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Assessing the Influence of Climate Services and Climate Change Adaptation Strategies on Smallholder Agriculture: A Systematic Literature Review

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ABSTRACT

Climate services and climate change adaptation practices are increasingly recognized as essential for supporting smallholder farmers. Despite numerous studies on climate impacts and adaptation strategies, limited systematic evidence exists on how climate services and adaptation interventions influence farming practices across regions. This study addresses the gap through a systematic literature review of Scopus-indexed publications over the past decade. Using the PRISMA approach, 1981 articles were screened, with 31 meeting the eligibility criteria. Of these, 23 focused on adaptation interventions and 8 on climate services. Geographically, 30 studies were concentrated in tropical regions Africa (n =16) and in Asia (n=14), while one study was outside the tropics. Findings show that climate information strongly supports the adoption of adaptation strategies (>60%), especially in technological interventions such as Climate-Smart Agriculture, ecosystem management, irrigation, and climate risk reduction. In terms of service delivery, basic climate service provision demonstrated greater effectiveness (80%) compared to advisory-based agricultural services (40%). Socio-demographic factors, particularly education and age, consistently influenced farmers' decision-making in adopting both climate services and adaptation practices. Overall, this review highlights the need for more integrated approaches that explicitly connect climate services with adaptation interventions. Strengthening these linkages is especially critical in tropical regions, where smallholder farmers remain highly vulnerable to climate variability and long-term climate change risks.

KEYWORDS
climate risk, decision making, intervention model, PRISMA, socio-demography

1. INTRODUCTION

Climate change has accelerated in recent decades, with its impacts increasingly amplified by extreme events (Cook et al., 2020; Gao et al., 2024; Supharatid and Nafung, 2021), significantly undermine agricultural productivity (Aadhar and Mishra, 2020). The impacts are highly heterogeneous across time and space and are compounded by large uncertainties in future projections, underscoring the urgent need for localized impact assessments and targeted adaptation strategies (Arifah et al., 2023; Iizumi et al., 2014). In this context, sustainable farming practices and stronger adaptive capacities are increasingly promoted, particularly for smallholder farmers who remain highly vulnerable to climate variability (Muhie, 2022; Sarkar et al., 2020).

Smallholders, who typically manage less than 10 hectares and rely heavily on family labor, play a central role in food security but face persistent structural barriers, including high input costs, limited access to credit, and restricted availability of climate information (Mossie and Chanie, 2024). Although they often perceive climate change and adopt local adaptation strategies, their responses are constrained by weak institutional support and insufficient extension services. Reliable, context-specific climate information is therefore critical for strengthening their adaptive capacity.

One of the most pressing risks for smallholders is water availability. A key example is the false start of the rainy season, when early rainfall is followed by a dry spell, often causing premature planting (Marjuki et al., 2016). In addition, water shortages during critical growth stages reduce grain yields and are frequently accompanied by drought symptoms such as leaf rolling, scorching, stunted growth, and empty grains, which further depress productivity (Wu et al., 2011).

Managing these risks is challenging because available climate information often lacks the resolution, accuracy, and usability needed for farm-level decisions. Global Climate Models (GCMs), while indispensable for long-term climate assessment, have coarse spatial resolution and inherent biases that limit their operational utility (Hidayat and Taufik, 2025; Kim et al., 2020). As a result, Seasonal Climate Forecasts (SCFs) and Sub-seasonal to Seasonal (S2S) forecasts have gained prominence for their potential to support short-term agricultural planning, such as estimating planting dates, anticipating drought severity, or optimizing input allocation (Amegnaglo et al., 2017).

However, the availability of forecasts alone does not guarantee their effective use. Barriers remain in how climate information is delivered, interpreted, and adapted to local contexts (Bruno Soares et al., 2018; Tall et al., 2018). While recommendations have been made to strengthen SCF systems, leverage historical and gridded datasets, and promote community-based and multi-stakeholder approaches, there is still limited evidence of their real-world effectiveness in smallholder contexts (Hansen et al., 2019). In particular, the connection between climate services and adaptive agricultural decision making remains poorly understood, especially in diverse and high-risk farming systems such as those in Indonesia.

This systematic literature review therefore aims to identify global research gaps and synthesize the key factors that influence the effectiveness of climate services and adaptation strategies for smallholder farmers. Using a climate risk framework that considers hazards, exposure, and adaptive capacity, the review seeks to inform the development of more actionable, context-specific climate services to strengthen smallholder resilience in Indonesia and beyond.

2. MATERIALS AND METHODS

2.1 Systematic Literature Review Using PRISMA

This study employed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to conduct a systematic and transparent literature review. The PRISMA methodology guided the identification, screening, and selection of relevant studies to address the research objectives. A structured research question was formulated to focus the review process, ensuring a comprehensive evaluation of the influence of climate services and climate change adaptation strategies on smallholder agriculture. The primary research question was: To what extent do climate service interventions and adaptation strategies impact smallholder farming practices? The secondary questions included:

1. How do climate services influence the selection of intervention types in smallholder farming practices?
2. How does climate information affect the determination of adaptation strategies in smallholder agriculture?
3. Within a climate risk framework, what are the key factors influencing the provision of climate services and the development of climate change adaptation strategies for smallholder agriculture?

These questions served as the foundation for defining the scope of the literature search and the review process.

2.2 Literature Search Strategy

The literature search was conducted using the Scopus database (https://www.scopus.com/ search/), targeting peer-reviewed articles published between 2012 and 2021. A combination of keywords and Boolean operators was used to identify relevant studies. The search string was: ("climate service*" OR "climate smart service*" OR "climate smart agriculture*" OR "smallholder farm*" OR "extension*" OR "rainfed field") AND ("climate innovation service*" OR "effective* climate" OR "climate uptake" OR "climate applicat*" OR "climate deliver*" OR "climate intervent*" OR "climate aware*" OR "effective* advisory" OR "climate communicate*" OR "climate adapt*" OR "climate monitor*" OR "knowledge" OR "interpret*" OR "impact*" OR "forecast*" OR "tailor*" OR "integrate*" OR "influence*" OR "efficient*" OR "rainfed*" OR "community*" OR "predict*") AND ("harvest*" OR "yield productivity*"). This search yielded a total of 1,981 articles, which were subsequently subjected to a rigorous screening process based on predefined inclusion and exclusion criteria.

The inclusion and exclusion criteria were established to ensure the selection of studies relevant to the research objectives. These criteria were based on the PICOS (Population, Intervention, Comparator, Outcomes, Study Design) framework, as outlined in Table 1.

2.3 Screening and Selection Process

The screening process was conducted in multiple stages to ensure the selection of high-quality, relevant studies. The process is summarized as follows:

Table 1. Inclusion and Exclusion Criteria for Literature Review

PICOS	Inclusion Criteria	Exclusion Criteria
Population	Smallholder farmers and communities	Large-scale agricultural enterprises
Intervention	Climate service interventions and climate change adaptation strategies	Non-climate-related interventions and strategies
Comparator	None	
Outcomes	Harvest, productivity, and other determining factors	Assessments of non-climate-related interventions and adaptations
Study Design	Studies assessing research activities related to methodologies, climate service intervention models, and climate adaptation adoption in agriculture	

1. Identification: A total of 1,981 articles were retrieved from the Scopus database. After removing 721 duplicates, 1,260 unique articles remained for further screening.
2. Screening: The titles and abstracts of the 1,260 articles were reviewed for relevance to the research questions, resulting in 83 articles being selected for full-text review.
3. Eligibility: The full texts of the 83 articles were assessed based on the inclusion criteria, focusing on studies that: (1) targeted small-holder farmers or communities; (2) employed quantitative methods; (3) implemented climate services or adaptation strategies with impacts on agricultural activities; and (4) reported outcomes related to production or productivity. This step resulted in 31 articles being selected for in-depth analysis.
4. Data Extraction: Data from the 31 selected articles were extracted, including author(s), publication year, methodology, climate variables, adaptation strategies, intervention models, and significant findings or impacts of climate services and adaptation strategies. The extracted data were organized to map research trends, geographic distribution, and outcomes.

2.4 Data Analysis

The extracted data were analyzed to identify patterns, trends, and gaps in the literature. The analysis focused on:

1. Mapping the evolution of research on climate services and adaptation strategies.
2. Assessing the geographic distribution of studies, with a focus on tropical regions and developing countries.
3. Evaluating the impact of climate services and adaptation strategies on smallholder agri-culture, including the influence of socio-demographic and biophysical factors.
4. Converting heterogeneous outcome units (e.g., yield, productivity) into standardized metrics, such as percentages or correlation coefficients (+/-), to facilitate comparison across studies.

The analysis was guided by a climate risk framework, considering hazards (e.g., extreme climate events), exposure (e.g., geographic and climatic conditions), and adaptive capacity (e.g., access to climate information and technology). This framework enabled the identification of key factors influencing the effectiveness of climate services and adaptation strategies in smallholder agriculture.

3. RESULTS AND DISCUSSIONS

3.1 Research characteristics and trends

The demand for climate information and adapt-ation strategies has risen significantly over the past decade, as reflected by the sharp increase in related studies between 2012 and 2021 (Figure 1, right panel). This trend underscores the growing emphasis on science-based and user-oriented climate services designed to strengthen resilience to climate variability and change (Brasseur and Gallardo, 2016). The temporal rise also suggests a shift from early exploratory work towards a more consolidated re-search domain, aligning with global policy frameworks that call for the integration of climate information into adaptation planning and decision making.

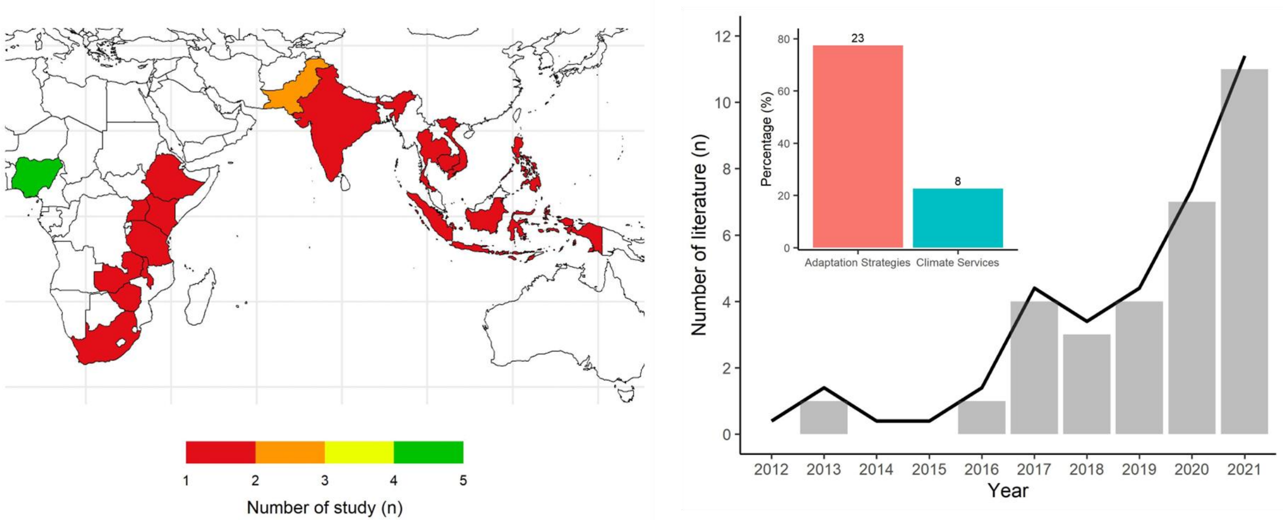

Figure 1. Spatial distribution and temporal trends of studies on climate information services and adaptation strategies (2012–2021). Research is concentrated in tropical Asia and Africa, with limited representation in other regions. Adaptation strategies dominate the literature, while climate services remain underexplored.

The spatial distribution of studies (Figure 1, left panel) reveals a pronounced geographical bias, with the majority of research concentrated in tropical regions of Asia and Africa. These regions are characterized by high exposure to climate hazards, limited adaptive capacity, and economies heavily reliant on smallholder agriculture, thereby making them focal points for climate adaptation research. Countries such as Nigeria, India, and Ethiopia appear as key hotspots of study activity, whereas large parts of South America and Central Asia remain under-represented. Strikingly, only one study was identified in Europe, reinforcing that scholarly attention is directed primarily towards the Global South, where climate vulnerability and risks to agricultural livelihoods are most acute (Prasanna et al., 2021; Wilson and VanBuren, 2022). While this concentration is understandable, it also highlights a gap in comparative research across diverse socio-economic contexts, particularly in developed regions where climate services may already be embedded but remain less documented in academic literature.

3.2 Research Themes and Focus

This review explores how climate services and climate information are integrated into adaptation strategies within smallholder farming systems. Based on 31 globally sourced studies, research activities are categorized into four themes: (1) exploring the link between climate information and adaptation strategies or pattern recognition, (2) evaluating the impact of climate information on adaptation, (3) comparing climate service and adaptation interventions, and (4) developing models for climate services and adaptation strategies (Figure 2).

Most studies addressing adaptation strategies focused on the early "understanding" phase (14 studies), followed by the "practice" phase (9 studies), and only one addressed framework development. This suggests that many smallholder farmers still lack scientific understanding of climate change impacts on the agricultural production chain.

Research on climate services tended to focus on the advanced application phase (4 studies), compared to fewer in the advisory (1 study) and basic (2 studies) service levels. This indicates that smallholders require more customized services aligned with their agri-cultural decision-making processes. For instance, SCF (Seasonal Climate Forecasts) can support irrigation management in Climate-Smart Agriculture (Mabhaudhi et al., 2025).

Crops most frequently studied included rice, maize, wheat, vegetables, and livestock. This aligns with global food consumption trends, where rice remains a staple for nearly half the world's population, particularly in Asia, Latin America, and Africa. Asia alone produces nearly 90% of global rice output (Muthayya et al., 2014).

3.3 Influence of Climate Information on Interventions

Thirteen studies directly examined the role of climate information in shaping both climate service interventions and adaptation strategies (Figure 3). The most widely applied parameters were basic climatic variables rainfall, temperature, humidity, and seasonal onset, which were reported in 80% of the studies as highly influential. Their predominance underscores the centrality of these variables in agricultural planning, yet it also reflects a reliance on relatively generic indicators.

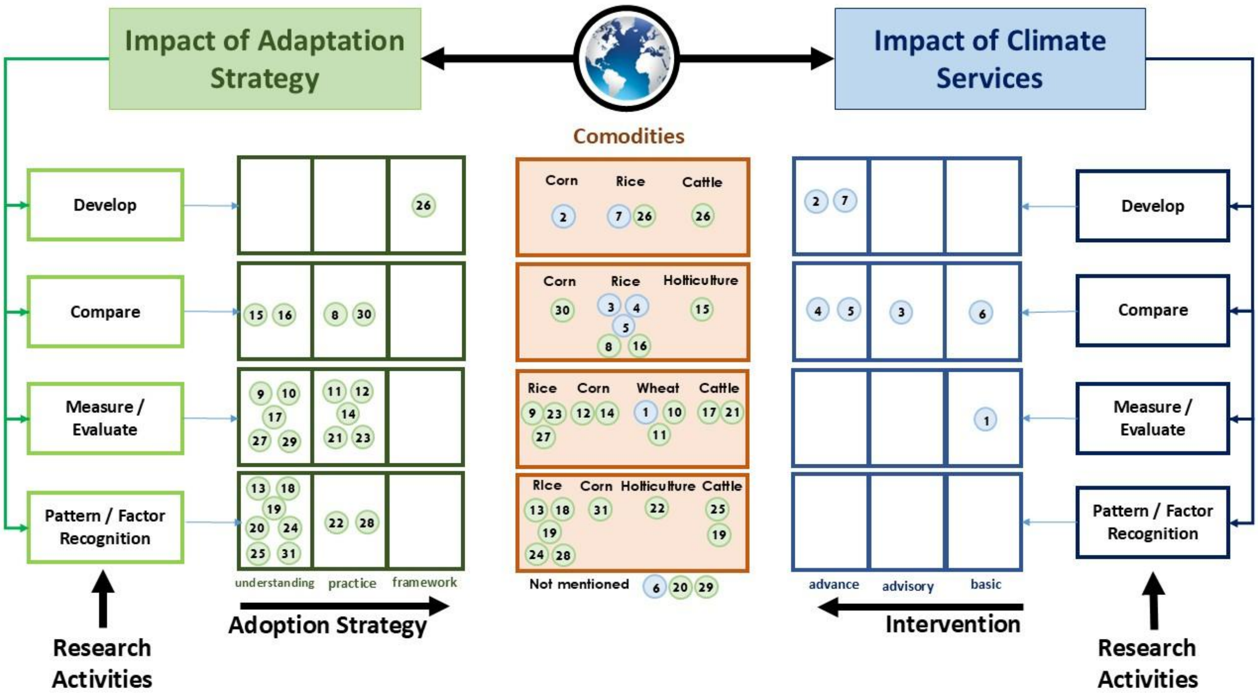

Figure 2. Geographic distribution of studies examining the influence of climate services on adaptation strategies. Numbers in circles correspond to the order of cited literature listed in Annex A1.

While these parameters provide essential baselines, greater benefits are expected from more tailored services that integrate climate information with crop- and location-specific requirements. For example, the integration of seasonal climate forecasts with crop phenology to project wheat yields in Spain demonstrated the added value of customized climate services for enhancing decision-making in agriculture (Sánchez-García et al., 2022).

Agro-advisory services showed moderate influence (40%), yet they emerged as particularly effective under normal or below-normal climate conditions by guiding critical farm management decisions such as crop diversification, input allocation, and harvest scheduling (Ramaraj et al., 2023). These findings suggest that advisory tools, while not universally adopted, play a pivotal role in enabling proactive adjustments and reducing risk exposure in routine agricultural practices. In contrast, adaptation strategies were more directly driven by climate extremes, particularly erratic rainfall and drought events, which shaped decisions on intervention types. More than 60% of adaptation measures were influenced by climate information, with significant emphasis on agroecosystem management, local knowledge integration, irrigation practices, and climate-smart agriculture.

Taken together, these insights highlight that climate information is critical not only at the onset of the production cycle but also throughout its entire duration, shaping both immediate decisions and long-term adaptive planning. To maximize its impact, climate information must be aligned with farmers' knowledge systems, accessible at the appropriate temporal and spatial scales, and delivered in forms that are actionable across different stages of agricultural production. Such alignment ensures that scientific outputs translate effectively into farm-level adaptation strategies, thereby bridging the gap between climate science and practical resilience-building.

3.4 Socio-Economic Implications

This review confirms that most studies focus on adaptation strategies rather than the direct implementation of climate services in smallholder agriculture. In low- and middle-income countries, the primary challenge remains building awareness and understanding of climate risks and adaptation options (Mohamed Shaffril et al., 2024). Studies assessing the impacts of adaptation strategies outnumber those evaluating climate service effectiveness, particularly in tropical and developing regions. This reflects the broader trend of adaptation technology adoption occurring predominantly in low- and middle-income settings (Elsen and Tietze, 2024).

Climate service provision remains at the basic information level in many developing countries, and barriers persist in terms of farmers' ability to interpret and act on climate data (Mohamed Shaffril et al., 2024). To better understand how climate information supports agricultural decision-making, this review assessed socio-demographic and biophysical characteristics of

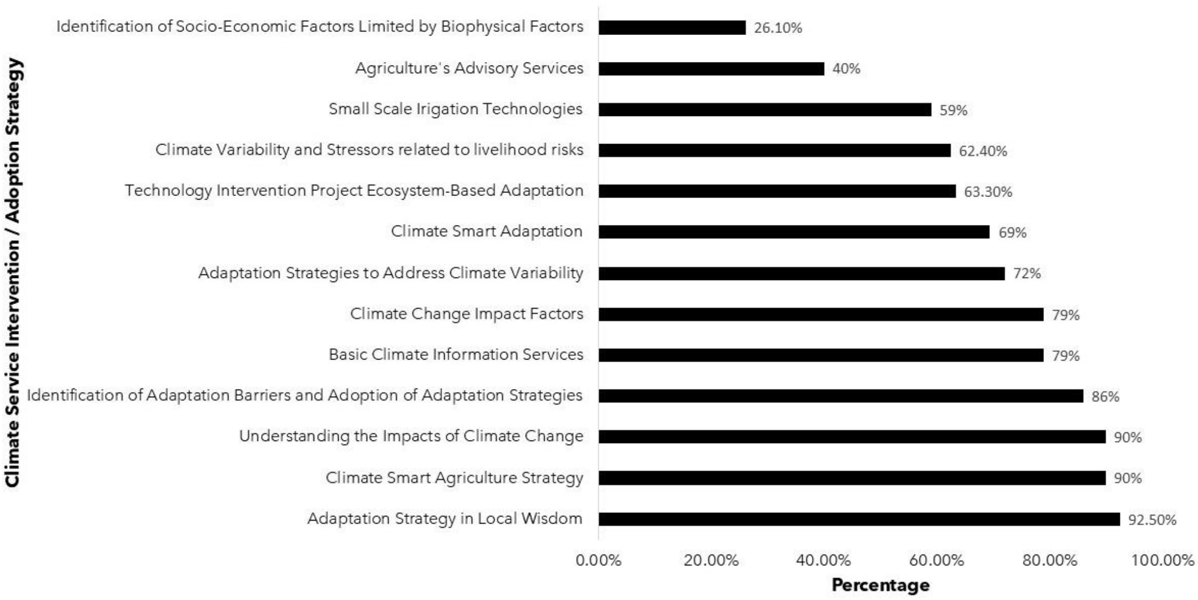

Figure 3. Influence of climate information on climate service interventions and adoption of climate adaptation strategies.

smallholders (see Table A2).

Education and age were the most significant factors, enhancing farmers' capacity to comprehend climate risks and choose suitable interventions. Other factors such as gender and income also shaped climate service uptake and adaptation strategies. Enhancing gender-sensitive adaptation through better access to information, skills, and resources can improve adoption rates (Chaudhary et al., 2025). Household size influenced awareness and the adoption of modern agricultural practices, while farming experience was linked to better land monitoring and use of smart agriculture.

Combining technical training with social empowerment for climate information users can lead to more responsive and effective climate services (del Pozo et al., 2024). Overall, climate information contributes significantly to the socio-economic performance of smallholder farmers, supporting long-term visions for local climate resilience and sustainable development (Swart et al., 2021). In this context, climate-informed agricultural practices are vital to achieving both food self-sufficiency and improved farmer welfare.

3.5 Analysis of research context gaps

Climate change has intensified agricultural climate risks, particularly for smallholder farmers. These risks are structured within three components of the climate risk framework: hazards (e.g., extreme events), vulnerability (e.g., socio-economic systems and adaptive capacity), and exposure (e.g., physical and geographical conditions) (Reisinger et al., 2020). Figure 5 summarizes the frequency of studies (conducted or not) related to climate services and adaptation strategies, mapped to these risk components.

Hazard-related gaps include limited research on increasing extreme climate events (impact drivers) and early warning system implementation. Capacity gaps include underutilization of seasonal climate models (SCF), decision-support tools, and crop-specific applications. Exposure gaps refer to a lack of studies assessing climate event impacts across agro-climatic zones.

Of the reviewed studies, 67.7% were conducted in tropical regions. Adaptation-focused research was more common (77.4%) than studies on climate service provision (22.6%). Within adaptation, most studies explored extreme climate impacts on agriculture (80.6%) and recommended intervention strategies (71.0%). Historical climate data were also frequently analyzed (61.3%) to understand changes in impact drivers and their implications for smallholders' agricultural and economic outcomes.

However, only a small portion of studies (9.7%) employed seasonal climate models, and just 16.1% simulated future climate extremes for risk analysis, early warning, or intervention planning. Similarly, research on the impacts of climate change on staple food security remains limited, despite tropical regions being the world's primary food producers.

Only 54.8% of studies addressed this theme, future research should prioritize climate service development for rice a key staple crop using seasonal climate simulations to assess impacts on productivity, which

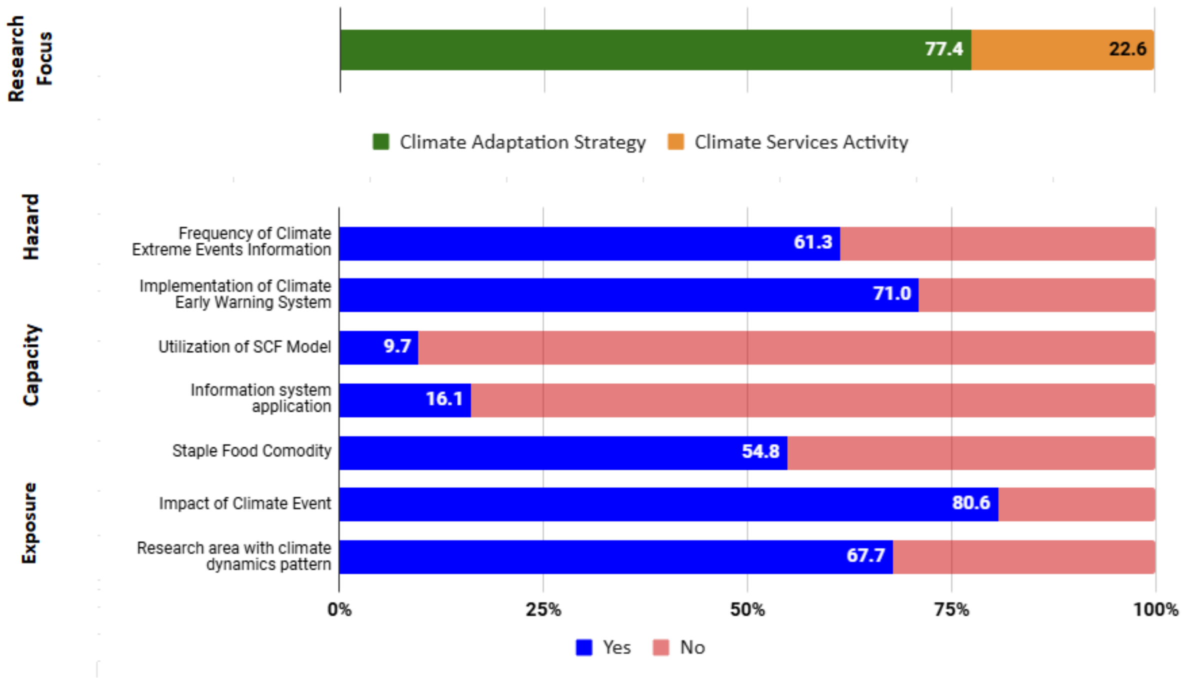

Figure 5. Frequency of research addressing (or not addressing) key climate service and adaptation strategy components based on the climate risk framework (%).

serves as a proxy for smallholder economic well-being. This approach is essential for projecting future climate impacts and tailoring localized intervention strategies in Indonesia.

4. CONCLUSIONS

This systematic review reveals that research on climate services and adaptation strategies for smallholder agriculture is predominantly concentrated in tropical regions—specifically Africa (16 studies), South Asia (7), Southeast Asia (7). These areas face high climate risks due to frequent exposure to extreme events, socio-economic vulnerability, and limited adaptive capacity within conventional agricultural systems. Most research was conducted in low- and middle-income countries, often under project-based funding, while advanced economies remain underrepresented.

Moreover, Small-scale farmers have significant differences in their perceptions of climate change across Indonesia's various climatic regions, with these perceptions proven to align with scientific data. Farmers adopt a variety of adaptation strategies tailored to local conditions, including crop diversification, land maintenance, and livelihood diversification. The availability of reliable and timely information on weather and agricultural parameters helps farmers make more informed decisions for pre-indicator in the adaptation process. However, the choice of these strategies is heavily influenced by gender, access to government support, and the availability of information (Andrista et al, 2025).

There is a clear upward trend in studies on climate services and adaptation strategies over the past decade. Research has gradually shifted from general information provision to more customized, location- and user-specific services (co-design). Similarly, adaptation strategy research has evolved beyond policy discussions toward context-specific implementation at the local levelAcross the reviewed literature, adaptation-focused research accounted for 81%, while studies on climate service provision comprised only 19%. Research activities were categorized into four thematic areas: development, exploration, comparison, and evaluation of climate service and adaptation models. These thematic areas offer a foundation for future research to strengthen both service delivery and strategic adaptation planning. Climate services play a significant role in influencing farmers' decision-making, with basic services having a greater influence than advisory-based services. Socio-demographic factors such as education and age are the most dominant variables influencing farmers' decisions to choose interventions. The research gaps regarding the utilization of seasonal climate models (SCF) and decision-support tools, as well as a lack of studies assessing the impact of climate extremes on staple food commodities. Therefore, future research needs to focus on developing climate services tailored to small-scale farmers in tropical regions, prioritizing rice as a target commodity, and integrating high-resolution seasonal forecasts with crop growth models to predict climate risks.

These research directions constitute the state-of-the-art pathway for climate service development in tropical agriculture. Integrating high-resolution seasonal forecasts with crop modeling enables the prediction of climate risks across crop phenological stages. This provides a practical foundation for selecting appropriate adaptation interventions to enhance food security and agricultural productivity, particularly in vulnerable regions like Indonesia.

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ANNEX

Table A1. List of cited literature. The numbering corresponds to the references used in Figures and Annexes.

No	doi
1	https://doi.org/10.3390/su13031308
2	https://doi.org/10.1016/j.cliser.2019.100106
3	https://doi.org/10.33687/ijae.008.03.3377
4	https://doi.org/10.1080/14735903.2016.1174811
5	https://doi.org/10.1016/j.worlddev.2017.04.028
6	http://arccarticles.s3.amazonaws.com/webArticle/articles/A47311.pdf
7	http://dx.doi.org/10.1088/1755-1315/335/1/012022
8	https://doi.org/10.1016/j.jenvman.2020.111407
9	https://doi.org/10.1007/s10708-019-10077-3
10	https://doi.org/10.1590/0103-8478cr20201109
11	https://doi.org/10.1002/agj2.20900
12	https://doi.org/10.1016/j.worlddev.2021.105618
13	https://doi.org/10.3390/atmos12111503
14	https://doi.org/10.1016/S2095-3119(20)63417-7
15	https://doi.org/10.18697/ajfand.104.19770
16	https://doi.org/10.1007/s10584-021-03128-7
17	https://doi.org/10.1016/j.jaridenv.2021.104485
18	https://doi.org/10.1007/s00267-020-01345-x
19	https://doi.org/10.3390/agriculture10090410
20	http://dx.doi.org/10.46469/mq.2020.61.2.5
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Table A2. Socio-Economic Influences on Climate Service Interventions and Adaptation Strategies.

		Climate Services Interventions		**Adaptation strategy**								
Determinant factor	**Significant variable**	Basic information	Land monitoring development	Climate impact	Awareness	Smart practice	Smart strategy	Local vs Modern Knowledge	Climate Stressor	Perception of Indicators	Adaptive Capacity (SNA)	Drivers of Perception
Socio-demographic	Education	+	+	+	+	+	+	+	+	+	+	+
	Age	+	+	+	+	+	+	+	-	+	+	+
	Martial status							+		+		
	Gender	+			+	+		+	+	+		-
	Occupation	+										
Biophysical	Income	+	+		+				+		+	
	Household size				+		+	+	+	+	+	
	Farming experience		+	+	+	+				+		
	Irrigation area	+										
	Agricultural output	+					+					
	Waqf land and cultivated area			+								
	Water source		+				+					