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Understanding Climate Risk and Agricultural Resilience: A Systematic Review of Crop Yield Studies on Rice and Tea in Sri Lanka

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Abstract

Climate change creates an escalating risk to global agriculture. This Systematic Literature Review (SLR) examines the intersection of climate risk and crop yield with the aim of identifying research directions that strengthen agricultural resilience under uncertainty. Key objectives are to map publication trends on climate risk and crop yield studies, to identify the moderating, and control variables influencing yield outcomes. The analysis started with 252 Scopus studies, 174 articles employed for descriptive analysis and 84 studies were examined thematically. The publication trend reflects rising global concern for food security under massive climate change, with a peak in 2024. Geographically, most research focused on Asia and Africa and apart from climatic variables, thematic synthesis showed that crop yields are shaped by moderating variables (education, finance, institutions, environmental context) and control variables (demographics, geography, socio-economic baselines, and climatology). Future research priorities were grouped into five themes: gender equity in climate resilience, ecosystem and biodiversity resilience, climate services and institutional systems, climate risk and governance, and technology and innovation for climate-smart agriculture. The review concludes that while literature provides important insights, it remains fragmented, regionally uneven, and overly technocratic. Addressing these gaps requires integrative and transformational approaches, ecological sustainability, and inclusive governance at the heart of agricultural resilience.

Keywords: Climate risk, Crop yield, Moderating variables, Future research directions

1. Introduction

Climate change has emerged as one of the most crucial global challenges of the twenty-first century which mainly affect ecosystems, human livelihoods and global agricultural systems and food security. Agriculture is particularly sensitive to climate variability because crop growth and productivity is determined by weather conditions like rainfall, temperature, and solar radiation. As a developing country, in Sri Lanka, agriculture remains as a backbone of rural livelihoods. In Sri Lanka the most important crop rice as the staple food of the whole population, while tea is considered

to be a major export commodity, both of which are directly threatened by climatic patterns. Rainfall variabilities and prolonged droughts have been linked to declining yields and increasing production uncertainty. There were many research studies conducted to identify the relationship between climate change and crop yield over the past two decades and that depicts the rapid necessity of understanding and mitigating agricultural risks. According to the preliminary analysis done using Scopus data, there is an increasing trend of publications which addressed the climate risk and crop yield since the early 2000s with a rapid rate of publications in the last ten years. The majority of the studies was based on Asian and African countries where food security is in acute level. Further, bibliometric trends derived from the collected dataset confirm that rainfall and drought are among the most frequently studied climate variables, reflecting their critical role in shaping agricultural outcomes. (Boateng, et al., 2024); (Cooper, et al., 2008)

In Sri Lankan context, several studies have highlighted the climate change vulnerability on rice and tea. (Chandrasiri, et al., 2022) Rice cultivation is especially in dry zone, heavily dependent on seasonal monsoons and shows minor shifts in precipitation. This study focuses specifically on the combined effects of rainfall and drought on rice and tea yields in Sri Lanka. Among studies done to identify the climate change impact on agriculture were on analysing the climatic impact in isolation or emphasizing single crops while leaving a gap of integrated analyses considering and comparing both crops under similar conditions (Al-Maruf, et al., 2021). Further, dataset used for this study also depicted the importance of moderating variables such as irrigation systems and crop variety which moderate the crop yield outcomes. The studies done for irrigation will depict the role of reducing yield variability during drought period while studies on varietal differences emphasize the adoption of drought tolerant rice strains or heat-resistant tea clones. However, there is a lack of empirical studies which are done including moderating factors and there are limited studies explicitly incorporate them alongside climate variables. Thus, this research gap highlights the need for systematic approaches that account not only for direct climate impacts but also for adaptation strategies that farmers already employ or could adopt in the future. Agriculture remains one of the most climate-sensitive sectors, were small changes in rainfall, drought frequency, or extreme weather events can significantly disrupt crop yields. Recent studies highlight that climate variability is a primary driver of yield instability, particularly in staple and export crops such as rice and tea (Gambhir, et al., 2022) The vulnerability of these crops is intensified by limited soil moisture, fluctuating water availability, and high sensitivity to atmospheric conditions such as relative humidity (Dantas, et al., 2020); (Czettritz, et al., 2023)

Among the multiple climate-related stressors, rainfall and drought emerge as dominant variables shaping agricultural outcomes. For example, prolonged droughts reduce water infiltration and soil fertility, while excessive rainfall increases the risk of flooding, crop damage, and soil nutrient loss (Zagre, et al., 2024); (Darjee, et al., 2023). Similarly, extreme weather events such as frost and storms further constrain productivity, reducing the stability of smallholder farming systems (Rahman & Rahman, 2015). These factors together shape the broader climate risk profile that determines crop performance over time. At the same time, moderating conditions such as irrigation infrastructure and crop availability influence the extent to which farmers can adapt. For instance, access to irrigation reduces dependence on erratic rainfall and stabilizes rice production across diverse agroecological zones (An-Vo, et al., 2021) (Balogun, et al., 2022) Likewise, the choice and availability of crops play a crucial role in resilience, enabling farming households to mitigate risks by diversifying production or adapting to more climate-resilient varieties ((Zagre, et al., 2024). There is an acute risk identified for rice and tea. Rice is highly water-dependent, making it vulnerable to rainfall variability, while tea production is closely linked to humidity and temperature stability, where drought and frost significantly affect both yield and quality (Darjee, et al., 2023) ; (Ndegwa, et al., 2020). Despite the growing literature, the evidence remains with studies addressing isolated variables or regional contexts rather than integrating climate, environmental, and moderating variables into a unified analysis of yield outcomes.

Despite the growing status of literature on this field of climate change, key gaps still remain for further exploration such as, In Sri Lankan context, there is a lack of district-level studies that capture localized climate crop interactions, despite strong regional differences in rainfall and temperature patterns. Limited studies employ composite indices to capture the multiple climate variables into a single measure of climate risk, and many studies considered rice and tea are studied separately but lack of comparative analyses assess the two critical crops respondence to climate risk. Therefore, addressing these gaps will not advancing academic knowledge but also for supporting policymakers and practitioners in meeting targeted interventions to safeguard agricultural economy in Sri Lanka. To address these gaps, this study adopts a systematic literature review (SLR) using Scopus-indexed publications to quantitatively synthesize knowledge on climate risk and agricultural yields. Specifically, the objectives are to:

1. Map publication trends on climate risk and crop yield studies focusing on rice and tea.
2. Identify and synthesize the climatic and moderating and control variables affecting yield outcomes.

3. Propose future research directions to strengthen agricultural resilience under increasing climate uncertainty.

By systematically analysing the literature, this review provides an integrated evidence base on how rainfall, drought, soil moisture, water availability, humidity, and extreme weather events influence rice and tea production, and how irrigation and crop availability moderate these impacts in Sri Lanka. Further, apart from identifying and reviewing empirical research on the impacts of rainfall and drought on rice and tea productivity and examining the role of moderating factors such as irrigation availability and crop variety. This review provides a comprehensive foundation for future research through analysing the publication trends, climatic and agronomic variables, methodological approaches. Finally, findings will also be helpful to developing indices regard to climate change in Sri Lankan agricultural context, while offering practical insights in different aspects to enhancing the resilience under climate uncertainty conditions. (Barrios-Perez, et al., 2021); (Baudracco, et al., 2022)

2. Theoretical Background

2.1 Climate Risk Theory

Climate Risk Theory core theoretical framework which expresses how agricultural systems respond to increasing climate uncertainty. Theory conceptualizes agricultural production as inherently exposed to climatic hazards, where risk is determined by the interaction of hazard, exposure, and sensitivity or vulnerability in agricultural context. (Hassna, et al., 2024)Further, risk can be interpreted as an interaction of key components such as,

- Hazard- the likelihood and severity of climate-related events such as droughts, floods, or heatwaves,
- Exposure - the degree to which people, infrastructure, and assets are situated in harm's way, and
- Vulnerability- the susceptibility of exposed systems, shaped by socio-economic, political, and institutional factors

Within this framework, variables such as rainfall, drought, soil moisture, water availability, humidity, and extreme weather events represent the primary sources of agricultural risk. As an application of this theory, this research frames resilience is not ability to withstand shocks, but as the capacity to anticipate, absorb, adapt to, and transform in response to climatic risks. Empirical studies show how these factors contribute to variability in rice and tea yields, with drought and rainfall emerging as the most significant determinants (Zagre, et al., 2024); (Gambhir, et al., 2022)This theory directly underpins the study's independent variables. (Balogun, et al., 2022) illustrates the role of digital infrastructure in reducing risk exposure in peri-urban

agricultural systems while risk identify as a function of both environmental and social systems.

2.2 Vulnerability and Resilience Theory

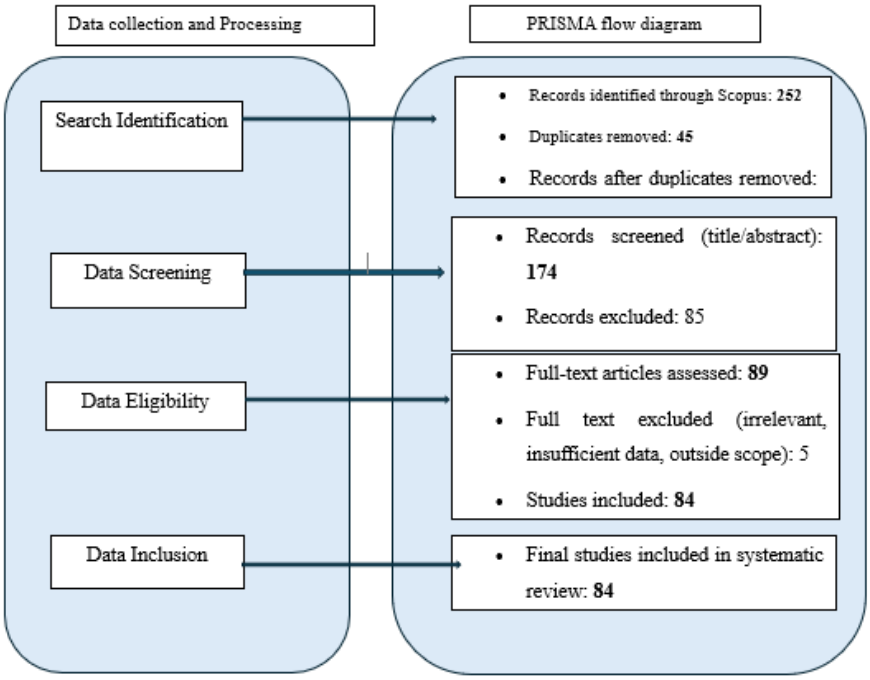
Vulnerability and Resilience Theory explain how agricultural systems respond to climate stressors by examining both their susceptibility and adaptive capacity. Vulnerability theory introduces conditions and processes that make individuals, communities, or systems susceptible to harm from external stressors. Further, this theory does not concern only climate hazards, but also social, economic, political, and institutional factors that constrain the ability to cope or recover. Resilience theory is based on analysis of how farmers and institutions can respond flexibly and proactively to climate impacts in agricultural contexts. Tea and rice farmers are highly vulnerable to extreme weather events, but the availability of irrigation and crop diversification enhances resilience, allowing households to buffer against climatic (Ndegwa, et al., 2020); (An-Vo, et al., 2021) (Balogun, et al., 2022)This theory supports the role of irrigation availability and crop availability as moderating variables that influence the extent of yield losses under climate stress.

2.3 Threshold Theory

Threshold Theory emphasizes that agricultural systems can tolerate climate stress up to certain limits, beyond which yield losses become abrupt and often irreversible. In agricultural context, this theory depicted that, precarious balance between climate hazards, ecosystem services, and human management. For example, prolonged drought or extreme rainfall may push rice yields below sustainable levels, while tea production is highly sensitive to humidity and frost events that exceed adaptive thresholds (Darjee, et al., 2023); (Ramón-Morte, et al., 2024). Further, this risk illustrates this by showing how climate-induced stress threatens the viability of high-value perennial crops, potentially crossing thresholds of viability in certain agro-ecological zones. Further, (Ramón-Morte, et al., 2024); (Rahman & Rahman, 2015) emphasize the necessity of spatial risk assessments in fruit production, as frost damage events may push vulnerable systems beyond their recovery thresholds. Apart from that, this theory highlights anticipation and early warning while detecting early signals of approaching thresholds declining soil fertility, recurrent crop losses, or farmer disinvestment which are essential for designing proactive adaptation strategies (Balogun, et al., 2022) provided insights or digital platforms that integrate climate data with decision-making, enabling early identification of risks before systems collapse. This framework is particularly relevant to identifying tipping points where adaptation strategies fail to protect crop performance.

3. Methodology

The review followed a priori protocol aligned with PRISMA 2020 model, covering identification, screening, eligibility, and inclusion. Further, PRISMA 2020 approach is mainly designed to fulfil three review objectives of identifying trends, determinants and future research designs. The SLR analysis provides results with high quality, minimized distortions, higher validity and replicability etc. (Vaio, et al., 2024). This study is comprised with two main phases; identifying, reading, and interpreting pertinent publications and bibliometric analysis for finalized articles (Vaio, et al., 2024). Further, this study follows Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method, comprised following steps to identify the published papers from repositories, data screening, selecting the eligibility of papers to final study.



As the starting point, database was selected mainly through Scopus. According to (Vaio, et al., 2024), Scopus gives the most comprehensive abstract and citation database to scholars, government institutions and business organizations. Further, review used Scopus data to ensure index standards with peer review quality consistency while enabling the structured metadata export bibliometric mapping and avoid duplication of database. To identify the impact of climate change on crop yield, journal articles published in English for a period over 25 years from 2000-2025 were

analysed. However, the database search revealed that the initial article on crop yield studies on rice and tea was only published in 2004. Further, the Scopus search was conducted using keywords related to three main concepts: climate risk, agricultural productivity, and geographical context.

("climate change" OR "global warming" OR "climatic variability")

AND

("agriculture" OR "agricultural productivity" OR "crop yield" OR "rice" OR "tea")

AND

("Sri Lanka" OR "Global (Mulinde, et al., 2021)")

Apart from that, filters at query follows documents type as journal articles and the selected language was English. The returned records include titles, abstracts, author keywords, citation counts, and access status. When determining the eligibility and screening of data set, study follows the PRISMA model under three steps such as identification, screening the abstract and full text eligibility. The final inclusion was 84 studies. The main study inclusion criteria involve peer reviewed articles which measure or analyze the yield or productivity relating to climate risks including rainfall, drought, temperature etc. The exclusion criteria for identifying datasets involved with non-peer reviewed journals, without yield or productivity outcomes and pure energy, urban, engineering piece lacking agriculture relevance and livestock, fisheries unless yield mechanisms are generalized to crop systems.

Throughout the study, the data extraction framework is aligned with research objectives. For research objective 1 descriptive analysis involves Authors, Title, Year, Source title, DOI, Citations etc. Further, for research objective1 mapping publications trends for the study area includes years of publication, geography analysis and source of title and in multi country basis. The second objective of study is comprised by identifying moderating variables and controlling variables and third objective of identifying future research directions through a thematic analysis. Finally, this study used secondary data analysis of published literature only, citation and data handling standards observed under ethical consideration.

4. Analysis and Discussion

4.1 Publication Trends

4.1.1 Year Based Analysis



Figure 1: Year-Based Analysis of Publication Trends

Figure 1 demonstrates the number of articles published regarding climate change impact on agricultural outcomes in different academic journals during the last two decades. When examining the publication trend of articles capturing the relationship between climate risks and crop yield has expanded substantially over the past 25 years, starting from 2000 the earliest publications in the data set recorded in year 2004 but articles sporadic until 2010. After year 2015, there is a rise of recorded articles coinciding with the post-Paris Agreement period when climate impact on agriculture considers in policy and research. There is remarkable peak of publication recorded in 2024 with 27 publications, and a three-year rolling average confirms a consistent upward trajectory. The most significant articles were published in the years 2024(17%) followed by 2021(14%), 2023 (11%), 2022(10%) and 2020(10%) respectively. In other years, on average 1- 3 papers have been published per year except 2007. This growth reflects the maturing scholarly field that increasingly emphasizes empirical evidence on how rainfall variability, drought frequency, and other climatic shocks shape agricultural productivity, particularly in staple crops such as rice and tea. The trend aligns with the global intention for resilience-focused agriculture under climate uncertainty.

4.1.2 Country Analysis

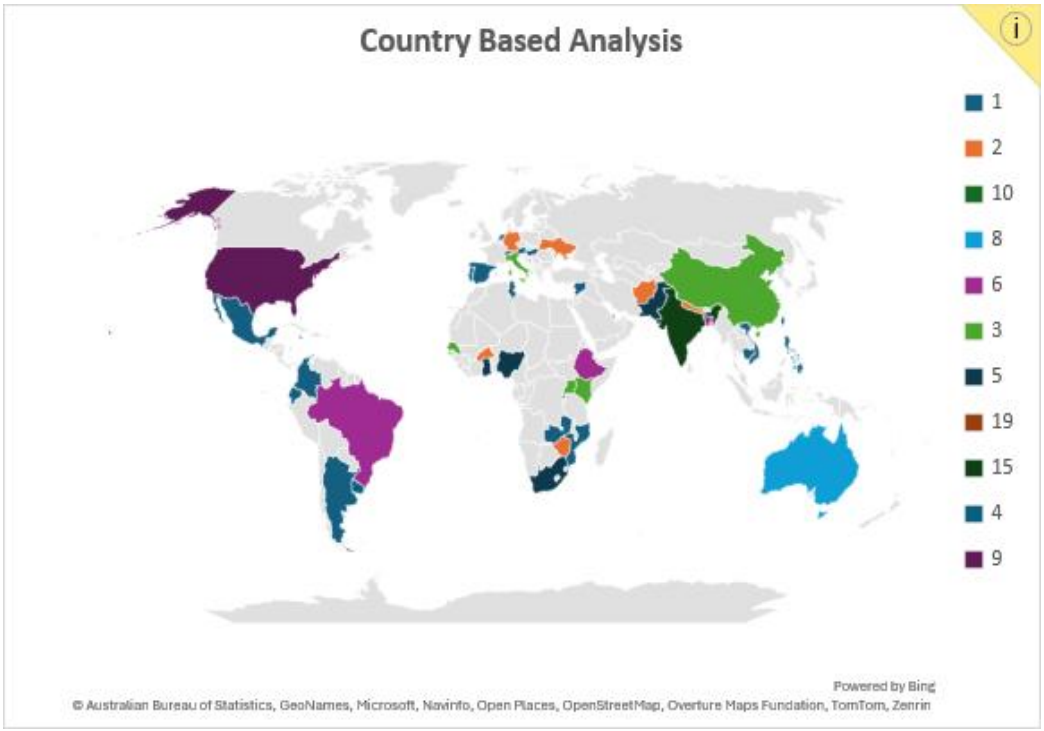


Figure 2: Country Based Analysis of Publications

The geographical distribution of publications depicted the dominant contribution from developed and emerging economies. The majority of the literature's geographical context was United States, leads with 40 publications followed by India (21), United Kingdom (16) Germany (14). China (12), Brazil (10), and several European countries such as Italy (8) and Switzerland (6) also feature prominently. India's strong presence in journal publication, depicts the importance of rice as both a staple food and climate-sensitive crop in South Asia, which is more similar to Sri Lanka. The country's representation from both developing and tropical categories indicates the growing recognition of region-specific climate risks, but the relative underrepresentation of smaller agricultural economies such as Sri Lanka suggests a research gap. This trend demonstrates how knowledge geographically spread while offering methodological approaches transferable to Sri Lanka's rice and tea systems (Aria & Cuccurullo , 2017).

4.1.3 Journal Analysis

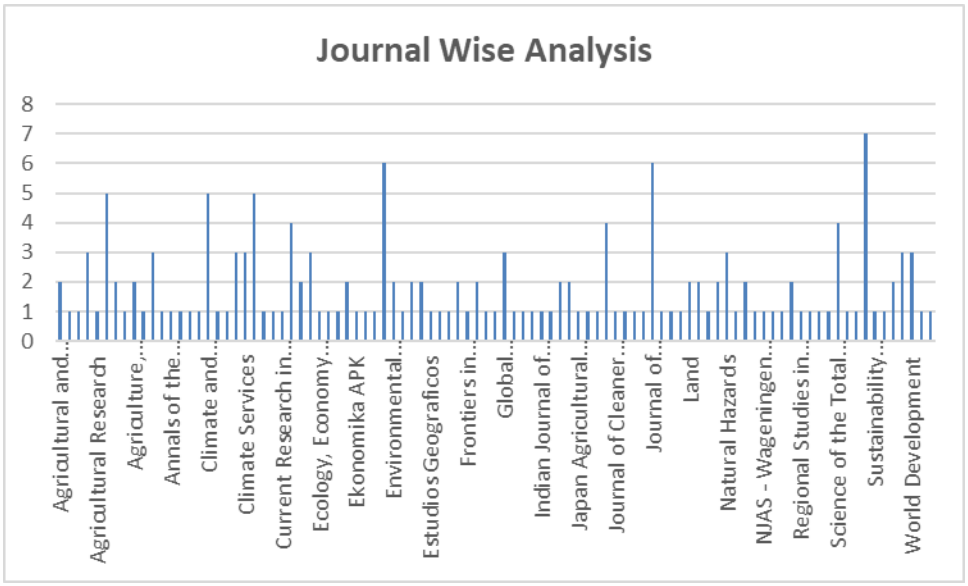


Figure 3: Journal -wise Distribution of Publications

The analysis of the publication data shows that total 174 articles have been published across 95 different journals, which are multi-disciplinary and domain-specific journals. The highest number of publications were published in *Sustainability (Switzerland)* with 7 articles, followed by *Environment, Development and Sustainability and Journal of Environmental Management* with 6 each. The same number of articles were published in *Agricultural Systems, Climate and Development,* and *Climatic Change*. The quantity was recorded as 5 highlighting their prominence in agriculture, environment, and climate-related research. Journals like *Ecological Economics, Journal of Agricultural Economics, and Science of the Total Environment,* which each have 4 publications showed medium level of contribution while journals like *Global Environmental Change, World Development, Weather and Climate Extremes,* and *Climate Risk Management* contributed 3. The majority of journals have one or two publications indicating a broad distribution of research outputs across many outlets, though only a few journals dominate in terms of frequency. Overall, trend among publication journals suggests that sustainability, environmental management, and climate-focused journals are the most influential platforms for disseminating research in this field.

4.2 Thematic Analysis of moderating and control variables

This section provides the major findings of moderating and control variables identified in the reviewed studies. Moderating variables influence the strength or

direction of the relationship between climate risk agricultural crop outcomes While control variables isolate the main effects by accounting for contextual or baseline differences. The identification of variables is very important to understand and estimate the complexity and heterogeneity of climate impact across farming systems.

After selecting the full articles, coding was conducted on extracted variables from each article using inductive analysis and code was counted across articles to determine frequency. Then based on conceptual similarity codes were grouped into broader thematic categories. Further, major themes of moderating variables included education, finance, institutions, and environmental context while control variables were grouped under the themes of demographics, geography, socio-economic baselines, and climatology. Under themes of moderating variables, education can be identified as one of the recurrent moderators. Farmers with proper education background have a capacity of understanding climate forecasting, shift for new farming practices with advanced technology. Therefore, the variable education acts as a moderator variable because it strengthens the relationship between climate change and agricultural practices while determining the speed of climate information and adaptive behavior. Many studies in Ethiopia and Ghana revealed that, literacy and education change farmers' perceptions of climate risk and their willingness to adopt climate services. (Antwi-Agyei, et al., 2018) Further, education plays a role as a cognitive filter shaping how climate information is processed rather than acting as a human capital. (Ndamani & Watanabe, 2017); (Tesfaye, et al., 2018)However, reliance on education can make a deeper inequality as illiterate farmers remain structurally excluded from adaptation opportunities. Finance and market access were also strong moderators, which consists of access to credit, stability of price level which are enabling the implementing adaptive practices, (Aryal, et al., 2018) reflected that adoption of climate-smart agriculture with access to credit and markets were significantly moving to farmers for diversifying crops and adopting improved varieties. Likewise, (Tesfaye, et al., 2018) Ethiopian smallholders expressed willingness to pay for climate services when linked to credit opportunities. Despite those facts, studies show that without supportive institutions, reliance on credit may deepen indebtedness, while volatile markets can discourage diversification finance can cut both ways. Therefore, considered market and finance moderators emphasize the structural dependence of climate adaptation on broader economic systems.

Policy and institutional framework also determine the opportunities and constraints for farmers. Accordingly, (Clay & King, 2019)depicted that, the state-led crop intensification program changes adaptation pathways by enforcing land consolidation and input use while creating uneven benefits such as wealthier farmers receiving positive benefits and poorer farmers facing maladaptation in Rwanda. (Vaughan, et al., 2017)Uruguay's SNIA reflects how strong institutions and cross-agency

coordination enhanced farmers' ability to use climate data for risk management. However, studies emphasize the dual role of institutions such as inclusive and participatory, which enable resilience where top down and enhance the vulnerability. In environmental context, climate variability also can be identified as moderating variables. Rainfall and temperature variability determine the adaptive strategies like crop diversification or conservation agriculture generated positive results. For instance, most Australian and South African studies depicted that diversification reduced the economic risks in moderate rainfall zones but ineffective or even counterproductive in dry zones. (Mubaya, et al., 2012); (Kandulu, et al., 2012) Thus, this concluded that identifying adaptation strategies cannot be viewed in isolation but can be evaluated through climatic context of operating. Control variables were used methodically to account for baseline differences across regions and populations. Geography and agro-ecological zones were the most commonly used controls applied to differentiate the impact among diverse farming systems. For instance, (79) revealed that rainfall variability in Uganda relied on 37 climate stations across multiple zones to capture regional differences and also Cotton zoning in Brazil controlled for soil and water balance conditions to assess regional suitability (70). Thus, these controls ensure that robustness but underscore how climate risks are spatially uneven, making geographic context indispensable in comparative research.

Further, studies have used demographics variables, such as age, gender, and household size as a controlled variable. (65,77,84) Studies across Chile, Brazil, and Africa routinely incorporated demographics to ensure that observed differences in adaptation outcomes were not simply reflections of household composition. However, treating demographic variables as a mere controls risk downplaying their substantive role in determining adaptive capacity, particularly with respect to gendered inequalities. (Antwi-Agyei, et al., 2018) Apart from those variables, there are several variables that can be identified by reviewing past literature such as baseline climatology and socio-economic context. Several econometric models, such as the Africa-wide Ricardian studies, controlled long-term climate averages to distinguish future change impacts from historical variability (84). simulation models in Asia and Central Asia incorporated fixed price assumptions, subsidies, or cotton quotas to isolate climate effects (68,69). Further, A consistent theme across the reviewed studies is that moderating variables largely determines the extent to which climate risks translate into agricultural vulnerability or resilience.

Overall, moderating variables depicted that enabling or constraining factors that shape adaptive responses, with education, finance, and institutions consistently effecting resilience. Control variables, Control variables, are methodological anchors that account for geography, demographics, and baseline climate. However, boundary between moderators and controls is not definite and varies from study to study. For

instance, education is identified as moderate variable but in others it was categorized as demographic control. Thus, this leads to doubt in research about whether certain factors are background characteristics or active determinants of resilience. Further, analysis underscores that adaptation is highly context dependent. Structural inequalities in education, finance, and institutional access repeatedly emerge as the decisive moderators, while geography and demographics are consistently invoked as controls. Ultimately, analysis findings suggested that climate risk is not a single function of climate exposure but determined through how social, economic, and institutional systems mediate that exposure. Thus, future research must go beyond descriptive controls and critically examine how these same factors actively shape vulnerability and adaptation pathways. (Bobojonov & Aw-Hassan , 2014)

4.3 Thematic Analysis for future directions

This analysis is based on addressing third research question of proposed future research directions to strengthen agricultural resilience under increasing climate uncertainty. Based on a systematic review of relevant literature, the key conceptual themes were identified and examined through advanced synthesis and identified five themes are: five core themes have emerged from the data: Gender Equity in Climate Resilience, Ecosystem & Biodiversity Resilience, Climate Services & Institutional Systems, Climate Risk & Governance, and Technology & Innovation for Climate-Smart Agriculture. Each theme reflects a critical domain for future inquiry and strategic investment. The following sections provide a detailed academic discussion of these themes, grounded in evidence from the reviewed literature.

Gender Equity in Climate Resilience, this theme refers to the necessity of addressing gender disparities in climate adaptation strategies, ensuring inclusive and equitable resilience-building approaches. This emphasizes that, both men and women face climate impact and access adaptive resources differently due to entrenched social, cultural, and institutional inequalities. As gender can be identified as critical concept but still under theorized dimension in climate resilience research. Recent studies depict that despite women being disproportionately affected by climate shocks, they are often excluded from access to land, credit, extension services, and decision-making platforms (Balogun, et al., 2022). However, digital innovations still keep bridged this gap and this is illustrated by the study of (Balogun, et al., 2022)while emphasizing the necessity of inclusive digital systems that amplify women's participation in climate governance. Further, (Zagre, et al., 2024)looking for adaptation frameworks that reflect intra-household roles and localized gender norms, but the current frameworks still remain descriptive and focus on vulnerability rather than empowerment. Therefore, future research must address transformative gender approaches, grounded in feminist political ecology, to address structural inequalities

and institutional barriers and for intersectional analyses to understand how gender intersects with class, ethnicity, and geography in shaping adaptation outcomes. (Breuer, et al., 2008)

Ecosystem and biodiversity resilience theme depicted the capacity of ecosystems and biodiversity to buffer agricultural systems against climate extremes and long-term environmental stress, while supporting productivity and sustainability. Agroecosystems mainly depend on biodiversity for services like pollination, pest regulation, and nutrient cycling. Thus, current agricultural models are often based on prioritizing productivity at the expense of ecological resilience and revealed that climate risks threaten the viability of high-value tree crops, calling for biodiversity-focused land-use planning. Therefore, more research moves towards ecosystem-based adaptation strategies which include agroecology, conservation agriculture, and landscape-level interventions. However, this gap of quantifying biodiversity thresholds, valuing ecosystem services economically, and modeling ecological tipping points under combined pressures of climate and land degradation. Therefore, there is a research need of addressing cross-scalar ecological monitoring and scenario-based modeling to guide ecosystem-aligned policy and planning. (Assad, et al., 2013)

Climate Services and Institutional Systems theme depict the way climate information services and institutional structures enable or constrain adaptive decision-making in agriculture. Reliable and accessible climate information is useful in proactive planning however, (An-Vo, et al., 2021)provided that forecasts is insufficient; institutions must ensure usability, credibility, and accessibility of data. The existing systems function in isolation, leading to mismatches between data availability and farmer needs. Thus, future research must focus on co-production of climate services including communities in designing and interpreting information. (Ceu & Gaspar, 2024); (Feng, et al., 2021)

Climate Risk and Governance include laws, policies, institutions, and participatory processes that regulate the management of climate risks in agricultural sectors. Assertation of climate risk, prioritization, and mitigation determined by governance. (Madaki, et al., 2023) (Ramón-Morte, et al., 2024) used GIS-based methods to map frost risk in fruit production; while emphasizing the importance of spatial data for localized governance but isolated data do not depict the resilience as institutional legitimacy, policy coherence, and public accountability are equally important. Therefore, research suggests polycentric governance can enable the adaptive learning while merging with multiple overlapping authorities. Future studies should explore participatory models that include farmers in scenario planning, anticipatory policy

design, and decentralized resource allocation. (Carvalho, et al., 2020); (Donnelly, et al., 2023)

Technology and innovation for Climate-Smart Agriculture is based on deployment of technological innovations such as AI, precision farming, and digital advisory platforms to enhance agricultural adaptation. This reflects the technological solutions that are central to climate-smart agriculture. However, if the access is uneven, and innovation often lacks social embeddedness (An-Vo, et al., 2021) depicted the climate forecasting technologies show potential, adoption is constrained by digital literacy, infrastructural gaps, and institutional disconnects. Therefore, future research must concern Participatory innovation, inclusive design, and local adaptation trials are key to ensuring equitable and context-responsive deployment. Further, long-term evaluations of technological sustainability are still rare in literature and must be prioritized.

Overall, thematic analysis of future research directions reveals the multidimensional aspects of five themes, gender equity, ecosystem resilience, climate services, risk governance, and technological innovation etc. The over-representation of techno-institutional solutions is a crucial reveal of literature, remote sensing, seasonal forecasting, and digital advisory systems are frequently positioned as silver bullets for climate adaptation (An-Vo, et al., 2021). Approaches are technologically deterministic, while strategies rarely interrogate the political, economic, and cultural contexts into which technologies are introduced. (Balogun, et al., 2022)advocate for digital platforms to enhance urban climate governance, the analysis falls short of addressing digital exclusion or the gendered dynamics of access and control. Further, analysis revealed short-term orientation across much of the literature (An-Vo, et al., 2021)depicted the importance of seasonal forecasts but focus on immediate uptake rather than institutional learning or policy evolution over time. Finally, this analysis suggests the necessity of paradigm shift in agricultural resilience research. Future studies must move beyond technical optimism and embrace complex systems' thinking, grounded in equity, participation, and ecological ethics. This is adopting interdisciplinary and co-produced methodologies, investing in longitudinal and place-based research, and fostering inclusive innovation systems that value farmer knowledge alongside scientific expertise.

5. **Conclusion**

This Systematic Literature Review (SLR) provides an intersection of climate risk and agricultural yields in rice and tea systems, guided by three objectives. The first objective mapped publication trends and geographical coverage. The second synthesized climatic, moderating, and control variables influencing yield outcomes, while the third proposed future research directions to strengthen agricultural

resilience. The theoretical background for this review is grounded by three major climate theories, Climate Risk Theory, Vulnerability and Resilience Theory, and Threshold Theory providing a multidimensional framework for interpreting how hazards, vulnerabilities, adaptive capacities, and thresholds shape agricultural systems under uncertainty.

The descriptive analysis was done to address research question 1, which employed 174 articles. Further, analysis on identifying publication trend of articles depicted the notable growth after 2014 and a peak in 2024. This illustrates the rising urgency of food security in climate discourse. Geographically, studies were concentrated in Asia and Africa, reflecting the global significance of rice and tea production in these regions. While addressing research objectives 2 and 3 The thematic synthesis of 84 articles showed that yield outcomes are shaped not only by climatic drivers such as rainfall variability, temperature extremes, and extreme weather events, but also by moderating and control variables. As a result of analysis, Education, finance, institutions, and environmental context emerged as key moderators, while demographics, geography, socio-economic baselines, and climatology function as important control factors. These findings provide insights from Vulnerability and Resilience Theory, while illustrating that risk outcomes depend on both biophysical stressors and systemic inequalities. Further, this is also supported by Threshold Theory, as rice and tea systems often exhibit non-linear responses to stress, with productivity collapsing once ecological or social thresholds are surpassed.

Finally, thematic analysis addressing research objective 3 of identifying future direction on climate and agriculture resilience field concluded that main five priority areas for future research such as: gender equity, ecosystem and biodiversity resilience, climate services and institutional systems, climate risk and governance, and technology and innovation for climate-smart agriculture. Further, identified themes of the analysis emphasize that need for equity-driven, interdisciplinary, and anticipatory approaches to resilience and still many studies remain siloed, privileging technical or ecological dimensions while neglecting social justice and governance. For addressing these gaps, future research must go beyond incremental adaptation toward transformational strategies that integrate ecological sustainability, institutional accountability, and social inclusion. Through this agricultural resilience research and practice can contribute to securing the productivity and livelihoods of rice and tea systems under escalating climate uncertainty.

References

Al-Maruf, A. et al., 2021. Piloting a Weather-Index-Based Crop Insurance System in Bangladesh: Understanding the Challenges of Financial Instruments for Tackling Climate Risks. *Sustainability,* Volume 13(15), p. 8616.

Antwi-Agyei, P., Dougill, A. J., Doku-Marfo, J. & Abaidoo, R. C., 2018. Understanding climate services for enhancing resilient agricultural systems in Anglophone West Africa: The case of Ghana. *Climate Services,* Volume 22.

An-Vo, D.-A.et al., 2021. A framework for assessing the value of seasonal climate forecasting in key agricultural decisions. *Climate Services,* Volume 22.

Aria, M. & Cuccurullo , C., 2017. bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics,* 11(4).

Aryal, J. P. et al., 2018. Adoption of multiple climate-smart agricultural practices in the Gangetic plains of Bihar, India. *International Journal of Climate Change Strategies and Management ,* Volume 10(3).

Assad, E., Martins, S. . C., Beltrão, N. E. d. M. & Pinto, H. . S., 2013. Impacts of climate change on the agricultural zoning of climate risk for cotton cultivation in Brazil. *Pesquisa Agropecuária Brasileira,* Volume 48(1).

Balogun, A.-L.et al., 2022. Digitalization for transformative urbanization, climate change adaptation, and sustainable farming in Africa: trend, opportunities, and challenges. *Journal of Integrative Environmental Sciences ,* 19(1).

Barrios-Perez, C. et al., 2021. How does El Niño Southern Oscillation affect rice-producing environments in central Colombia?. *Agricultural and Forest Meteorology,* Volume 306.

Baudracco, J., Lazzarini, B., Rossler, N. & Gastaldi, L., 2022. Strategies to double milk production per farm in Argentina: Investment, economics and risk analysis. *Agricultural Systems ,* Volume 197(1-2).

Boateng, B. O., Mensah, H., Simpeh, E. K. & Opoku, P., 2024. Tackling local environmental challenges with livelihoods strategies: insights from small-scale farmers in the vulnerable region of Ghana. *International Journal of Agricultural Sustainability,* Volume 22(1).

Bobojonov, I. & Aw-Hassan , A., 2014. Impacts of climate change on farm income security in Central Asia: An integrated modeling approach. *Agriculture, Ecosystems & Environment,* Volume 188.

Breuer, N. E., Cabrera, V. E., Ingram, K. T. & Broad, K., 2008. AgClimate: A case study in participatory decision support system development. *Climate Change,* Volume 87(3).

Carvalho, M. Â. C. C. d., Uliana, E., Silva, D. D. d. & Venâncio Aire, U. R., 2020. Drought Monitoring Based on Remote Sensing in a Grain-Producing Region in the Cerrado–Amazon Transition, Brazil. *Water,* Volume 12(12).

Ceu, M. S. d. & Gaspar, R. M., 2024. A Review on Climate Change, Credit Risk and Agriculture. *Rural Sustainability Research,* Volume 51(346).

Chandrasiri, C., Tsusaka, T. W., Ho, T. D. N. & Zulfiqar, F., 2022. Impacts of climate change on paddy yields in different climatic zones of Sri Lanka: a panel data approach. *Asia-Pacific Journal of Regional Science ,* Volume 7(2).

Clay, N. & King, B., 2019. Smallholders' uneven capacities to adapt to climate change amid Africa's 'green revolution': Case study of Rwanda's crop intensification program. *World Dev..*

Cooper, P., Dimes, J., Rao, K. P. C. & Shapiro, B., 2008. Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: An essential first step in adapting to future climate change?. *Agriculture Ecosystems & Environment,* Volume 126(1-2).

Czettritz, H. J. v., Hosseini-Yekani, S.-A., Schuler, J. & Kersebaum, K. C., 2023. Adapting Cropping Patterns to Climate Change: Risk Management Effectiveness of Diversification and Irrigation in Brandenburg (Germany). *Agriculture,* Volume 13(9).

Dantas, L. G., Santos, C. A. . C. d., Olinda, R. & Brito, J. . I., 2020. Rainfall Prediction in the State of Paraíba, Northeastern Brazil Using Generalized Additive Models. *Water,* Volume 12(9):2478.

Darjee, K. B., Neupane, P. . R. & Köhl, M., 2023. Proactive Adaptation Responses by Vulnerable Communities to Climate Change Impacts. *Sustainability ,* p. 15(14).

Donnelly, D., Fricaudet, M. & Ameli, N., 2023. Accelerating institutional funding of low-carbon investment: The potential for an investment emissions intensity tax. *Ecological Economics.*

Feng, L., Li, Z. & Zhao, Z., 2021. Extreme Climate Shocks and Green Agricultural Development: Evidence from the 2008 Snow Disaster in China. *International Journal of Environmental Research and Public Health,* Volume 18(22).

Gambhir, A., George, M., McJeon, H. & Arnell, N., 2022. Near-term transition and longer-term physical climate risks of greenhouse gas emissions pathways. *Natural Climate Change,* Volume 12(1).

Hassna, B., Namany, S., Alherbawi, M. & Elomri, A., 2024. Multi-Objective Optimization for Food Availability under Economic and Environmental Risk Constraints. *Sustainability,* Volume 16(11).

Kandulu, J., Bryan, B. A., King, D. & Connor, J. D., 2012. Mitigating economic risk from climate variability in rain-fed agriculture through enterprise mix diversification. *Ecological Economics,* Volume 79.

Madaki, M. Y., Kaechele, H. & Bavorova, M., 2023. Agricultural insurance as a climate risk adaptation strategy in developing countries: a case of Nigeria. *Climate Policy,* Volume 23(2).

Mubaya, C. P., Njuki, J., Mugabe, F. & Nanja, D., 2012. Climate variability and change or multiple stressors? Farmer perceptions regarding threats to livelihoods in Zimbabwe and Zambia. *Journal of Environmental Management.*

Mulinde, C., Mwanjalolo, M. J. G., Twinomuhangi, R. & Mfitumukiza, D., 2021. Perceived climate risks and adaptation drivers in diverse coffee landscapes of Uganda. *NJAS - Wageningen Journal of Life Sciences,* Volume 88(1).

Ndamani, F. & Watanabe, T., 2017. Determinants of Farmers' Climate Risk Perceptions in Agriculture—A Rural Ghana Perspective. *Water,* Volume 9(3).

Ndegwa, M. K., Shee, A., Turvey, C. G. & You, L., 2020. Uptake of insurance-embedded credit in presence of credit rationing: evidence from a randomized controlled trial in Kenya. *Agricultural Finance Review,* Volume 80(5).

Rahman, M. A. & Rahman, S., 2015. Natural and traditional defense Mechanisms to reduce climate Risks in coastal zones of Bangladesh. *Weather and Climate Extremes.*

Ramón-Morte, A., Moreno, D. P. & Moltó-Mantero, E., 2024. Mapping frost risk in fruit trees using GIS-based analysis: a case study in the province of Alicante (Spain). *International Review of Geographical Information Science and Technology,* Issue 33.

Tesfaye, A., Hansen, J. W., Kassie, G. . T. & Radeny, M., 2018. *Estimating the economic value of climate services for strengthening resilience of smallholder farmers to climate risks in Ethiopia: A choice experiment approach,* s.l.: s.n.

Vaio, A. D. et al., 2024. Digitalization and artificial knowledge for accountability in SCM: a systematic literature review. *Journal of Enterprise Information Management,* Volume 37(2).

Vaughan, C. et al., 2017. Creating an enabling environment for investment in climate services: The case of Uruguay's National Agricultural Information System. *Climate Services,* Volume 8.

Zagre, I. et al., 2024. Climate change adaptation strategies among smallholder farmers in Senegal's semi-arid zone: role of socio-economic factors and institutional supports. *Frontiers,* Volume 6.