lowland areas of Odisha, is flash floods that wash away rice plants for 10–15 days. The paddy crop fails due to irregular rainfall and delayed southwest monsoon in the inland districts of Odisha. However, the farmers of Odisha are changing the nature of agricultural production. To cope with climate change, they are switching from conventional farming to CSA practices (Tanti et al., 2022). Farmers of Odisha are gradually adopting a basket of CSA practices such as rescheduling planting, crop rotation, crop diversification, drought-resistant seeds and smart soil practices (Sahu and Mishra, 2013).

No significant micro studies have captured the impact of the adoption of CSA practices in the vulnerable regions of Odisha. It has been proposed in many empirical studies that researchers should investigate the difference in income and yield that exists between small-scale farmers who adopt CSA practices and those who do not adopt them. This could provide information about the benefits derived from taking steps to adapt to climate change. The main research question addressed by this chapter is: How does CSA adoptions impact paddy yield and farm income in rural Odisha?

Given the above background, this research primarily focuses on assessing the effects of implementing CSA practices on the yield of paddy and the income of households, which provides a valuable addition to the existing literature. The rest of the article is organized as follows. The literature review section discusses the importance of CSA practices for sustainable agricultural development (See Chapter 2). It also reviews some smart practices and technologies that potentially impact the farmers' welfare. The materials and method section discusses the study area, sampling method, selection of variables and econometric estimation techniques. Next, the results (descriptive and regression) are presented and discussed in section four. We have concluded the chapter in section five by providing a summary and a few policy implications.

5.2. Materials and Methods

5.2.1 Study Area

Odisha, one of the states in eastern India, was selected as the area of study. Odisha's economy is based mostly on agriculture and farming. About 83% of its population is from a rural background, and about 61.8% of its 17.5 million people work in the agricultural sector, with 18% of the state's GDP coming from the same. A sample of three districts has been drawn for the impact analysis. Four hundred ninety-four household observation data from the three study districts of Odisha is used to assess the impact of CSA on income and yield. The description of sampling and data collection is discussed in Chapter 4. The following sections discuss data description and the econometrics method used for the impact analysis.

5.2.2 Data Description

5.2.2.1 Endogenous Variable/Adoption Variable

We required a specific data set for the econometrics analysis: we took two endogenous variables, which were different adoption strategies followed by the farmers. The endogenous variables had two household groups: the adopter group and the non-adopter group, which was also the basis for our endogenous variable. The endogenous variables are binary: 1 holds if the household is an adopter of the specific CSA practice; otherwise, 0. As an endogenous variable, we took two popular CSA practices, crop rotation and integrated soil management practices in the region. We have selected these two CSA adoption practices based on the extension officers' recommendations and preliminary observations from the field.

5.2.2.2 Income and Yield

The total farm income of the household in a year was taken as a dependent variable in the study. We have calculated total farm income by adding the total net income self-reported by the household from the Kharif and the Rabi seasons. We have asked the household to report the total net income (total agriculture income in a year – total expenses incurred for agricultural operations). We have not included the secondary or off-farm income they receive from other sources. The significant income from paddy, maize, cotton and vegetables per annum was included. The dependent variable has been transformed using its natural logarithm to deal with the outliers in the sample, to make the data distribution smooth and to interpret the coefficient in percentage terms. Our second dependent variable is the total paddy yield. We have arrived at the total paddy yield by dividing the total paddy production in a year by the total cultivated land size. The cultivated land size is the summation of the total owned land holding and the land taken on lease for cultivation.

5.2.2.3 Instrumental Variables

We have followed previous studies for the two-stage least square analysis (Card, 1993; Cawley et al., 2018; Di Falco et al., 2011; Sellare et al., 2020) to identify the relevant instrumental variables. We have used two instrumental variables for our analysis: distance to the agriculture extension office from the household and percentage of multiple adapters in the village.

Our first instrument is the distance to the headquarters of the agriculture extension office from the household. The closer the extension office, the higher the chances for farmers to engage in agricultural activities. Also, the extension officers make frequent visits to the nearby villages. Hypothetically, we can conclude that the higher the interaction between the extension staff and the household, the greater the adoption of CSA practices among the farmers. Table 1 shows the negative correlation between the distance to the Block Extension Office and the adoption of CSA practices. There is no correlation between the instrument and outcome variable. Being nearer to the block extension office could be associated with easier access to inputs and knowledge. Proximity to the extension office helps to quickly acquire information related to climate change and sustainable agricultural practices. It allows the extension officers to observe the adoption activities and give feedback to the farmers.

The second instrument we have selected is the farmer-to-farmer extension (Cawley et al., 2018). Peer interaction has a positive impact on farmers' adoption practices. The village with more adoption density will tend to adopt positively. We have taken seven CSA practices and calculated the number of farmers doing multiple adoptions. The percentage of multiple adopters has been calculated by dividing the number of adopters who have done more than one adoption by the total number of farmers in the village. Table 1 shows that the instrument positively correlates with the endogenous variable, not the outcome variable. Both instruments were supposed to affect farmers' decisions about whether or not to adopt CSA practices, regardless of their attributes or how effectively their farms undertook these practices. These instruments are also used together to improve the estimation method.

5.2.2.4 Other Covariates

The aggregate value of the independent variables impacts all outcome variables. We have included household characteristics, farming experience and education of the household head as explanatory variables. We have used the following institutional variables: access to government extension, access to cooperative credit and access to subsidies.

We have constructed an index of agricultural machinery. The agricultural mechanization index[4] is constructed by accessing agricultural implements and machinery. This index is calculated by using Principal Component Analysis (PCA). The model uses the index indexes as controlled explanatory variables. These variables can impact farm performance. These controls help improve the exogeneity of the instruments. They reduce the impact of the error term on the instrumental variable.

5.2.3. Econometrics Specifications

5.2.3.1 Two-stage Least Square Method

Several problems are associated with assessing an impact study. The possible problems that arise with an impact study in agriculture development are endogeneity, information flow and market efficiency, government control and cyclical development of farmers (Birkhaeuser et al., 1991). Among them, endogeneity is a significant issue in the impact study. The endogenous variable correlates with the error term (Wooldridge, 2013). If the endogeneity arises, the estimated coefficient will be inconsistent and biased as the error term will influence its magnitude and not the dependable variable. So, necessary care

[4] Mechanization Index is constructed by using Principal Component Analysis and the following 8 Components are used for the analysis:
1. If own tractor drawn equipment=1, Otherwise 0
2. If own rice transplanter=1, Otherwise 0
3. If own chaff cutter=1, Otherwise 0
4. If own spray machine=1, Otherwise 0
5. If own sprinkler =1, Otherwise 0
6. If own harvester=1, Otherwise 0
7. If own water pump=1, Otherwise
8. If own tractor=1, Otherwise

should be taken to avoid the wrong interpretation of the study.

Cawley et al. (2018) discuss the causes of endogeneity issues in an impact evaluation model. The first one is the omitted variable bias, which creates a problem in representing the precise impact of an adoption technique. The impact of CSA would depend on a few farmers' inherent qualities, such as the farmers' innate abilities, effort, ambition or motivation. Still, this data has not been captured or observed. The second issue is the self-selection bias, a common econometric challenge that arises when conducting impact evaluations using cross-sectional data (Wooldridge, 2002). Generally, this problem occurs when participants enrolled in a typical development programme adopt practices the researcher does not observe. Not considering such omitted variables in the analysis can lead to a distorted estimation of the effects of the development programme being studied. If the selection bias is not identified, it will lead to endogeneity and inefficient estimations, which may lead to misinterpretations.

Self-selection bias is considered an overlooked methodological error, where the adopter intentionally decides to adopt the CSA practices or not (Nordin et al., 2017). Farmers could select the adoption practices by unobservable characteristics of the farmer that may influence their personality and willingness to adopt. A few external factors could also moderate the farmers to adopt practices not reflected in an exogenous variable setup. As the adoption of CSA practices is not undertaken randomly by the farmers but with the support of some agencies, agriculture extension services encourage selected farmers to adopt certain CSA practices on a targeted basis. A few farmers go in for adoption by observing others and experiencing it in their vicinity.

The endogeneity problem could be dealt with through various approaches. The Instrumental Variables (IV) technique is considered the most efficient in the impact evaluation paradigm. Identification and use of appropriate instrumental variables could help the problem of endogeneity. It could give unbiased estimates of the impact of CSA adoption. The selection of Instrumental Variables follows two basic assumptions. If it signifies these two assumptions, the instruments could be valid instruments for the impact analysis (Burgess et al.. 2016; Murray, 2006; Cawley et al., 2018). The first assumption is that there should be a significant positive correlation between the IV and endogenous variables. Secondly, IV should not correlate with the dependent variable and error term (valid). If a valid instrument is identified, we could compute a coefficient for the endogenous variable that is consistent and unbiased. The two-stage least squares regression (2SLS) method could be used for the analysis. It follows two stages of estimation. A predicted value is generated in the first stage by regressing the IV with an endogenous variable. Then, in the second stage, the predicted value is used as an exogenous variable and regressed with the outcome variable (Gujarati, 2003).

We use the following reduced-form equation for y_2; the first stage of the 2SLS method is to use the reduced form of the equation, which reflects the endogenous variable as the dependent variable.

$$y_2 = \gamma_0 + \gamma_1 z_1 + \gamma_2 z_2 + \gamma_3 z_1 z_2 + \gamma X + \nu_2 \text{ .... (1)}$$

In the above equation, y_2 is our endogenous regressor (Climate Smart Agriculture Practices). γ_k is our estimated coefficient parameter to estimate, z_k are our instrumental variables (z_1=Distance to Extension Office, z_2= percentage of multiple adapters in the village), X represents the vector of explanatory variables and ν_2 is the error term. The requirement of a positive correlation between z_k and y_2 confirms that the instruments rightly impact the endogenous regressor. From the first equation, the predicted values $\hat{y}$ are generated and substituted in the structural equation model 2.

Our second stage structural equation follows the following structure:

$$y_1 = \beta_0 + \beta_1 \hat{y}_2 + \beta X + u_1 \text{ .... (2)}$$

In the above equation, y_1 denotes the dependent variable (total agricultural income and paddy productivity), which is also an unbiased estimator. β_j is the estimated coefficient parameter, $\hat{y}_2$ is our replaced endogenous variable, X is the vector of all other explanatory variables, and u_1 is our error term. Post-estimation tests have been conducted to validate the model's and the instruments' significance. To determine the significant impact of instrumental variables on an endogenous variable, the Multivariate Cragg-Donald Wald F test has been conducted. The rule of thumb to determine the significance of the model and instrument is that the F-statistic must be greater than 10. The significant F-statistic validates the instruments as strong predictors of endogenous variables (Stock et al., 2002; Cawley et al., 2018).

Table 5.1: Correlation between Instrumental Variables, Outcome Variables and Endogenous Variables

	Multiple Adopter Percentage in Village	Distance to Extension Office	Net Agricultural Income (log)
Crop Rotation	-0.4432 (0.000) ***	0.4608 (0.00) ***	-0.0255(0.5733)
Crop Diversification	0.3710 (0.000) ***	-0.4241(0.00) ***	0.0459 (0.3083)
Improved Variety Seeds	0.4586 (0.000) ***	-0.5093 (0.00) ***	0.0014 (0.9745)
Integrated Soil Management	0.4815 (0.000) ***	-0.4337(0.000) ***	0.0144 (0.7508)

*Significant at 10% level; **Significant at 5% level; ***Significant at 1% level, p value in parenthesis

The Sargan statistic shows significant for the IV models, which evaluates the overidentification test of instrument validity and is a feature of the 2SLS method (Howley et al., 2015; Cawley et al., 2018).

5.2.3.2. Propensity Score Matching

Propensity score matching (PSM) is a popular impact evaluation technique used in research, including in recent studies such as Sellare et al. (2020), Vanderhaegen et al. (2018), and Akoyi and Maertens (2018). The PSM (Propensity Score Matching) model eliminates the self-selection bias caused by observable characteristics by pairing a subset that engages in adoption activities with a subset that does not possess similar observable characteristics. This approach ensures that self-selection bias caused by observables do not influence the results.

According to the desired outcome, two groups have been compared as adopters and non-adopters in shared assistance (Becker and Ichino, 2002). In the first-stage logit model of PSM, the adoption status of each farmer is regressed on the factors that potentially influence the choice to adopt CSA practices. PSM derives the propensity scores for each observation from this first-stage regression. Each farmer's propensity score assesses his inclination to undertake CSA practices. A propensity score (p-score) is generated; the score lies between 0 and 1. If the score is nearer to 1, then the farmer is likely to adopt CSA practices, and if the score is nearer to 0, then the farmer is less likely to adopt them. In the second stage of PSM, two balanced groups will be created based on their estimated propensity score. Various matching methods are used to create the balance group.

Various matching techniques are suggested in the literature, including kernel matching, k-nearest neighbour matching, Mahalanobis matching and radius matching (Pearl, 2009; Dehejia and Wahba, 2002; Heckman et al., 1999; Rosenbaum and Rubin, 1983). To estimate the ATT, we used the first three matching techniques: 1. nearest neighbour matching, 2. radius matching, and 3. kernel matching. The ATT captures the difference between an alternative outcome where the same households had not implemented CSA practices and an outcome by households that had adopted CSA practices. A t-test for statistical significance determines the difference between the matched treated and untreated observations in the PSM model. This test establishes whether the results obtained from the matched treated and untreated observations are statistically significant. The treatment works as expected if the difference is statistically significant and positive. Eliminating the potential bias that may have existed in the collected data is done by using sample probabilities from a logit model in the first stage and then determining the treatment and control groups based on these probabilities.

5.3 Results and Discussion

5.3.1 Descriptive Statistics

Table 2 shows the descriptive statistics of dependent, endogenous, instrumental and controlled variables. The total annual agriculture income from various crops reported by households is presented in rupees. The average farm income the farmers in the study region earns is INR 92,810.192. The highest income reported is INR 4,73,000, and the lowest is INR 2400. The uneven land distribution is an important causal factor for this income gap. The average paddy productivity is reported at 16.5 quintals per acre. The maximum paddy productivity reported is 31.2 quintals per acre, while the minimum is 7.5 quintals per acre. Farmers who use improved varieties of seeds and have suitable land for cultivation are likely to get higher productivity than those who use traditional varieties of seeds and depend on rainfed agriculture. Around 62% of the farmers undertake integrated soil management practices, while 59% have adopted crop rotation.

Seasonal or annual crop rotation entails the switching of crops in the field. It is an essential component of CSA since it helps maintain soil health, control pests and weeds, and maintain soil organic matter. The farmers from the Balangir district follow rice–vegetable, rice–oilseeds, maize–pulse/oilseeds and fibre–pulses systems of crop rotation annually. Farmers follow the crop sequence, such as jute–rice–pulses and rice–green gram/black gram/groundnut in the Kendrapada district. The rice–mustard/linseed/Bengal gram/safflower/black gram/lentil/green gram system of crop rotation is followed annually. Around 31% of the farmers in the study district followed crop diversification. Paddy is a dominant crop in the study districts, but due to climate uncertainty and market condition, paddy production and profit is not up to the mark. The farmers have adopted soil management measures such as gypsum application, enhancing the height of field bunds, mulching and crop rotation. Shrubs are planted, and stone bunds are constructed along the fence of the farm plots to restrict soil erosion.

The average distance from the sampled village to the Block Agriculture Extension Office reported is 13 km. The shortest distance covered is 2.5 km. The longest distance to reach the extension office is 30 km. It is a two-way process when farmers visit the extension office to get information about different schemes and programmes. Farmers also visit the office to get subsidies for seeds and other benefits given by the government. The block agriculture staff also visits the farmers. We learnt that the village-level agricultural worker visits the village and the fields twice or thrice weekly. The second instrumental variable used in the model is the percentage of multiple adopters in a village. An average of 64% of farmers follow multiple adoption practices. They practise at least two adoptions. This instrument will act as a peer effect in the model and encourage a maximum number of farmers to undertake multiple adoptions, thus triggering adoption by other farmers.

Farmers reported that 70% of them get access to extension services within the sample. Male-headed households constituted our sample, with their mean age of 50.7 years, and, on average, there were five members. Almost seven years of education had been attained by the family heads. Also, the mean cultivable land size within the sample was 2.8 acres, where an average of 19% of the land was irrigated, and 81% of the land depended on rainfed agriculture. About 59 % of the land had fertile soil. These lands have black clay and loamy soil, which can hold water and moisture. The black soil in the Balangir district is suitable for cotton cultivation.

5.3.2 IV Results – First Stage Results

The result of the first stage IV is presented in Table 3. This result confirms the instrument's relevance in the farmers' adoption decision. In our case, the endogenous variables that adopt CSA are jointly significant with the instrumental variables. Both instruments, individually and together, had significant explanatory factors in adopting CSA practices. Both instruments remain significant at the signs expected. A significant negative relationship exists between CSA adoption and the distance to the extension office. There is a positive and significant relationship between the percentage of multiple adopters and the adoption of CSA practices. The result is expected and significant when we take both instruments to curb endogeneity. But it could be seen that the coefficient became weak when we combinedly took two instruments. The Cragg-Donald Wald F statistic illustrates the joint significance of the instruments. In our case, some models' (Stock et al. 2002) limit of 10 is easily exceeded, and we can conclude that the instruments are relevant.

Table 5.2: Descriptive Statistics

Variables		**Mean**	**Std. Dev.**	**Min**	**Max**
Dependent	Net Agriculture Income (Log)	11.021	0.964	7.783	13.067
	Net Agri-Income/ Year	92810.192	85673.872	2400	473000
	Total Paddy Productivity	16.513	6.464	7.5	31.25
Endogenous	Crop Diversification	0.311	0.462	0	1
	Crop Rotation	0.587	0.493	0	1
	Integrated Soil Management	0.617	0.487	0	1
	Improved Variety Seeds	0.784	0.411	0	1
Instrumental	Distance to Extension Office	13.334	7.418	2.5	30
	Multiple Adopter Group 1	64.712	33.694	0	100
Controlled Variables	Total Area	2.872	2.223	0	8.75
	Farming experience	25.603	12.79	1	65
	Age	50.719	11.687	18	82
	Govt Extn	0.703	0.458	0	1
	Education	7.788	5.37	0	17
	Credit from Cooperative	0.462	0.499	0	1
	Access to Subsidies	0.281	0.45	0	1
	Access to Electricity	0.226	0.418	0	1
	Access to diesel	0.138	0.345	0	1
	Access to Kerosine	0.038	0.019	0	1
	Multiple Energy	0.165	0.375	0	1
	Mechanization Index	-4.01e	1.3779	-1.163	5.628
	Kendrapara	0.293	0.456	0	1
	Balangir	0.21	0.408	0	1
	Mayurbhanj	0.497	0.501	0	1

Total Sample Size: 494

5.3.3 IV – Second Stage Results

In the second stage of the IV process, the predicted values of the endogenous variables obtained from the first structural equation are included in the second structural equation model. This predicted value will work as an exogenous variable with the dependent variable in the second structural equation model. The main variable of interest is focused on and displayed in the result section, while the other control variables are ignored. The full table with control variables is attached in the appendix section. The main results of OLS estimates are highlighted to compare both results. There is a positive and significant impact of CSA adoption practices on the annual income of the farmers (Fentie and Beyene, 2019; Sadar et al., 2021). Since the measurement error does not influence the IV estimate, it typically has a larger value than the OLS estimate. The IV estimate is larger than the OLS estimate because IV estimates the local average treatment effect (ATE) (Oreopoulos 2006; Sadar et al., 2021). OLS estimates the ATE over the entire population. The OLS estimate shows no significant relationship between the exogenous and dependent variables. But with intervention IV, the model shows a positive and significant impact on the dependent variable (Abid et al., 2016).

Adopting crop rotation has a positive and significant impact at a 5% significance level. The farmers who change their crops and try different crops in the same plot over the year will likely get 42-52% more net farm income than their counterfactual. If a farmer diversifies the crop, then the farm income of adopters will be enhanced by 59% more than the non-adopters. But in case of crop diversification the f-statistics is lower than 10 shows the instrumental variables used are weak. So, the used IV in this model doesn’t predicts truly. Farmers who use the improved variety of seeds which gives both yield and safeguard from climate-induced hazards such as flood and drought likely to get 52% more net farm income than non-adopters. The farmers in the study region largely use an improved variety of seeds, such as drought-tolerant and high-yielding seeds.

Table 5.3 1st Stage OLS Regression Result

	Distance Extension	% Multiple Adopter	Combined	
			Distance Extension	% Multiple Adopter
Crop Rotation	- 0.0277(0.000) ***	0.0060(0.000) ***	-0.0121(0.021) ***	0.0040(0.000) ***
Crop Diversification	-0.0244(0.000) ***	0.00432(0.000) ***	-0.0291(0.000) ***	0.000643(0.549)
High Yielding Seeds	-0.02761(0.000) ***	0.0049(0.000) ***	-0.02463(0.00486) ***	0.00076(0.393) **
Integrated Soil Management	-0.0252(0.000) ***	0.00566(0.000) ***	-0.00927(0.064) *	0.0041(0.000) ***

Significant at 10% level; **Significant at 5% level; ***Significant at 1% level, p values in parenthesis

Table 5.4 Second Stage 2SLS Result for Distance to Block Extension Office

	Net Agricultural Income (log)			
IV: Distance to Extension Office	(1)	(2)	(3)	(4)
Crop Rotation	0.521**			
	(0.2250)			
Crop Diversification		0.592**		
		(0.251)		
High Yielding Seeds			0.524**	
			(0.2199)	
ISM (Soil Management)				0.572**
				(0.2353)
Total Land	0.0844***	0.0858***	0.0950***	0.0921***
	(0.0202)	(0.0202)	(0.0198)	(0.0193)
Access to Electricity	0.215*	0.244**	0.281**	0.271**
	(0.1193)	(0.1134)	(0.1100)	(0.1082)
Access to Diesel	0.105	0.141	0.175	0.240**
	(0.1369)	(0.1301)	(0.1270)	(0.1247)
Access to Kerosine	0.0645	0.114	-0.0441	0.0756
	(0.2217)	(0.219)	(0.2188)	(0.2112)
Multiple Energy source	0.145	0.106	0.119	0.112
	(0.1160)	(0.1149)	(0.1146)	(0.1128)
Farming experience	0.00646*	0.00693*	0.00524	0.00611*
	(0.0037)	(0.0037)	(0.0036)	(0.0035)
Age	0.00105	-0.000226	-0.000489	0.00263
	(0.0040)	(0.0040)	(0.0040)	(0.0039)
Govt. Extn.	0.165*	0.190**	0.196*	0.195**
	(0.0932)	(0.088)	(0.0868)	(0.0851)
Cooperative credit	-0.303***	-0.273***	-0.265***	-0.233***
	(0.0827)	(0.080)	(0.0798)	(0.0800)
Machinery subsidies	0.00409	0.0612	0.0547	0.0226
	(0.0957)	(0.0945)	(0.0931)	(0.0906)
Education	0.0180**	0.0154**	0.0160*	0.0158**
	(0.0074)	(0.0074)	(0.0072)	(0.0070)
Mechanization Index	0.0526	0.0568	0.0565	0.0548*
	(0.0335)	(0.0332)	(0.0324)	(0.0318)
Kendrapara	0.440***	0.500***	0.476***	0.523***
	(0.1165)	(0.1231)	(0.1178)	(0.1237)
Balangir	0.845***	0.814***	0.827***	1.029***
	(0.1423)	(0.1360)	(0.1361)	(0.1757)
_cons	9.747***	9.872***	9.658***	9.473***
	(0.2366)	(0.2140)	(0.2491)	(0.2938)
N	491	491	491	491
F stat	10.64	8.21	13.16	13.71

Table 5.5 Second Stage 2SLS Result for Percentage of Multiple Adopters in A Village

	Net Agricultural Income			
IV: % of Multiple Adopter	(1)	(2)	(3)	(4)
Crop Rotation	0.423**			
	(0.2118)			
Crop Diversification		0.592**		
		(0.2947)		
High Yielding Seeds			0.522**	
			(0.2571)	
ISM (Soil Management)				0.452**
				(0.2169)
Total Land	0.0849***	0.0858***	0.0950***	0.0911***
	(0.0199)	(0.0198)	(0.0199)	(0.0192)
Access to Electricity	0.232**	0.244**	0.281**	0.278**
	(0.1172)	(0.1148)	(0.1102)	(0.1075)
Access to Diesel	0.123	0.141	0.175	0.232*
	(0.1345)	(0.1314)	(0.1272)	(0.1240)
Access to Kerosine	0.0615	0.114	-0.0438	0.0699
	(0.2188)	(0.2200)	(0.2201)	(0.2100)
Multiple Energy source	0.151	0.106	0.119	0.125
	(0.1144)	(0.1185)	(0.1155)	(0.1118)
Farming experience	0.00643	0.00693*	0.00524	0.00614*
	(0.0036)	(0.0036)	(0.0036)	(0.0035)
Age	0.00104	-0.000225	-0.000484	0.00229
	(0.0040)	(0.0040)	(0.0040)	(0.0039)
Govt. Extn.	0.179**	0.191**	0.196**	0.205*
	(0.0915)	(0.0892)	(0.0875)	(0.0843)
Cooperative credit	-0.298***	-0.273***	-0.265***	-0.243**
	(0.0816)	(0.0805)	(0.0798)	(0.0793)
Machinery subsidies	0.00863	0.0612	0.0546	0.0238
	(0.0944)	(0.0948)	(0.0934)	(0.0901)
Education	0.0177**	0.0154*	0.0160**	0.0160**
	(0.0073)	(0.0073)	(0.0072)	(0.0070)
Mechanization Index	0.0537	0.0568	0.0565*	0.0555*
	(0.0330)	(0.0328)	(0.0324)	(0.0316)
Kendrapara	0.428***	0.500***	0.475***	0.492***
	(0.1147)	(0.1274)	(0.1206)	(0.1209)
Balangir	0.825***	0.814***	0.827***	0.968***
	(0.1398)	(0.1339)	(0.1380)	(0.1688)
_cons	9.793***	9.957***	9.659***	9.583***
	(0.2314)	(0.2160)	(0.2633)	(0.2810)
F Stat	11.35	6.78	10.32	14.87

Table 5.6 Second Stage 2SLS Result for Both the Instrumental Variable

	Net Agriculture Income			
IV: Combined	(1)	(2)	(3)	(4)
Crop Rotation	0.460**			
	(0.2066)			
Crop Diversification		0.592**		
		(0.2507)		
Improved Variety Seeds			0.523**	
			(0.2192)	
ISM (Soil Management)				0.488**
				(0.2129)
Total Land	0.0847***	0.0858***	0.0950***	0.0914***
	(0.0200)	(0.0198)	(0.0198)	(0.0192)
Access to Electricity	0.226*	0.244**	0.281**	0.276**
	(0.1174)	(0.1137)	(0.1100)	(0.1076)
Access to Diesel	0.116	0.141	0.175	0.235
	(0.1348)	(0.1304)	(0.1270)	(0.1241)
Access to Kerosine	0.0626	0.114	-0.0441	0.0717
	(0.2198)	(0.2200)	(0.2188)	(0.2103)
Multiple Energy source	0.149	0.106	0.119	0.121
	(0.1149)	(0.1170)	(0.1145)	(0.1118)
Farming experience	0.00644*	0.00693*	0.00524	0.00613*
	(0.0037)	(0.0037)	(0.0036)	(0.0035)
Age	0.00104	-0.000226	-0.000488	0.00239
	(0.0040)	(0.0040)	(0.0040)	(0.0039)
Govt. Extn.	0.174*	0.190**	0.196**	0.202**
	(0.0916)	(0.0872)	(0.0868)	(0.0844)
Cooperative credit	-0.300***	-0.273***	-0.265***	-0.240**
	(0.0819)	(0.0805)	(0.0798)	(0.0793)
Machinery subsidies	0.00692	0.0612	0.0547	0.0235
	(0.0949)	(0.0945)	(0.0931)	(0.0902)
Education	0.0178*	0.0154**	0.0160**	0.0159**
	(0.00733)	(0.0073)	(0.0074)	(0.0072)
Mechanization Index	0.0533	0.0568	0.0565*	0.0553
	(0.0332)	(0.0328)	(0.0324)	(0.0317)
Kendrapara	0.432***	0.500***	0.476***	0.501***
	(0.1150)	(0.1136)	(0.1178)	(0.1206)
Balangir	0.832***	0.814***	0.827***	0.987***
	(0.1401)	(0.1360)	(0.1360)	(0.1676)
_cons	9.776***	9.872***	9.658***	9.549***
	(0.2312)	(0.2136)	(0.2488)	(0.2786)
F Stat	11.07	7.71	12.38	14.23

(Above Table 5.4, 5.5 and 5.6 the * denotes the Significant at 10% level; **Significant at 5% level; ***Significant at 1% level, Standard error in parenthesis)

Farmers who adopt integrated soil management practices are likely to get 45–57 % higher agricultural income than those who do not adopt smart soil practices. The consistency of the estimates over the three specifications validates the instruments as strong predictors of CSA adoption practices, making it possible to successfully identify the causal impact of CSA adoption on farm family income in a given year.

These effects were calculated with the other control variables as with the above endogenous variable. As expected, land size, farming experience, access to extension service, education, farm mechanization and access to credit impacted family farm income. Adopting farm mechanization has a positive and significant impact on the total farm income of the farmers. Farmers who adopt farm mechanization are likely to get 5% more net farm income than those who do not use mechanization for agricultural operations. There is a negative and significant relationship between access to credit and farm income. Farmers who access agricultural credit from cooperative societies are likely to make 30% less farm income than those without credit in their accounts.

The inverse relationship between cooperative credit and farm income is due to the improper use of credit. From the field observation, it has been noticed farmers who get agricultural credits are more likely to spend on non-agricultural household work purposes.

The land size has a significant positive impact on the net agricultural income of the farmer. The farmer with a larger land size is likely to have a higher net farm income. One unit increase in the land size will likely increase the net agricultural income by 8% more than non-adopters.

Access to energy sources for the operation of farm machinery and irrigation is likely to increase the net agricultural income of the adopters. Farmers with access to electricity near their fields will likely get 21-28% higher net agricultural income than non-adopters.

Access to regular government extensions has a positive impact on the net agricultural income of adopters. Farmers who frequently visit and access government extension services will likely get a surplus of 16-21% more net agricultural income than non-adopters.

The experience of farming activities also positively impacts the net agricultural income. A higher year of experience farmer is likely to generate more net agricultural income. The result shows that one year increase in experience has a positive impact of 0.06% more net agricultural income.

Education or years of schooling has a significantly positive impact on the net agricultural income. The result shows a year increase in education tends to generate 1% more net farm income. Educated farmers are likely to embrace modern CSA technologies.

5.3.4 Result of PSM

The average treatment effect on the treated (ATT) for the impact studies using the PSM technique is presented in this section. The outcome variables are paddy yield (quintal/acre) and total agriculture income (per annum). This method removed bias from the sample selection process between adopters and non-adopters. The ATT demonstrated the distinction between individuals who adopted the CSA and those who did not while having comparable propensity scores regarding the results.

The first-stage probit regression results are an important intermediate step in PSM because they lay the foundation for matching. However, we have not gone into detail about the findings of the probit models because this study’s primary goal is to show the impact of CSA adoption on farmers’ primary agricultural income and productivity. The balancing test results are provided in each of the adoption sections. These test results show no statistically significant mean difference between adopters and non-adopters of CSA practices across the PSM covariates, which is a desirable property for good matching. The overlapping of propensity scores between treated and control observations is plotted before and after matching. All the figures display the overlapping propensity score provided in each section of the adoption practices. The plots show that the overlapping propensity scores after matching are significantly better than before for all outcome indicators. This is a desirable characteristic of good matching.

5.3.4.1 Impact of Crop Rotation on Yield and Income

ATT for total agriculture income relative to the non-adopter group is statistically significant. The difference in mean of total agricultural income is 0.424 (Radius), 0.455 (Kernel), 0.427 (5-nearest neighbour) according to the matching method. Likewise, adopters and non-adopters of crop rotation practices have a positive yield difference per acre. On average, there is a 1.98–2.54 quintal difference in the yield per acre if a farmer has adopted crop rotation practices. The result is significant for the all-matching method. The balancing test in Table 2 shows a proper balance of covariates after matching. The overlapping graph also indicates an appropriate balance between adopters and non-adopters.

Table 5.7: Average Treatment Effect for Yield and Total Agriculture Income

Outcome Variables		**Crop Rotation**	
	Matching Methods	**ATT**	**SE**
Yield per Acre	Radius	1.98***	0.452
	Kernel	2.02***	0.459
	5-Nearest neighbour	2.54***	0.6022
Total Agricultural Income	Radius	0.424***	0.079
	Kernel	0.455***	0.822
	5-Nearest neighbour	0.427***	0.116

*Significant at 10% level; **Significant at 5% level; ***Significant at 1% level

Table 5.8: Impact of Covariates Balancing Before and After Matching

Adoption Practice	Indicators of Covariate Balancing	Before Matching	After Matching
Crop Rotation	PseudoR2	0.093	0.006
	LR chi2	61.87	4.62
	a p-value of Log likelihood	0.000	0.990
	Median absolute bias	12.7	3.6
	Total % bias reduction (%)	75.1	18.1

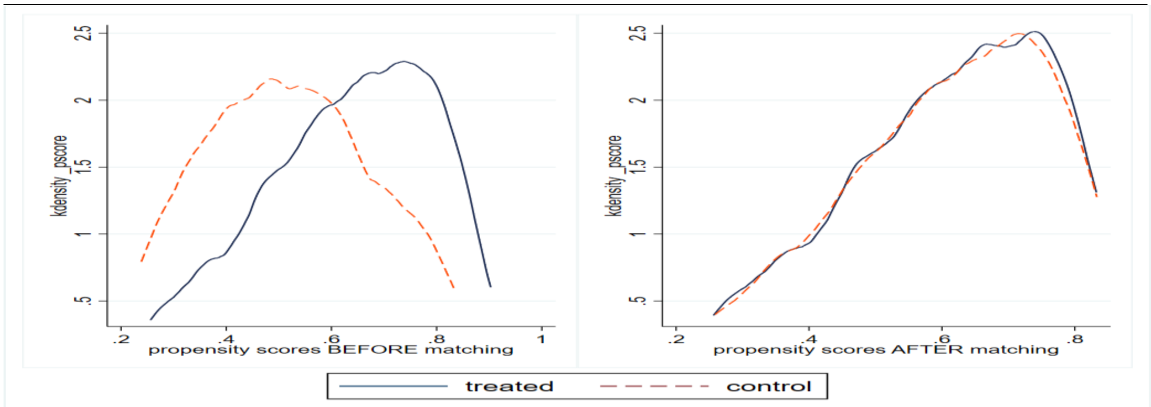

Figure 5.1: Propensity score overlapping between treat and control groups, before and after matching for crop rotation**.**

5.3.4.2 Impact of Crop Diversification on Yield and Income

Crop diversification helps farmers to diversify the risk of crop loss. Framers grow multiple crops to compensate for recovering the cropless. Crop diversification has 19-27% significant impact on the net agricultural income of the adopter farmers. Crop diversification has a significantly positive impact on yield. The adoption of crop diversification has 1.35-1.41 quintals of yield per acre. The balancing table and graph show that the data is balanced after matching. The covariates of adopters and non-adopters have been balanced accurately.

Table 5.9: Average Treatment Effect for Yield and Total Agriculture Income

Outcome Variables		Crop Diversification	
	Matching Methods	**ATT**	**SE**
Yield per Acre	Radius	1.41***	0.492
	Kernel	1.35***	0.498
	5-Nearest neighbour	0.934	0.650
Total Agricultural Income	Common radius calliper	0.199*	0.108
	Kernel	0.214*	0.109
	5-Nearest neighbour	0.271**	0.140

Significant at 10% level; **Significant at 5% level; ***Significant at 1% level

Table 5.10: Impact of Covariates Balancing Before and After Matching

Adoption practice	Indicators of covariate balancing	Before matching	After matching
Crop Rotation	PseudoR^2	0.082	0.020
	LR chi^2	50.10	1.84
	p-value of Log likelihood	0.000	0.864
	Median absolute bias	18.9	6.4
	Total % bias reduction (%)	71.8*	33.6*

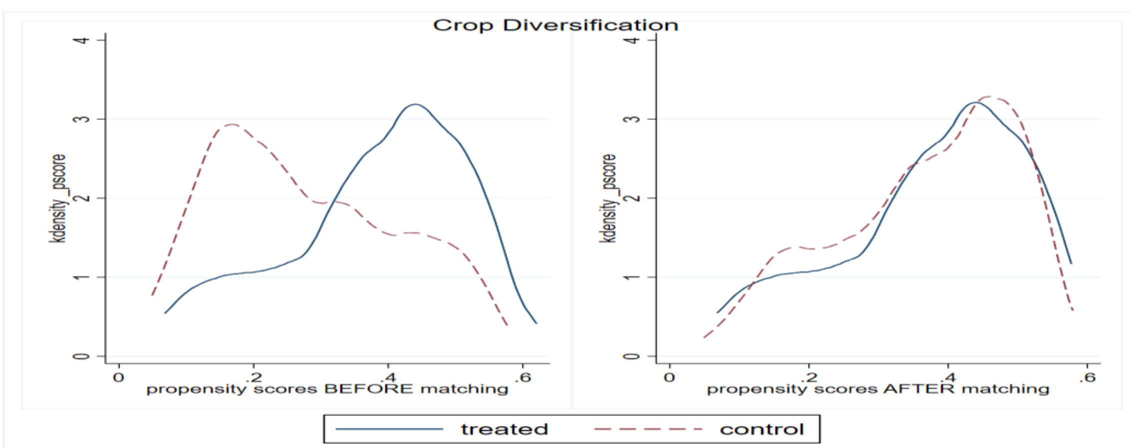

Figure 5. 2: Propensity score overlapping between treat and control groups, before and after matching for soil treatment

5.3.4.3 Impact of Improved Variety Seeds on Yield and Income

Many farmers have shifted from the traditional to the improved variety of seeds. The improved variety of seeds helps to cope with the adverse impact of climate change. The farmers of this region were using drought and flood-resistance seeds. Farmers use early-maturity variety seeds due to the region's lack of irrigation facilities and uneven rainfall. The farmers from the coastal region use flood-resistance seeds. Due to the lack of ditches and proper drains, farmers often face flash floods. The farmers face big losses due to crop damage during the harvesting period.

Table 5.11: Average Treatment Effect for Yield and Total Agriculture Income

Significant at 10% level; **Significant at 5% level; ***Significant at 1% level

Outcome Variables		**Improved Variety Seeds**	
	Matching Methods	**ATT**	**SE**
Yield per Acre	Common radius calliper	1.25***	0.568
	Kernel	1.12*	0.578
	5-Nearest neighbour	0.646	0.662
Total Agricultural Income	Common radius calliper	0.259***	0.114
	Kernel	0.279***	0.116
	5-Nearest neighbour	0. 291***	0.132

Table 5.12: Impact of Covariates Balancing Before and After Matching

Adoption practice	Indicators of covariate balancing	Before matching	After matching
Improve Variety Seeds	PseudoR2	0.082	0.017
	LR chi2	41.87	15.58
	p-value of Log likelihood	0.000	0.340
	Median absolute bias	18.2	6.6
	Total % bias reduction (%)	73.8*	31.0*

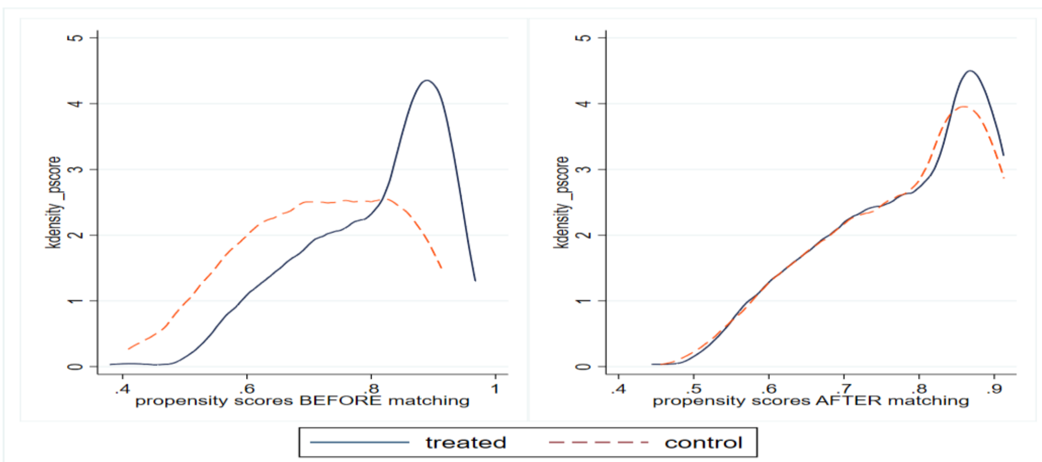

Figure 5.3: Propensity score overlapping between treat and control groups, before and after matching for Improved Variety Seeds

5.3.4.4 Impact of Integrated Soil Management on Yield and Income

Soil treatment is a vital CSA practice to maintain soil health. Overuse of fertilizers, pesticides, drought and other natural hazards degrade the fertile soil into hard soil. The soil becomes acidic and hard. Soil testing, recommended use of fertilizer doses, and soil treatment using gypsum, papermill sludges and other nutrients enhance the nutrition level of the soil. Soil treatment practices significantly positively impact yield and total agriculture income. ATT shows that the mean difference between adopters and non-adopters on net agricultural income is 27–34%. Adopting soil treatment increases productivity by 2-3 quintals of paddy yield on average.

Table 5.13: Average Treatment Effect for Yield and Total Agriculture Income

Outcome Variables		Integrated Soil Management	
	Matching Methods	**ATT**	**SE**
Yield per Acre	Common radius calliper	2.85***	0.529
	Kernel	3.017***	0.537
	5-Nearest neighbour	2.59***	0.685
Total Agricultural Income	Common radius calliper	0.324***	0.1162
	Kernel	0.346***	0.1183
	5-Nearest neighbour	0.277**	0.1523

Significant at 10% level; **Significant at 5% level; ***Significant at 1% level

Table 5.14: Impact of Covariates Balancing Before and After Matching

Adoption practice	**Indicators of covariate balancing**	**Before matching**	**After matching**
Crop Rotation	Pseudo R^2	0.155	0.009
	LR chi^2	101.20	7.16
	p-value of Log likelihood	0.000	0.928
	Median absolute bias	19.6	5.1
	Total % bias reduction (%)	99.7	22.0

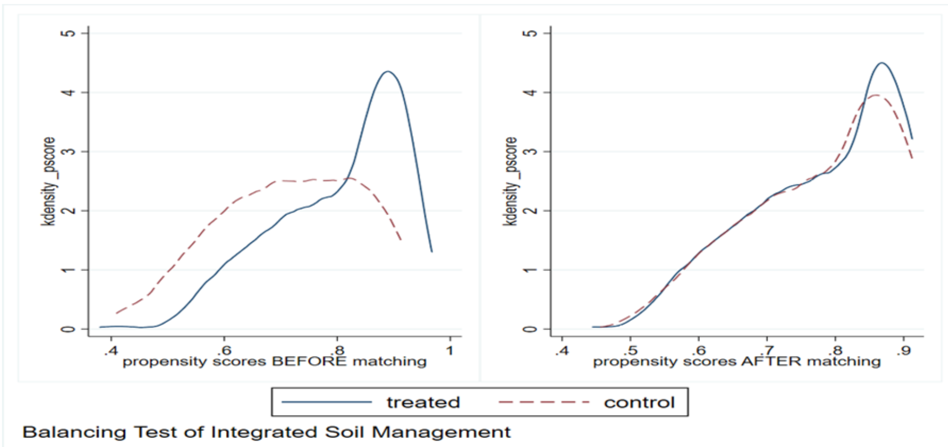

Figure 5.4: Common Support; Nearest Neighbor (5), Kernel, and Radius matching method

5.4 Discussion

In general, the findings highlight the significance of innovations within CSAs at the farmer level in terms of constructing resistance to the effects of climate change and other issues on the farm that are related to production. Using CSA practices mitigates the negative effects of climate change on food production and farmers' incomes. When complementary CSA improvements such as improved variety seeds (stress-tolerant) and integrated agriculture practices (crop rotation and crop diversification) are used in diverse combinations, CSA's benefits increase to a greater extent. The increased impact may occur due to the combined effect of implementing the innovations, which improves soil nutrient usage, soil fertility, pest and disease stress, and climatic stress. The findings are consistent with the growing body of research that demonstrates how adopting multiple CSA practices can simultaneously have a multiplicative effect on several variables associated with welfare, including productivity and income. Certain studies by Khonje et al. (2018), Makate et al. (2017), Tambo and Mockshell (2018), Teklewold et al. (2013), Wainaina et al. (2017), Lunduka et al. (2019) have also found a significant impact of CSA on the yield and income of farmers. Amadu et al. (2020) found that adopting CSA practices increased yield by 53% in the drought year of 2016. These studies discovered that smallholder farmers who used sustainable agricultural practices saw greater increases in both their productivity and their income. Additionally, it was observed that implementing many conservation agriculture practices simultaneously had a cumulative effect on income. Expanding the usage of this technology would help farmers become more resilient to the adverse effects of climate change by increasing their household incomes and the likelihood that they will have strong food security.

Odisha is a vulnerable state with frequent climatic shocks that destroy the crops in the region multiple times. Adopting CSA practices in this region and their cumulative benefit on productivity will motivate non-adopter farmers to adopt CSA practices. The farmers who are rich and have a consistently high income may not be in dire need of an extra INR

10,000–20,000 income, but for the marginal and small farmers, any increase in their income profile is desirable. If the income increases, the farmers will come out of the vicious circle of poverty, and their lives will become more sustainable.

5.5 Conclusion and Policy Implication

This chapter aims to analyse the impact of CSA adoption on farmers' income and yield per acre. We used our primary survey database of 494 households in Odisha. We have used two popular methods to find the impact of CSA on the productivity and income of the farmer households. To study the effect of adoption on crop yield and income, we had to ensure that no selection bias occurred. Therefore, the propensity score method was employed to ensure this. The results were as expected: there is a significant and positive impact of multiple CSA adoption on paddy yield and farm income. To remove self-selection bias and endogeneity, we have used two instruments, i.e., distance to the extension office and percentage of multiple adopters in a village. We analysed the impact using the TSLS method, which gave us an unbiased result and removed the endogeneity issue. The TSLS method shows that for every adoption of CSA, there is a positive increase in the percentage of income. All the results from the different models are similar, implying that the instruments have worked correctly to predict the impact of adopting CSA practices. Much of the literature has justified the positive association of CSA with productivity and income, so this study is also in line with previous literature. Therefore, there is a clear indication of an increase in income and productivity associated with adopting CSA practices. The main challenge in the IV approach is identifying suitable instruments to confirm the exogeneity of the error term. As a result, it is important to interpret the estimates obtained from this approach with caution.

The finding suggests a positive association between the adoption of CSA and increased farm income and productivity. These associations have various policy implications. The farmers' participation and peer interaction are needed to adopt CSA practices. Thus, farmers should be educated about the benefits of participation to enhance engagement and achieve policy goals. If the farmer-to-farmer extension works effectively, it boosts the adoption and helps to increase income and productivity. The extension engagement should be more frequent, and the extension office setup should be located near the farmer to increase the adoption of CSA practices.

CHAPTER 6

SUMMARY AND CONCLUSION

6.1 Overview

The previous chapters of this research covered three broad areas to understand how CSA can integrate with adoption strategies for smallholder mixed farming landscapes in rural India and Odisha- an Eastern Indian state. This first broadly looked into the adoption of farm mechanization due to climate change issues persisting in the agriculture sector in a rural part of India. The study tried to determine the factors determining the rural farmers' adoption of agriculture mechanization. Further, the impact of mechanization on farmers' net agriculture income and food security has been assessed and established; if a farmer adopts modern mechanical-driven machinery for farm use, then likely to get an advantage of an increase in agricultural income and is likely to secure food resources in the family. The empirical study on the vulnerable regions of Odisha state of India showed the different patterns of CSA adoption in the region and the factors that determine the adoption of the practices among the rural farmers. The qualitative empirical evidence showed the socio-economic challenges and gender roles confronting smallholder farmers' adoption decision to CSA practices. The qualitative study thoroughly discussed the ongoing challenges and the adoption of climate-resilient practices among the male and female farmers of the study district. The third area looked into the impact of CSA adoption on net agricultural income and yield. The dissertation addressed four specific research questions. i) What factors determine the adoption of farm mechanization, and how does adoption impact farmers' income and food security? ii) What is the factor that motivates rural farmers to adopt CSA practices? iii) what are the challenges and gender roles to adopting CSA practices in Odisha? iv) What is the impact of CSA adoption on the yield and income of the farmers?

The remaining sections of this chapter discuss the main summary and findings that correspond to each of the chapters. In the end, I concluded this dissertation with an evaluation of the limitations of our study and suggestions for further investigations.

The first chapter highlighted the issue of dealing with climate change's consequences on rural agricultural settings. The technology, capacity, and resources needed for climate change adoption and mitigation are unavailable to 85% of the world's smallholder farmers. Climate change and extreme weather are likely to worsen this problem, and they may also cause significant changes to the world's systems for producing food for the poor. The chapter covered how climate change incidents have affected agriculture and farmers' means of subsistence. This chapter introduced the study's background by explaining the idea of CSA practices. The chapter covered the theoretical underpinnings of CSA practice adoption. The chapter has outlined the general and particular research problems. The chapter includes a discussion of the study's goals.

The systematic study of pertinent literature that addressed our research questions was extensively covered in Chapter 2. The influence of climate change issues on agriculture has been reviewed in this section. The empirical findings of the diverse literature have been discussed on the implementation of CSA practices worldwide and in India. The adoption of sustainable agricultural mechanization and the elements associated with it have also been covered in the review. This chapter has covered the many studies on the impact evaluation of agricultural practices. The theoretical and empirical research on gender concerns in agriculture development was also a focus of the gender lens literature.

6.2 Research findings

Chapters 3, 4 and 5 are based on the study's empirical findings. A detailed summary of these chapters has been discussed below.

6.2.1 To identify the key determinants of adopting agricultural mechanization and its impact on farmers' income and food security among rural farmers in India.

Chapter 3 of the dissertation examined the key determinants of adopting agricultural mechanization and its impact. A nationwide household survey IHDS-II of 10253 households drawn from most states of India has been used for the analysis. Multivariate probit model results show that the education level of the household head, access to institutional credit, availability of extension services, and landholding size are the major determinants in the adoption of agricultural machinery in India. Implementing effective agricultural credit mechanisms and policies can potentially increase the adoption rate among rural farmers, thereby promoting sustainable agricultural production. The primary outcome of the research indicates that households that encounter frequent climatic shocks tend to adopt mechanized farming practices. Farm machinery such as tractors, power tillers, and threshers facilitate the planting and harvesting processes, resulting in increased efficiency and reduced time consumption. Agricultural machinery is a supplementary component to the overarching effort of adapting to climate change.

To assess the impact of machinery adoption on the outcome variables, the endogenous switching regression (ESR) model is used. The first stage of ESR, a probit model, reveals the determinants of mechanization: access to credit, climatic shocks, access to irrigation, farmer cooperative membership, household assets, and household size. The average treatment effect estimates from the second stage outcome regression reveal that adopting tractors and electric pumps positively affects net agricultural income and household income. In contrast, the adoption of diesel pumps does not have a significant effect on income. On the other hand, the adoption of all three types of machinery has a positive impact on the food security indicator.

6.2.2 To investigate the role of key factors determining the adaptability of CSA technologies in rural Odisha.

Chapter 3 investigates the primary empirical study conducted to test the hypothesis on key factors determining the adoption of CSA practices in Odisha. Administering a structured questionnaire survey among the 494 rural farming households of an eastern Indian state, Odisha, the study explores the key determinants of CSA adoption. Three districts, one from the state's coastal and two from the inland regions, are chosen for the study. Most respondents (85%) perceive an increase in temperature, and (76%) perceive a decrease in rainfall due to climate change in the region. The respondents have adopted a range of CSA practices such as rescheduling planting (74.5%), crop rotation (59.3%), crop diversification (31.2%), soil conservation (62.1%), drought-resistant seeds (36%) and agroforestry (10.3%) to adapt to these weather anomalies.

This chapter employed a multivariate probit model in which the findings of econometric modelling have been triangulated to explore the key determinants of the adoption of CSA practices. The key variables include climate change perception, agricultural extension services, and access to energy for irrigation motivates farmers to adopt CSA practices. Those who have experienced climate shocks and believe similar events may occur in the future are more likely to practice rescheduling planting, crop rotation, crop diversification, soil conservation, and drought-resistant seeds. Access to extension services is the main incentive for rural farmers to embrace CSA practices. Crop advisory and crop management training, demonstrations, farmers' field schools, machinery and seed subsidies, and access to institutional credit all help rural farmers improve their adaptability. Furthermore, access to inexpensive irrigation energy sources positively influences farmers' adoption behaviour. Subsidies from the government on power use and electricity infrastructure in farmers' fields can help to increase adoption.

6.2.2.1. To investigate the gender issues in adopting and monitoring CSA practices.

The subsection of chapter 4 explores the role of gender in adopting CSA practices. Gender has not been used to determine CSA adoption decisions in the multivariate probit regression model because about 95% of the sampled households have reported a male member as the household head. FGDs were used to collect qualitative data in the study area.

The key findings of this chapter are: women farmers from the Balangir district are aware of crop diversification and its potential benefits. They motivate their spouses to diversify cotton and paddy to minimize the risk of crop loss. Similarly, women farmers from Kendrapara are aware of integrated farming. They engage in activities such as livestock rearing, fisheries, and growing horticultural crops and paddy. Women farmers constitute a significant portion of the workforce but are underpaid compared to their male counterparts, believing that women cannot operate manly agricultural activities.

Further, this chapter shows the gender roles in the commencement of agricultural activities. The patriarchy-dominated agricultural sector gives freedom to male farmers to take the major decision of farming activities. 72% of male members make major decisions about farming activities; in 8% of the households, it is the female members. In the remaining 20% of the households, male and female members decide on major agricultural activities.

Odisha women farmers lack land, credit, and technology. Despite social, economic, and environmental constraints, rural women farmers adopted climate-resilient agricultural practices to boost productivity and climate change adoption. They used drought-resistant seed, agroforestry, conservation agriculture, and off-farm livelihood diversification.

6.2.3 To examine the impacts of adopting CSA practices on the productivity and income of the farmers.

Chapter 5 finds the impact evaluation of adopting CSA practices in Odisha. The adoption practices considered to conduct impact evaluations are crop rotation, crop diversification, improved variety seeds and integrated soil management. The impact of the adoption of

CSA practices on income and productivity is analyzed using propensity score matching (PSM) and two stage least square method (2SLS). Two instrumental variables were used to remove self-selection bias and endogeneity, i.e., distance to the extension office and percentage of multiple adapters in a village. Both models show a positive and significant impact of adoption on the productivity and income of the farmers.

The adoption of crop rotation has led to an increase of 46–48 % in farm income, and the adoption of integrated soil management has led to an increase of 47–58% in farm income than their counterfactual. Adopting the above practices has led to reporting a difference of 1–2 quintals of paddy between adopter and non-adopter farmers.

6.3 Research contribution

The research has made contributions in different fonts. The examination of both primary data and secondary data helped to synchronise the study on a large scale with the spatial scale. The contributions of this research have been discussed in the following points.

1. The study established an overview and dynamics of the adoption of agriculture mechanization in the larger discourse of rural farmers in India. The paucity of studies has found this angle of this dynamics. The significant contribution of the research is impact evaluation on agriculture development.
2. Empirical evidence on CSA: Limited studies provide evidence on adopting climate resilient practises at a regional scale across different agroecological zones. This research provided local-level empirical studies from smallholder farms that are required to understand the complexities of CSA and determine the optimal adoption practices and institutional structures for smallholder farmers. FGDs and multilevel interviews helped understand the CSA from an institutional and farmers' perspectives.
3. The research helped the rural farmers understand CSA practises' technology during the FGD. After FGDs and interviews, non-adopters' farmers got the idea to implement CSA practises in their future farming activities. The research helped

capacity building rural poor and marginal farmers, enhancing their adaptive capacity.

4. Scholarly contributions were made through peer-reviewed publications in the Scopus and SCI-indexed international journals and book chapters as Lead Author**.** The findings were presented at national and international conferences, which helped the participants to understand the study dynamics on a regional scale.

6.4 Research limitations

Even though the research for the thesis had been carefully planned and organized, a few limitations could not be avoided. The limitations of this research are enlisted below.

1. **Funding and time:** Due to constraints of the academic period and lack of financial and human resources, the primary study could not cover more than three districts and more than 500 sample size**.** The scope of data collection was restricted to three districts; only more districts could be included more representation of samples could be obtained.
2. **Sample and Data**: The primary dataset from three districts is the cross-sectional dataset. But farmers' adoption practices and their impact are always dynamic. The study will be more dynamic in assessing the adoption process and its impact if the data set has a panel. Repeated surveys were impossible due to the time and resource constraints of collecting primary data.
3. **Ignored Mitigation:** This study has not covered the mitigation impact of CSA adoption. The impact of CSA adoption on the environment has not been assessed. The mitigation impact of CSA studies is important in the present period because the international communities are focusing on net zero emissions.
4. **Applicability:** As primary data has been collected from a state's specific locations and rural setup, this may limit the applicability of the findings to other populations, rural-urban mixed setup and community-based programs.

6.5 Future research direction

However, I have learned many things during the survey and dissertation process that could help future research projects. The impact of the CSA practices could be made by collecting another survey round. This could help to compare the impact of CSA adoption over the years. As the adoption of CSA practices is continuous and long, it will give a more robust impact evaluation over the year. Institutional access is a major determinant of CSA practices. In the future, more analysis could be done on monitoring farmers and institutional relationships, particularly regarding how they are constructed, maintained, strengthened, or dissolved over time. In future, the mitigation impact of CSA practices could be studied in this study area.

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APPENDICES

Questionary

National Institute of Technology Karnataka, Surathkal-575025

School of Humanities, Social Sciences and Management

Title of the study- Essays on the Adoption and Impact of Climate Smart Agriculture Practices: Insights from Rural Farmers of Odisha

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"The questionnaire is about to understand the prioritization of rural farmers regarding CSA technology adoption, to assess the impact of such adoption on household's economic wellbeing and the Government/Non-government organizations play to foster adoption of CSA strategies. To attain the objective of our research we kindly need your cooperation. We persuade you that all information you give during the interview is stored strictly confidential and used only for scientific purposes, no part of the information will be used for any other purposes."

Are you agree to attend the survey? Y/N…………….

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1. General Information

Questionnaire Number:		Date of Interview	
Time Starts Interview:	Time Ends Interview:	Name of the Interviewer	
Agro- Climatic Zone:		Latitude:	Longitude:

1. Name of respondent:	2. Gender:	3. Caste/tribe:	4. Religion:
5. Contact No.:	6. Village:	7. Block:	8. Police station:
9. District:	10. How long you have been in farming (years)?	11. In what crop you are specialized?	

1. HH member	2. Relation to head[a]	3. Sex[b]	4. Age	5. Civil status[c]	6. Education (Years of schooling)	7. Occupation and Income			
						7.1 Primary		7.2 Secondary	
						7.1.1 Vocation	7.1.3 Income(INR)	7.2.1 Vocation	7.2.3 Secondary income (INR)

1) **DEMOGRAPHY INFORMATION** (Include family and non-family members living permanently in the household & taking food from the same kitchen)

Relation to head[a] 0= Household head 1=Wife/Husband 2= Son 3=Daughter 4=Parents 5=Grandparents 6=Son/Daughter-in-law 7=Grandson/daughters 8=Parents-in-law 9 = Brother/Sister-in-law 10 = Brother/Sister 11 = Nephew/Niece 12 = Uncle/Aunt	**Sex[b]**:1=Male, 2=Female **Civil status[c]** 1=Married, 2=single, 3= widow **Vocation** 1=Agriculture(farming) 2=Salaried job (Govt. as well as private employee) 3=Service (carpenter/ blacksmith/ barber etc.) 4= business 5=Non-farm labourer	6=Agricultural laborer 7=Household job 8=Handicraft/processing/cottage industry 9=Livestock/poultry farming 10=Fisherman 11=Mechanic (electrical repairing/ electronic repairing/ plumber/fitter/motor cycle gar- age/etc.) 12=Student 13=Others 14 = Domestic helper 15.=Others

2) A. DETAILS OF TOTAL LANDHOLDING

1) Particulars	Total area (local unit)
2) Owned	5) Aquaculture area
3) Homestead	6) Long-term pasture
4) Cultivated land	7) Leased-in
	8) Leased-out

B. DETAILS OF AGRICULTURAL LANDHOLDING

1. Parcel Name	2. Plot No.	3. Area (unit_)	4. Topography[a]	5. Soil type[b]	6. Tenurial status[c]	8. Sources Of irrigation[d]	9. Parcel location[e]	10. Irrigation method[f]	11. Sources of energy[g]

(Local land measurement reference- 1 Guntha=4 Cent, 1 Bharana = 33 or 28 Cent,1Bharana=32 Niyati, 1 Mano= 100 Cent, 100 cent= 1acre, 2.5 acre= 1 ha)

[a]. **Topography**	[b]. **Soil type**	[c]. **Tenurial status**	[d]. **Sources of irrigation**	e. Parcel location	f. Irrigation method	g. Sources of energy
1=Upland (bunded) 2=Upland(unbounded) 3=Medium 4=Lowland 5=Very lowland	1=Clay 2=Clay loam 3=Sandy clay loam 4=Sandy loam 5=Loamy sand 6=Loam	1=Owned 2=Leased-in (share cropping) 3=Leased–in (fixed rent) 4=Leased-out 5=Mortgage-in	1=Community T/W (GSP) 2= Cluster T/W (CTW) 3=Joint invested pvt. T/W(JWE) 4= Own private T/W 5=Dugwell 6=Canal 7=River lift, 8=Pond, 9= Unirrigated	1=Head 2=Middle 3=Tail	1=Gravity flow 2=Sprinkler 3=Drip	1=Electric motor 2=Diesel motor 3= Kerosene motor

C. LANDUSE DURING KHARIF (Rainy season), RABI (Post rainy) AND SUMMER

1. Parcel	2. Plot	3. Crop Name	4. 1=Sole,2= Inter3= mixed cropping	5. Variety Name	6. Seedsource¥	8. CroppedArea (Local unit)	10. Planting Time (MM-WW)	11. Har-vesting Time (MM- WW)	12. Freq.of irrigation	13. Duration of water Supply		14. Howmuch do you pay/investfor availing	15. Unit €	16. Main Product		17. By-product	
										13.1 Normalyear	13.2 Dryyear			16.1 Pro-duction (local unit)	16.2 Price (Rs)	17.1 Pro- duction (localunit)	17.2 Price (Rs)
Khariff Season																	
Rabi Season																	
Summer Season																	

¥ Seed source: 1: own, 2: neighbour farmer, 3: seed dealer, 4: govt. seed farm, 5: seed company, 6: others:

€Unit=per: 1-Hour, 2= Guntha, 3= Bharana of 28 decimal, 4= Bharana of 32 decimal, 5= acre, 6= crop, 7=year, 8= others

B. Income

Source	Normal Year ( )		Flood/Drought year ( )	
	Source	Net Income/ (Local Currency)	Source	Net Income/ (local currency)
Sales from rice				
Sales from 2nd important crop				
Sales from vegetables				
Sales from other crops				
Sales from crop by-products				
Sales from large animals				
Sales from small animals/poultry				
Sales from animal by-products				
Fisheries				
Wages from off-farm income				
Non-farm				
Remittances				
Wage employment				
Salary(govt/private)				
Business				
Service provider				
Others (Rent etc)				

3.A **Agricultural Extension Services**

No	a. Sources	b. Frequency of Contact in a Season	c. Name of Activities	d. Frequency of Participation
1	**Input Dealer**			
2	**Cooperative Societies**			
3	**Agricultural Department or ATMA (Agriculture Technology Management Agency)**			
	VLW			
	AAO			
	AO			
	DDA			
4	**Kisan Call Centre**			
5	**Krishi Vigyan Kendra (KVK)**			
6	**Agricultural University Extension**			
7	**NG0**			
8	**Others**			

c. Name of Activities: 1) Training Programme 2) Demonstrations 3) Field Visit 4) Group Meetings 5) Agricultural Exhibitions 6) Krishi Mela 7) Educational Tours

B. Media Extension Service:

Sl No.	a. Name of The Media	b. frequency	c. Programme/Contents
1	**TV**		
2	**Newspaper**		
3	**Radio**		
4	**Mobile Internet/SMS/YouTube**		
5	**Others Specify**		

4. Perception Regarding Climate Change

	Perceptions A	Response B
1	Do you feel that climate/weather in your area is changing over the last 15 years in your area?	Yes/No/Doesn't know
2	Do you feel weather in your area /region become unpredictable?	Yes/No/Doesn't know
3	If yes, what do you mean climate change in your own words?	Yes /No/Doesn't Know
4	Have you noticed any long-term changes in the temperature over the last 15 years?	
5	Have you noticed any shortage in the rainfall over the last 15 years?	Increased/Decreased/constant/Doesn't know
6	Do you think the frequency of drought and dry spell has increased in your area over the year?	Yes/No/Doesn't know
7	Do you think the frequency of flood has increased in your area over the year?	Yes/No/Doesn't know
8	Do you think the frequency of flood has increased in your area over the year?	Yes/No/Doesn't know
9	Do you think there have been any changes in the timing of monsoon rainfall (June-sep) over theyears? (Explain)	Yes/No/Doesn't know
10	Do you think there have been any changes in the timing of pre-monsoon rainfall (Jan-may) overthe years? (Explain)	Yes/No/Doesn't know Coming Early / Coming Late
11	Do you think there have been any changes in the timing of post-monsoon (Oct-Dec) over theyears? (Explain)	Yes/No/Doesn't know Coming Early / Coming Late
12	Are there any changes in Rainfall Spell? (Explain)	Yes/No/Doesn't know Coming Early / Coming Late
13	Do you think insects and pests are increasing day by day?	Yes/No/Doesn't know
14	Do you think is there increase in the number of cold days?	Yes/No/Doesn't know

5.1 Peer Effect on Adaptation

Sl No		A. Response	B. Input Use	C. Innovative Farming	D. Mechanization	E. Harve-sting	F. Marketing
1.	Do you motivate to your neighbor in agricultural activities?	Yes/No /Occasionally					
2.	Does your neighbor influence by you in your agricultural activities?	Yes/No /Occasionally					
3.	Are you involved in any Group Agriculture Activities?	Yes/No /Occasionally					

5.2 Adaptation activities / Crop and Farm related Adaptation

Activities	**Whether Practicing (Yes/No)**	**Year of change How long using?**	**Reason for change/ adaptation**	**Before Adaption**	**Cost of Adaption**
	A	B	C	D	E
3. Crop Diversification					
4. Crop Rotation					
5. High Yielding varieties seeds					
6. Drought resistant Seeds					
12. Row Cropping					

a. **Soil related Adaptation**

Adoptions	Yes/No	Year of change	Reason for change adaptation	Before Adaptation	Cost of Adaption
	A	B	C	D	E
1.Soil Testing					
2.Soil amendment with Gypsum, lime, paper mill sludge in acidic soil					
3.Application of vermi compost					
4.Application of FYM					
5.Use of Integrated Nutrient Management practice					
6.Soil conservation					
7.Minimum tillage					
8.Changing tillage practice					
10.Creating bunds across the slope for checking soil erosion					
11.Organic soil cover (crop residue in field)					
12.checking erosion through reduced tillage intensity					
14.Agroforestry					
16.Green Manure					

Remarks:

C. Water related Adaptation

Activities	Yes/No A	Year of change How long using? B	Reason for change adaptation C	Before Adaptation D	Cost of Adaption E
1.Surface Reservoirs					
2.Borehole and Tubells					
3.Canal irrigation					
4.Sprinkle Irrigation					
5.Drip Irrigation					
6.Insitu water conservation					

d. Fertilizer related Adaptation

Activities	**Yes/No** A	**Year of change How long using?** B	**Reason for changeadaptation** C	**Before adaptation** D	**Cost of Adaption E**
1.Organic Fertilizer					
2.Insecticides					
3.Pesticides					

e. Precision Agriculture

i. Do you know about Precision Farming? Yes /No (If yes than go for Qn iii.)

ii. Size of land practicing Precision Farming? (In Acre)

iii. From which sources you came to know about precision Farming?

iv. Different Precision Farming Technology Adopted

f. Precision Agriculture Practices

Sl No.	Activities	Using Yes/No/Doesn't Know	Cost of Adaptation (In Rupees)	Year of Adaptation
1	Soil Sampling			
2	Soil analysis			
3	Observation of crop characteristics (height, leaf)			
4	Laser land levelling			
5	Variable Rate Applicators/ Techniques			
6	Yield Monitors			
7	Crop sensors			
8	Deciding the grid size of the Land			
9	Formation of grid size using GPS			
10	Solar Pump			

g. **Barriers to Adaptation**

Sl No	**Barriers**	**Strongly Agree**	**Agree**	**Undecided**	**Disagree**	**Strongly Disagree**
1	Lack of Information to the weather					
2	Lack of information to climate change					
3	Lack of credit/Saving					
4	Adaption is expensive					
5	Adaption is not profitable					
6	Lack of proper markets access					
7	Lack of government Support					
8	Old age					
9	Lack of awareness of Technology					
10	Not Interested					

6.a Subsidies:

Source	Seeds A			Fertilizer B			Machinery C			Direct Transfer of Income D		
	Name Schemes	Cost (in Rs.)	Year	Name Schemes	Cost (in Rs.)	Year	Name Schemes	Cost (in Rs.)	Year	Name Schemes	Cost (in Rs.)	Year
Government												
NGO												
Private												
Others (Specify)												

b. Market Access:

1. Did you get market information before selling? Yes/No
2. What is the distance to input market from your home?..
3. What is the reason that you failed to sell your crop?...

(Low price/No buyer/unable to meet desirable quality /late payment/others)

4. Where you used to sell your crop? (Government agency/wholesaler/local retailer/brokers)
5. What is the distance of seed/fertiliser market?
6. What is the distance of machinery and parts market?
7. Did you get MSP for your crop ?_Yes/No

c. Institutional Credit Support:

Sources	Amount of credit (Rs.)	Year	Interest Rate (%)	Repayment Time (Year)	Any Collateralfor the loan?	Spent on which Part of agricultural activity	Reason for ineligibility ofloan
	A	B	C	D		E	F
1.Public sector bank							
2.Cooperatives							
3.Regional Rural Banks							
4.Private Bank							
5.SHG							
6.Micro Finance							
7.Farmer Associations							
8.Landlords/Local Lander							
9.Relatives							
10.Trader							
11.Input dealer							
12.Other, specify							

d.1. Did your loan wave recently? Yes/No
2. which year?...
3. What is wave amount?...
4. Are you currently paying off the debt or is it already paid (still paying/ already paid)

e. Insurance

1	Are you aware of the crop Insurance in your area to cover drought/Flood losses?	Yes/No
2	Do you have Crop Insurance?	Yes/No
3	Which Insurance do you have? PMFBY/RKBY/NAIS	
4	If no, what is the reason? 1.Not important 2. Too expensive 3. Don't know about the schemes 4. Complicated process 5. Others(specify…)	
5	Did you receive any compensation from crop insurance in the last drought/flood year?	Yes/No
6	How much payment you received from crop insurance?	
7	How much time did it take to receive the compensation (months)?	
8	Has crop insurance changed your cropping patterns?	Yes/No
9	Has crop insurance made you to try for better crop in next season?	Yes/No/Doesnt Know
9	Do you think the premium you pay is fair?	Yes/No/Doesnt Know
10	On what purpose you spend your compensation amount? 1. Food consumption/2.Medicine/3. Agriculture (provision for next season/4. Livestock purchase/ 5. Other please specify	

f. Migration Details:

Do household members migrate for work? Yes=1, No=2 If yes,

Household Member	When left (year)	How Many yearsOutside?	Reason for Migration	How often h sends money?	Current resident (City/Town/District/State)	Occupation	Whether return? If yes reason?	Remittances sent(Rs)
A	**B**	**C**	**D**		**E**	**F**	**G**	

Reason for Migration: 1. Loss of wage labour /2. Loss of agriculture /3. Compensate household income /4. Food insecurity /5. Drought

g. Shocks and Risks:

Type of risks/shocks	**How many timeshappened in last10 yrs.?**	**When didhappen? (Year)**	**What kind of changes/losses in agriculture and livestock? (Rupees)**	**What kind of other losses?** (House Damage/ Human Life Loss)
A	**B**	**C**	**D**	**E**

Type of risks/shocks
1. Drought 6. Increase in price of agricultural input 9. Hail Strom 14. Output price volatility
2. Flood/submergence 7. Theft of crops 11. Livestock Disease 15. Unseasonal rain
3. Crop pests & disease 8. Theft of agriculture tools 12. Land fragmentation 16. Unexpected weather fluctuation (low night temperature/high
4. Sudden fire burning the output 9. Animal menace 17. Rodent attack day temperature)
5. Decrease in agricultural output 10. Land/Soil infertility 13. Unavailability of improved seeds

h. Other Copping Strategies during drought

Sl No	Copping Strategies	Yes/No	Sl No	Copping Strategies	Yes/No
1	Sold Livestock		6	Migration	
2	Sold HH Assets		7	Consumption Reduction	
3	Took Additional loans		8	Use of Saving	
4	Sold Land		9	Use Early Maturity Variety Seeds	
5	Increased Non-Farm Activities				

7 A. Housing Amenities

Sl. No.	Amenities A	Present Status B	5 Years Ago, C
1	House ownership	Rented /Own	Rented /Own
2	Type of dwelling	Pucca/ Kuccha/ Semi-pucaa	Pucca/ Kuccha/ Semi-pucaa
3	Roofing	Concrete or cement/Bricks/ Mud/Iron sheet/Thatch/straw/Tile/ Asbestos/Other	Concrete or cement/Bricks/ Mud/Iron sheet/Thatch/straw/Tile/Asbestos/Other
4	Electricity	Yes/No	Yes/No
5	Source of drinking water	Open dug well/ Tube well/hand pump/Tank/ reservoir/River/canal/lake/pond/stream / Tap water	Open dug well/ Tube well/hand pump/Tank/ reservoir/River/canal/lake/pond /stream/ Tap water
6	Toilet or latrine	Yes/No	Yes/No
7	Fuel for Cooking	Wood/Kerosene/LPG	Wood/Kerosene/LPG

B. Farm machinery & equipment				
	Whether uses? Y/N	**If yes own/rented**	**Cost of Machinery /Rent**	**Number of uses**
a. Tractor				
b. Tractor drawn equipment				
c. Power tiller				
d. Rice transplanter				
e. Mechanical Weeder				
f. Thresher				
g. Chaff cutter				
h. Seed drill				
i. M. B. plough				
j. Sprayer/ duster				

k. Harvester				
l. Diesel Water Pump				
m. Electric Water Pump				
n. Sprinkle/Drip Irrigation Set				
o. Small implements				
p. Others1:				

Live Stocks	Values	Cost	**Live Stocks**	Values	Cost
a. Cow			f. Pig		
b. Bullock/ox			g Chicken		
c. Calf			h Ducks		
d. Goat					
e. Sheep					

C. Social Capital (Member

Name of the Social Capital A	Yes/No B	Year of Joining C	Name of the Social Capital A	Yes/No B	Year of Joining C
1. Mahila Mandal			7. Other cooperative		
2. SHG			8. Youth club/Rotary club		
3. Social Group			9. Farmers' Producer Organization		
4. Saving Group			10. Farmers' Interest Group		
5. NGO			11. Farmers' Club		
6. Religion Group			12. Agricultural/Milk Cooperative		

8 Decision Making /Adaption to agriculture

No	Decision Making	Response (M/F/B)
	A	B
1	Who decides Major activities of agriculture?	
2	What crops to plant (or whether to fallow or keep perennial crops)	
4	Inputs to be used (What variety and type of fertilizers and seeds?)	
5	Planting (Labour hired, timing, machinery or animal power)	
7	Who decides to hire labour (or not hire labour)?	
8	Who decides when to begin harvesting?	
9	Crop Management (Top Dressing, disease control, pest management, irrigation)	
10	Harvesting (When to Harvest, how to harvest, transport from field)	
11	Post Harvesting or Processing	
12	Who decides how much of the harvest to sell?	
14	Who in the household are the owners of the animal?	
16	Who is usually in charge of the animal health?	
18	Who decides how many animals have to sell?	

Field Work Gallery






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1. Jena, P. R., & Tanti, P. C. Effect of Farm Machinery Adoption on Household Income and Food Security: Evidence from a Nationwide Household Survey in India. Frontiers in Sustainable Food Systems, 7, 257.
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1. Tanti, P. C., & Jena, P. R. (2021). Adoption of Climate-Smart Technologies in Agriculture: Evidence from an Eastern Indian State. http://ageconsearch.umn.edu/
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3. Purna Chandra Tanti and Pradyot Ranjan Jena (2021). "Prediction of the Key Determinants of Climate-Resilient Technology Adoption: A Case study of Odisha" presented at

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2. Purna Chandra Tanti and Pradyot Ranjan Jena (2021). "Adoption Of Climate-Smart Technologies in Agriculture: Evidence from Eastern Indian State" presented at International Conference of Agricultural Economist (ICAE 2021). 17-3, August 2021.

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4. Pradyot Ranjan Jena & Purna Chandra Tanti (2021), "Understanding the Determinants of Decision making to adopt Climate Smart Technologies among the Rural Farmers of Odisha" presented at INSEE 11th Biennial Conference, IIITD, December 15-17, 202.

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