CLIMATE RISK MANAGEMENT OF SMALL DAIRY FARMERS IN REGIONAL SOUTH INDIA

A Thesis submitted by

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ABSTRACT

Climate risk in dairy farming is complicated and pervasive. Extreme climate events such as heatwaves, drought, and heavy rainfall translate into milk production and price risks, significantly impacting the income and profitability of dairy farmers. Milk production has faced numerous challenges in India over recent decades. These include fluctuations in yield, low milk prices, feed management challenges, animal health issues, and breeding aspects. More importantly, an increase in year-to-year and intra-seasonal variability in rainfall across the country has posed major challenges to dairy farmers and has harmed milk production. This emphasises the need to develop robust risk management strategies to effectively manage climate risk in dairy farms in rural areas in India. However, studies on dairy farmers' response to climate risks and how these risks affect their income generation in India are limited. The objectives of this PhD research project are as follows: 1) To investigate smallholder dairy farmers' perceptions of climate risks and their impact on dairy activities, examine the current risk management strategies, and identify hindrances and opportunities and factors driving their choice of coping and adaptation strategies for climate-change-related risks in their dairy farming system; 2) To understand the knowledge of existing livestock insurance and factors that influence their willingness to pay for index-based cattle insurance products and; 3) To assess and quantify the impact of climate impact change on milk production and how much of an impact they have in the study area. A total of (N=104) dairy farmers spread across Bengaluru urban, Bengaluru rural, and Chikkaballapur districts of Karnataka were surveyed for this study. The data was statistically analyzed with farmer responses and preferences for climate risk management, and their willingness to pay for index insurance assessed, as well as their perspectives on a range of different climatic factors most affecting milk production. The study's findings indicate that dairy farmers see drought, pests, diseases, and high temperatures as the primary risks of climate change. This has led to a decrease in dairy income and an increase in management requirements such as nutrition and temperature control methods. The coping mechanisms adopted include buying livestock insurance, keeping low debt obligations, and growing drought-tolerant grass varieties. Further, the research shows that the uptake of current cattle insurance is low (6%) due to a lack of awareness of its benefits. However, most farmers face significant challenges in adopting these strategies due to high costs and weak institutional support. Most importantly, the study found that certain factors like age, education, number of earning family members, milk production, cost of production, and farm holdings significantly influenced climate risk adaptation strategies that were adopted. The study recommends that providing reliable seasonal climate forecasts, access to new technologies for feeds and fodder preservation, implementing improved policies in cattle health services, affordable cattle insurance, and strong institutional support systems and extension services can help dairy farmers become more resilient to climate change and improve their livelihoods.

CERTIFICATION OF THESIS

I, **Anupama Shantharaju,** declare that the PhD Thesis entitled *Climate Risk Management Of Small Dairy Farmers In Regional South India* is not more than 100,000 words in length, including quotes and exclusive of tables, figures, appendices, bibliography, references, and footnotes.

This Thesis is the work of Anupama Shantharaju except where otherwise acknowledged, with the majority of the contribution to the papers presented as a Thesis by Publication undertaken by the student. The work is original and has not previously been submitted for any other award, except where acknowledged.

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STATEMENT OF CONTRIBUTION

The articles produced from this study were a joint contribution of the student and supported by the supervisory team. The details of the scientific contribution of each author in the publications are provided below:

Paper 1:

Anupama Shantharaju, Md Aminul Islam, Jarrod M.Kath, Shahbaz Mushtaq, Arun Muniyappa, Lila Singh Peterson, (2024)." Understanding Constraints and Enablers of Climate Risk Management Strategies: Evidence from Smallholder Dairy Farmers in Regional South India". *Sustainability 2024, 16(5), 2018.* DOI: https://doi.org/10.3390/su16052018

The overall contribution of Anupama Shantharaju was 65% to the concept development, analysis, drafting, and revising of the final submission; Md Aminul Islam contributed 25% to concept development, statistical analysis, and providing critical inputs; Shahbaz Mushtaq, Jarrod M.Kath and Arun Muniyappa contributed 20%, for editing and provided comments on the manuscript.

Paper 2:

Anupama Shantharaju, Jarrod M.Kath, Shahbaz Mushtaq, Arun Muniyappa, (2024).” Willingness to Pay for Index-based Cattle Insurance among Dairy Farmers in Southern India”.

The overall contribution of Anupama Shantharaju was 70% to the concept development, analysis, drafting, and revising of the final submission; Jarrod M.Kath and Shahbaz Mushtaq contributed to concept development, statistical analysis, and providing critical inputs 10% each, respectively, Arun Muniyappa contributed 10% for editing and provided comments on the manuscript.

Paper 3:

Anupama Shantharaju, Jarrod M.Kath, Shahbaz Mushtaq, C.G.Shashank, Thanveer Shaik, Arun Muniyappa, (2024).” Climate variability impacts cattle milk production across three villages in regional south India”

The overall contribution of Anupama Shantharaju was 65% to the concept development, analysis, drafting, and revising of the final submission, Jarrod M.Kath, Shahbaz Mushtaq, C.G. Shahshank Thanvee Shaik contributed 35% to the concept development, statistical analysis, and providing critical inputs respectively, Arun Muniyappa contributed for editing and provided comments on the manuscript.

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CHAPTER 1: INTRODUCTION

1.1 Background

Climate change & climate risks across regions of the world demand attention, particularly in the dairy industry (Eisen et al. 2020; Sattar 2020; Masson-Delmotte et al. 2021). The rapidly increasing human population combined with dwindling environmental resources and a changing climate impacts grazing lands, fodder, and water sources for the dairy industry (Devkota et al. 2011; Pulwarty & Sivakumar 2014; Eisen et al. 2020). In many regions of the world, cow's milk is traditionally a significant food source. It remains important despite various changes, such as technological advancements, policy and regulatory shifts, and socioeconomic impacts affecting different dairy systems. These systems range from small, large-scale operations in poor and developing countries to developed nations' industrialized milk production systems (Aryal et al. 2020; Jatwani & Swain 2020; Woetzel et al. 2020; DAHD 2021a).

The dairy sector in India plays a crucial role in supporting livelihood opportunities for 81 million dairy farmers (DAHD 2021a), predominantly small dairy farmers and the landless in rural areas. These small farmers with between 2 to 5 cattle contribute to 62% of the country's milk production (Jatwani & Swain 2020). It is highly livelihood-concentrated and has grown into a vital secondary source of income for millions of rural families and has assumed the most valuable role in providing employment and income-generating opportunities, especially for small farmers (Rajeshwaran et al. 2015; Eisen et al. 2020; Hu 2020; Sattar 2020).

Cattle, along with buffalo, are the most common species kept by the dairy and farming community in India. Dairy milk production in rural India, China, Nepal, Pakistan, and Ukraine takes place as a household activity and hardly ever employs hired labour (Budhathoki et al. 2019; Eisen et al. 2020; Hu 2020; Sattar 2020). Over 90% of the tasks associated with the maintenance and supervision of cows are mainly performed by family members (Rangnekar & Thorpe 2001).

Approximately 48% of the total milk produced in India is consumed or sold locally in rural areas, leaving 52% available for sale in urban areas (FICCI 2020). Out of the marketable milk surplus, approximately 40% is handled by the Dairy Corporative Societies (DCS), which consists of 16.93 million farmers from over 190,516 villages as of March 2019 (NDDB 2019).

The dairy sector in India faces several challenges, including low cattle productivity, persistent shortages of feed and fodder, poor animal health care, lack of suitable immunisation and hygienic programs, inadequate cold chain logistics in milk transportation, and unorganised marketing. These challenges are exacerbated by climate variability and change. Indeed, according to the Ministry of Agriculture and Farmers Welfare (MAFW), about 16 districts in the Karnataka province experienced 10 droughts between 2001 and 2015 (KSNDMC 2018; Government of India & Welfare 2019; DAHD 2021a). Such patterns in climate variability and change may get worse in the next few years in several districts in Karnataka, particularly Bengaluru (rural and urban) (Surie & Sharma 2019). Additionally (KSNDMC 2018) estimates that the Chikkaballapur district will experience drought situations with a probability of 86% in the near future, which is the highest drought likelihood among districts in the state of Karnataka. It is anticipated that the impacts of climatic events will pose more serious risks, particularly drought, to these regions (Kumar Goyal et al. 2023; Santhosh & Shilpa 2023).

Smallholder farmers traditionally have taken various adaptive and environmentally friendly measures, including opportunistic seasonal mobility such as shifting cattle to better pasture available areas (seasonal grazing), mixed agriculture crop-livestock farming, and efficient water harvesting, to cope with extreme climatic events (Herrero et al. 2015). However, with the increasing adverse impacts of constraints (shortage of feed and fodder, poor animal health care services, and lack of cold chain logistics), the coping mechanisms have become ineffective (Kumar et al. 2011). While a few development-based solutions (cow-monitoring technologies not visible to normal eyes, such as sensor systems and radio frequency identification tags) have shown encouraging results, their impact remains limited (Prokopy et al. 2015).

The financial sector and insurance companies, such as Pradhan Mantri Fasal Bima Yojana, can offer insurance coverage to smallholder farmers. However, they are not linked with private insurance companies, which leads to several challenges. For instance, premiums are often deducted from the farmers' accounts without their knowledge (Tiwari et al. 2020). The role of state and federal governments in such insurance schemes remains limited and unclear, despite the projected population growth trend and urbanization change for the next four decades. It is estimated that India might need 600 million tonnes of milk and milk products (FICCI 2020). With the projected change in climate across Indian milk-producing regions (IPCC 2014), there is a critical need to develop improved climate risk management for the dairy sector in India.

Several studies highlight the importance of understanding the socio-economic factors that influence farmers' actions toward climate risks, their perceptions of these risks, and their uptake of insurance products (Devkota et al. 2011; Kumar et al. 2015; Eitzinger et al. 2018; Amare et al. 2019; Budhathoki et al. 2019; Ndlovu et al. 2020). More importantly, farmer's ability to adapt to climate risks and climate change is constrained by severe technological, socio-economic, and institutional barriers (Ada et al. 2006; Barnes & Toma 2012; Adeyinka et al. 2015; Bishu et al. 2018; Singh et al. 2020; Masson-Delmotte et al. 2021). This research aimed to address the challenges mentioned above for small dairy farmers in the Indian context.

1.2 Statement of the problem

Milk is one of the staple foods for the vast amount of the population living in poverty in India (DAHD 2021a). It serves as an important indicator of food security, nutrition, and income for rural families. The growth of India's milk production is inspiring in comparison to other major milk producing countries especially given that it is a tropical country with a hot and humid climate. This commendable progress is due to millions of small farmers with holdings of one to four animals, which is a livelihood opportunity for most rural households (Rajeshwaran et al. 2015).

The dairy sector in India, especially Karnataka, is famous for milk production, however, it faces various climate-related risks, similar to the agricultural sector. These risks include production, market, credit, technological, institutional, and human resource risks (Kumar et al. 2016). The agricultural environment is susceptible to frequent and severe fluctuations due to extreme climate events such as droughts, floods, cyclones, hurricanes, typhoons, tornadoes, and wildfires (Masson-Delmotte et al. 2021). The challenges in livestock, especially in the dairy sector, and agricultural risk are exacerbated by a changing climate (Moran 2009; Douphrate et al. 2013). The main challenge in the current mode of production is the inevitable climate risks and weather uncertainty.

Dairy farming has become uncertain due to climate change-driven natural disasters, particularly droughts and floods, which directly cause extremely variable production outcomes in terms of supply and threaten food security (Barnes & Toma 2012). These climate risks threaten millions of smallholder farmers who depend on dairy farming for their livelihoods.

To achieve resilience in dairy farming, farmers need to develop integrated climate change adaptation and risk transfer approaches and identify cost-effective approaches(Reddy 2015). It is essential to establish innovative coping mechanisms, as well as develop risk management strategies and insurance solutions to ensure the sustainability of the dairy industry. Additionally, there is a need for a comprehensive investigation into the adaptation strategies chosen by farmers to develop effective climate-responsive adaptation plans. Furthermore, limited research has been conducted to assess the knowledge and perceptions of dairy farmers in Southern India (Below et al. 2015; Alam et al. 2017; Islam et al. 2020; Koç & Uzmay 2022). Therefore, it is vital to understand smallholder dairy farmers' perceptions of climate change and coping mechanisms.

The Indian government views insurance as a key risk management strategy. However. despite efforts to address challenges faced by livestock insurance in India, the uptake has been minimal (Bora 2017; Rohith 2019; Chand et al. 2023). The insurance programs and products have been criticized for not involving stakeholders in developing suitable products, making the insurance products irrelevant to the risks faced by dairy farmers (Shirsath et al. 2019; Ghosh et al. 2021). Given the diverse agro-climate conditions, perceptions and willingness to purchase insurance of farmers vary. Therefore, there is a need to study the farmer's preferences and willingness to pay for index-based insurance products tailored to a given area.

1.3 Research aims and objectives

The main purpose of this research is to assess and understand key climate risks, and how these risks are perceived and handled by small dairy farmers under varying socio-economic and environmental settings in India. Specifically, this research aims to:

1) Analyse risk perceptions and risk management strategies to adapt and mitigate climate risks among rural dairy farmers.

2) Analyse drivers of the adoption of cattle insurance products and farmers' Willingness to Pay (WTP) for insurance.

3) Examine the climate variables most affecting milk production among rural dairy farmers.

1.4 Scope

To achieve these objectives, the work was segmented into different tasks as follows:

a) To understand dairy farmers' perceptions a survey was carried out to explore their perceptions of climate risk, how it impacts their dairy farming system, the coping strategies they employ, and the barriers they face when implementing these strategies. The survey also investigated the factors that facilitate the adoption of adaptation measures.
b) To assess the WTP for index insurance and farmers' knowledge of existing cattle insurance schemes, a survey was conducted between December 2022 and January 2023. Based on key climate risks affecting the region, hypothetical insurance product were discussed, and responses were drawn from dairy farmers. The study further investigated what drives their decisions to take up insurance products using Generalised Linear Model (GLM) analysis with logistic regression.
c) Using a dataset of milk production for the years (2019-2022), the impact of climate variables on milk production was assessed across 3 different villages. Periodically, the region faces drought and high temperatures impacting milk production, and availability of feed and water resources resulting in a noticeable impact on the dairy incomes of farmers and milk poured over the years. A subset of data concerning to the study villages was extracted to present dairy farm characteristics and farm management strategies.

1.5 Thesis organisation

This thesis is presented as a Ph.D. by publications and is subdivided into three main chapters. A general conclusions section that summarizes the findings and contributions of this study was included. A total of three articles produced from this research are presented below:

- **Article 1**: Anupama Shantharaju, Md Aminul Islam, Jarrod M.Kath, Shahbaz Mushtaq, Arun Muniyappa, Lila Singh Peterson, (2024).” Understanding Constraints and Enablers of Climate Risk Management Strategies: Evidence from Smallholder Dairy Farmers in Regional South India”. *Sustainability 2024, 16(5), 2018.((Impact Factor: 3.9 and SNIP:1.31, Scopus rated Q1, 88th percentile in* Geography,Planning and Development) DOI: https://doi.org/10.3390/su16052018
- **Article 2**: Anupama Shantharaju, Jarrod M. Kath, Shahbaz Mushtaq, Arun Muniyappa, (2024).” Willingness to Pay for Index-based Cattle Insurance among Dairy Farmers in Southern India“. *Environment, Development, and Sustainability,(under review, submitted on July 2024). (Impact factor 4.7 (2023), Q1*)
- **Article 3**: Anupama Shantharaju, Jarrod M.Kath, Shahbaz Mushtaq, C.G.Shashank, Thanveer Shaik, Arun Muniyappa, (2024) Climate variability impacts cattle milk production across three villages in regional south India”. *Regional Sustainability,(under review, submitted on July 2024). (Impact factor 4.3 (2023), Q1*)

The ***first objective*** of this study was to analyse risk perceptions and risk management strategies to adapt and mitigate climate risks among rural dairy farmers. In (Chapter 3/Article I), the results indicate dairy farmers in the region perceive drought, pests and diseases, and high temperatures as the major risks associated with climate change, which has resulted in decreased dairy income, animal health problems, reduced fertility, and food intake problems for their cattle. In response to climate variability, dairy farmers have adopted various coping strategies among which the most important strategies include buying livestock insurance, keeping low debt obligations, and growing drought-tolerant grass varieties. Most importantly, the study found that certain factors such as age, education, number of earning family members, annual milk production, monthly cattle expenses, and landholdings significantly influenced dairy farmers’ strategies for adapting to climate change.

The ***second objective*** of this study (Chapter 4 / Article II), was to analyze the factors driving Willingness to Pay for index-based cattle insurance. This study found that farmers who spend more time on dairy activities have larger landholdings, earn more from dairy, have younger cattle, and are more willing to participate in index-based cattle insurance. Interestingly, farmers opt to prioritize protecting younger cattle over older ones, likely due to their higher future value and increased susceptibility to risks.

The ***third objective*** of this study was to investigate the impact of climate variables on cattle milk production in three villages in regional south India. This study found that rainfall significantly affected milk production and dairy incomes positively, and Mean Tmax and Mean Tmin significantly affected milk production and dairy incomes negatively.

A schematic flowchart is presented in Fig. 1.1 to depict the links between the studies and articles in this thesis.

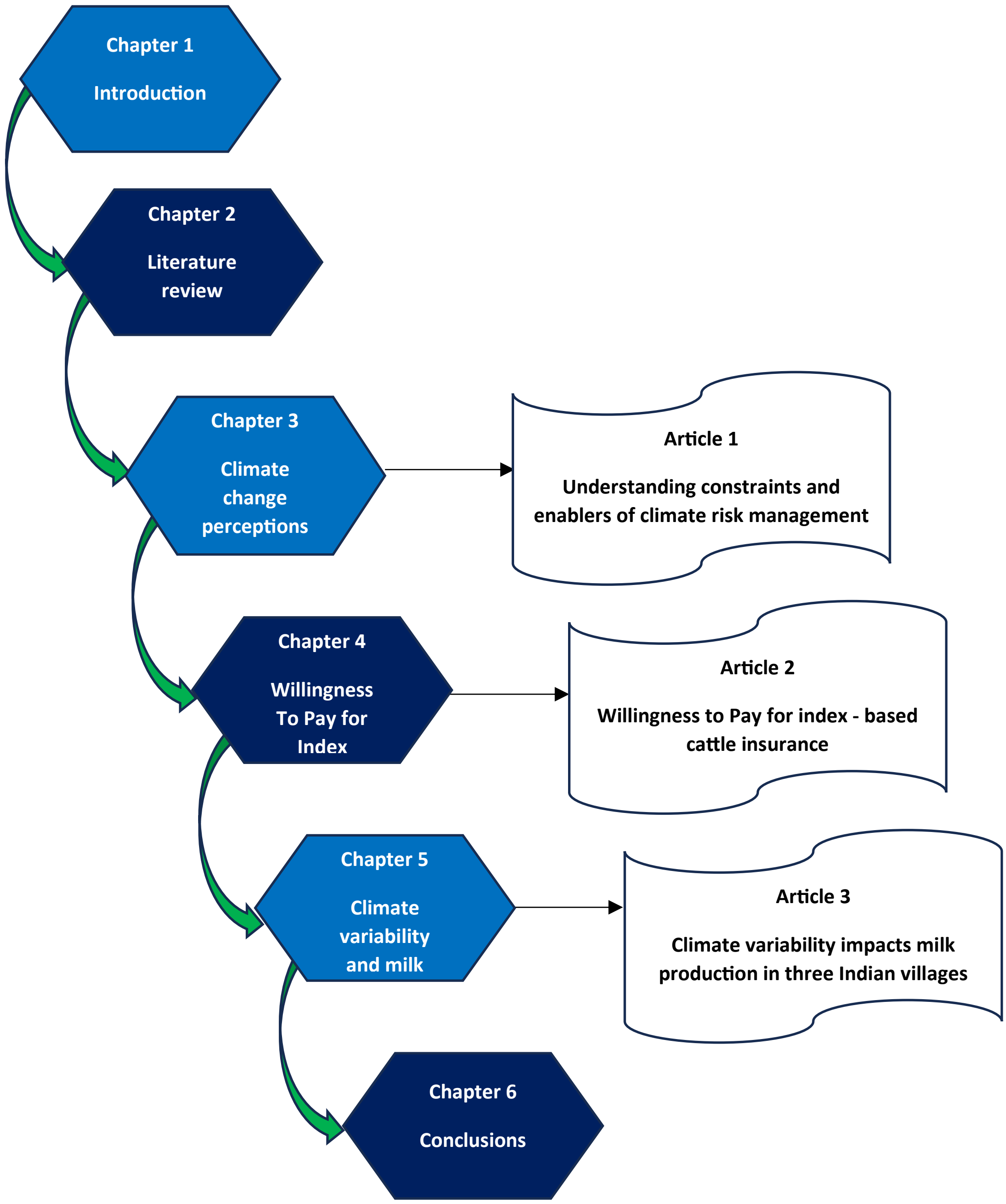

Figure 1.1: Flow diagram of the thesis

1.6 Summary

India's smallholder dairy farmers are facing significant challenges from climate change, which not only threatens their dairy activities but also the well-being of their livestock, which are valuable possessions. A better understanding of smallholder farmers' perceptions of climate change and coping strategies helps in better planning of the mitigation strategies and protecting their livelihoods. The development of improved index-based insurance products/schemes with affordable premiums is expected to attract smallholder farmers and help provide financial support in extreme climate years. It is critical to identify the regions with the best conditions for cattle milk production and improve these areas for expansion. There is a need to create awareness of cattle insurance benefits to increase dairy farmers' participation. The coping mechanisms adopted include buying livestock insurance, keeping low debt obligations, accessing better animal healthcare services, and growing drought-tolerant grass varieties to make dairy farming profitable. This study provides valuable information about dairy farm management strategies that can be used to establish an appropriate management recommendation for dairy farmers located in India and other regions with similar demographic and socioeconomic conditions.

CHAPTER 2: LITERATURE REVIEW

2.1 Smallholder dairy farmers’ perceptions of climate risk and adaption strategies in South India

India has been the largest milk-producing country in the world for nearly two-and-a-half decades. India contributes 23 % to global milk production (DAHD 2022a). At present, global milk production is growing at a rate of two percent per annum, whereas in India, its growth rate is over six percent per annum (DAHD 2022a). The per capita availability of milk in India is also much higher than the world average. In the last three decades, the daily milk consumption in the country rose from 107 grams per person in 1970 to 427 grams per person in 2020-21, compared to a world average of 322 grams per day during 2021 (DAHD 2022a).

The dairy sector in India plays a crucial role in supporting livelihood opportunities for 81 million dairy farmers (DAHD 2021b), predominantly smallholder dairy farmers (i.e. 2-5 cattle per farm family) and the landless, particularly in the rural areas of the country. These smallholder dairy farmers contribute to 62% of milk production in the country (Jatwani & Swain 2020). Dairy farming is highly livelihood-concentrated and has grown into a vital secondary source of income for millions of rural families and has assumed a valuable role in providing employment and income-generating opportunities, especially for small farmers (Rajeshwaran et al. 2015; Eisen 2020; Hu 2020; Sattar 2020).

The dairy cooperative societies that coordinate farmers at the village level have not only made the farmers self-sufficient but have also broken the shackles of gender, caste, religion, and community. Women producers form the major workforce of the dairy sector in the country and the sector is an important job provider and plays a strategic role in women’s empowerment (DAHD 2021b). However, this vital sector of the country is facing tremendous pressure from climate change impacts, which ultimately threaten sustainable livelihoods in the rural areas of India.

Dairy farmers around the globe operate their farming activities in an external farm environment, which has become very uncertain due to abrupt changes in environmental factors induced by climate change. Climate change-driven natural disasters, particularly droughts and floods, directly cause extremely variable production outcomes in terms of supply and threaten food security (Barnes & Toma

2012). While climate change and associated risks are a global phenomenon, the large number of small dairy holdings in developing countries like India and a growing dependence on dairy farming where the cattle are vulnerable to climate change could affect the country more than other big dairy producers such as the US or Brazil (Thornton et al. 2022). The challenges in livestock, especially in the dairy sector, and agricultural risk are exacerbated by changing climatic and extreme event conditions, with droughts, floods, heat, and strong winds, hailstorms, and cyclones becoming more intense (Silanikove & Koluman 2015). These have emerged as a massive threat to the sustainable development of dairying and protecting the livelihoods of millions of small producers (Moran 2009; Douphrate et al. 2013; Birthal, P. S. 2022; Thornton et al. 2022).

In India, mixed farming systems are most often benevolent due to the complementary nature of crop and livestock production. Much of the feed to animals is derived from agricultural remains and by-products. Because of the lack of relevant information, managing the multi-faceted risks associated with climate, feed, and milk prices in dairy farms is challenging (Birthal et al. 2006; Patel et al. 2016; Rohith 2019; Sarkar & Dutta 2020). This challenge is more relevant for smallholder farmers dairy farmers as ever pressing climate risk decreases bearing capacity due to externally operating farming systems, which are more vulnerable to climate exposures (Schaper et al. 2010; Aidoo et al. 2014; Elum et al. 2017; Amamou et al. 2018; Bishu et al. 2018; Eitzinger et al. 2018). There is a need for a thoughtful understanding of prospects of decision-making that are site-specific to help smallholder dairy farmers battling the wave of climate risks (Ahmed & Suphachalasai 2014; Byrareddy et al. 2021; Singh & Kagweza 2021).

India has been experiencing widespread drought for many years, greatly affecting dairy farming since the 1990s. The southern semi-arid regions have been hit particularly hard by changes in rainfall patterns (Muralikrishnan et al. 2022). Temperature, sunlight, humidity, water, and air pollution all have a bearing on the cattle immune system, resulting in infectious disease occurrence. For example, FMD (Foot-and-mouth disease) is a prime disease of livestock in India. It causes dairy farmers substantial economic losses, which have been reported to be more prevalent under extreme and abrupt changes in climatic parameters such as rainfall and temperature (Nejash & Kula 2016; Eskdale et al. 2022; Subramaniam et al. 2022).

A significant number of studies have been conducted worldwide on the farmers' perceptions of climate change issues concerning livelihood adaptations in the cropping sector, signifying the importance of farmers' perceptions of climate change and coping strategies. However, most of the existing studies on the farmers' perceptions of the climate change discourses mainly concentrate on the climate change impacts on the livelihood aspects of the cropping sector farming communities, and their locally preferred adaptation strategies (Below et al. 2015; Alam et al. 2017; Islam et al. 2020; Koç & Uzmay 2022). However, a limited number of studies have been conducted to investigate farmers' perceptions of climate change and adaptation strategies in the livestock sectors. For example, Montcho et al. (2022) reported that farmers adopted locally practiced measures to adapt to their perceived climate change (e.g. low rainfall, increased dry season) which had negative impacts on their livestock productivity (e.g. decrease in herd size, milk production, and fodder availability). However, smallholder dairy farmers' adaptation choices and determinants of these coping strategies did not get much attention in the existing studies, which could have policy implications for developing climate-responsive adaptation planning on a large scale. In addition, the susceptibility of dairy farmers and animal production to climate risks in the Indian context is poorly documented (Singhal et al. 2005; Sejian et al. 2016).

Furthermore, limited studies have been conducted to evaluate the knowledge and perceptions of dairy farmers in southern India, highlighting the need for additional research. Moreover, a thoughtful understanding of site-specific decision-making prospects could have profound potential to help small dairy farmers battling the wave of climate risks (Ahmed & Suphachalasai 2014; Singh & Kagweza 2021). It is, therefore, important to understand smallholder dairy farmers' perceptions of climate change issues as well as coping strategies with factors affecting farmers' adaptation choices. Formulating site-specific adaptation policies to combat climate change in the dairy sector would be helpful.

2.2 Willingness to Pay for Index-based Cattle Insurance among Dairy Farmers in Southern India

Climate change and impacts such as drought, extreme heat waves, floods, and other extreme weather events pose a significant threat to agricultural productivity and livestock production which are central to the livelihood protection of millions in India (Oduniyi et al. 2020; Singh & Agrawal 2020). The main challenge in the current mode of production is the inevitable climate risks and weather uncertainty. Temperatures rise between 2.3 and 4.8℃ anticipated over the entire country, together with increased precipitation because of climate change, is likely to aggravate risks in farming, depending on the season and location (Sirohi & Michaelowa 2007).

Dairy farming in India considerably contributes to food security and plays a helpful role in agriculture from misfortunes (Radhakrishnan & Gupta 2017). It is crucial to educate farmers about adopting climate-resilient technologies to counter the adverse impact of climate risks on food production (Patil et al. 2012). Dairy cattle are affected both directly and indirectly due to climate change-induced risks. Climate factors such as air temperature, humidity, strong winds, and other factors influence animal performance, including growth, production, health, and fertility. Long stretches of hot periods along with altered patterns of rainfall are likely to result in heat stress particularly in climate sensitive like semi-arid tracts, leading to decreased milk production and susceptibility to pests and diseases. Farmer's ability to adapt to climate change and associated risks is constrained by severe technological, socio-economic, and institutional barriers (Ada et al. 2006; Barnes & Toma 2012; Adeyinka et al. 2015; Bishu et al. 2018).

The introduction of weather index insurance schemes in recent years has gained traction due to new ways of controlling moral hazard and the growing concerns about increasing climate risks due to global warming. The uptake of weather index insurance products is below expectations despite the various benefits (functional potentiality, lessened moral hazard and adverse selection, timely indemnity payouts) that can be generated (Giné et al. 2008; Suarez & Linnerooth-Bayer 2010; Jensen & Barrett 2017).

The Index-Based Livestock Insurance (IBLI) project in Northern Kenya has shown that remotely sensed Normalised Difference Vegetation Index (NDVI) can be used to assess drought-related livestock mortality and help reduce the risk that pastoralists of arid and semi-arid lands are facing (Mude et al. 2010; Chantarat et al. 2013). This project has demonstrated the viability of predicting drought-related livestock mortality through remote sensing data overall and opens new prospects in this field of research (Mude et al. 2010; Chantarat et al. 2013; Amare et al. 2019). As drought significantly drives down prices for livestock affecting costs for farmers and making them vulnerable, weather insurance could be an answer on a larger scale for pastures (Adeyinka et al. 2015; Adeyinka et al. 2016).

Although various attempts to address Livestock Insurance challenges in India have been made, earlier initiatives were based on a top-down approach, thus lacking local stakeholders, particularly dairy farmer's involvement in the program design processes (Shirsath et al. 2019; Gaurav & Chaudhary 2020; Singh & Agrawal 2020; Ghosh et al. 2021). The main challenge is that farmers fail to be engaged in the design of programs they pay for. As such, their priorities, needs, and constraints facing them on the ground are not always considered.

In a study by Escarcha et al. (2018), the importance of researching climate change impacts and adaptation in mixed crop-livestock systems was emphasised. They suggested that research in this area could provide valuable insights into the sustainability of mixed crop-livestock production systems and the preservation of farmers' livelihoods in the face of a changing climate. Despite its significant capacity for improving agricultural growth and poverty reduction, India's livestock sector remains understudied by social scientists and less appreciated in public policy, partly because of the lack of public data (Birthal 2022a).

Regarding literature on the adoption of risk management strategies and their impact, it is not adequate to draw credible inferences to support their inclusion in agricultural development policies. Research on farmers' adaptation measures against several climate shocks remains limited in India and is a requirement to address multiple farmers' issues(CSTEP 2021; Birthal 2022b). There's a need to address these research gaps and gain a better understanding of the risks posed by climate change to dairy farming in general and, more importantly, for different breeds of cattle at the state or district level.

Although studies have been carried out to understand farmers' level of awareness, perception, and willingness to pay for traditional livestock Insurance and index-based livestock insurance in developed and developing countries (Mude et al. 2010; Singh & Hlophe 2017; Aina et al. 2018; Amare et al. 2019; Dong et al. 2020; Subedi & Kattel 2021) but barely any attention is paid to these critical aspects in the context of South Indian dairy farmers.

2.3 An overview of livestock insurance in India

Small and marginal farmers in India are involved in the practice of integrated farming, which comprises crops and livestock. Although the crop sector is vulnerable to climate change and weather deviations to a greater degree, the livestock sector also has challenges as a result of natural calamities. Indian agriculture, which is known for its exposure to the vagaries of monsoon, benefits from livestock, particularly cattle in mitigating, associated risks, as dairying provides an alternative source of work &income to millions of farmers (Dalwai 2017). Livestock rearing is a practice of more than 70 percent of rural households, which by gender accounts for 70 percent of women participation alone. This section is seen as a class whose lives are entwined with animal farming (Dalwai 2017; Chand et al. 2023).

Over four decades now, both central and state governments have played a significant role in livestock insurance with the thought of asset building goals among the poor segment of farmers. The private cattle insurance market in India experienced significant growth in 2003 following its deregulation. The private sector was granted permission to create and market their insurance products. Despite this, the state-owned General Insurance Corporation and its subsidiaries still hold the majority share of the livestock insurance market in India (Singh, A. et al. 2020).

Between 2005-06 and 2006-07, India piloted a centrally sponsored livestock insurance scheme as part of the 10th five-year plan. In 2014, the introduction of the National Livestock Mission (NLM) aimed to improve both the quality and quantity of livestock production systems and provide capacity building for all stakeholders. Livestock insurance did gain importance as a tool of risk management in this mission, but the uptake is barely 6 percent at the national level, excluding poultry (Bora 2017; Rohith 2019; Chand et al. 2023).

Despite the efforts of state and central governments, participation in livestock insurance schemes has always been low, and a matter of concern. What’s more shocking was the findings of the Parliamentary Standing Committee (PSC) on Agriculture, Animal Husbandry, and Food Processing report that said not even a single livestock was insured during 2022-23, whereas during 2021-22, 1,74,061 animals were insured (DAHD 2022b). Currently, only two factors, age, and types of cattle, are being used by insurers to determine premium rates for cattle insurance in India. Risk-based pricing has not been adopted (Doss & Pathak Tiwari 2022).

The Agriculture Insurance Company of India Limited (Akaichi et al.) is the primary agency responsible for implementing the Pradhan Mantri Fasal Bima Yojana, the government's flagship crop insurance scheme. AIC is now expanding its insurance product offerings in the livestock domain with Saral Krishi Bima and Sampoorna Pasudhan Kavach (PIB 2023).

Saral Krishi Bima is a special type of insurance that provides coverage to cattle farmers against financial losses caused by unfavorable weather conditions. This insurance product uses specific weather parameters like temperature, rainfall, and relative humidity to determine economic losses. Cattle farmers often face the challenge of decreased milk production in their livestock due to the temperature rise. The heat stress experienced by cattle during hot weather can result in reduced feed intake, dehydration, and ultimately, decreased milk production and sometimes losing the animal in the process (Gupta et al. 2022; Thornton et al. 2022). Recognizing this challenge, the Agriculture Insurance Company of India Limited has introduced the "Saral Krishi Bima" an insurance product that offers coverage for economic losses suffered by cattle farmers due to heat stress in the Indian state of Kerala (PIB 2023)[1]. It is currently unclear how widely Saral Krishi Bima has been adopted, and further analysis is necessary to fully assess its effectiveness. This study has the potential to provide valuable insights and refine the implementation of this agricultural insurance program.

2.4 Climate variability and change, and its impacts on Indian dairy

The climate zones in India include the cold glaciated Himalayas, the humid subtropical north, centre, and east, the tropical south and southwest, and the arid and semi-arid west and southern centre (USAID 2017). According to the Global Climate Risk Index 2021 published by Germanwatch, India was the seventh worst-hit country in 2019 (Trivedi 2021). In that particular year, 1.8 million people were displaced in India because of floods caused by heavy rains (Trivedi 2021). The intense monsoon during the same period affected 11.8 million people, with an appraised economic damage of USD 10 billion (Rs 72,900 crore at USD 1= INR 72.9). Moreover, there were eight tropical cyclones in 2019, of which six were classified as very severe cyclones on record in the North Indian Ocean, impacting around 28 million people, with an economic loss of USD 8.1 billion (Rs 59,066 crore). Temperatures are projected to increase over the coming decades, which likely will increase heat stress in dairy

[1] https://pib.gov.in/PressReleasePage.aspx?PRID=1915851

animals, unfavorably affecting the animal's productive and reproductive performance, and reducing fodder area, thereby making dairy cattle uneconomical (Sirohi & Michaelowa 2007). Dairy farming in India considerably contributes to food security and plays a helpful role in agriculture from misfortunes (Radhakrishnan & Gupta 2017). The susceptibility of animal production to climate risks is hardly documented in the Indian context and experimental studies dealing with effects of seasonal and climate variability on production, and other physiological limits of dairy animals (Singhal et al. 2005; Sejian et al. 2016). It is crucial to educate farmers about adopting climate resilient technologies to counter the adverse impact of climate risks on food production (Patil et al. 2012).

Climate risk across India is erratically distributed with its diverse climate zones, ecosystems, and topography. Snowballing temperatures and added severe dry seasons are likely to intensify drought impacts, and by 2030 India's agriculture sector is expected to suffer more than USD 7 billion of annual losses due to drought alone (USAID 2017). Warming trends will increase heat stress on dairy animals (mainly water buffaloes and cows), leading to a decrease in milk (Jingar et al. 2014). Wind and rain during the summer and winter seasons increase heat loss and cold stress in cattle (Jingar et al. 2014). Based on the predominant climate during inhabitation, the productive and reproductive abilities of cattle and buffaloes were observed (Soumya et al. 2016).

India is the world's largest producer and consumer of milk, and it has the world's largest dairy herd, comprising water buffalo and indigenous and crossbred cattle (Landes et al. 2017). For most Indians, milk is the major source of protein, and dairy farmers are the pillars behind nutritional security. Livestock production systems are broadly categorized as mixed rainfed, mixed irrigated, grassland, and landless/industrial (Kruska et al. 2003). In India, livestock are raised as part of mixed farming systems. Mixed rainfed systems are practiced on 46% of land and mixed irrigated systems on 37% of land, while grassland and industrial systems are limited to 4% and 13% of land, respectively (Birthal et al. 2006; Moran 2009, 2015; NDDB 2019). Small livestock is indispensable to populations in rural regions to manage the evolving risks caused by climate variability and change. Milk as a product is a stable source of cash income and live animals are key natural assets for small dairy farmers, which can be easily settled/sold for cash during emergencies (Thomas & Rangnekar 2004).

With a more affluent and urbanized population anticipated to grow noticeably in the coming decades comes an enormous appetite for dairy milk products. Dairy cow's crucial livelihood functions in smallholder systems, such as nutrition, income, asset provision, and insurance, are seldom considered while there is a singular focus on livestock associated environmental impacts (Herrero et al. 2015). Given the increasing climate variability, the ability to cope with unforeseen circumstances and become aware of the potential risks is critical to the success of any farming activity. Kumar et al. (2015) highlighted the need for key information on climate change impacts and adaptation strategies that would be imminent to address the climate impacts on feed scarcity environments and shelter management of livestock to protect all breeds. Livestock researchers must recognize how livestock systems are changing, beyond broader sector growth, with specific attention to be paid to knowing/understanding how the poor /small dairy farmers can benefit from emerging opportunities, which, of course, will require targeted research and developmental interventions (Birthal et al. 2006).

Dairying activity consists of a mix of individuals, livestock, natural resources, technology, economics, and finance. Such activity is subject to various challenges and risks, e.g., how much grass can be grown; the amount of milk their cows will produce through the productive years and the quality of the milk and the price it would fetch for them; to what extent they are liquid lies in their ability of savings and paying interest on borrowings in case they loaned it to support dairying activities and the worth of it.

To achieve food security, tackle poverty, generating employment opportunities for vast rural communities dairy plays a crucial role in rural households across all the poor and developing countries in the world (Revanasiddappa 2017; Abbas et al. 2019; Eisen et al. 2020; Hu 2020).

Addressing climate risks is of the utmost importance to the health of dairy cows. While the agricultural sector is being blamed, it is also adversely impacted by climate change. The direct impacts of any climate risk must be understood in the context of a geographically defined area as they manifest locally (Hewitt & Stone 2021; Masson-Delmotte et al. 2021). There are differences between provinces and within provinces.

Rising climate risks might, therefore, cause dairy systems to fail, for example, if key milk production hubs are affected. Mitigating and adapting to climate change now and in the future will not be solved by extreme measures, but rather by some middle ground, which is yet to be realized in the dairying systems of developing countries.

2.5 Summary and research gaps

Despite the widely acknowledged relevance of risk management in dairy farming, the literature review in these areas shows that there is a knowledge gap in understanding climate impacts on milk production in regional south India and cattle insurance. Limited documentation exists on the sensitivity of dairy animal production to climate risks highlighting the need for targeted research. There is a lack of comprehensive region-specific studies on climate risk management in dairy farming focused on small dairy farmers that are required for better decision-making and getting to know risk management measures is key to addressing the impacts in any given geographical region.

The adoption of effective coping and adaptation strategies is necessary for successful adaptation to the impacts of climate change in the dairy sector. However, little attention has been paid to understanding the perceived constraints and motivations toward such strategies. Addressing these gaps through participatory research that reflects dairy farmers' opinions and experiences is crucial for the sustainable growth of the dairy industry in India.

Further research has been scant on the crucial elements of climate and the necessity for enhanced insurance, including index-based insurance products, in any given area of India. The small dairy farmers in rural areas are vulnerable to climate variability due to changing precipitation patterns and rising temperatures, which considerably impact cattle milk production. Therefore, understanding the relationship between changing trends and milk production would advance our knowledge regarding the impacts of local climate changes and dairy farmers' livelihoods.

This study aimed to explore the dairy farmers’ perception of climate risk, how it impacts their dairy farming system, the coping strategies they employ, the barriers they face when implementing these strategies, and their willingness to pay for proposed hypothetical index-based cattle insurance. Further, this study aims to understand climate variability impacts on milk production in three villages of regional south India.

CHAPTER 3: PAPER 1: UNDERSTANDING CONSTRAINTS AND ENABLERS OF CLIMATE RISK MANAGEMENT STRATEGIES: EVIDENCE FROM SMALLHOLDER DAIRY FARMERS IN REGIONAL SOUTH INDIA

3.1 Introduction

This chapter delves into the thorough investigation of farmers' autonomous adaptation choices, which is crucial for developing climate-responsive adaptation planning on a large scale. It is also important to document the susceptibility of dairy farmers and animal production to climate risks in the Indian context, as small-scale farmers are highly threatened by climate change.

3.2 Published paper

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Understanding Constraints and Enablers of Climate Risk Management Strategies: Evidence from Smallholder Dairy Farmers in Regional South India

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Abstract: The adoption of effective coping strategies is crucial for successful adaptation to the impacts of climate change in the dairy sector. However, little attention has been paid to understanding the perceived constraints and motivations toward such strategies. A survey was conducted among 104 dairy farmers from three semi-arid regions of South India. The aim of the survey was to explore the dairy farmers' perception of climate risk, how it impacts their dairy farming system, the coping strategies they employ, and the barriers they face when implementing these strategies. The survey also investigated the factors that facilitate the adoption of adaptation measures. The results indicate dairy farmers in the region perceive drought, pests and diseases, and high temperatures as the major risks associated with climate change, which has resulted in decreased dairy income, animal health problems, reduced fertility, and food intake problems for their cattle. In response to climate variability, dairy farmers have adopted various coping strategies. The most important strategies include buying livestock insurance, keeping low debt obligations, and growing drought-tolerant grass varieties. However, most farmers face significant constraints in adopting these and other strategies including a lack of climate forecast data, the high cost of adaptation activities, and weak institutional support. On the other hand, the key enabling factors that support the adoption of these strategies include milk production security, suitable feed growing conditions, and family interest. Most importantly, the study found that certain factors such as age, education, number of earning family members, annual milk production, monthly cattle expenses, and landholdings significantly influenced dairy farmers' strategies for adapting to climate change. The study recommends that providing timely climate forecasts, implementing improved policies such as vaccination and cattle health services, and establishing strong institutional support systems can help dairy farmers become more resilient to climate change and protect their livelihoods.

Keywords: risk perceptions; adaptation constraints; adaptation facilitation; institutional support; access climate forecast

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1. Introduction

India has been the largest milk-producing country in the world for nearly two-and-a-half decades. India contributes 23% to global milk production [1]. At present, global milk production is growing at a rate of two percent per annum, whereas in India, its growth rate is over six percent per annum [1]. The per capita availability of milk in India is also much higher than the world average. In the last three decades, the daily milk consumption in the country rose from 107 g per person in 1970 to 427 g per person in 2020–2021, compared to a world average of 322 g per day during 2021 [1].

The dairy sector in India plays a crucial role in supporting livelihood opportunities for 81 million dairy farmers [2], who are predominantly smallholder dairy farmers (i.e., 2–5 cattle per farm family) and the landless, particularly in the rural areas of the country. These smallholder dairy farmers contribute 62% of milk production in the country [3]. In India, dairy farming systems are most often benevolent due to the complementary nature of crop and livestock production. Much of the feed to animals is derived from agricultural remains and by-products. Although dairy farming has been reported as an age-old and complementary agricultural practice, particularly for the marginal and landless farmers in India [4], it has gained much popularity and attracted attention of the large farming households in recent decades [5–7].

However, this vital dairy industry in India is facing tremendous pressure from climate change impacts, which ultimately threatens sustainable livelihoods in the rural areas of most of the regions of the country [8]. Dairy farmers are similarly exposed to uncertainty regarding changing climatic conditions that produce abrupt changes in environmental factors. For example, the southern semi-arid regions of the country have been hit hard by changes in rainfall patterns, and widespread drought for many years, which has greatly affected dairy farming operations in the last few decades [9].

Climate-change-induced abrupt precipitation patterns and rising temperatures have heightened risks to the health and welfare of livestock [8,10]. For instance, foot-and-mouth disease (FMD), which is a dominant livestock disease in India, has been reported to be more prevalent under extreme and abrupt changes in rainfall and temperature [11–13]. Moreover, health risks of livestock animals are predicted to be accelerated due to a likely increase in average temperature by 2 °C by 2050 in the coming decades [14], as heat stress can inhibit the immune system of livestock leading to an increase in the potential outbreak of infectious diseases [12,15–17].

The quality and quantity of milk, wool, and meat associated with climate variability and extreme weather have also led to a drop in the market prices of final products [8,10,18], resulting in variable production supply that threatens food security [19–23]. However, managing the multi-faceted risks associated with climate change impacts (e.g., health risks, feed availability, milk prices) in the dairy farming industry is becoming more challenging due to a lack of relevant climate information [24–27]. Thus, there is a need for a thoughtful understanding of the prospects of decision making that are site-specific to help smallholder dairy farmers battling the wave of climate risks [28–30].

Numerous studies have been conducted worldwide on farmers' perceptions of climate change and their adaptation strategies in the cropping sector. These studies highlight the significance of understanding farmers' perceptions of climate change and their coping mechanisms. However, most existing studies have focused on the impacts of climate change on the livelihoods of farming communities in the cropping sector and their locally preferred adaptation strategies [31–34]. Limited research has been conducted on farmers' perceptions of climate change and their adaptation strategies in the livestock sector.

For example, a study by Montcho et al. [35] found that farmers adopted local measures to adapt to perceived climate change, which had negative impacts on livestock productivity, such as reduced herd size, milk production, and fodder availability. However, existing studies have paid little attention to the autonomous adaptation choices of smallholder dairy farmers and the factors that motivate them to adopt these strategies [36,37].

A comprehensive investigation of farmers' autonomous adaptation choices is crucial for developing climate-responsive adaptation planning on a large scale. It is also important to document the susceptibility of dairy farmers and animal production to climate risks in the Indian context. Furthermore, limited research has been conducted to assess the knowledge and perceptions of dairy farmers in southern India, highlighting the need for additional research [28,30,38]. Therefore, it is imperative to understand smallholder dairy farmers' perceptions of climate change and their coping strategies while considering the factors that affect their adaptation choices.

This study aims to investigate how smallholder dairy farmers perceive climate risks and how these risks affect their dairy activities. The study will also examine the current risk management strategies used by farmers, as well as the obstacles and opportunities for adaptation. Furthermore, the study will identify the factors that influence dairy farmers' choice of coping strategies for climate-change-related risks in their dairy farming system.

2. Material and Methods

2.1. Selection and Description of the Study Area

Karnataka is the second most vulnerable state in India to be impacted by climate variability and change as it comprises the aridest and driest regions [39]. Karnataka's agriculture and socio-economic settings act as an appropriate representative unit for South India's semi-arid regions. Dairy farming is one of the major livelihood activities besides agriculture in most Indian states. The state has variable rainfall, diverse soil types, and cropping patterns, and the state is divided into 10 agro-climatic zones [40]. The climate-change-induced risks and impacted zones can cause distress to cattle health and other dairying activities. Hence, it is important to study the dairy farmers' perception of various climate risks and impacts, adaptation, and mitigation strategies in the semi-arid pastoral regions in southern India (Bengaluru Rural/Urban and Chikkaballapur).

The reason for choosing these regions is because of their vulnerability to drought, livestock feed constraints, and water availability issues [39]. Bengaluru and Kolar-Chikkaballapur milk unions are the top two in the state, contributing around 25% to total dairy cooperatives and milk producers in Karnataka while adding about 34% to average milk procurement [41]. The study area receives erratic rainfall averaging 661–1086 mm per annum and high temperatures of over 29–39 °C in summer. Figures S1 and S2 show average rainfall and temperature trends from 2000 to 2022. From the Karnataka state, the study regions (e.g., districts) were selected based on the secondary sources where climate change impacts on the dairy sectors were reported in the literature. Then, from the districts, eight villages were selected to administer the survey. The selected villages were Adde Vishwanathapura, Byatha, Chalahalli, Kadathanamalli, Marelenahalli, Neralaghatta, Tharabanahalli, and Bachuvarihalli (Figure 1).

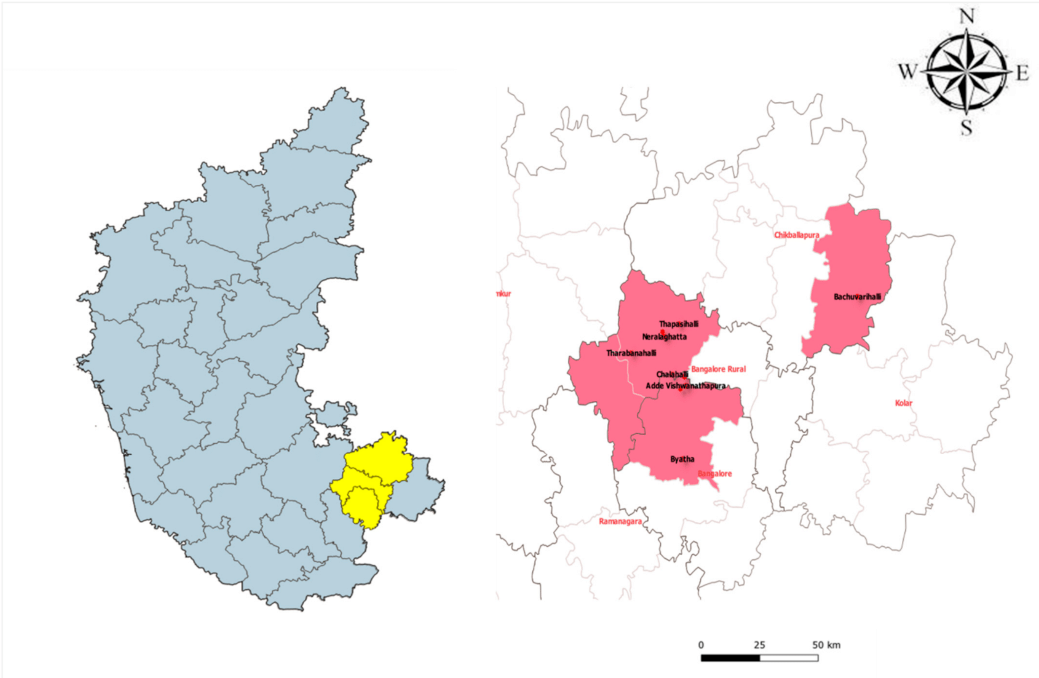

Figure 1. The location of the study areas (red polygons—**right** insert) on the regional map was selected in the state of Karnataka, covering the districts of Bengaluru (rural and urban) and Chikkaballapur (yellow polygons—**left** insert).

2.2. Survey and Data Collection

Primary data were collected through a survey using a pre-tested and structured multiple-choice questionnaire where respondents were able to select different answer options for each question. The initial questionnaire of the study was prepared following Phellas et al. [42]. Having preliminary contact with some of the key informants in the study area, the lead author organized several phone calls with several smallholder dairy farmers to pre-test the questionnaire. By addressing the comments returned during the pre-testing, the initial questionnaire was then restructured and finalized, and employed for data collection. A similar procedure of pre-testing a structured questionnaire was also used in several studies exploring farmers' perceptions of environmental changes [43,44].

The questionnaire was divided into sections to collect information on dairy farmers' socio-economic characteristics; cattle information and consumption patterns; climate risks and impacts (peril) that farmers experienced in the last decade in the region; the climate risks impact on dairy activities that farmers consider (relevant/nonrelevant); a list of barriers and enablers, that farmers need toward their adaption and mitigation measures; and the climate risk management strategies that are (important/not important) to dairy farmers.

Before administering the survey in the studied area, human resources ethics clearance was sought, and approval was gained from the University of Southern Queensland (H22REA088). Following ethics approval, a field trip was organized to administer the survey. The lead author carried out the surveys in a face-to-face interview with each of the 104 respondents.

To operationalize the survey, a stratified sampling procedure was followed to select the respondents, where the individual dairy farming household was considered a primary sampling unit. Firstly, the study regions (e.g., districts) were selected based on a literature review of reported climate change impacts on the dairy sectors. Then, eight villages were selected from the districts to administer the survey. The selected villages were Adde Vishwanathapura, Byatha, Chalahalli, Kadathanamalli, Marelenahalli, Neralaghatta, Tharabanahalli, and Bachuvarihalli. From each village, the smallholder dairy farmers (i.e., respondents) were selected based on recommendations from dairy heads in each village and the availability of participants, to obtain a representative (in terms of gender, cattle ownership) sample of farmers. Thus, a total of 104 diverse socio-economic-centric rural dairy and agricultural farmers were selected from the study region. A similar stratified sampling procedure was also reported in a study that explored farmers' perceptions of climate change and adaptation strategies [45]. In addition to primary data collected from dairy farmers, this study also utilized secondary data (documents and reports) from public institutions such as the Department of Animal Husbandry and Dairying to support its findings.

Farmers' perceptions regarding the climate risks, impacts, coping strategies, barriers of adaptation, and enablers of adaptation were gathered on the predefined (structured) statements focusing on whether they agree with the statements (i.e., yes/no, important/not important). The details of various dimensions relevant to climate risk perception, adaptation, etc., elicited through farmer's survey are depicted in the flow chart (Figure 2) for a clear understanding.

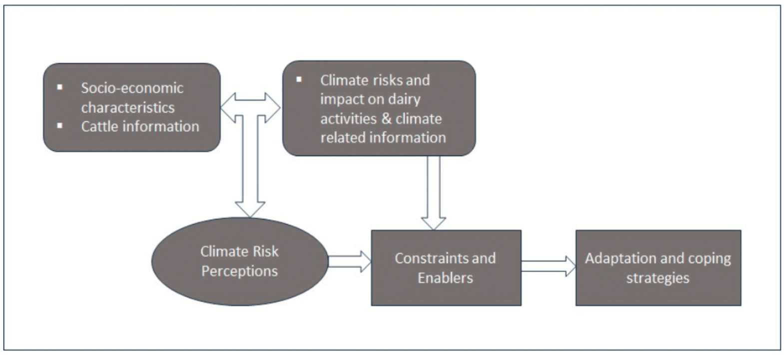

Figure 2. Conceptual framework of data collection process on various factors by dairy farmers.

2.3. Statistical Analysis

Farmers' perceived responses to different issues of climate risks affecting dairy farming, and adaptation choices were presented in terms of "yes" and "important" to demonstrate that the farmers agreed with the statement asked through a structured questionnaire. Similar analysis and results presentation were also reported in studies of farmers' perceptions of climate change in the agricultural sector [35,46].

Following gathering responses on the different variables, these "yes/important" were then coded with a number, and analyzed using SPSS statistical software (version 28.0.1.0 (142)) [47]. Non-parametric chi-square tests were conducted to show the relationship between some of the independent variables and farmers' knowledge of climate change. Furthermore, a chi-square test was carried out to demonstrate the differences among the farmers' perceptions in different dimensions of climate change and adaptation strategies, the constraints of adopting these strategies, as well as facilitating factors in their adoption of these coping strategies, and expressed in percentages.

Additionally, a logistic regression test was conducted to explore the factors affecting farmers' choices of coping strategies using whether each of the selected adaptation strategies (e.g., cash in hand, using drought tolerant grass varieties, buying livestock insurance) was important or not important using the dependent variable with the socio-economic characteristics of the respondents (e.g., gender, age, education, family member, land holding) as independent variables. This analysis identified whether socio-economic, sociopsychological, and related variables contributed to the adaptation strategies chosen, leading to meaningful inferences from the study.

3. Results

3.1. Socio-Economic Characteristics of Respondents

The socio-economic characteristics of the smallholder dairy farmers surveyed are summarized in Table 1. The mean age of the respondents was 50.55 years, having 8.32 years of schooling. The average landholding capacity of the respondents was 3.26 acres across the eight surveyed villages in Karnataka. The average annual income was 108,928 INR and the annual milk production per cattle was 3499 L.

Table 1. Socio-economic characteristics of the respondents surveyed in this study. Number of surveyed farmers = 104.

Socio-Economic Characteristics (Unit of Measurement)	Mean	Std. Deviation	S.E
Age (Number)	50.55	13.55	1.32
Education (Schooling years)	8.32	4.19	0.41
Landholding capacity (Acres)	3.26	2.89	0.28
Annual Income (INR)	108,928	60,751	5957
Herd size (Number of animals)	2.21	1.19	0.11
Annual milk production per cattle (Liter)	3499	1319.07	129.34
Annual expenses per cattle (INR)	45,450	15,625.24	1532.18

3.2. Relationship of Socio-Economic Features of the Smallholder Dairy Farmers and Their Knowledge of Climate Change

The majority of the socio-economic characteristics of the respondents had a significant relationship with the dairy farmer's knowledge of climate change, except for the gender and age of the respondents. The results of these relationships among the socio-economic characteristics and knowledge of climate change in terms of "yes" responses are presented in Table 2. Among the respondents, 56% of males and 44% of females reported knowledge of climate change. In terms of age of the respondents, the vast majority (51.5%) of respondents who held knowledge of climate change were between "31 and 50" years of age, followed by the 51–70 years age group (35.4%). In connection to the educational qualifications, the vast majority (53.5%) of the respondents who mentioned "yes" have a high school level of education. Results also revealed that the highest "yes" responses (96%) indicating having knowledge of climate change were recorded from the respondents whose primary occupation was agriculture. Furthermore, in terms of landholding capacity, the highest "yes" responses (41.4%), indicating that they have knowledge of climate change, were reported from the marginal landholding group of farmers followed by small landholding farmers (34.3%), as presented in Table 2.

Table 2. Relationship among the socio-economic features of the respondents and their knowledge of climate change.

Socio-Economic Features		% of Respondents Mentioned "Yes"	Chi-Square
Gender	Male	55.6	2.42 ns
	Female	44.4	
Age	<30 years	5.1	4.13 ns
	31–50 years	51.5	
	51–70 years	35.4	
	>70 Years	8.1	
Education	Illiterate	11.1	8.75 **
	Primary	14.1	
	Middle school	11.1	
	High School	53.5	
	University	10.1	
Primary occupation	Agriculture (Dairy and crops)	96.0	14.23 **
	Other business	1.0	
	Dairy only	3.0	
Landholding	Marginal (<2.47 acre)	41.4	3.14 *
	Small (2.47–4.94 acre)	34.3	
	Medium (4.94–9.88 acre)	20.2	
	Large (>9.88 acre)	4.0	

ns = not significant (i.e., $p > 0.05$); * $p < 0.10$ ** $p < 0.05$.

3.3. Farmers' Perception of the Risks of Climate Change on the Dairy Farming Systems

Smallholder dairy farmers' perceptions of climate change risks on their dairy farming system are presented in Figure 3. Risks related to drought and to pests and disease were the two most highly ranked risks. When asked about drought, 91% of the respondents mentioned "yes" as drought was a severe climate change risk. Similarly, 89% of the respondents reported an increase in pests and diseases as a result of climate change, and 81% of the farmers identified heat stress as a climate change risk. Regarding erratic rainfall, hailstorms, and floods, 78%, 68%, and 64% of the farmers recognized these as climate change risks, respectively.

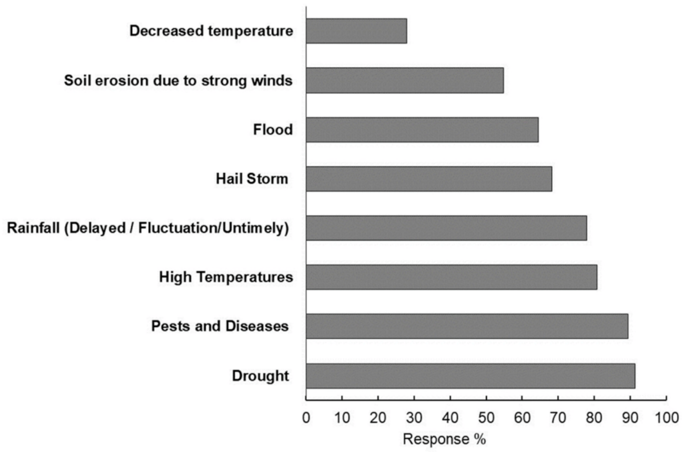

Figure 3. Main climate risks identified during the survey and corresponding farmers' responses (in percentage). Number of farmers surveyed = 104.

3.4. Farmers' Perceptions of the Impacts of Climate Risks on the Dairy Farming System

Smallholder dairy farmers were asked whether they agreed (yes) or not (no) with the impacts of each of the climate change risks on their dairy farming system, and their responses indicating "yes" they agreed are presented in Figure 4. Most farmers agreed that climate change has a negative impact on their dairy farming activities, especially in terms of labor and income. They attributed this to a decrease in milk production. Additionally, 99% of the farmers noted that animal health issues were a direct result of high temperatures, particularly during the summer months (March to May). The farmers also reported experiencing severe drought in the region, which has resulted in a decrease in food intake (98%) and feed issues (96%) due to the high temperatures (see Figure 4).

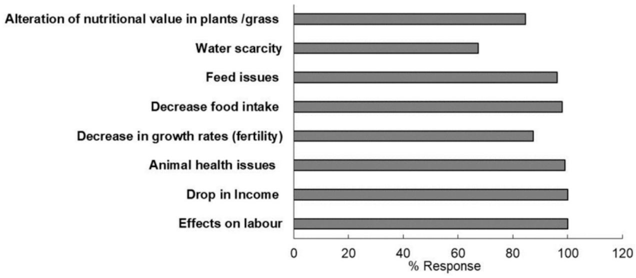

Figure 4. Farmers' perceptions of the impacts of climate risks on the dairy farming system. Number of farmers surveyed = 104.

3.5. Dairy Farmers Adaptation Strategies

Farmers were asked to share their thoughts on the impact of climate risks on dairy activities and which adaptation strategies they deemed important to mitigate these effects. These responses were expressed in percentages of farmers who mentioned that the specific adaptation strategy was important. The study revealed a range of adaptation strategies that are commonly used in the dairy industry to combat climate-change-induced risks. Results indicated that in terms of buying livestock insurance and low debt obligations, 100% of the respondents mentioned these coping strategies are important, followed by using drought-tolerant variety grass (99%), value addition of dairy products, and keeping cash in hand (98%), off-farm employment (88%), and selling livestock (80%) as the most important adaptation strategies to climate change impacts, However, regarding income diversification, crop insurance, and increasing herd size, farmers' responses were divided by both important and not important, which indicated by 61%, 60%, and 58% toward "yes" the adaptation strategies are important respectively (Figure 5).

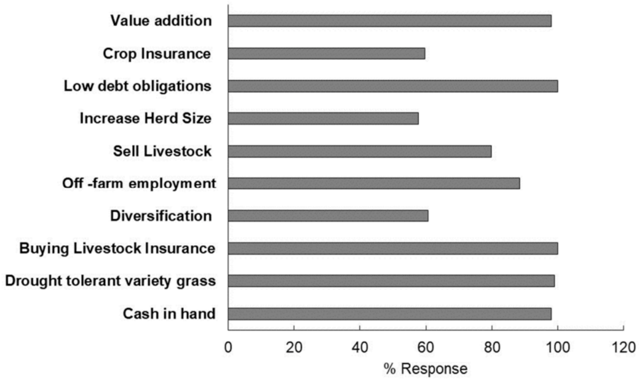

Figure 5. Coping/adaptation strategies adopted/practiced by the smallholder dairy farmers. Number of farmers surveyed = 104.

Following an understanding of the perceived coping strategies for dealing with climate change impacts, this study then investigated how these perceptions varied according to the salient socio-economic features of the respondents (Table 3). The study found that farmers were divided on the importance of adaptation strategies based on the gender of the respondents. However, in terms of the primary occupation of the respondents, more than 95% of those farmers whose occupation was agriculture (livestock and dairy) mentioned all the perceived adaptation strategies were important to them, while only 5% of them perceived coping strategies were not important. Similar trends were also observed in the case of the educational qualifications of the respondents. The findings demonstrated that many of the respondents who had high school-level educational qualifications (~50%) mentioned that adaptation strategies were important to them (Table 3).

Table 3. Farmers' perceived coping strategies for climate change impacts as influenced by different socio-economic features.

Adaptation Strategies	% of the Respondents Mentioned the Adaptation Strategies as Important										Chi-Square
	Gender		Occupation			Educational Qualification					
	Male	Female	Agriculture	Business	Dairy	Illiterate	Primary	Middle School	High School	University	
Value addition	53.8	46.2	95.7	1.1	3.2	14.0	16.1	9.7	50.5	9.7	64.65 **
Crop Insurance	54.8	45.2	93.5	1.6	4.8	14.5	11.3	9.7	58.1	6.5	3.84 *
Low debt obligation	53.8	46.2	94.5	1.1	4.4	11.0	16.5	13.2	49.5	9.9	58.50 **
Increase herd size	53.3	46.7	93.3	1.7	5.0	11.7	16.7	11.7	51.7	8.3	2.46 ns
Sell livestock	51.8	48.2	94.0	1.2	4.8	12.0	15.7	10.8	49.4	12.0	36.96 **
Off-farm employment	54.3	45.7	95.7	1.1	3.3	12.0	15.2	10.9	51.1	10.9	61.53 **
Diversification	46.0	54.0	93.7	1.6	4.8	15.9	12.7	9.5	52.4	9.5	4.6 **
Buying livestock insurance	54.0	46.0	94.0	1.0	5.0	13.0	16.0	12.0	50.0	9.0	88.61 **
Cash in hand	52.9	47.1	94.1	1.0	4.9	12.7	15.7	11.8	51.0	8.8	95.15 **
Drought-tolerant grass cultivation	47.1	52.9	94.1	1.0	4.9	12.7	14.7	11.8	51.0	9.8	96.15 **
Alternative income sources	55.1	44.9	94.9	0.0	5.1	12.2	16.3	12.2	50.0	9.2	81.38 **

ns = not significant (i.e., $p > 0.05$); * $p < 0.10$, ** $p < 0.05$.

3.5.1. Barriers to Adaptation

Apart from perceived important adaptation strategies and factors influencing adaptation in this study, we further assessed the barriers to their adaptation by dairy farmers. Findings indicated that most of the farmers agreed with the perceived statements of the adaptation barriers, such as "lack of climate forecast", "adaptation strategies were expensive", and "weak institutional support". The "yes" responses toward these statements were 100%, 99%, and 84%, respectively, while the case of "policies of dairy co-operatives" yielded a similar proposition of the responses toward "yes" it is important, and "no" it is not as important (Figure 6).

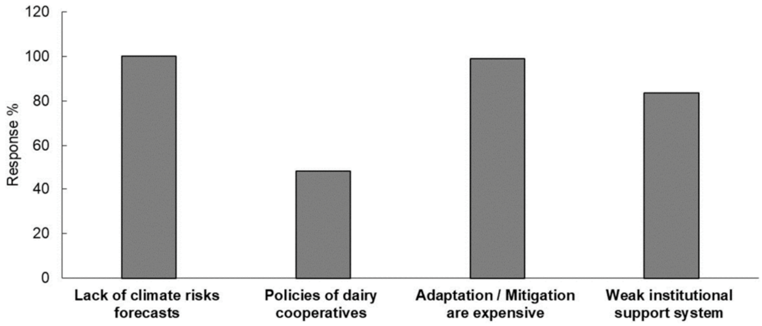

Figure 6. Barriers to adaptation reported by dairy farmers. Number of farmers surveyed = 104.

3.5.2. Motivating Factors for Adopting the Climate Impact Adaptation Strategies

Despite the barriers to adaptation, some factors drove the local farmers to act upon and adopt appropriate and timely measures. The findings of this study revealed that in cases of "family interests", "milk production security", and "economic interests", and "suitable growing feed condition" were reported as the most important motivating factors, as almost 99% of the respondents mentioned "yes" toward these statements. In comparison, 90% of the respondents mentioned "no" toward the statement of a motivating factor as "taking collective action for climate risks" (Figure 7).

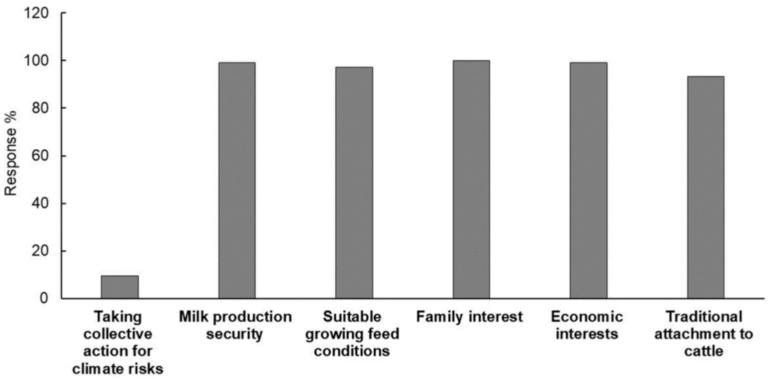

Figure 7. Motivating factors to adopt adaptation strategies. Number of farmers surveyed =104.

3.5.3. Determinants of Dairy Farmers' Coping Strategies to Climate Change Impacts

The results show that the eight variables are critical in one or multiple adaptation strategies adopted by smallholder dairy farmers (Table 4). Gender has a significant influence

($p < 0.05$) when considering diversification in dairy farming, and female farmers preferred this over male dairy farmers. Age affected the adoption of cash in hand, the decision to grow drought-resistant grass, increasing the herd size, and low debt obligation. Farmers with more experience in the dairy industry tend to prefer conservative adaptation strategies such as diversification and using drought-tolerant grass varieties as livestock feed. Education also had a positive effect on similar adaptation decisions. The more years spent in education, the more farmers chose diverse adaptation measures to counter the risks of climate change. Higher education positively affected the consideration of crop insurance as an adaptation strategy. More earning family members opted for off-farm employment and this positively affected crop insurance adaptation by 6%, which shows the additional income makes the farmer capable of buying risk-sharing strategies like insurance. Annual dairy income influenced the farmers to opt for growing drought-tolerant varieties of grasses, which makes sense in so far as additional investment is required for such an adaptation measure apart from regular dairy operations. The cattle expenses affected farmers' decisions on the amount to be held in the form of cash for unforeseen circumstances and affected the decisions to adapt diversification and consider off-farm employment significantly ($p < 0.05$). Land holdings of farmers impacted the decision to obtain off-farm employment. It positively influenced the growth of drought-tolerant grass varieties and value addition to dairy farming activities in terms of better hygiene conditions for cattle in place on the relevant farm. In this study context, value addition meant improved conditions for cattle in terms of hygiene and other actions taken for the protection and welfare of animals.

Table 4. Coefficient estimates from a logistic regression on the factors influencing/affecting different adaptation measures (coping strategies) adopted by dairy farmers.

Predictors Variables	Response Variables (i.e., Adaptation Measures)									
	Cash on Hand	**Drought-Tolerant Variety Grass**	**Buying Livestock Insurance**	**Diversification**	**Off-farm Employment**	**Sell Livestock**	**Increase Herd Size**	**Low-Debt Obligation**	**Crop Insurance**	**Value Addition**
Gender (0 for male, 1 for female)	NS	NS	NS	−0.63 **	NS	NS	NS	NS	NS	NS
Age	−0.86 *	0.951 *	NS	NS	NS	NS	0.007 *	0.029 **	NS	NS
Education (y)	NS	NS	NS	NS	NS	NS	0.01 *	0.11 *	0.007 *	NS
Earning family members	NS	NS	NS	NS	1.19 **	NS	NS	NS	0.06 **	NS
Annual income	NS	0.00 **	NS	NS	NS	NS	NS	NS	NS	NS
Annual milk production	−0.018 **	NS	−0.001*	NS	NS	NS	NS	−0.00 **	NS	NS
Expenses per cattle per month	0.016 *	NS	NS	0.00 *	−0.001 **	NS	NS	NS	NS	NS
Landholding	NS	NS	NS	NS	0.021 **	NS	NS	NS	NS	NS

Statistical significance; * indicates $p < 0.1$; ** indicates $p < 0.05$, NS = not significant (and so coefficient not shown). Dependent variable: Not important = 0, Important = 1.

4. Discussions

Exploring the perceived constraints and enabling factors of the coping strategies is imperative to successfully plan for climate change adaptation. However, the existing discourses of perceptions of climate change adaptation studies are overwhelmed by the crop sector studies, which are predominantly focused on risk and adaptation and pay little attention to perceived constraints and facilitating factors. To understand these issues, a structured questionnaire survey was adopted in this study to investigate the smallholder dairy farmers' perceptions of climate change and their coping strategies, as well as barriers and enabling factors to adopt these coping strategies, which could help to plan comprehensive adaptation actions. This section discusses the findings of this study in the following subsections.

4.1. Smallholder Dairy Farmers' Knowledge of Climate Change and Their Perceptions of Climate Risk and Impacts

The socio-economic characteristics of dairy farmers are important because they influence their economic behavior and determine the ability of farmers to adequately adopt climate risk management strategies. The results of this study demonstrated a significant relationship between their knowledge of climate change and most of the socio-economic characteristics of the farmers (Table 2). These results were found to be consistent with previous studies, indicating that dairy farmers understanding and knowledge of climate change are key drivers to their adaptation approaches [46]. Further, socio-economic features play a vital role in farmers' perceptions of climate change issues, which, in this study, was a driving indicator of adopting coping strategies. For example, the existing literature has demonstrated that education levels play a key role in the enactment of climate adaptation measures based on perceptions of farmers and climate-related information [48]. In addition to local indigenous knowledge, climate science education would help farmers acquire further knowledge and skills to read and understand a wide range of climate-related information and determine how it impacts dairy. The level of a farmer's education also influences the quality of decisions made by dairy farmers whenever a climate risk triggers an adaptation response.

Results further indicated significant associations among the respondents in connection to the impacts of educational qualification on their knowledge of climate change. The results showed that the farmers who were more aware of climate change had completed high school education, followed by those who had completed primary education. On the contrary, most respondents who indicated that they did not know about climate change were illiterate or held primary levels of educational qualification. Results also revealed that land holdings of dairy farmers had a significant association with their knowledge of climate change; in particular, those farmers with marginal and small landholdings agreed they had knowledge of climate change, which dominated in this sample study. These findings are consistent with another study, which indicated that farmers' perceptions play a significant role in the adaptation process [49].

The study conducted in the region has shown that farmers consider drought as the most devastating climate risk, followed by increased pests and diseases, erratic rainfall, hailstorms, and floods. Moreover, the farmers' views on climate change have been verified by comparing them with the observed rainfall and temperature data obtained from the meteorological stations in the region between 2000 and 2022, as illustrated in Figure S1. The meteorological records reveal that the region has experienced 23 years of erratic annual average rainfall, with seven years (2011–2014, 2016, 2018, 2019) in the last decade having below-average rainfall, leading to droughts as shown in Figure S2. Additionally, drought periods were characterized by high mean temperatures ranging from 34 and 39 degrees, which were reported frequently. Therefore, the perceived climate risks by farmers in the region are consistent with the reported data in the existing literature.

In addition, farmers reported heat stress and increased pest and disease incidence in cattle could be a result of drought and high mean temperatures. Rainfall data show a fluctuation trend notably in the years (2020–2022) with heavy rainfall posing different challenges to dairy activities, particularly the landless and small land-holding farmers who depend on pasture grazing around water bodies. Thus, the findings of this study regarding farmers' perceptions of climate change issues were consistent with the meteorological records, signifying that farmers were closely connected to weather and climate cycles and were able to describe environmental factors affecting their dairy farming activities. As most farmers were involved in agriculture production, they were mainly concerned about drought and above-average rainfall years (2020–2022) in the region since they caused a series of crop failures. This experience created further worry for future cultivation and cattle feed security. The foot and mouth disease (FMD) outbreak in the years 2013 and 2018 was confirmed [11] as an extreme challenge by dairy farmers in the study. Unfortunately, stress on cattle is just one way that extreme heat is challenging dairy farmers with small herd sizes.

The reported list of climate change impacts on dairy activities in this study was found to be consistent with previous studies that also indicated similar implications on dairy farming [46,50–52]. The findings of this study are consistent with [35,53–55], who reported that climate change impacted risks, particularly, heat stress affects milk production in cattle. Persistent dry spells and severe rain were also found to affect the availability of fodder [56] and, in turn, the cost of feed. Thus, the findings of this study were consistent with previous research on the pressures of soaring cattle feed costs and water scarcity issues that led to severe distress from season to season in terms of climate-associated risks [39,57,58], compelling farmers to review their decisions. Previous research has mainly concentrated on the environmental effects that affect livestock productivity, such as the availability of food, shelter, and milk production [59,60]. However, this study has taken into consideration animal welfare concerns, particularly, nutrition, which were previously overlooked.

4.2. Smallholder Dairy Farmers' Coping Strategies, Constraints, and Facilitating Factors in Adopting These Strategies

The findings of this study have shown that a vast majority of the smallholder dairy farmers opined that buying livestock insurance is the most important adaptation strategy to cope with the climate change impacts, followed by growing drought-tolerant variety grass and off-farm employment (Figure 4). Farmers' primary occupations and educational qualifications were found to be the major factors influencing their coping strategies for climate change impacts. In fact, a range of socio-economic, political, institutional, and region-specific environmental factors have a bearing on the adaptive capability of the livestock sector toward climate change. The findings also demonstrated that those farmers with marginal land holdings subject to droughts and unpredictable rainfall are often required to seek off-farm employment, which can involve migration to nearby towns to cope with the financial distress caused by climate change.

The study found that farmers agreed to keep cash in hand as an important adaptation measure to climate risk. Saving money has been a long-standing practice among farmers to tackle tough times by making lifestyle changes when required. Keeping low debt obligations and not depending on money lenders was preferred due to the exorbitant interest rates they charged, which has led fellow dairy farmers to fall into a debt trap. In small-scale mixed crop–livestock systems, farmers have limited economic opportunities compared to cropping systems [61]. Previous studies have shown that keeping cash on hand is the most important risk management strategy for dairy farmers [62,63].

Previous studies also indicated that frequent and persistent droughts lead to the drying of natural pastures, which causes feeding problems for animals and affects the availability of water and the quality of fodder resources in the region [35,64]. Thus, those farmers facing fodder deficiencies made sure to stock some seasonal-based crop residue, purchasing from nearby localities. In addition to diversified feedstock (e.g., drought-tolerant grass, drumstick tree leaves), farmers also introduced diversified livestock to keep their livelihood sustainable through alternative income generation activities and to enhance their livelihood resilience by spreading risk across a number of income channels. For example, farmers reared goats/sheep to gain extra income, particularly to support the period when milk production is usually reduced due to the gestation period. Some women farmers have started chicken farming and selling eggs to earn extra income when their land is not used for agriculture.

Many farmers chose to take advantage of cattle insurance offered by dairy co-operatives, who subsidized the insurance premium by 50%. Although insurance was purchased regularly over the years, some farmers reported losing their animals if they missed a year. A few well-educated farmers were aware that the insurance policy was put in place to deliver protection mechanisms to the cattle rearers against any eventual loss of their animals due to death and to validate the benefit of cattle insurance. They also knew the scheme was designed to achieve improvements in the health of cattle and their products. However, the illiterate farmers were not aware of this scheme in place to support their business. According to [65,66], cattle holding size positively affected the adaptation decisions of dairy farmers. Those farmers in this study who had experienced a series of losses in agriculture operations preferred to increase their herd size to sustain their living standards.

Farmers may face crop failures, loss of income, and additional expenses during climate change. To offset these challenges, they may be forced to sell some of their livestock [49,64]. Additionally, farmers concerned about the potential impact of pest and disease outbreaks on their animals or reduced milk production due to diseases may prefer to sell some of their livestock. This situation is further exacerbated by the threat of increased livestock mortality due to extreme temperature events in the region.

Another strategy adopted by some farmers was to plant additional shade trees in the study regions, particularly for those farmers who lacked an animal shelter. This was considered an excellent adaptation strategy to prevent animals from the impacts of excessive heat stress. Planting trees also served as supplementary fodder sources. An example of a tree that is suitable for the region is *Moringa olifera*, also known as the 'drumstick tree' [67]. It is drought-resistant, can withstand varying temperature ranges, and grows rapidly and vigorously. Leaves of the tree have high protein content with other essential amino acids [67]. Thus, this kind of tree provides shade to the smallholder dairy farmers and provides nutritious feed to the livestock. This tells us how farmers keep indigenous practices in place and how these traditionally practiced mechanisms hold their importance even after multiple generations. Their perception of its effectiveness was based on the belief that it can lower the negative effects of rising temperatures on cattle health and quality milk production.

Moreover, various, green-dried fodder mixes offered to cattle are an experimental strategy to fight climate change, particularly during hot and rainy months, as reported by farmers in the study region. Besides averting the adverse impact of climate change on agricultural and cattle milk production in the future, planting fodder trees for cattle and ruminants is emerging in the region as a practical solution. This approach not only helps with sustainability but also generates income through growth and harvesting. While crop insurance was another potential strategy, some farmers deemed other strategies as important in the study region to their farming approach.

Findings of this study have shown that dairy farmers in the studied region perceived "lack of climate forecast", "high cost of adaptation strategies", and "weak institutional support" as the most important constraints of adopting the coping strategies. In addition to the lack of farmers' knowledge, easy accessibility to available climate forecasting is also a barrier to dairy operations mentioned by the respondents of this study. This was particularly relevant for the landless farmers who were entirely dependent on natural pastures for animal feed and were worried that along with cattle's health, the operator's health was at stake in extreme weather conditions. Therefore, it is of the utmost importance to establish institutions that will help coordinate and implement farmer-friendly measures and provide educational support to access and interpret climate-related information.

In addition, farmers who had experienced crop failures in agriculture operations were solely dependent on income from milk sales and the sale of manure from the cattle owned. This being the case with most farmers in the study region, adaptation activities became expensive, requiring farmers to make tough choices daily considering the best interest of their animals. Farmers in this study reported that feed costs had jumped 30-40%, while the milk price had not changed to keep pace with additional costs in dairy operations.

Farmers appreciated vaccination programs, but those who lost cattle did not receive support, except for insurance claims. Dairy-cooperative-associated doctors were unable to provide timely information. The required help did not reach farmers on time, resulting in conflicts with policies. Some suggested that more money was needed to buy healthy cattle and that a lack of communication between policy changes and farmers resulted in a lack of support. Lack of support and relevant information affected farmers, particularly when rainfall fell short of expectations. The study found that fundamentally improving access to essential services can effectively protect farmers' livelihoods and enhance their resilience to climate-change-induced risks, but there were some challenges around communication and access to critical services remaining that needed to be addressed.

Despite these barriers to adaptation discussed above, there were some factors that motivated the local farmers to act upon and adopt timely coping strategies. This study found that in cases of "family interests", "milk production security", "economic interests", and "suitable feed growing condition" are reported as the most important motivating factors that could facilitate farmers' adoption of climate risk management. Since climate-change-induced risks gravely affect dairy farmers' operations, they adopt various measures to minimize the impact when encountered. Furthermore, this study found that many farmers had recently built cattle housing on their farms, which was influenced by their strong bond with the animals they raised. The idea of taking collective action at the village level did not seem to drive them to adaptation as only 10% of farmers agreed it may be workable because of income differences, but other aspects took precedence over this. Although a labor-intensive activity, many women preferred to utilize their time in other ways than to become involved in low-productive activities, especially for those who were solely managing every dairy activity. These findings provide an understanding of dairy farmers' requirements and priorities, which can help guide researchers and policymakers in their effort to develop and align comprehensive strategies to tackle the climate change impacting dairy in Karnataka, India, and other countries with a similar set of dairy systems.

4.3. Determinants of Dairy Farmers' Coping Strategies for Climate Change Adaptation

In this study, the factors influencing the adaptation strategies were examined by logistic regression analysis. Results revealed a significant positive relationship between most of the socio-economic variables and climate-induced adaptation measures of dairy farmers in the studied region (Table 4). The study results were consistent with previous findings indicating dairy farmers' socio-economic variables and other factors associated with dairy related to the location, which affected adaptation decisions and coping mechanisms. For instance, Abbas et al. [49] reported that farmers' education, farming experience, herd size, and access to extension services influenced adaptation strategies such as selling weak/deceased animals, migration, and off-farm income activities in their study of dairy farmers in Punjab, Pakistan.

Furthermore, the age of the farmer, tropical livestock unit, type of animal breed, perceived benefits of the technology, access to extension, and farmer group membership influenced the adoption of climate-smart Brachiaria grass among dairy farmers in Eastern and Western regions of Kenya [68]. Farming experience, cattle herd size, non-agricultural income, membership in an organization, number of farm assets, level of education, and climate zone were the major variables affecting farmers' adaptation strategies among cattle farmers in Benin and Turkey [34,69]. Thus, to make the policies effective aiming at climate change adaptation, it is, therefore, necessary to take into account the local farmers' understanding of how dairy farmers perceive climate change, the differences in perception, and what factors influence them to adopt various strategies and decision making in a regional setting.

5. Conclusions

India's smallholder dairy farmers are facing significant challenges from climate change, which not only threaten their dairy activities but also the well-being of their livestock, which are valuable possessions. Understanding smallholder farmers' perceptions of climate change and coping strategies could help better plan and ultimately protect their livelihood options. This study in regional South India investigated dairy farmers' perceptions of climate change risk impact on dairy, as well as adaptation strategies. First, dairy farmers perceived significant changes in the local climate, and impacts such as drought, lengthy periods of high temperatures, pests, and diseases in cattle, and changing rainfall patterns affected dairy production in the study area. Second, farmers indicated how this has affected animal health, with exceptionally high temperatures followed by heavy rainfall for those who are dependent on natural pastures grazing their livestock, highlighted as being particularly important.

Third, in response to the changing local climate, dairy farming households are adopting multiple response measures to avoid hazards in milk production and cattle health. Among diverse adaptation strategies, buying livestock insurance, keeping low debt obligations, and growing drought-tolerant varieties of grass appeared to be the most adopted adaptation measures, while crop insurance, diversification, and increasing herd size were reported as moderately adopted strategies. Financial constraints and lack of information were regarded as the greatest barriers to dairy farm-level adaptation. Regression analysis further revealed that dairy farmers' age, education, land holdings, annual milk production, and cattle expenses influenced the types of adaptation strategies undertaken. The findings of this study also demonstrated that dairy farmers' adaptation to climate risks is largely associated with their access to essential institution-led services such as climate forecasts and extension services.

The use of a survey based on the recall method of eliciting information from farmers itself was a limitation. In addition, the study results may not generalize to other areas well as the data were confined to only two districts of southern India. Nonetheless, based on our study findings, we suggest that relevant institutions, policymakers, and stakeholders should improve farmers' access to essential services that could enhance their ability to prepare for and adapt to climate hazards in order to increase their climate resilience. Finally, the study findings highlight where future studies should focus to better understand dairy farmer perspectives, priorities, and needs, and importantly how to incorporate these into climate change adaptation.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su16052018/s1, Figure S1. Mean monthly rainfall and temperature in the study area (data presented is the average of 2000–2022). Figure S2. Annual total rainfall in the study area.

Author Contributions: A.S. conducted survey, literature review, analyzed the data, and drafted the manuscript. M.A.I. helped improve data analysis and made essential edits on multiple versions. J.M.K. advised on conceptualization and made essential edits. S.M. advised on conceptualization and made comprehensive edits and critical revisions to the manuscript. A.M. helped in conceptualization and essential edits. L.S.-P. advised on conceptualization and essential edits with grammar in the manuscript. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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3.3 Links and implications

Dairy farming, both contributing to climate change and being affected by climate change, needs a transformation to become more sustainable and climate resilient by improving farmers' livelihoods and cattle productivity. Transforming small dairy farmer systems in developing countries like India requires greater attention to their perceptions and related concerns, climate risks, adaption strategies, barriers, and enablers to climate adaptation. This study demonstrates that understanding farmers' perceptions of climate risks could help avoid maladaptation and improve climate risk communication between researchers and dairy farmers. In the context of improved climate risk management, continuous adoption of targeted adaptation measures is essential to sustain the growing demand for dairy products.

CHAPTER 4: PAPER 2: WILLINGNESS TO PAY FOR INDEX-BASED CATTLE INSURANCE AMONG DAIRY FARMERS IN SOUTHERN INDIA

4.1 Introduction

In developing countries like India, climate-related risks are among the leading causes of production and efficiency losses in smallholder agriculture and dairy production. Subsequently, the identification of suitable tools to help manage the risks related to climatic extremes is increasingly contemplated as among the key pillars of any agenda to augment agricultural growth and welfare in regions of India. This chapter describes the factors influencing the willingness to pay for index-based cattle insurance, which is touted to be a promising innovation in insurance that seeks to bring the benefits of formal insurance to help manage the weather-related risks faced by dairy producers in low-income countries.

4.2 Submitted paper

Willingness to Pay for Index-based Cattle Insurance among Dairy Farmers in Southern India

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Abstract :

Dairy farmers in India face many risks from extreme weather events, which detrimentally impact their milk production. To assist these vulnerable dairy farmers in managing risks and preventing income loss, the government subsidizes livestock insurance by paying 50% of the premiums. However, despite considerable subsidy, only 6-7% have taken advantage of this scheme. To understand why, a study was conducted in south India, which surveyed dairy farmers and identified factors that influence their interest in insurance as well as their willingness to pay for a hypothetical alternative index-based livestock insurance option. Approximately 41% of farmers were interested in purchasing the proposed index-based insurance scheme and were on average willing to pay a premium ranging from INR 500 - 1000 per annum for a payout of INR50,000. This premium amount is similar to cattle insurance under the current subsidized scheme offered by dairy cooperative societies in the region. This suggests that the cause of low insurance uptake cannot be attributed to high insurance premiums. Our study found that farmers who spend more time on dairy activities have larger landholdings, earn more from dairy, and have younger cattle are more willing to participate in index-based cattle insurance. Interestingly, farmers opt to prioritize protecting younger cattle over older ones, likely due to their higher future value and increased susceptibility to risks. To increase dairy farmers' participation in cattle insurance, the information on the benefits of insurance should be better communicated. Policymakers should design insurance schemes with an understanding of farmers' needs and other critical factors that influence participation in cattle insurance schemes.

Keywords: Cattle Insurance, Willingness to Pay, Index Insurance, Dairy farmers, Climate risks

1. Introduction

India is the world's largest producer and consumer of milk, with the world's largest dairy herd, comprising water buffalo, as well as indigenous and crossbred cattle (Landes et al. 2017). India leads global dairy milk production with a contribution of 23 percent (DAHD 2022). This is largely due to the millions of small farmers who own one to four animals, providing a livelihood opportunity for rural households (Rajeshwaran et al. 2015). As a result, livestock rearing is essential to nearly 500 million Indians, with 80 million households relying on dairy farming as their primary source of income (DAHD 2022).

Climate change, drought, heat waves, floods, and other extreme weather events pose a significant threat to agricultural productivity and livestock production, which are central to the livelihood protection of millions in India (Oduniyi et al. 2020; Singh & Agrawal 2020). The main challenge in the current mode of production is the inevitable climate risks and weather uncertainty. Temperature rise is anticipated to be between 2.3 and 4.8°C over the entire country, while uneven precipitation causing either flood or drought, as a consequence of climate change, is likely to aggravate risks in farming, depending on the season and location (Sirohi & Michaelowa 2007). Dairy cattle are affected both directly and indirectly due to climate change-induced risks. Climate factors such as air temperature, humidity, strong winds, and other factors influence animal performance including growth, production, health, and fertility. Prolonged hot periods, combined with altered rainfall patterns, can result in heat stress, especially in climate-sensitive semi-arid regions, leading to reduced milk production and increased susceptibility to pests and diseases (Gwazdauskas 1985; Lacetera 2018; Cheng et al. 2022).

The introduction of weather index insurance schemes in recent years is gaining traction as concerns grow about increasing climate risks due to global warming. One example is the

Index-Based Livestock Insurance (IBLI) project in Northern Kenya, which has demonstrated that remotely sensed Normalised Differenced Vegetation Index (NDVI) can be utilized to evaluate drought-related livestock mortality. This has helped to lessen the risk that pastoralists of arid and semi-arid lands are facing (Mude et al. 2010; Chantarat et al. 2013). However, despite the potential benefits such as reduced moral hazard, adverse selection, and timely payouts, the adoption of these insurance products has been lower than expected (Giné et al. 2008; Suarez & Linnerooth-Bayer 2010; Jensen & Barrett 2017).

Several attempts have been made to tackle the challenges faced by Livestock Insurance in India, but the uptake has only been 6-7% of the cattle population at the national level (Bora 2017; Rohith 2019; Divya Mary Suraj 2020; Chand et al. 2023). However, previous insurance programs designed followed a top-down approach and lacked the involvement of local stakeholders, especially dairy farmers(Shirsath et al. 2019; Gaurav & Chaudhary 2020; Singh & Agrawal 2020; Ghosh et al. 2021). Thus, making the program less relevant to the risks faced by dairy farmers. India, being quite diverse in agro-climatic conditions, there cannot be a ‘one size fits all’ rule. Consequently, their needs, priorities, and constraints on the ground are often overlooked (Chantarat et al. 2013; Doss & Pathak Tiwari 2022).

Several studies have investigated the awareness, perception, and willingness of farmers to purchase traditional and index-based livestock insurance in various developed and developing countries. More prominent studies include (Mude et al. 2010; Singh & Hlophe 2017; Aina et al. 2018; Amare et al. 2019; Dong et al. 2020; Subedi & Kattel 2021). However, there is a notable gap in the literature regarding these critical factors concerning dairy farmers in South India. A few studies have explored the willingness of dairy farmers in western India, Haryana, and Punjab to invest in traditional livestock insurance (Khan et al. 2013; Chand et al. 2016; Singh & Arora 2022). However, research has been scant on the crucial elements of climate and the necessity for enhanced insurance, including index-based insurance products, in any given area. This study is an effort in that direction.

This study aims to fill that gap by addressing the following questions: 1) What is the level of understanding and knowledge of existing livestock insurance? 2) What factors influence their willingness to pay for index-based cattle insurance products? This research is relevant to policy actions in India and other Asian countries with similar demographic and socio-economic conditions, assisting policymakers in understanding the factors that drive the uptake of index-based insurance schemes and device plans for better participation in dairy states across the country. Therefore, the key objective of the study is to examine the level of awareness and determine the factors that influence the willingness to pay for an index-based cattle insurance product among dairy farmers in South India.

2. Materials and Methods

2.1 Study Area

Karnataka, the eighth largest state in the country in terms of geographical area (19.1M. sq. km), is home to 29 million livestock (20^{th} Livestock Census) holding 9^{th} position among livestock rearing states of the country (Dalwai 2017; DAHD 2021, 2022). Karnataka is the second most arid state with the largest rainfed agriculture area in the country (about 7.01M Ha out of the net cultivated area of 10.5 M Ha). A vast extent of geographical area is drought-prone, with 88 of the state's 176 taluks, spread across 18 of its 30 districts being affected (IISc 2014).

The rainfed agriculture in the state is highly dependent on seasonal monsoon rainfall. Out of an average annual rainfall of approximately 1150 mm, over 70 percent is received during the southwest monsoon season. The distribution of rainfall being unpredictable, has a significant impact on agriculture and livestock-related activities.

As part of this study, the villages in Bengaluru (both rural and urban) and Chikkaballapur districts were intentionally selected. These districts were among the top two in Karnataka in terms of livestock insurance adoption, and have been covered under the National Livestock Insurance scheme since its implementation in 2006-2007 (Pallavi et al. 2019; Rohith 2019).

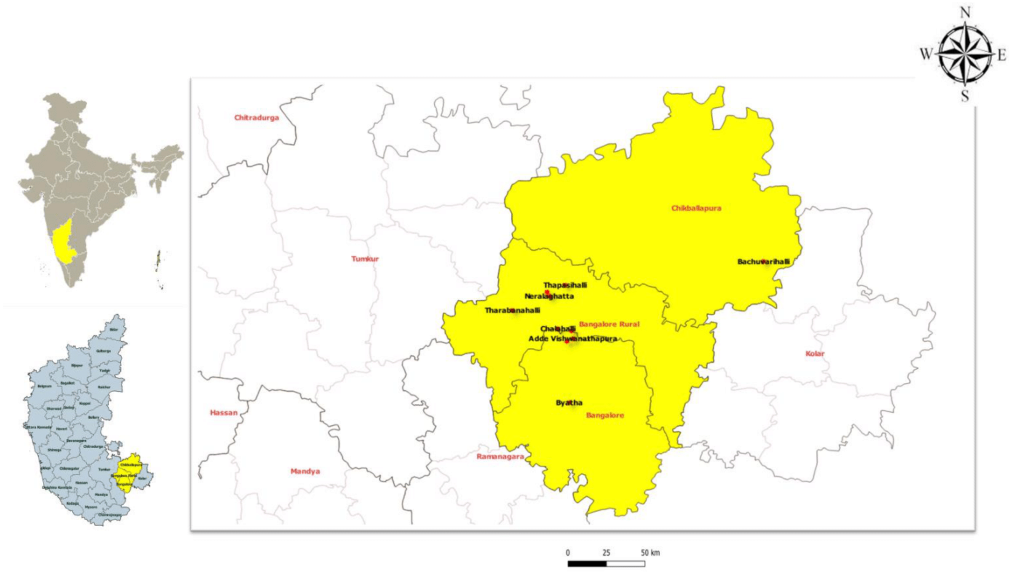

Fig 1: Map of the study region, showing the state Karnataka, India, and the villages in the districts of Bengaluru rural & urban and Chikkaballapur where the dairy farmers were surveyed.

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2.2 Sampling Method & Data Collection

Historically (even post-independence in 1947), Indian farming, and animal rearing, is predominated by small farmers. Small marketable surpluses were usually sold locally or in nearby urban locality. Milk production with low-yielding local varieties was the practice. The 'White Revolution', a movement coined by Dr. Verghese Kurian in the 1970s organized the small dairy farmers through the 'Operation Flood Programs' paving the way for the formation of Milk Producer's Cooperative Societies (MPCS), federated into District Milk Unions and further into State Cooperative Federation. Such organizing supported the procurement, processing, and distribution of several milk and milk products across the nation. Initially, the Anand Milk Union Limited (AMUL established in 1947 and strengthened post) followed by the Karnataka Milk Federation (KMF established in 1974) are among the successful dairy cooperative brands in India. With the success of the cooperative business model in dairying, many private companies have ventured. Presently the milk marketing in the country is an oligopoly business.

The present study is held in Karnataka state where the KMF is based and functional. Out of the 31 districts in Karnataka state, Bangalore and Chikkaballapur districts were selected, as per the aforementioned reason that they had relatively greater adoption of livestock insurance. These two districts encompassed 1152 and 1083 MPCS and memberships of 2.12 lakh and 1.50 lakh and an annual milk collection of 825 and 380 thousand tonnes respectively. The two districts contributed about 12% to the state's milk production pool (DES 2021). The sampling strategy to select dairy farmers in this study entailed the following:

In the two districts being purposively selected, 7 MPCS were randomly selected for the present study. A list of dairy farmers in each village was collected from the concerned MPCS (dairy co-operative). We then identified the regular milk-pouring farmers and obtained their contact details from the local dairy manager. Next, we selected farmers who had adopted cattle insurance for at least a year or more. Finally, we personally contacted the selected farmers in each village to arrange an interview at a time and place convenient for them. The survey was conducted between December 2022 and January 2023.

The questionnaire for the dairy farmers survey was prepared based on current WTP literature in the subject area(Aina et al. 2018; Dong et al. 2020; Oduniyi et al. 2020; Wang et al. 2022). The questionnaire elicited information in three parts. The first part covered socio-economic characteristics and cattle-related information; the second part pertained to the farmer's perceptions of climate risks and their impact on the dairy operations, and the third part inquired about livestock insurance that’s in place and their willingness to pay (WTP) for Index-based cattle insurance. On average, each interview took 60 minutes to complete.

The socioeconomic characteristics of the respondents are important because they affect economic behavior and determine the capability of dairy farmers to adequately buy insurance and other preparedness in dairy operations. We asked dairy farmers to determine which climate-related risks were most important to consider when purchasing cattle insurance. We provided them with a list of potential concerns related to climate change, including drought, changing rainfall patterns, strong winds, higher temperatures, pests and diseases, lower temperatures, hailstorms, and others (floods and erosion). The list was developed by reviewing previous studies in semi-arid regions (Dhanya & Ramachandran 2016; Yadav & Lal 2018; Singh & Chudasama 2021) and consulting with experts in the index insurance field (Kath et al. 2018).

Further, we inquired with dairy farmers who expressed interest in purchasing the proposed insurance about their reasons and considerations for buying the product, as well as their experiences with previous insurance products. Respondents were allowed to tick more than one option that in their knowledge was relevant to them.

Willingness to pay (WTP) for a product may be described as the amount of money a person is willing to pay for purchasing a product given her/his income, risk preferences, and other associated characteristics. A contingent valuation method (CVM) was utilized to determine the willingness to pay (WTP) of small-scale dairy farmers for index-based cattle insurance. CVM is a reliable method for assessing the value that an individual places on intangible goods or services (Aina et al. 2018; Oduniyi et al. 2020). To obtain accurate data, an open-ended CV method was employed, as index insurance is not yet established in the study area and traditional insurance is currently used by surveyed dairy farmers as a risk transfer solution. By using the open-ended technique, each farmer's average willingness to pay and maximum willingness to pay could be evaluated without any predefined values influencing the results.

2.3 Data Analysis

The data elicited from the primary survey of milk producers were subjected to descriptive statistics and analytical procedures. Both descriptive and inferential statistics were used for analysis. We analysed the data in the JASP version 0.17.3 and Microsoft Excel. Descriptive statistics such as frequency counts, percentages, and mean values were used to interpret dairy farmers' socio-economic characteristics. We employed a Generalized Linear Model (GLM) analysis with logistic regression to examine the factors that influence dairy farmers' willingness to pay for index-based cattle insurance.

A total of 104 (dependent variable= WTP for IBCI (Yes-43/No-61, coded Yes=1, No-0) responses were analyzed in the logistic regression model. Predictors used were gender, dairy farmer's age (years), earning family members, daily time spent on dairy activities (hours), land holding size, herd size, education, district, annual dairy income (INR) and cattle age to be insured. During this model building step, although many independent variables were considered, a multicollinearity diagnostics was run to eliminate predictors that had variance inflation factor (VIF) greater than or equal to 10. In our final model the mean VIF was 1.97, with none of the variables with a VIF greater than three.

3. Results

3.1 Dairy farmer's socio-economic characteristics

In general, the majority of the respondents were adults, and about 25 percent of farmers were above 61 years of age. Table 1 shows that male dairy farmers are slightly higher (54%) than females (46%), with most males doing the labour-intensive tasks related to agriculture and dairy farming. Women were responsible for all the household tasks, looking after children as well as dairy-related and farming activities. The education level of dairy farmers has a role in shaping the quality of the decisions made in day-to-day dairy operations and insurance adoption. Farmers often need to classify, measure, govern, and screen risks and potential losses associated with their dairy farming. The distribution of respondents according to various socio-economic characteristics is summarised in Table 1.

Table 1: Socio-economic characteristics of the survey respondents

Characteristics	Sub Characteristics	Statistics (N=104) N	%
Gender	Male	56	54
	Female	48	46
Age (Average)	18-30	5	5
	31-40	20	19
	41-50	32	31
	51-60	21	20
	>61	26	25
Education	Illiterate	13	13
	Primary School	16	15
	Middle School	12	12
	Highschool	53	51
	University	10	10
Occupation	Agriculture	98	94
	Dairy	5	5
	Business	1	1
Cattle investment decision-maker	Male	73	70
	Female	31	30
Dairy Labour	1	27	26
	2	54	52
	3	12	11
	4	10	10
	5 and above	1	1

The majority of the dairy respondents had attended high school (51%), while 13 % never went to school. Alongside dairy farming, the majority of farmers (94%) engage in crop husbandry as their primary occupation. The male heads of households tend to make most decisions related to cattle, particularly in rural areas of South India where male family members play a critical role in farming and dairy decisions. Results also show that 52% of the respondent's households have two people to provide dairy-associated labour, 26% have one person, and 11-10% have more than two people.

3.2 Farmers ranked high temperatures, heavy rains in a single day, changing rainfall patterns, and drought as the most posing challenges in the region.

The weather incidents most impacting dairy farmers and its severity are presented in Fig 2. According to this survey, dairy farmers expressed concerns about high temperatures, heavy rain, drought, and unpredictable rainfall patterns affecting their operations. They also mentioned pests and diseases as additional challenges. Particularly, high temperatures and drought have multifaceted effects, including reduced grass productivity, limited availability of green pastures for grazers, poor cattle conditions, low milk productivity, and loss of dairy income and family welfare. This was indicative of what would be farmers' expectations in terms of index-based livestock insurance products.

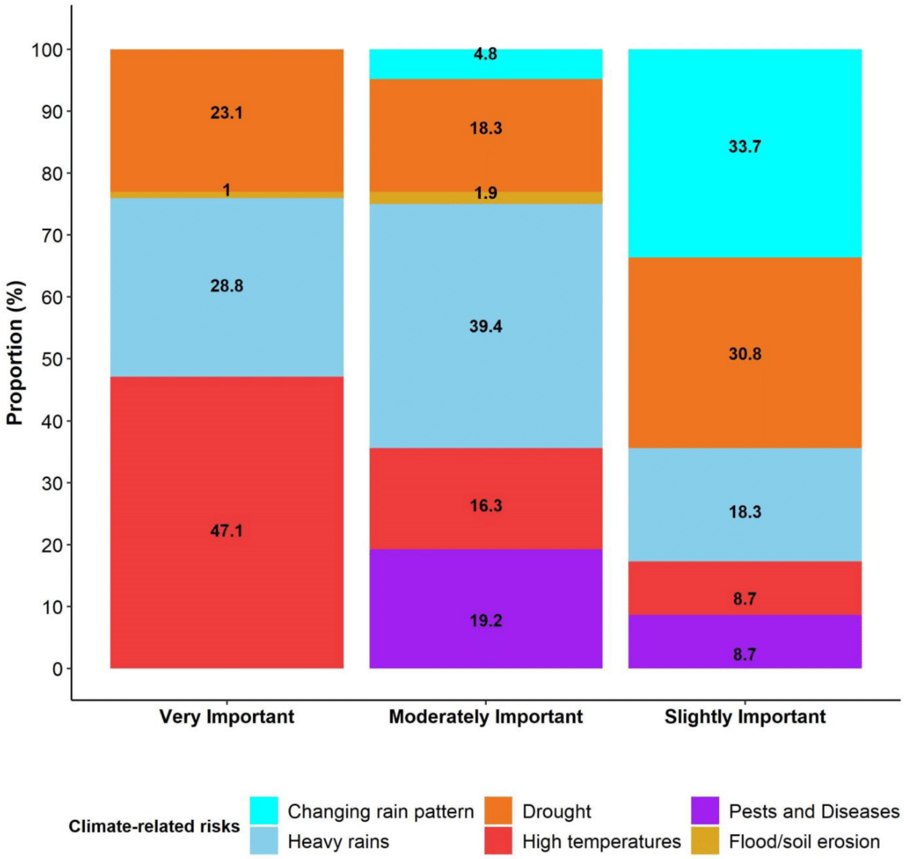

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Fig.2. The proportions of dairy farmers' response to climate risks affecting dairy activities in the region, which were rated very important, moderately important, or slightly important.

These results signal that dairy farmers face single and compounded risks during a given annual production cycle with their cattle holdings. This suggests that index-based livestock insurance products are promising risk management tools that could help alleviate the effects of climate risks to stabilize the milk production of cattle and protect farmers' income in the study region. Hence, index-based livestock insurance may be required to combat some of the risks and could be a potential risk transfer solution for dairy farmers in this region.

3.3 Male farmers' had greater knowledge about the current cattle insurance scheme.

We inquired about dairy farmers' knowledge of cattle insurance and its benefits in the study region (Table S1). Our findings revealed that of the farmers we surveyed that had insurance only 55% of males had knowledge of the insurance scheme, while only 33% of females were aware of it and the associated benefits of making a purchase. We further asked these farmers how many times they had insured their cattle in the last 15 years and interestingly, 54 % of female farmers had taken cattle insurance for the previous years, while 30% of males had taken it for 10 years (Table S2). Farmers who were aware of the scheme said that the dairy co-operatives had deducted the insurance at the start of the year from dairy income without the farmer's knowledge, and some fellow farmers were not aware of this. Presently, in Karnataka, cattle are insured under the National Livestock Insurance Scheme under the National Livestock Mission (NLM) & Cattle Group Insurance Scheme (CGIS) (Rohith 2019).

As per the present study, 55 % of farmers owned 2 -3 cows, while 25% had only one. Only a minority of farmers had more than 3 cows in their possession (Table S3). The range of insurance premiums paid per cattle, by these farmers ranged between INR 300 and 1500, with 4% of farmers being uncertain of their premium amount paid (Table S4).

3.4 Enrolment into the present cattle insurance was done voluntarily by dairy farmers and 36% of farmers weren't happy about the current scheme.

In the study area, most dairy farmers chose to take cattle insurance on their own accord, but many did so without fully understanding the coverage and benefits. A few farmers stated that they were required to insure their cattle in order to obtain a cattle loan from banks. A small percentage (7%) of farmers felt pressured by the dairy co-operative to take insurance, but none had direct involvement with the insurance agency. Those who enrolled voluntarily mentioned that they were influenced by observing other farmers at the local dairy co-operative society during milk pouring times.

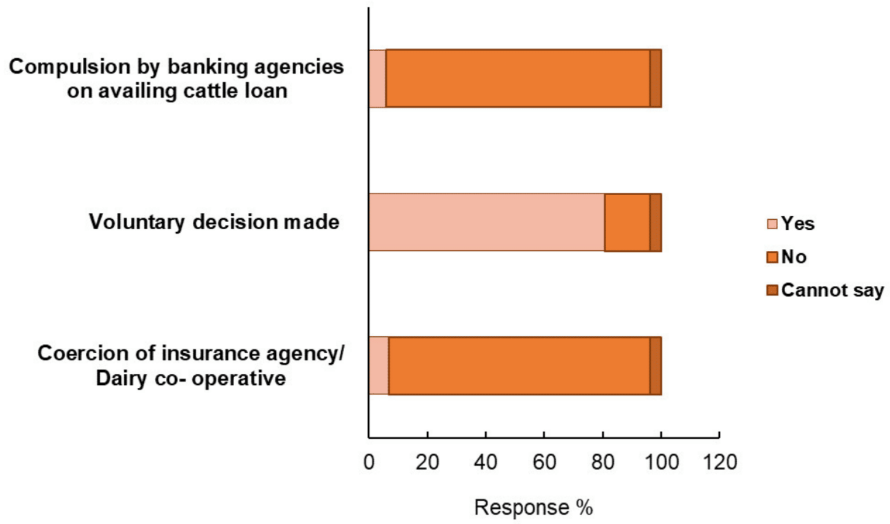

Fig 3: Ways of enrolment of dairy farmers into the present cattle insurance scheme in the study region. Dairy farmers chose the options that answered their enrolment related aspects.

Further in the survey, dairy farmers were asked to score what they felt about the cattle insurance scheme. The results showed that 36% of the farmers were not satisfied at all, while only 3% scored the scheme as extremely good and beneficial for them. Another 14% of dairy farmers weren't able to have an opinion on the cattle insurance scheme.

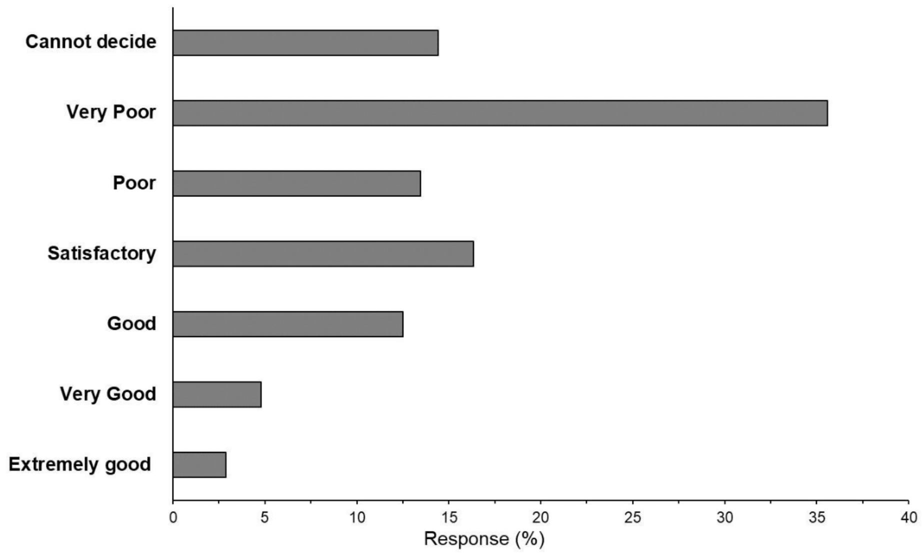

Fig 4: Farmers scoring of the present cattle insurance scheme. Each dairy farmer chose the best fitted option to describe the present cattle insurance scheme.

3.5 Premium payment

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The dairy farmers were asked about how they financed cattle insurance premiums and the majority of farmers paid it through personal savings. A small percentage of farmers paid premiums by selling their crops and other modes of borrowings known to them.

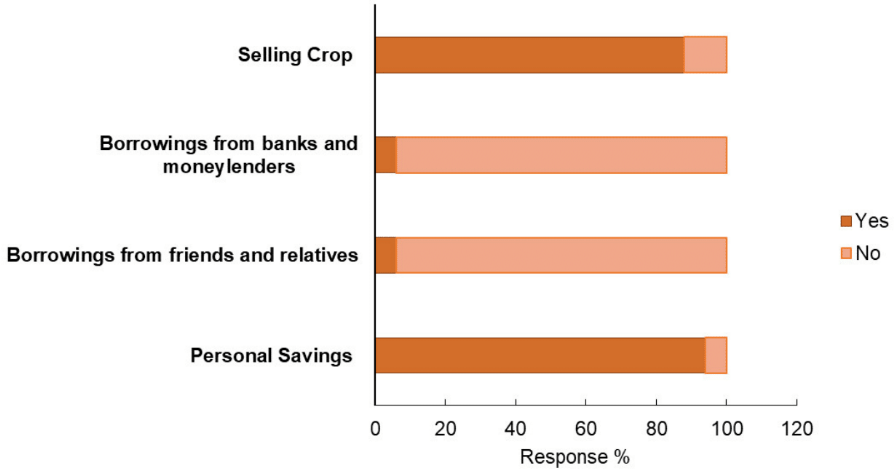

Fig 5: Method for paying the cattle insurance premiums. Dairy farmers chose option Yes/No to each of the options presented above.

3.6. About 41% of dairy farmers liked the idea of index-based cattle insurance (IBCI) and were willing to participate if such a product was offered in the future.

In the study, we proposed dairy farmers with an index-based insurance product for their cattle, which would protect against weather-related risks such as high temperatures and rainfall. We asked the farmers to share their maximum willingness to pay for this type of insurance, as they had observed a significant drop in milk production during such scenarios. During the interview, we provided farmers with an explanation of the key features of index-based livestock insurance, outlining the differences from traditional insurance schemes, the potential coverage, and the benefits associated with this type of product.

After asking if they were willing to participate, we followed up with questions to determine the maximum price a dairy farmer would be willing to pay for index-based cattle insurance (IBCI). This would cover cattle worth INR 50,000 on the market. Based on historical premium rates from 2006-2017 in Karnataka, the hypothetical premium amount was 4.5% per cattle at 2250 (Rohith 2019). However, only 7.69% (Table S6) agreed to pay the hypothetical premium in this study. For those who rejected the premium, we asked how much they would be willing to pay per cattle per year for a loss-reducing insurance scheme. The results are presented in Table 2, where around 21% of farmers agreed to pay INR 600, which is 1% of the sum assured. The maximum amount farmers were willing to pay was INR 1000. In this study, most farmers paid between 400-1000 INR for their existing cattle insurance (Table S4).

Table 2: Amount dairy farmers are willing to pay for IBCI.

Amount (INR) WTP	Frequency	Percentage(%)
0	61	58.65
500	14	13.46
600	22	21.15
800	1	0.96
1000	6	5.77
Total	**104**	**100**

3.7. Determinants of Dairy Farmers' Willingness to Pay for proposed Index-Based Cattle Insurance

Results of the fitted model to identify the factors influencing dairy farmers' willingness to pay for index-based cattle insurance are displayed in Table 3. The variables that have a significant impact on dairy farmers' willingness to pay are the daily hours spent on dairy activities on the farm, land holding size, dairy annual income, cattle age, and dairy farmers located in Bengaluru Urban district would be more likely to purchase IBCI.

If dairy farmers spend more time working in the dairy each day, their likelihood of accepting IBCI increases by 0.548 units on the log odds scale. Therefore, farmers spending long hours in dairy activities are more like to purchase IBCI. In addition, land holding size emerged to be a positive influencer of accepting livestock insurance and thus farmers with larger land holdings are more likely to buy IBCI. Further, the higher dairy incomes seem to have a positive influence as well.

Cattle age to be insured has a negative co-efficient estimate, implying that the higher the age of the cattle, the less probability of purchasing IBCI. The age of cattle seems to be a matter of risk management, as in the early years, cattle are more vulnerable. Particularly, the climatic conditions on cattle conception, gestation, calving, and productivity result in significant economic losses that are a serious concern for small dairy farmers.

Table 3: GLM - Logit estimates of the factors influencing farmers' willingness to pay for index-based livestock insurance

Independent Variables	Estimate	Standard Error
Gender	-0.367	0.855
Dairy farmer's age (Years)	-0.026	0.039
Earning family members	-0.392	0.435
Daily time spent on dairy activities (Hours)	0.548**	0.194
Land holding size	0.421**	0.137
Herd size	-0.277	0.427
Education	-0.061	0.141
District Bengaluru Urban	2.747 *	1.522
District Chikballapur	23.198	1637.898
Annual dairy income (INR)	2.305×10^{-5} **	1.066×10^{-5}
Cattle age to be insured	-1.817 *	1.026

(Intercept)	-4.559	3.866
Chi-Square (X^2)	82.447	

Note:** and * are statistically significant at p<0.05 and p<0.1 respectively.

3.8 Minimising disastrous outcomes and shock recovery are the reasons behind the willingness to purchase and participate in insurance schemes.

Interestingly, all farmers agreed that insurance is to minimise disastrous outcomes and recover from the shock associated with climate change to dairy activities. A majority (53%) of farmers agreed that participation in insurance is to get access to credit (Figure 6). The secure feeling associated with the purchase decision from experience and learning from other dairy farmers' mistakes was also important to most farmers. Additionally, many farmers prioritize insuring their herd as they expand, but high premiums can make it difficult to decide which cows to insure.

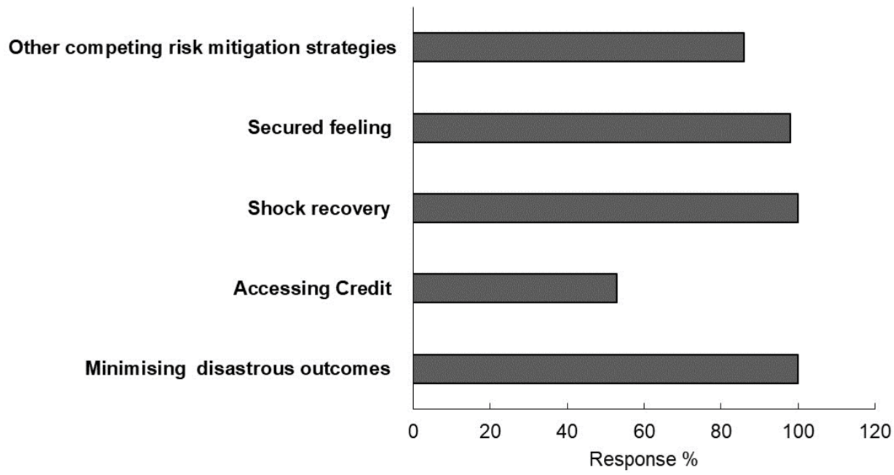

Fig 6: Dairy farmer's reasons behind the decision to take up cattle insurance. Each dairy farmer responded Yes/No to all that’s applicable in their context. Other

competing risk mitigation strategies included low debt obligations and diversification to increase non-milk income.

4. Discussion

4.1 Awareness and understanding of the existing cattle insurance scheme

Dairy farmer’s awareness and understanding of cattle insurance is one of the important aspects of insurance purchase decisions. It was imperative to know in detail how farmers were aware of cattle insurance in place for them, which would help us identify critical factors in determining the success of livestock insurance in achieving the protection of the livelihoods of small and marginal farmers and help secure cattle which are prime productive assets. Our study results from interactions with farmers have shown that the level of awareness and knowledge among male farmers of the existence of cattle insurance schemes was higher compared to female counterparts.

Our interactions with dairy farmers revealed that about 37 % of farmers found the current cattle scheme an acceptable cattle insurance option, rating it satisfactory to extremely good. The remaining 63 % (Fig 4) weren’t happy about the insurance and some farmers expressed that it is not farmer-friendly which could be one of the prime reasons for low uptake. The basic premise which implies investing money in return for an uncertain payout to cover a hypothetical adverse occurrence is not innate. Understanding insurance products presumes a certain level of education and enrolment is positively linked with farmers' education, financial literacy, and training (Panda 2013; Biswal & Bahinipati 2022).

Cattle insurance adoption is driven by the farmer's socio-economic and household characteristics and most importantly in a developing country like India, agriculture insurance adoption is primarily induced by economic factors such as liquidity constraints, the income of farmers, credit constraints, and the premium/price of insurance (Khan et al. 2013; Biswal & Bahinipati 2022). The majority of dairy farmers in this study paid for cattle insurance out of personal savings and the selling of crops. Educating dairy farmers with basic financial literacy and cattle insurance products will possibly increase the demand for livestock insurance since many dairy farmers are not familiar with basic calculations and understanding of how insurance works in the study region. (Hill et al. 2013) demonstrated that improving farmers' awareness through a variety of formal training programs can increase insurance purchasing by 5%.

Further in this study, those dairy farmers who thought that the present cattle insurance scheme was worse, on further probing revealed prior experiences where they did not get the claims in time and the amount received was lower and did not help them indemnify the real financial loss due to the loss of cattle. They expressed displeasure over the valuation exercise of their cattle which is based on visual estimation of veterinary practitioners. Although it is about the animal's age and production capacity it must be noted that it varies with geography and type of cattle and farmers find this exercise not fair and considerate of their animal's real value. They felt that the present animal husbandry support system from dairy is merely an exercise on paper, and the issues faced by farmers are rarely fully addressed. (Mahul et al. 2012) opined that timely indemnity payment to farmers increased their adoption rates. Although across the world, insurance is used to transfer risk and mitigate such shocks, unfortunately, high costs imposed by actuarial data collection, adverse selection, checking for moral hazard, and validating claims make traditional insurance policies ineffective (Jensen et al. 2015; Jensen & Barrett 2017; Birthal 2022; Singh & Arora 2022).

4.2 Factors affecting the WTP for index-based cattle insurance product

In India, cattle are the fundamental store of wealth and source of livelihood for small and marginal farmers, and much more in arid and semi-arid regions of the country which face tremendous risks from frequent climate shocks. Loss of cattle or a drop in milk production can be catastrophic, due to the poverty that characterizes the system. Climate and associated shocks can thrust prosperous dairy farming families into chronic deprivation. As the existent conventional indemnity based insurance suffers from limitations such as the high cost of administration and vulnerability to moral hazard and hence not being viable, index-based insurance which is free of information asymmetry, moral hazard, and adverse selection has shown considerable promise (Jensen et al. 2016; Doss & Pathak Tiwari 2022). Efforts are being made to develop index-based cattle insurance in India, aiming to protect dairy farmers from losses associated with climate shocks, and in that direction, we focused on studying demand by proposing a hypothetical new index-insurance product option.

Our empirical analysis shows that dairy farmers' willingness to purchase IBCI is not influenced by age, gender, earning family members, herd size, or education (schooling years). This is in disagreement with earlier studies that showed age would impact the farmers' willingness to participate in insurance for both younger (Doherty et al. 2021) and older farmers (Yufei et al. 2022) respectively. However, (Singh & Hlophe 2017; Dong et al. 2020) studies demonstrated that age is not a behavioral factor that would affect herders' decisions to participate in livestock husbandry insurance policies. (Khan et al. 2013; Njue et al. 2018; Dong et al. 2020) work has reported that gender doesn't impact the livestock and crop insurance decisions of farmers in India, Kenya, and Mongolia.

The daily hours invested into dairy activities and land holding size both have a positive influence and are significant in dairy farmers ' willingness to purchase index insurance. Both factors are associated with the productivity of farmers and cattle productivity in terms of milk production and income and the ability to pay for risk transfer solutions and new products like index insurance. Consistent with other research on farmers' purchase decisions for weather index insurance options (Giné et al. 2008; McIntosh et al. 2013), those dairy farmers with better land holding sizes are more likely to purchase IBCI. This is particularly so for farmers who are reliant on dairy income and with bigger herd sizes. A bigger landholding means the farmer has sufficient fodder resources since part of land use is foremost for fodder in the region among farmers owning land. Those with meager landholdings would demand insurance to disperse risk than herders with large land holdings, while better-off farmers have adequate means of managing risk through informal risk-sharing mechanisms, diversification of income, or access to monetary resources (Binswanger-Mkhize 2012). Similar results have been reported in Mongolia where the area of grassland contracted influenced herders' decision to purchase livestock husbandry insurance (Dong et al. 2020).

Inconsistent with studies (Nahas et al. 2017; Amare et al. 2019) that reported a positive link between herd size and respondents' willingness to pay for index-based livestock insurance in our analysis, herd size was not significant in the IBCI purchase decision. Other studies have found that education (schooling years) is significantly associated with buying insurance (e.g.:(Akinola 2014; Nahas et al. 2017; Dong et al. 2020), this was not evident in our study on willingness to purchase IBCI. We found that on average, dairy farmers would be willing to pay INR 500-1000 for the proposed insurance option IBCI. However, it is with weaker evidence to conclude anything from the theoretical expectations of farmers who consider premiums as a "loss" and not as a "cost" because of the mental math they do. Individuals are risk-averse when it comes to choosing between probable gains. These very individuals are risk-takers when confronted with "bad" choices. When a certain premium is pitted against a large loss that is less likely but can have detrimental financial implications, loss aversion stirs avoidance of the certain loss, thus blocking the buying of insurance (Chatterjee & Oza 2017).

The coefficient of the variable representing the district Bengaluru Urban is positive and significant suggesting that relative to other dairy farmers in Chikkaballapur and Bengaluru rural, dairy farmers in Bengaluru Urban are more likely to purchase IBCI. It could be due to the region having an edge over its counterparts in terms of implementing and promoting livestock insurance or access to other resources.

Pure income from dairy farming is significant in willingness to pay for IBCI. Thus farmers with better incomes from dairy are more willing and accept the proposed index-based cattle insurance. Our results are consistent with the findings of other studies (Sadati et al. 2010; Tsikirayi et al. 2013), that farmers with high incomes are more likely to purchase agricultural insurance as farmers would have adequate cash to pay premiums.

The results showed that cattle age to insure (years) had a significant negative preference for the proposed IBCI among dairy farmers. Most farmers in the study were willing to start insuring the cattle between 1-2 years of age, whereby these animals are significantly susceptible to pests and diseases and climate change-induced risks. Also, the farmers who are into dairy with a focus on milk production are more inclined to protect the female cattle population, however, it is inconclusive and to this end, there is a need for more research to determine if the cattle age is a significant attribute for the participation and willingness to pay.

Dairy farmers who indicated that they worried about extreme weather events tended to favour IBCI. The final attribute, premium (cost) was the most important to these dairy farmers, highlighted during the individual interviews and the displeasure over traditional cattle insurance schemes in the region.

Further, these results suggest that there is scope to re-design and overhaul the existing cattle insurance scheme in the country, with weather-indexed assessments, which are currently available to agricultural farmers in India or many other countries. The combination of continued insurance and this method of assessment may help overcome the familiar and widely known issues of moral hazard associated with traditional insurance schemes, whereby once the cattle have insurance the incentive to reduce risks to dairy farmers is smaller. One of the potential benefits of IBCI is that the coverage has a positive impact on subjective, economic, and health-related indicators of well-being (Jensen et al. 2015).

From dairy farmers' perspective, policy measures or insurance schemes that offer lower premiums to encourage adaptation and improve farm resilience are always beneficial. This may have the dual- advantage of providing dairy farmers with financial certainty against extreme weather damage, while also encouraging small dairy farmers to invest in farm resilience and adaptation measures as reported by (Beckie et al. 2019; Shantharaju et al. 2024). However, the caveat here is that in the case of indexed insurance products, adaptation, and resilience would benefit the dairy farmers but not the insurance provider, since the insurance contract will pay out once the threshold weather conditions are reached irrespective of the actual damage that has occurred on the dairy farm. While this may prevent the incentive to offer a discount to dairy farmers from the insurer's outlook, it could be an attractive prospect for a public insurer (such as the government) and more predominantly in developing countries like India where they want to encourage better livestock insurance adaptation to promote economic, environmental, and social sustainability across dairy farming communities. Given that cost (premiums) was the most important attribute of most farmers in interviews of this study anything lessening the burden on dairy farmers is always appealing.

4.3 Reasons for WTP and Participate in Cattle Insurance Schemes

Minimizing disastrous outcomes, shock recovery, and having a secure feeling with decisions made both past and present stood out in this study relative to other aspects of WTP and participation in cattle insurance schemes. This group of farmers mentioned another reason is competing mitigation strategies impacting insurance decisions as they in their experience felt buying insurance was a better option for them especially when the agricultural land holdings are meager and do not prefer other risk reduction strategies that could be favourable to other fellow dairy farmers in the region (Binswanger-Mkhize 2012; Budhathoki et al. 2019; Shantharaju et al. 2024). Cattle insurance is only one of the many risk management strategies and one that distributes the risk rather than reducing it.

The major impediments for farmers to purchase cattle insurance were a lack of understanding of the scheme, a lack of trust in the insurance providers, and the cost of premiums and management practices (see Table S7). Despite the participation over the years, some farmers reported that the scheme is not farmer-friendly as it is arduous and cumbersome administration associated with it, especially the attitude of officers towards them whenever the paperwork has to be documented over the loss of cattle and claims. They reiterated there's always incompatibility over the valuation of their cattle and actual payouts, which is a reason for the low uptake, which is also highlighted previously by (Budhathoki et al. 2019; Johnson et al. 2019)

4.4 Limitations

The study looked at demand-side analysis based on dairy farmers' preferences, and we did not investigate the practicalities of offering the insurance product from a supply end, including the potential scheme costs. For example, we did not have information on individual dairy farmer cattle holding and types to determine the actuarially fair price for insurance for individual cattle, and therefore the levels of cost attributes were informed by literature on the subject in India and the views of dairy farmers during their interviews. Secondly, the insurance product idea presented was relatively simple, using prior tested ideas in African countries while in reality index insurance products are complex. However, explaining all attributes of index-based insurance to farmers who are poor in financial literacy can affect their ability to process all information when making informed choices.

Particularly in this study, we were interested in understanding the knowledge of farmers and examining their WTP information that may give a glimpse into promoting wider cattle insurance adaptation. However, our study is limited in that we did not capture how dairy farmers' risk preferences may affect their preferences for the proposed IBCI. Besides, as demonstrated by several studies, basis risk is an important determinant in explaining the low acceptance of weather-indexed insurance in developing countries (Carter et al. 2014; Gaurav & Chaudhary 2020) and we did not investigate in our study about how communicating this would have impacted the WTP for IBCI.

5. Conclusion

Even though the cattle insurance scheme offers several benefits, its adoption rate is low in India. The purpose of this study was to understand the level of knowledge of existing cattle insurance & WTP for index-based cattle insurance that has been in discussion for some time now in policy circles for dairy farmers in India. Our results from the ground suggest that 41 % of farmers are interested in using IBCI as a means to adapt to increasing risks posed by extreme weather events and are willing to purchase. It presents how different socio-economic factors affect financial decision making among dairy farmers, which may form the basis for developing a theory.

Our study found that dairy farmers who invest more time in dairy activities have larger landholdings, earn more from dairy, and keep younger cattle are more likely to participate in new proposed index-based cattle insurance. Interestingly, farmers opt to prioritize protecting younger cattle over older ones, likely due to their higher future value and increased susceptibility to risks.

The results also suggest there may be scope to redesign existing cattle insurance schemes and pave the way for index-based insurance that could foster risk transfer solutions while providing dairy farmers with the assurance of financial protection from damages caused by climate change-induced risks.

The results also suggest a need to improve financial literacy that targets enhancing dairy farmers' awareness about insurance to help them make informed decisions about purchasing insurance products. Also, farmers' interactions from this study suggest that there's a need for improvement and access to better animal husbandry services. Overall, successful uptake and scale-up of proposed IBCI insurance requires successfully integrating the insurance scheme with the local development process.

Declaration of conflict of interest

The authors declare no conflict of interest.

Acknowledgments

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Supplementary Tables :

Table S1: Understanding and knowledge of cattle insurance across surveyed districts

Gender	Yes	No
Male	31 (55 %)	25(45%)
Female	16(33%)	32 (67%)

Table S2: Years of insurance taken for cattle in the last 15 years.

Gender	Years of insurance cover	Frequency	Percent	Valid Percent	Cumulative Percent
Female	1	3	6.25	6.25	6.25
	2	1	2.08	2.08	8.33
	3	8	16.67	16.67	25.00
	5	6	12.50	12.50	37.50
	6	1	2.08	2.08	39.58
	7	1	2.08	2.08	41.67
	8	2	4.17	4.17	45.83
	10	26	54.17	54.17	100.00
	Missing	0	0.00		
	Total	48	100.00		
Male	1	7	12.50	12.50	12.50
	2	13	23.21	23.21	35.71
	3	9	16.07	16.07	51.79
	5	3	5.36	5.36	57.14
	7	1	1.79	1.79	58.93
	8	4	7.14	7.14	66.07
	10	17	30.36	30.36	96.43
	15	2	3.57	3.57	100.00
	Missing	0	0		
	Total	56	100		

Table S3: Cattle holdings of the surveyed dairy farmers

Herd size	Frequency	Percentage
1	26	25.00
2	51	49.04
3	17	16.35
4	4	3.85
5	3	2.89
6	1	0.96
7	2	1.92
Total	104	100

Table S4: Insurance premium paid towards existing livestock insurance scheme

Insurance premium paid	Frequency	Percent
0	4	3.85
300	1	0.96
370	1	0.96
400	70	67.31
450	3	2.89
490	7	6.73
500	3	2.89
1000	11	10.58
1230	2	1.92
1500	2	1.92
Total	104	100

Table S5: Willingness to participate in index-based cattle insurance

IBCI	Frequency	Percentage
Yes	43	41.346
No	61	58.654
Total	104	100

Table S6: Dairy farmer's willingness to pay premium IBCI

IBCI premium	Frequency	Percent
No	96	92.31
Yes	8	7.69
Total	104	100

Table S7: Reasons for not purchasing cattle insurance

Reasons to not participate in cattle insurance	Yes (%)	No (%)
Cost of Premium	76.44	23.25
Management Practices	95.34	4.65

4.3 Links and implications

This chapter provides insights for policymakers on how to help small dairy farmers manage risks associated with extreme climate weather events by determining farmers' willingness to pay for index-based cattle insurance and what features dairy farmers most consider and value for the uptake of livestock insurance schemes. The most fundamental part of livestock insurance schemes is getting potential and existing farmers to understand them. Experience increases participation and influences neighbors' decisions. Nonetheless, policymakers must pay attention to and address the needs and priorities of dairy farmers to promote participation. Most emerging markets have failed to promote livestock insurance, and insurers are unwilling to approach individual animal owners. Hence, there's a need to understand dairy farmers' perceptions, design strategies for specific geographical locations, and make efforts to uptake cattle insurance.

CHAPTER 5: PAPER 3: CLIMATE VARIABILITY IMPACTS ON CATTLE MILK PRODUCTION ACROSS THREE VILLAGES IN REGIONAL SOUTH INDIA

5.1 Introduction

The productivity of cattle in various rural regions across India is significantly impacted by the escalating climate variability, leading to challenges such as reduced water availability and forage production, as well as diminished forage quality. In light of the growing impacts of climate change and the rising demand for milk products, there is an increasing need to prioritize the improvement of milk production to address these pressing challenges. In this chapter, the study looked into how climate variability affected milk production across three Indian villages in regional south India (2019-2022), which is essential for implementing strategies to alleviate the adverse effects generated by climate change. Tropical agro-climatic zones are predicted to face an early rise in exposure to an increase in temperature and erratic monsoons.

5.2 Submitted paper

Climate variability impacts on cattle milk production across three villages in regional south India

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Abstract

India is a leading producer of milk in the world, with significant growth in recent years. However, small dairy farmers in rural areas are vulnerable to climate variability due to changing precipitation patterns and rising temperatures, which considerably impact cattle milk production. To generate insights into how climate variability impacts cattle milk production in three villages in regional south India, we analyzed data collected from milk cooperatives consisting of 316 dairy farmers for the period 2019-2022 which consisted of yearly milk production, income, and milk poured-times. Rainfall has a positive correlation (0.75) with Yearly milk production, whereas mean/maximum temperature has a negative correlation

(-0.52). The Ordinary Least Squares (OLS) regression analysis highlights that climatic factors such as total rainfall (Apr-Sep) and mean/maximum temperatures are significantly correlated with milk production (litres/year). The OLS results, with an R-squared value of 0.558 and 0.658 for total rainfall (Apr-Sep), indicate a substantial impact on milk production and income. While the R-squared value of 0.526 for mean Tmin, indicated a substantial impact on dairy income. These findings emphasize the necessity for strategic interventions, such as enhancing cattle shading, improving barn ventilation, and employing cooling techniques like water sprays. Such measures are particularly crucial in arid and semi-arid regions of South India, where high temperatures can severely affect livestock productivity. By adopting adaptive strategies such as growing drought-tolerant grasses, fodder preservation, farm diversification, drought-resistant cattle, and buying livestock insurance dairy farms can better manage the high-temperature effects and bolster resilience against the adverse effects of climate variability. A better understanding of temperature and rainfall effects on milk production will help in improved management of dairy cattle farming and making the livestock sector sustainable.

Keywords: Climate variability, milk production, rainfall, temperature, cattle

1) Introduction

India has seen a significant increase in milk production and is currently the leading global producer with a 24% share (DAHD 2024). Milk output has surged by 61%, increasing from 137.7 million tonnes in 2013-14 to 221.1 million tonnes in 2021-22 (DAHD 2024). The agrarian risk environment fluctuates with high frequency and severity because of extreme climatic events like droughts, floods, cyclones, hurricanes, typhoons, tornadoes, wildfires, and others (Megersa et al. 2014; IPCC 2021). The challenges in livestock, especially in the dairy sector, are exacerbated by a changing climate which can cause extremely variable production outcomes (Moran 2009; Barnes & Toma 2012; Douphrate et al. 2013). As a result of climate risks, cattle are susceptible to numerous diseases, and on occasion, these may cause huge morbidity and mortality losses (Godde et al. 2021; Soumya et al. 2022).

Threatened by climate change impacts, cattle are the livestock species that are most vulnerable to water and feed shortages (Seo et al. 2010). Consequently, cattle farmers are reportedly responding to environmental changes by adjusting herd composition, for example, by keeping more resilient livestock species such as goats (Shantharaju et al. 2024). Cattle raised in tropical environments are prone to numerous environmental challenges like lack of nutrition and fodder availability which can challenge the ability of animals to cope (Shashank et al. 2023). When cattle are subjected to climate extremes, it leads to weak development, which later impacts growth and weakens adaptive capability (Shashank et al. 2022).

Long-term changes in regional or global climate, particularly declining and changing patterns of rainfall and increasing temperatures, are normally used to understand the impacts and assess climate change (Abbass et al. 2022). For India, the available evidence emphasizes the greater importance of trends and variability in precipitation (Kundu et al. 2014; Chatterjee & Rangarajan 2022; Kishore et al. 2022; Chandra Gouda et al. 2023) over temperature changes

(Nath et al. 2023). This stems from the damaging effects of droughts on livelihoods that are dependent on rain-fed agriculture or dairy farming (Algur et al. 2021). Therefore, climate change has already brought about observable changes in regional south India, such as changing rainfall patterns, changing rainfall seasonality, and increasing incidences of droughts (Chandra Gouda et al. 2023; Shantharaju et al. 2024).

Droughts and swiftly declining groundwater simultaneously can cause severe challenges to water security in regional India and the frequency. The frequency and severity of these challenges may increase with climate change (Mishra 2020; Upadhyay & Sherly 2023). The issue with droughts is that they lead to a depletion in the cattle population by increasing mortalities and forcing dairy farmers to sell their animals (Shantharaju et al. 2024). Droughts deteriorate grazing land, and hinder proper cattle feeding and growth of cattle (Oba 2001).

Water scarcity due to warming and drying trends in climate negatively affects the range-land production, which affects the nutrition quality of forages (Gauly & Ammer 2020). Soaring temperatures heighten the influence of moisture stress on plant growth and thermal stress on animals and decrease precipitation, reducing the primary production and forage quality (Megersa et al. 2014). Likewise, (Shashank et al. 2022) demonstrated calves subjected to high temperatures & nutritional shortage had a detrimental impact on growth and adaptive capabilities. Similarly, (Craine et al. 2010) showed that declining precipitation and rising temperatures shrink the crude protein and digestible organic matter of fodder grasses. As a result, these conditions hinder the production potential of milk production.

The global risk of climate extremes on dairy production systems has been well documented in numerous studies under future global climate scenarios (Carvajal et al. 2021; Thornton et al. 2022; North et al. 2023). However, relatively little attention has been given to the trends and associations of climate variables with local milk production systems within specific geographical areas, such as regional south India, which is the focus of this study. Despite its reputation for milk production, regional south India faces several climate challenges that threaten the viability of smallholder dairy farmers.

Milk production is a highly relevant study aspect in India for several reasons. First, there is a substantial reliance of the poor on livestock activities like dairy farming where more than 70 million households produce milk in India (Janssen & Swinnen 2019). Second, although labour-intensive activity dairying is generally expected to offer better income prospects for income growth to the poorest rural households with little land. Governments over the years in India have vastly promoted this sector given its potential for pro-poor growth. The widely known Operation Flood program which became operational in the 1970s to increase milk production and income for small rural farmers happens to be one of the world's largest rural development programs to date (Janssen & Swinnen 2019; Gaillard & Dervillé 2022).

Therefore, understanding the relationship between changing trends and milk production would advance our knowledge regarding the impacts of local climate changes and dairy farmers' livelihoods (Thornton et al. 2009). This study, therefore, aimed at investigating important climate factors affecting milk production and how much of an impact they have on milk production across study villages of Karnataka in regional south India.

2. Methods

2.1 Study area

Agriculture and dairy farming play a significant role in the overall socio-economic growth in Karnataka and rural smallholder livelihoods. The three studied villages (Kadathanamale, Neralaghatta, and Bachuvarihalli) were part of districts Bengaluru urban, Bengaluru rural, and Chikkaballapur, which are located in the southeast of the south Indian state of Karnataka, India (Figure 1). During summers, this study area is characterized by relatively high temperatures

(Nautiyal & Goswami 2022; Shantharaju et al. 2024). The rainfall data indicate that out of 11 consecutive years (from 2009 to 2019), 8 to 9 years Chikkaballapur faced droughts (DDMA 2020; Hema et al. 2021). Further, the Bengaluru area records around 948mm of annual rainfall & Chikkaballapura records 756 mm (Reichenbach et al. 2021; Harishnaika et al. 2022).

2.2 Data collection

Milk Production Data

The milk production data from 2019 to 2022, gathered yearly from April 1st to March 31st, was obtained from the village dairy cooperative societies (VDCS) of Bachuvarihalli, Kadathanamale, Neralaghatta. These villages were chosen during the survey as they were found to have reliable datasets and differences in climatic conditions. The selection was made in consultation with the heads of VDCS. It's worth noting that milk producers at a village level join together to form a VDCS (Yadav et al. 2016). For more information on the survey and village selection see Shantharaju et al. (2024). In this study, data was collected from VDCS that consisted of 316 dairy farmers milk production, income, milk poured times, distributed across Bachuvarihalli (N=51), Kadthanamale (N=133), and Neralaghatta (N=132) for the period (2019-2022) and summarized for data analysis (Total observations N=1264). Milk is produced all year long and dairy farmers pour milk at collection points every morning and evening, at specific times scheduled by VDCS. A representative sample of milk is drawn to test the quality of milk. Most farmers here had a cattle holding size of 1 to 3, which is typical of the dairy production systems in India, with the majority being small and marginal farmers (Kishore et al. 2016; John & Philip 2017; Jatwani & Swain 2020).

Dairy farm characteristics

In addition to an analysis looking at climate impacts on dairy production a survey of dairy farmers from these villages was also undertaken. This was done to check and compare the results from the empirical analysis with the farmer's responses to climate impacts and management strategies in dairy farming. A total of 44 dairy farmers in Bachuvarihalli (11) Kadathanamale (11), and Neralaghatta (22) were interviewed to understand the general characteristics of dairy farming in their respective villages. This part of the study dataset is subsetted from the dairy farmers' survey data collected, and the details of the survey are given in Shantharaju et al. (2024). This set of farmers was identified in consultation with heads of VDCS, who have been part of society since inception and had a track record of regularly pouring milk. Data consists of cattle type, types of fodder fed to cows, and climate risk management strategies (see Tables S1 and S2).

Temperature & rainfall data :

We used climate data from the TerraClimate dataset (~ 4 km resolution) (Abatzoglou et al. 2018). TerraClimate uses interpolation with high-spatial-resolution climatological normals from the WorldClim dataset that is integrated with coarser resolution time varying (i.e. monthly) data from CRU Ts4.0 https://data.ceda.ac.uk//badc/cru/data/ cru_ts/ and the Japanese 55-year Reanalysis (JRA-55) https://jra.kishou.go.jp/JRA-55/index_en.html. For the milk producing period (April 1st to March 31st) each year, monthly data of total rainfall, and minimum and maximum temperatures, were extracted for the three study villages. Climate data analysis was performed to see a comparison among the study locations (Fig. 2). The climate data was analysed for the annual and Apr-Sep periods to compare and identify the important period to use for analysis. The April-Sep period is focused for analysis because it is the most important period for fodder growth, water, and cultivation of crops (Rai et al. 2014).

2.3 Statistical Analysis

Data analysis was conducted using Python and JASP version 0.18.3. The data encompassed various types of cattle and their fodder consumption, which were analyzed to discern distribution patterns depicted through proportions and frequency distributions. Additionally, climatological data from three villages Kadthanamale, Neralaghatta, and Bachuvarihalli were visualized using box plots to display variations in total rainfall and temperature ranges (Fig 2). A correlation matrix was also utilized to elucidate the relationships between different climatic factors and milk production variables.

These visualizations are crucial for identifying correlations between climate factors, such as Mean Tmin, Total rainfall, Mean Tmax, and key dairy production indicators such as mean milk poured (MMP) (times/year), mean milk production (MMPr) (litres/year), and dairy income expressed as mean income INR (amount/year) (Fig 5).

The climate data (rainfall, Tmin, and Tmax) were calculated for the period of Apr-Sep to reflect the seasonal differences. About 70% of the annual rainfall occurs during this period (Apr-Sep) and also variability in Tmin and Tmax temperatures (Fig.2d-f). Therefore, the Apr-Sep period is selected for performing the analysis and quantification of climate impact on milk production.

The study employs Ordinary Least Squares (OLS) regression analysis to assess the impact of specific climatic factors—total rainfall (Apr-Sep), mean maximum temperature (Mean Tmax) and mean minimum temperature (Mean Tmin) on pivotal milk production variables: the mean number of times milk was poured per year (MMP (times/year)), the mean volume of milk produced per year (MMPr (litres/year)), and the mean annual income from milk production (Mean income INR (amount/year)). These analyses aim to illuminate how variations in climatic conditions, specifically rainfall and temperature, affect milk production outputs (Table 3).

The dataset includes observations from 316 farmers across three distinct villages over four years, from 2019 to 2022. The variables under consideration encompass milk production frequency, volume, income, and climatic factors. To enable a detailed analysis with the OLS regression, which is well-suited for continuous dependent variables, these milk production variables were analyzed directly without binary transformation. This approach allows for a nuanced exploration of the direct influence of climatic variables on milk production factors. The OLS model is mathematically expressed as follows:

$$Y = \beta 0 + \beta 1 X1 + \beta 2 X2 + \beta 3 X3 + \epsilon$$

where:

- Y represents the continuous dependent variables such as MMP (times/year), MMPr (litres/year), and mean income INR (amount/year),
- *X1, X2, and X3* represent the independent variables total rainfall (Apr-Sep), Mean Tmax, and Mean Tmin for the period Apr-Sep, respectively
- $\beta 0$ is the intercept,
- $\beta 1$, $\beta 2$ and $\beta 3$ are the slope coefficients that quantify the effect of each climatic predictor on the milk production factors.
- ϵ is the error term of the model.

This model provides a framework for understanding how changes in climate factors total rainfall (Apr-Sep), mean Tmin and mean Tmax may influence milk production outcomes MMP (times/year), MMPr (litres/year), and mean income INR (amount/year) in the context of rural dairy farming.

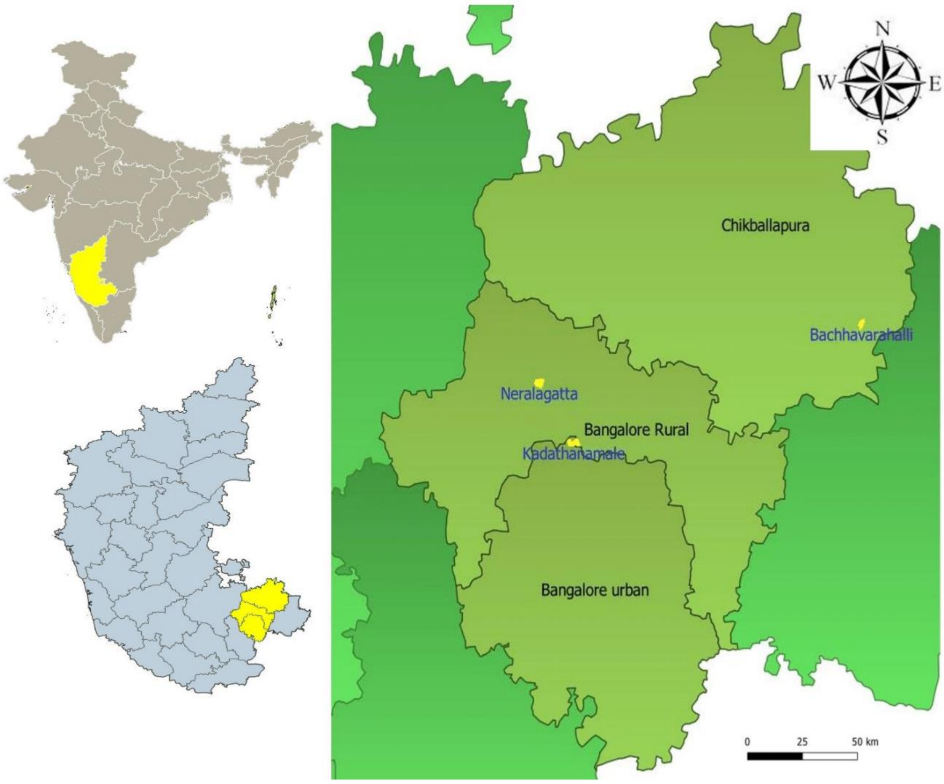

Figure 1: Study area map of Karnataka showing the villages (Kadthanamale (N=133), Neralaghatta (N=132), Bachuvarihalli (N=51) and Total observations N=1234) in districts of Bengaluru Urban, Bengaluru rural, and Chikkaballapur.

3. Results

3.1 Cattle types, fodder, and milk production descriptives across the study region.

The cattle types owned by dairy farmers in the villages generally were Holstein Friesian (HF), Jersey, and Desi Cow (Native Indian Cow), or a combination of these (Table S1). The desi cow milk consumption was for households and the milk from other cows was sold to dairy co-operative societies.

The dairy farmers feed the cows a mix of green and dry fodders, along with other feeds (store-bought) available based on land they kept for growing grasses for the animals. A range of 0 to 45 kgs of green fodder, 0 to 25 kgs of dry fodder, and 1 to 6 kgs of store-bought feed were given to the cattle among the sampled dairy farmers (Table S2). The feeding strategies of animals were dependent on a combination of factors, particularly land holdings, land used for grass cultivation, dairy income, and other income streams available to small dairy farmers.

Across the study period (2019-2022), farmers' daily milk production averaged about 11.30 litres/day in Bachuvarihalli, 15.09 litres/day in Kadathanamale, and 11.80 litres/day in Neralaghatta respectively (Table 1). Neralaghatta has the highest frequency and low variability for milk poured (591.52 times/year) (Table 1). Kadthanamale leads in milk production (3675 litres/year) and sees higher variability. For dairy income, Kadthanamale shows the highest income (100576 INR/year) and variability, while Bachuvarihalli has the lowest values in all categories with relatively low variability (Table 1).

Table 1: Descriptives of milk production variables across the study region

Variable	Villages Names	N	Mean	SD	SE	Coefficient of Variation
Mean milk poured (times/year)	Bachuvarihalli	51	446.66	36.83	18.41	0.08
	Kadthanamale	133	487.07	62.74	31.37	0.13
	Neralaghatta	132	591.52	19.75	9.88	0.03
Mean milk production (litres/year)	Bachuvarihalli	51	2520.86	185.64	92.82	0.07
	Kadthanamale	133	3675.09	461.17	230.58	0.13
	Neralaghatta	132	3490.98	297.82	148.91	0.09
Mean Income INR (amount/year)	Bachuvarihalli	51	64702.32	2825.11	1412.56	0.04
	Kadthanamale	133	100575.67	12820.17	6410.09	0.13
	Neralaghatta	132	94836.31	5783.25	2891.62	0.06

3.2 Rainfall and temperature variation across the study region

The climatic patterns across three villages Bachuvarihalli, Kadthanamale, and Neralaghatta reveal distinct variations in rainfall and temperature. Bachuvarihalli experiences a broad range of total rainfall with significant outliers and a lower median around 770 mm, indicating occasional heavy rainfall events. In contrast, Kadthanamale exhibits more consistent rainfall, devoid of significant outliers, and a median close to 940 mm, suggesting a stable precipitation regime (Fig 2a). Neralaghatta's rainfall distribution is relatively uniform with a median near 960 mm but includes outliers that indicate sporadic heavy rainfall. In terms of temperatures, Bachuvarihalli's mean minimum temperature hovers around 19.6°C, indicating warmer nights with less fluctuation. Kadthanamale records cooler nights with a consistent median minimum temperature near 18.8°C, while Neralaghatta has a broader temperature range of around 19.0°C, reflecting greater variability (Fig 2b). For Tmax, Bachuvarihalli again shows higher variability with a median of around 31.0°C (Fig 2c). Kadthanamale and Neralaghatta exhibit more stability in daytime temperatures, though Neralaghatta occasionally experiences significant temperature spikes (Fig 2c). Overall, Bachuvarihalli is marked by wider climatic swings, both in temperature and rainfall, whereas Kadthanamale demonstrates greater consistency across climatic measures. Neralaghatta, while generally stable, is punctuated by occasional extremes that disrupt its moderate climate profile. The total rainfall in the Apr-Sep period recorded about 70% of the total annual rainfall, and the Tmin and Tmax recorded higher temperatures in the Apr-Sep period compared to the annual mean (Fig. 2d-f). Hence, the climate variability is higher in this period.

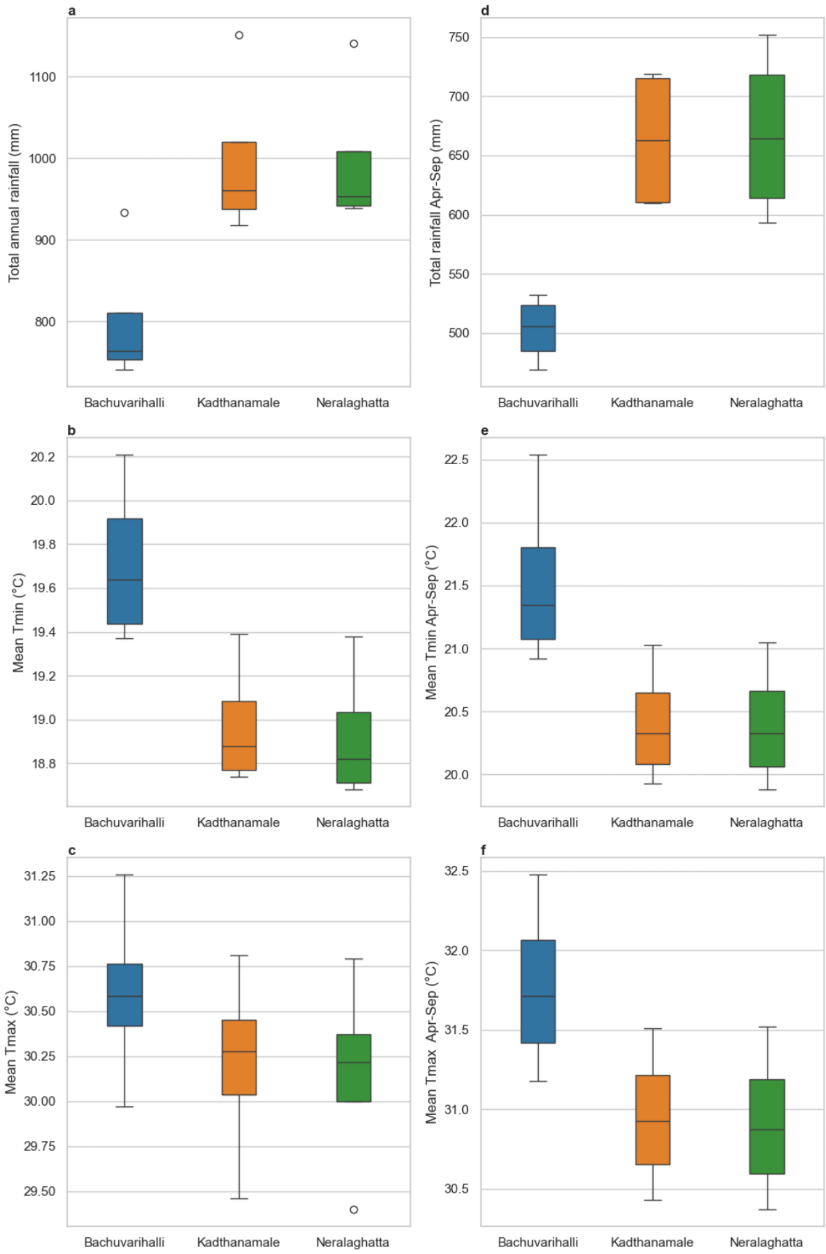

Figure 2: Boxplots of (a) Total annual rainfall (mm), (b) mean minimum temperature, (c) mean maximum temperature, (d)Total rainfall Apr-Sep (mm), (e) mean minimum temperature Apr-

Sep, (f) mean maximum temperature Apr-Sep, for each village in the study region during 2019 -2022. The upper and lower border of the boxes represent the 3rd and 1st quartiles, respectively. The line within the box represents the median value. Bars extend to the minimum and maximum values. Black circles are the outliers.

3.3 Variation in milk production across the study region

Notably, the ANOVA results for “MMP (times/year)” and ($F(2, 9) = 11.79$; $p = 0.003$) indicate a strong effect on the frequency of milk poured (Table 2). While "MMPr (litres/ year)" demonstrated significant differences between villages and ($F(2, 9) = 13.74$; $p = 0.002$), suggesting that milk production levels are significantly influenced by local climatic conditions that vary from one village to another. The mean values of milk poured per year range from 2521 litres in Bachuvarihalli to 3675 litres in Kadathanamale (Table 1), indicating substantial variability that could be attributed to factors such as farming practices, breed types, and localized climate (rainfall and temperature) conditions. In the case of mean income INR, the results were even more pronounced with a high F-statistic of 21.65 and a significant p-value ($p < 0.001$) indicating a strong effect on dairy income (Table 2).

Conversely, for “mean Tmax,” the ANOVA analysis indicated no significant differences among the villages ($F(2, 9) = 0.77$; $p = 0.49$), implying that the maximum temperatures are fairly consistent across the regions studied (Table 2). This temperature uniformity suggests that temperature-induced stress may not be a differentiating in milk production across these villages. It allows for a more standardized approach to managing heat impacts on crops and livestock, assuming other climatic conditions like humidity and rainfall are also consistent.

However, “total annual rainfall” displayed significant variations ($F(2, 9) = 5.44$; $p = 0.028$), highlighting how differing precipitation levels could influence milk production. With rainfall ranging significantly, from about 800 mm in Bachuvarihalli to 1000 mm in Kadthanamale and

Neralaghatta (Fig 2a), water availability could be a critical factor influencing dairy farming decisions, fodder growth needs, and ultimately milk productivity. These differences are crucial for resource management, especially in planning for water-intensive periods and mitigating drought impacts.

Table 2: ANOVA of milk and climate variables across villages.

Variable	Sum of Squares	df	Mean Square	F	p-value
MMP (times/year)	44702.92	2	22351.46	11.79	0.003**
MMPr (litres/year)	$3.076\times10^{+6}$	2	$1.538\times10^{+6}$	13.74	0.002**
Mean Income INR (amount/year)	$2.971\times10^{+9}$	2	$1.485\times10^{+9}$	21.65	0.001**
Mean Tmin	1.57	2	0.78	6.96	0.015**
Mean Tmax	0.47	2	0.23	0.77	0.49
Total rainfall	103242.19	2	51621.09	5.44	0.028**

Note :**are statistically significant at $p<0.05$. MMP – mean milk poured, MMPr – mean milk production.

The box plots (Fig 3 a,b,c), highlight statistically significant differences in milk poured, milk production, and income derived from milk production among the three villages, as confirmed by the p-values associated with each milk variable. Kadthanamale exhibits higher milk production compared to the other two villages. Neralaghatta tends to have higher milk poured times but shows less income compared to Kadthanamale. In contrast, Bachuvarihalli consistently shows lower values in all milk variables with narrower inter-quartile ranges, indicating less variability.

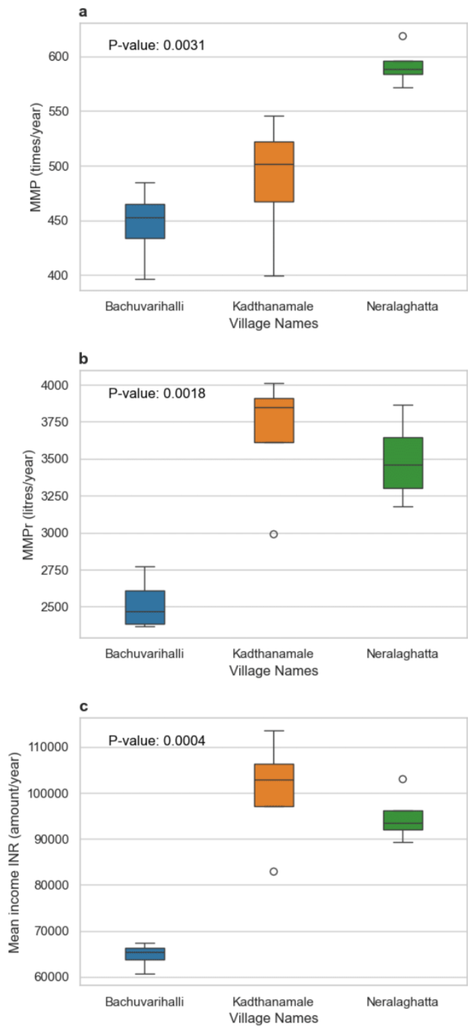

Figure 3**:** Boxplots of (a) MMP (times/year), (b) MMPr (litres/year), and (c) Mean income INR (amount/year), for each village in the study region during 2019 -2022. The upper and lower border of the boxes represent the 3rd and 1st quartiles, respectively. The line within the box represents the median value. Bars extend to the minimum and maximum values. Black circles are the outliers. For each, the P-values from the Anova-test comparing mean values are shown (significant difference at $P < 0.05$)

3.3 Trends, and the relationship between climate factors & milk production

A key notable observation in Fig. 4 is where there's a strong negative correlation between the mean minimum temperature (Mean Tmin) and mean income in INR (Mean income INR), suggesting that cooler temperatures might enhance dairy income, potentially due to improved milk production. In contrast, higher maximum temperatures (Mean Tmax) show a negative correlation with both income and mean milk production (MMPr), indicating that extreme temperatures may adversely impact these areas. Additionally, increased rainfall demonstrates a positive correlation with milk production, implying that more rainfall could boost milk production and, consequently, the incomes of dairy farmers. Furthermore, the positive relationship between the number of milk poured days (MMP times/year) and mean income INR (amount/year) highlights the significant impact of milk production on economic performance. The matrix also reveals that rainfall generally has positive effects, while minimum and maximum temperatures might have detrimental impacts. This emphasizes the complex interactions between various climatic factors and their influence on economic outcomes.

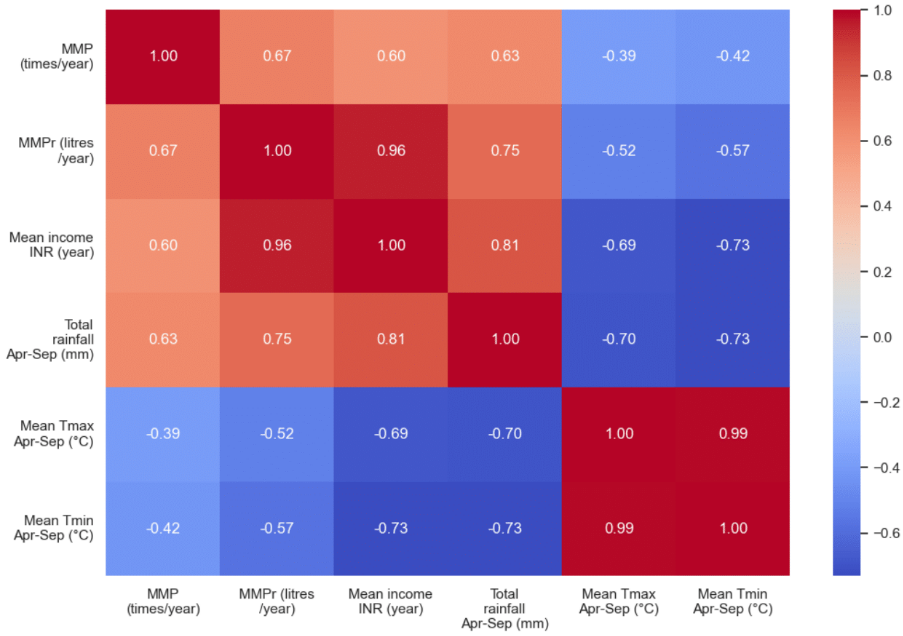

Figure 4: Correlation heatmap to show the correlation between milk production variables and climate factors.

The trend analysis presented (Fig 5) explores the interactions between climate and milk production variables, specifically focusing on how mean minimum temperature, total rainfall (Apr-Sep), and mean maximum temperature influence mean milk pour times, mean milk production, and mean income. These relationships are visually represented through scatter plots enhanced with trend lines and confidence intervals, offering a statistical insight into the patterns (Fig 5).

Interactions with total rainfall (Apr-Sep) indicate a positive correlation, suggesting that increased rainfall tends to enhance milk production (both in terms of times poured per year and volume per year). This positive trend is likely due to improved water availability for fodder crops and leading to better grazing pastures for the animals. Additionally, the positive trend in milk poured times implies that increased rainfall may result in more days favorable for milk production. The income from milk production also demonstrates a positive trend with increased rainfall, indicating that better feeding options for cattle due to more rainfall can boost milk production and improve incomes for dairy farmers during the period.

Concerning mean maximum temperatures, the data reveals a distinct negative correlation with milk production. Higher maximum temperatures are associated with reduced milk production (both in terms of times poured per year and litres per year), likely due to the impact of high-temperature stress on dairy cattle, which negatively impacts their health and reduces the number of milk production days. Similarly, the income from milk production shows a negative trend with rising maximum temperatures, suggesting that higher temperatures adversely affect milk production and potentially disrupt dairy farming operations, leading to lower incomes for dairy farmers.

In the relationship involving mean minimum temperature, we see that MMP (times/year) and MMPr (litres/year) exhibit a clear negative correlation, suggesting a decrease in milk production as minimum temperatures rise. This might indicate that lower temperatures are more conducive to higher milk production and milk poured times have a negative association, where higher minimum temperatures seem to correlate with fewer days suitable for milk production. Mean income shows a minor negative trend, suggesting that warmer minimum temperatures could be linked to a decrease in dairy incomes, although this relationship appears less pronounced compared to milk production.

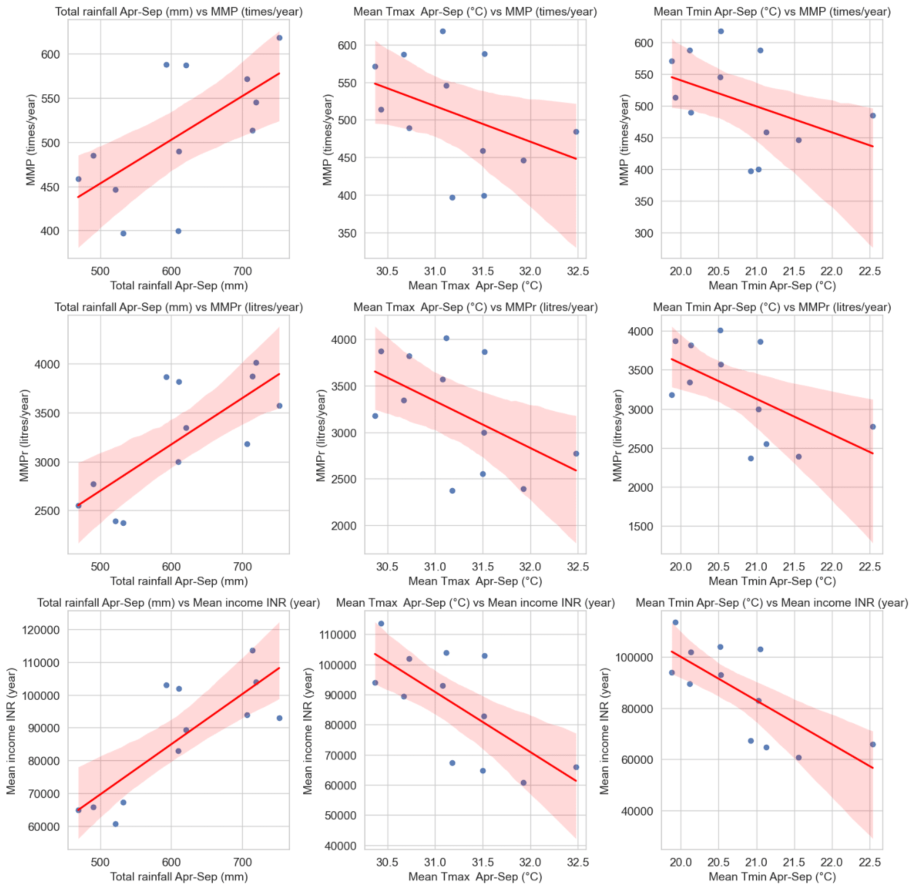

Figure 5: Trends among climate and milk production variables for the period (2019-2022). Blue dots are observations, the red line is the line of best fit and the shaded red areas are 95% confidence intervals.

3.4 Milk production explained by climatic factors

Table 3 provides a comprehensive overview of the Ordinary Least Squares (OLS) regression results, which analyze the relationship between climatic conditions (rainfall and temperature) and milk production outcomes, as discussed in section 2.3 Statistical Analysis.

Total rainfall (Apr-Sep), on the other hand, presents stronger correlations, particularly with MMPr (litres/year), Mean income INR (amount/year), and MMP (times/year), where the models demonstrate substantial explanatory power with R-squared values of 0.558, 0.658 and 0.401, respectively. About 51.4 % of the variation in milk production and 62.4% in dairy income is due to total rainfall (Apr-Sep) in the period, indicating that increased rainfall leads to better milk production and income for dairy farmers. These results underline the critical role of rainfall in affecting milk production and income, particularly during monsoon, reflecting the direct impact of climatic variations on dairy farming outcomes (Table 3).

For MMPr (litres/year) and dairy income, Mean Tmax presents a marginally significant negative relationship. Approximately, 19.3% of the variation in milk production and 42.1% of dairy income is due to maximum temperatures during the period (Apr-Sep), indicating the potential impact of higher temperatures on milk production negatively and the result of dropping incomes for dairy farmers.

Regarding mean Tmin, we see that it affects incomes significantly (Mean Income INR), and milk production marginally with no significant effect on milk pouring (times/year). Around 26.2 % of the variation in milk production and 47.9 % of the variation in income suggest high MeanTmin are associated with lower milk production and income to dairy farmers. These results underline the critical role of Tmin in affecting milk production and income, reflecting the direct impact of climatic variations on dairy farming outcomes (Table 3). This nuanced approach helps delineate the specific climatic factors that are significant drivers of milk production and economic outcomes in dairy farming.

Table 3: Regression results between climate factors and milk production variables across the three villages

Independent Variable	Dependent Variable	Coefficients	P-value	R-squared	Adjusted R-squared
Total rainfall (Apr-Sep)	MMPr (litres/year)	0.7471	0.005**	0.558	0.514
Total rainfall (Apr-Sep)	Mean income INR (year)	0.8112	0.001**	0.658	0.624
Total rainfall (Apr-Sep)	MMP (times/year)	0.6331	0.027**	0.401	0.341
Mean Tmax (Apr-Sep)	MMPr (litres/year)	-0.5157	0.086	0.266	0.193
Mean Tmax (Apr-Sep)	Mean income INR (year)	-0.6880	0.013**	0.473	0.421
Mean Tmax (Apr-Sep)	MMP (times/year)	-0.3944	0.205	0.156	0.071
Mean Tmin (Apr-Sep)	MMPr (litres/year)	-0.5739	0.051	0.329	0.262
Mean Tmin (Apr-Sep)	Mean income INR (year)	-0.7253	0.008**	0.526	0.479
Mean Tmin (Apr-Sep)	MMP (times/year)	-0.4219	0.172	0.178	0.096

Note: **are statistically significant at $p<0.05$, MMP – mean milk poured, MMPr – mean milk production.

Additionally, we analyzed the subsetted survey data for farmers' responses to key climate risks affecting milk production (Fig 6), the majority of the farmers in the study regions (Buchuvarihalli (71%), Kadthanamale (73%) and Neralaghatta (69%)) reported that high temperature is a very important climatic factor affecting milk production. Farmers report that excess rainfall is moderately to slightly important in all three villages affecting milk production. Drought is another important factor affecting milk production, in Bachuvarihalli about 29% of farmers feel drought is very important, and 45% of farmers moderately important. While at Kadthanamale 27% of farmers report drought is very important and moderately important for 34% of farmers affecting milk production. Farmers at Nerlaghatta feel 31% very important and 25% moderately important affecting milk production respectively. Farmers reported pests and diseases moderately (ranging from 31% to 26%) to slightly important (ranging from 28% to

27%) in affecting milk production in the study regions (Fig 6). Overall, the farmer's responses confirm the OLS regression results that rainfall and temperature variation significantly affect milk production.

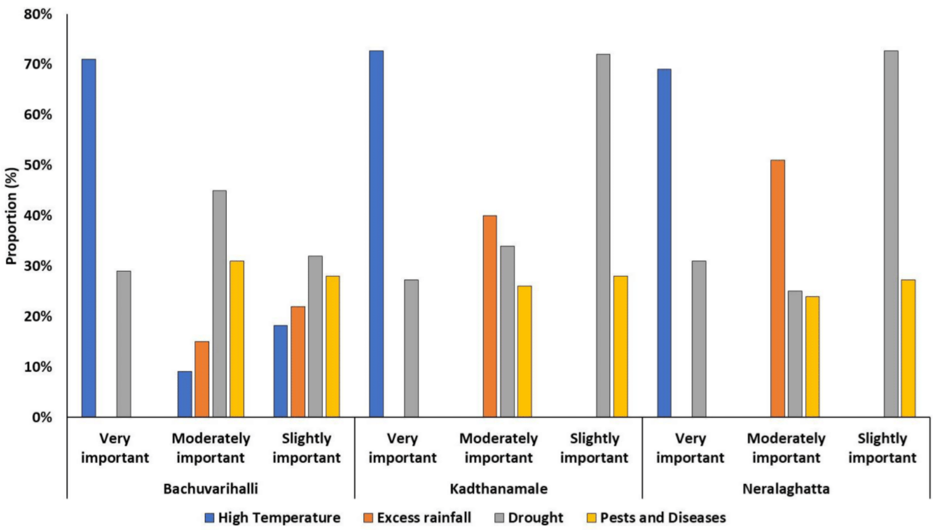

Figure 6: Dairy farmers' responses to key climate risks to milk production across the three villages (Buchuvarihalli, Kadthanamale, and Neralaghatta).

The subsetted farmer survey data for the three villages is analyzed for the climate risk management strategies (Fig 7), all of the farmers (100%) at Kadthanamale prefer to grow drought-tolerant grass, buy livestock insurance, farm diversification, and off-farm income to mitigate climate risks faced. At Neralaghatta village majority of the farmers grow drought-tolerant grass (95%), livestock insurance (100%), farm diversification (86%), and off-income (100%), while farmers at Kadthanamale village prefer to grow drought-tolerant grass (100%), livestock insurance (100%), farm diversification (100%) and off-farm income (100%), respectively. Farmers at Bachuvarihalli prefer a high proportion (55%) of drought-resistant cattle due to lower rainfall and high temperature (Fig 2d-f) compared to other dairy farmers in Neralaghatta (9%) and Kadthanamale (0%) (Fig 7).

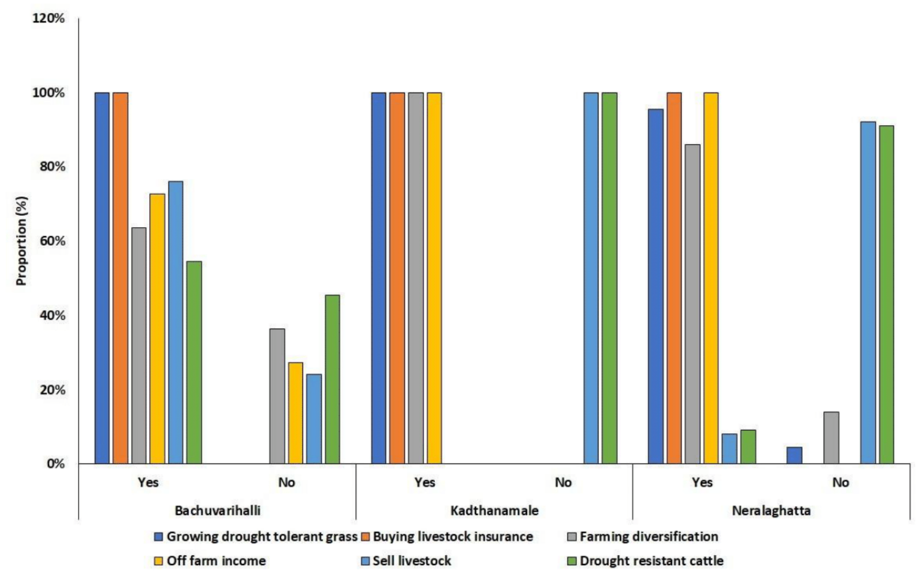

Figure 7: Dairy farmers' responses to climate risk management strategies across the three villages (Buchuvarihalli, Kadthanamale, and Neralaghatta).

4. Discussion

It is widely acknowledged that both individual cow characteristics and environmental conditions, such as temperature, significantly influence milk yield and composition (Yano et al. 2014). Numerous studies have quantified the impact of higher temperatures on milk production. The consensus from these studies indicates that higher temperatures lead to lower milk production (Barash et al. 2001; West 2003; Bohmanova et al. 2007) and this alters milk production potential as dairy cows thrive in cooler environments (McDowell et al. 1976; Schneider et al. 1988). The results from the study reveal that mean Tmin has a negative correlation with milk production, and dairy income across all studied regions. Further, we observed total annual rainfall has a positive correlation with the milk poured (times/year), milk production (litres/year), and a strong positive correlation on dairy income (Fig. 4)

Our results show the critical role of localized climatic conditions in shaping milk production. It suggests that total rainfall (Apr-Sep), mean Tmax, and mean Tmin vary significantly across villages, which affects the overall milk production and income (Fig 2d-f). Both MMP (times/year) and MMPr (litres/year) showed significant differences between the villages, suggesting that local climatic conditions uniquely affect milk production. For instance, villages with higher annual rainfall and moderate temperatures (Kadthanamale) appeared to have higher MMPr (litres/year) (Fig 3). The study by Baumgard and Rhoads (2013) indicates that up to a 50% reduction in milk production is due to high temperatures. Varying precipitation along with higher temperatures are likely to decrease milk production (Hernández-Castellano et al. 2019; Godde et al. 2021). In line with these findings, our present study observed a decrease in average milk production corresponded with an increase in mean Tmax, which also correlated with a reduction in income for farmers (see Figures 4 and 5). This study showed a decrease of 59% in milk production with an increase in mean Tmin and Tmax temperature (Fig 5). The descriptive statistics showed (Table 1) a change in milk poured (times/year) across the villages, from a lower average in Bachuvarihalli (447) to a much higher one in Neralaghatta (592).

Based on the Ordinary Least Squares (OLS) regression analysis, the findings elucidate distinct relationships between climate variables (rainfall and temperatures) and milk production factors as well as dairy income. Notably, the OLS models emphasize total rainfall (Apr-Sep) and play significant roles in influencing milk production, with MMPr (litres/year), milk poured (times/year), mean income INR (amount/year) showing strong statistical significance, and positive influence. In tropical regions such as South India, an increase in rainfall is generally beneficial to milk production, aligning with findings by Emediegwu and Ubabukoh (2023), which suggest that wetter conditions may enhance the productivity of dairy cattle (Usman et al. 2013; Nalianya et al. 2020). The farmer's responses show that high temperature is very important (Fig 6) affecting milk production confirming OLS results of high mean Tmax and Tmin substantially decreasing milk production and income (Table 3). Further farmer's responses show that drought decreases milk production (Fig 6), and the regression results confirm favorable rainfall conditions increase milk production (Table 3). These results corroborate previous studies, such as those by (Campbell 1931) and more recent research by (Barash et al. 2001), (Gantner et al. 2011), and (Fabris et al. 2019), highlighting that temperature variations markedly affect milk production.

Furthermore, the OLS results reveal that abrupt changes in maximum and minimum temperatures during seasonal transitions can impact milk output, supporting findings by (Ahmed et al. 2022) that emphasize the sensitivity of milk production to sudden climatic fluctuations. Studies by Gisbert-Queral et al. (2021) and Vroege et al. (2023) also reinforce that extreme temperatures can adversely affect not only the quantity but also the quality of milk produced.

Further regional South India faces feed and fodder issues, dairy cattle are generally maintained on poor-quality grasses available in pasture lands or stall-fed mainly on crop residues that impact its milk production (Shantharaju et al. 2024). Milk production is a continuous process and quantifying climate impacts in mixed farming systems in countries like India is a difficult exercise. Hence, dairy farmers are often exposed to extreme weather risks with limited options to ensure milk production. Farmers in the study regions responded that they are mitigating climate risk by adopting strategies such as growing drought-tolerant grass, buying livestock insurance, farming diversification, off-farm income, selling livestock and drought-resistant cattle (Fig 7) (Opiyo et al. 2015; Shrum et al. 2018).

Finally, the analysis provides critical insights into how rainfall and temperature affect milk production, this emphasizes there is a need for developing specific strategies to overcome the climate hazards. We understand there is a need for awareness of climate risks among different stakeholders (smallholders, cooperatives, policymakers, etc) in the dairy supply chain to develop improved mitigation strategies.

Limitations and future directions

The limitation of our research is our data set is collected for a short period. Therefore, gathering datasets for a longer time would help in performing critical analysis and quantification. Determining a causal relationship between climate variables and milk production/income is difficult. Other factors, such as feed quality, veterinary services, and farm management practices, also play substantial roles.

Future studies can look into comparing the climate change and mitigation strategies in different agro-climate zones to capture large variations over the landscape level. More informed data on milk parameters would help to compare the quality aspects with climate variability and farm incomes.

5. Conclusion

In India and other developing countries with similar dairy farming systems, climate change will affect the future availability of milk, and other products from cattle more so in arid and semi-arid regions, and it causes concern for food security. Particularly the impacts of higher temperatures and changes in precipitation would vary across geographical regions and socioeconomic capacities need to develop localised management adaptation strategies.

Milk production and dairy incomes were affected by extreme temperatures, and rainfall under conditions experienced in the study region. With the projected increase in drought and water availability issues in India, it is critical to identify the regions with the best conditions for cattle milk production and expand in those regions. As both temperature and rainfall impact milk production, these results will provide useful input in the planning and management of the livestock sector in the state of Karnataka.

Declaration of conflict of interest

The authors declare no conflict of interest.

Acknowledgments

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Supplementary Tables :

Table S1: Cattle type owned by farmers

	Bachuvarihalli	**Kadthanamale**	**Neralaghatta**
Cattle type	Frequency	Frequency	Frequency
HF	1	4	7
Jersey	1	0	4
Desi Cow	0	1	0
HF& Jersey	0	1	1
HF & Desi	9	5	9
Jersey & Desi	0	0	1
Total	11	11	22

Table S2: Fodder consumption of cattle

	Daily Green Fodder (Kgs) frequency				Daily Dry fodder (Kgs) frequency				Other fodder frequency			
	Qty	Bachuvarihalli	Kadthanamale	Neralaghatta	Qty	Bachuvarihalli	Kadthanamale	Neralaghatta	Qty	Bachuvarihalli	Kadthanamale	Neralaghatta
	0	0	2	0	**0**	4	1	0	**1**	0	1	0
	20	0	0	0	**5**	3	8	0	**2**	1	0	15
	25	2	0	2	**10**	2	0	3	**2.5**	0	0	4
	30	5	6	10	**15**	0	0	8	**3**	0	1	0
	35	0	2	9	**20**	2	2	9	**4**	0	0	2
	40	3	1	1	**25**	0	0	2	**5**	10	8	1
	45	1	0	0					**6**	0	1	0
Total		**11**	**11**	**22**		**11**	**11**	**22**		**11**	**11**	**22**

5.3 Links and implications

Climate change will affect the future availability of milk and milk products. The impacts of higher temperatures, changes in rainfall, and severe weather events will vary across geographical regions and socioeconomic capacity for adaptation. This study demonstrated the impact of climate variability among smallholder dairy farmers in three villages in regional south India, affecting milk production and dairy incomes. To mitigate against the imminent impact of climate risks in smallholder dairy farming systems, both short-term and long-term preventive measures are required. Such measures include the use of shades in the form of trees, hay, or straw shades to reduce temperature effects and the provision of adequate feed and water at all times for cattle to maintain health and production ability across weather changes. Further studies can explore the wider effects of climate risks on milk quality and growth in smallholder dairy farming in India with longitudinal datasets.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

Understanding dairy farmers' perceptions about climate change and the factors influencing their adaptation and coping strategies is key to effectively planning and developing adaptation strategies tackling climate change risks. This was the first part of this research. Findings from this research showed that farmer’s education level and landholdings were related to knowledge of climate change and adaptation strategies. Drought was perceived as the most severe climate risk having an impact on dairy farming. Dairy farmers primarily considered buying livestock insurance and diversification as key strategies for managing climate risks. Although dairy farmers’ family interests and economic security motivated them to adopt strategies, lack of climate forecasts and communication of scientific knowledge related to climate risks, and high adaptation costs in the region impeded adoption.

Logistic regression analysis also showed how socio-economic variables influenced the adaptation decisions of farmers in the studied region. Further, it is important for policies to consider local perceptions and factors driving dairy farmers’ decision-making for effective climate change adaptation in dairy farming as they present unique environmental, economic, and social characteristics prevailing in each region. The results also indicated dairy farmers in the region perceive drought, pests and diseases, and high temperatures as the major risks associated with climate change, which has resulted in decreased dairy income, animal health problems, reduced fertility, and food intake problems for their cattle.

A concern over extreme weather events in the study region and discontent with the traditional insurance scheme influenced the preference for hypothetical index-based cattle insurance. Based on the results daily hours spent on dairy activities, land holding size, and income from dairy farming affected farmers’ willingness to pay for index-based cattle insurance. Based on the findings of the study, a small number of farmers found the existing cattle insurance acceptable, not being farmer-friendly (particularly valuation exercise) and transparency affected the uptake according to dairy farmers surveyed in the study.

Despite the potential benefits of insurance, dairy farmers considered inadequate understanding, trust issues with insurance providers, and high premiums as barriers to participation in cattle insurance. However, dairy farmers perceived insurance as a more efficient risk management strategy, provided that the design of the insurance product took into account farmers' preferences and ensured affordable premiums. This study emphasized the importance of addressing the issues of dairy farmers that would help the uptake of cattle insurance in India. It is concluded that it is crucial to address multiple factors to promote wider uptake of insurance products is highly unlikely. First, there is a need to enhance the affordability of these products, making them more accessible to a broader demographic region. Secondly, there should be a concerted effort to educate the public about insurance policies, ensuring that potential customers are well-informed about their options. Lastly, it is crucial to establish partnerships with reliable insurance agencies to facilitate the availability and distribution of these products.

The third part of the study aimed to evaluate the effect of climate variability on milk production and income in the south Indian dairy cattle industry. Milk yields and dairy incomes negatively correlated with mean Tmin and mean Tmax and positively correlated with rainfall under conditions currently experienced in the studied villages. Particularly under smallholder dairy systems prevalent in India challenges like pests and diseases, feed shortages, and water shortages would further aggravate cattle milk production challenges during the hot and dry months of the year

Given the projected increase in global temperatures, it is anticipated that the dairy industry will face significant challenges in maintaining milk production. These challenges include an elevated risk of pests and diseases due to changing climate conditions, potential shortages of animal feed caused by altered growing patterns, and the increasing threat of water scarcity. All of these factors combined will make it increasingly difficult to sustainably meet the growing demand for milk in the future. These findings have important implications in terms of investing in mitigation measures and further future developments in the dairy sector of India, which is of high importance to millions of farmers, particularly in arid and semi-arid regions.

6.1 Significance and scientific contribution of the study

The livelihood of millions of small dairy cattle farmers in southern India is at risk due to various climate-related challenges and uncertainties. For most small cattle farmers, animals are their prime productive assets, wealth reservoir, and nutrition source. Improving the productivity and sustainability of cattle dairy farmers in the face of climate risks will strengthen their ability to cope with these challenges now and in the future. To enhance resilience to climate disasters, millions of small dairy farmers can benefit from implementing tailored adaptation measures such as upgrading cow shelters to withstand extreme weather events and adjusting feed supply to account for potential shortages caused by climate-related challenges. Additionally, the implementation of risk transfer strategies through livestock insurance can further provide small dairy farmers with the necessary tools to mitigate potential financial burdens resulting from climate-related disturbances.

This research study focused on dairy farmers' perceptions of how climate impacts their dairy operations, the practices they adopt, and how these perceived risks influence their choices regarding adaptation and mitigation strategies. The study also investigated the factors that drive farmers to adopt cattle insurance and their willingness to pay for index-based cattle Insurance.

The key contribution of the study is that it helps in better understanding of small dairy farmers' needs and priorities which would help researchers, dairy cooperative societies, cattle insurance providers, and other policymakers in their effort to develop and coordinate a comprehensive strategy to address various climate risks and their impacts on dairying activities across the study region and elsewhere in India. The study outcome filled a gap in knowledge relating to dairy farming to improve the knowledge about climate risks in the region and examined its impacts and the role and functioning of cattle insurance as a risk management tool.

At the industry level, it is expected that this knowledge and information from regional south India will be used as a benchmark for better decision-making and risk management for all the stakeholders in the dairy industry. Improved management of dairy cattle and improving insurance options are a way to protect cattle and strengthen the incomes of small dairying systems.

At the policy level, this study generates more insights into designing cattle welfare and cattle insurance programs specific to each region. Finally, this work aligns well with other work in the dairy/climate research community and will support cattle welfare and milk production as well as make poor and rural households more resilient and resistant to adverse climate conditions.

6.2 Limitations of the study

Some of the limitations of the study are that surveying climate perceptions and adaptation strategies among dairy farmers presents practical challenges. This study was impacted by the COVID-19 pandemic and affected the sample size and number of study locations. The dependence on self-reported data introduces potential biases such as recall bias, where respondents may not accurately recall events. Additionally, the use of survey instruments translated into local languages may not fully capture differences in respondents' understanding of climate risks or adaptation measures, despite efforts to ensure linguistic accuracy through back-translation and piloting. Variability in climatic conditions, socioeconomic conditions, and dairy practices across different regions within South India may affect the applicability of findings to other geographic areas.

Lack of availability of historical climate data sets specific to farm level, the data on the uptake of cattle insurance schemes, products, and payout triggers, and longer period data sets for milk production, fodders, and specific climate impacts. In addition, the study results may not be generalised to other areas, as the data were confined to only two districts of southern India. Hence, this prevented the identification and quantification of the specific adaptation strategy for each location.

The study of index-based cattle insurance adoption among dairy farmers using the hypothetical willingness to pay (WTP) has inherent limitations that demand careful consideration. One primary concern is hypothetical bias, where respondents may provide WTP estimates that do not align with their actual behavior in real-world scenarios. Despite efforts to mitigate this bias through clear communication, inconsistencies between stated preferences and actual behaviors may persist due to the abstract nature of hypothetical situations.

Additionally, strategic bias presents a challenge, as respondents may tactically manipulate their responses to influence study outcomes. While incentive-compatible mechanisms like experimental auctions and artifactual markets offer potential solutions to these biases, practical constraints such as logistical complexity and resource limitations in field settings often limit their application.

6.3 Key recommendations

Collectively, findings from this research can be used as a guiding tool to rethink and develop long-term strategies such as optimizing feed and nutrition of cattle, providing timely climate forecasts, implementing improved policies related to vaccination and cattle health services, and establishing institutional support systems to manage inevitable climate change and protect the cattle which would enhance milk production in India and other tropical areas.

To increase dairy farmers' participation in cattle insurance, the information on the benefits of insurance should be better communicated. Policymakers should co-design insurance schemes with an understanding of farmers' needs and other critical factors that influence participation in cattle insurance schemes and their viability.

By adopting strategies such as growing drought-tolerant grasses, fodder preservation, farm diversification, drought-resistant cattle, and buying livestock insurance, dairy farmers can better manage the high-temperature effects and strengthen resilience against the adverse effects of climate variability. Overall better understanding of temperature and rainfall effects on milk production will help in improved management of dairy cattle farming and making the livestock sector sustainable.

Encouraging research and development initiatives through institutional funding and budget provision can help identify vulnerable regions and developing tailored programs for the upliftment of the climate risk impacted dairy farming communities through a participatory approach would address multiple issues.

With the increase in demand for milk products, a prime focus must also be on helping dairy farmers benefit from developing low-cost cost environmentally friendly animal shelters for improved cattle production and wellness. Further development of a strategy for the prevention of production diseases in dairy cattle relies upon the management of nutrition which must be communicated through dairy cooperative channels at each village level throughout the year.

6.4 Recommendations for future work

Research is a continued process and necessary condition to understand different approaches to climate risk adaptation by different social groups in developing economies, which would have wider economic and environmental implications for changes happening in smallholder dairy farming systems. Interactions concerning climate change and cattle production are still not well understood, despite extensive research. In recognition of this fact, recommended future research to focus on :

1) Replicating this study with the historical long-term datasets would provide an opportunity for robust analysis and quantification of extreme climate impacts. Particularly concerning a study on perceptions, would recommend studying changing aspects of the dairy farmers' complex livelihood system to identify adaptation pathways for farmers to cope with climate change. By examining the changing aspects that include economic, social, and environmental factors, research can identify adoption pathways in the context of feed and management practices to mitigate drought impacts, selection of heat-tolerant cattle types, training in pest management, and financial literacy, alongside diversifying income sources.
2) A follow-up study could go beyond investigating the general interest in index-based cattle insurance to quantify dairy farmers' willingness to pay for insurance premiums. This also includes conducting longitudinal studies to track changes in the demand for index-based cattle insurance over time. This could include assessing the factors influencing farmers' decisions to adopt or discontinue insurance and how perceptions of climate risks change.
3) Conducting integrated impact assessments that consider not only climate variability but also socio-economic factors, market dynamics, and policy interventions would help evaluate factors influencing milk production, dairy farm income, and overall livelihoods.
4) To investigate gender-specific factors influencing the demand for index-based cattle insurance. Analyzing differences in insurance uptake, risk perceptions, and access to information and resources between male and female farmers.
5) To improve the applicability of findings on dairy farmers' climate adaptation in regional South India, future research should emphasize longitudinal studies to track adaptation practices in dairy farming over time and across different climatic conditions. Comparative studies across diverse agricultural regions within South India and inclusive sampling strategies that combine diverse dairy farmers would provide insights into region-specific adaptation challenges and strategies. Integrating both quantitative surveys and qualitative methods would

offer a broad understanding of adaptive capacities and contextual factors influencing farmers' adaptation decisions.

The recommended research directions aim to address critical gaps in understanding climate risk adaptation among smallholder dairy farmers in developing countries. Replicating studies with historical datasets would facilitate rigorous analysis of climate impacts, informing evidence-based policy interventions. Investigating farmers' willingness to pay for insurance premiums and conducting longitudinal studies on insurance adoption dynamics is crucial for designing effective risk management strategies for dairy farmers' needs. These research possibilities not only advance scientific knowledge but also offer practical insights for policymakers and stakeholders seeking to enhance the sustainability and resilience of dairy farmers' livelihoods amidst climate risks and climate change.

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