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**Exploring the potential and limitations of Weather-Water-
Climate-Services for strengthening climate change adaptation
and disaster risk reduction in northwestern Cambodia**

Policy thesis

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Executive summary

Cambodia is among the most climate-vulnerable countries in Southeast Asia, highly exposed to floods, droughts, and increasing temperature extremes. These risks are especially pronounced in northwestern Cambodia, where high poverty levels and limited adaptive capacity intersect. While national policies increasingly emphasise climate change adaptation (CCA) and disaster risk reduction (DRR), their translation into effective, locally specific action remains limited. In this context, Weather-Water-Climate-Services (WWCS) are promoted as tools to support climate resilience, yet their practical application in Cambodian agriculture remains underexplored, and weather and climate information are not translated into actionable guidance for farmers, leaving the “last-mile” gap unaddressed. This policy thesis aims to assess the current availability and use of weather and climate information in the agricultural sector of northwestern Cambodia, explore the potential of different WWCS to strengthen CCA and DRR, and identify social, cultural, institutional, economic, and technical factors that enable or constrain their effective implementation.

The study adopts an exploratory qualitative approach, combining a comparative case study, key informant interviews, focus group discussions, and a desk review from an NGO perspective. By acknowledging the success of the Cambodia’s national multi-hazard early warning system, EWS1294, it investigates the drivers and barriers of a conceptual WWCS, designed to provide tailored, farm-level agrometeorological advice.

Findings indicate that smallholder farmers in northwestern Cambodia generally have access to basic weather information, mainly through social media and smartphone-based applications, but perceive this information as insufficiently localised. There is a clear demand for simple, timely, and crop-specific advisory services, particularly related to fertiliser and pest management, planting and harvesting decisions, and improved water-use efficiency. A tailored WWCS could therefore support behavioural change and reduce climate-related production risks, while complementing existing DRR-focused systems. At the same time, substantial barriers persist, including low digital literacy, mistrust of digital services, strong reliance on traditional practices, limited willingness to pay, and institutional fragmentation. The experience of EWS1294 highlights the importance of simplicity, inclusive design, multi-channel dissemination, and strong collaboration between NGOs and public institutions as key enabling factors.

The thesis concludes that WWCS can meaningfully strengthen climate resilience among smallholder farmers in northwestern Cambodia if they are user-centred, context-specific, and embedded within trusted extension and governance structures. Rather than being developed as stand-alone technical solutions, WWCS should be integrated horizontally with existing public systems and agricultural extension services, emphasising co-production, incremental piloting and scaling, and two-way communication. Aligning WWCS development with national CCA and DRR strategies is essential to ensure institutional ownership, sustainability, and long-term impact.

Keywords: climate change adaptation, climate change resilience, disaster risk reduction, climate resilient agriculture, climate smart agriculture, weather-water-climate-services, climate services, weather-climate-services, agrometeorological services.

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List of abbreviations

AC	Agriculture Cooperative
CAISAR	Climate Adaptive Irrigation and Sustainable Agriculture for Resilience
CAO	Commune Agriculture Officer
CCA	Climate Change Adaptation
CCCSP	Cambodia Climate Change Strategic Plan
DRR	Disaster Risk Reduction
DVI-KE	Digital Village Initiative Knowledge Exchange
ENSO	El Niño-Southern Oscillation
EWS	Early Warning System
FGD	Focal Group Discussion
FWUC	Farmer Water User Community
GDP	Gross Domestic Product
ICT	Information Communication Technology
KII	Key Informant Interview
MAFF	Ministry of Agriculture, Fishery and Forestry
MHEWS	Multi-Hazard Early Warning System
MOWRAM	Ministry of Water Ressources and Meteorology
MRD	Ministry of Rural Development
NCDM	National Committee for Disaster Management
NGO	Non-Governmental Organization
NHMS	National Hydrometeorological Service
OMC	Oddar Meanchey
PCDM	Provincial Committee for Disaster Management
PDAFF	Provincial Department of Agriculture, Fishery and Forestry
PDWRAM	Provincial Department of Water Ressources and Meteorology
PEARL	Partnerships for Ecologically Sound Agriculture and Resilient Livelihoods in the Northern Tonle Sap Basin
PIN	People in Need
PPP	Purchasing Power Parity
SDG	Sustainable Development Goal
SESAME	Specialized Expert System for Agro-Meteorological Early Warning
Tmax	Temperature maximum
WWCS	Weather-Water-Climate-Service

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1 Introduction

Cambodia is among the most climate-vulnerable countries in Southeast Asia, with high exposure to floods, droughts, and extreme weather events (WBG & ABD 2021). Its hot and humid monsoonal climate is characterised by a dry season from November to April and a wet season from May to October, with interannual variability influenced by the El Niño–Southern Oscillation which affects rainfall patterns and the frequency of extreme events (ENSO) (Phy et al. 2022; WBG 2024). The country, classified as a lower-middle-income country, has undergone a rapid growth over the last decades. Cambodia’s GDP per capita PPP increased from USD 2,988 in 2010 to USD 7,969 in 2024, with a current per-capita growth rate of 4.7% (WBG 2025). Despite this economic progress, agriculture remains a key sector, accounting for 22.3% of GDP in 2022 (FAO 2022a). Rice production is the dominant agricultural subsector and the primary source of income and food security for rural households (Khun & Lim 2023).

Climate change projections indicate that increasingly severe floods and droughts could reduce national GDP by up to 10% (WBG & ADB 2021). The agricultural sector, particularly rice production, is highly sensitive to climate variability, including altered rainfall patterns and rising temperature extremes (Kim 2025). Climate risks are especially pronounced in agriculturally intensive and poorer regions, notably along the Mekong River, the Tonle Sap basin, and northwestern Cambodia, where exposure to floods, droughts, and heatwaves overlaps with high poverty levels (WBG 2023; WBG 2024). In northwestern Cambodia, agriculture plays a central role in livelihoods, with rice as the staple crop, followed by cassava, maize, and mungbean (Touch et al. 2016). Agriculture and water resources are therefore key priority sectors for national climate change adaptation (CCA) efforts (Nop 2022). While Cambodia has made progress in integrating CCA and disaster risk reduction (DRR) into national strategies, significant challenges remain in translating these frameworks into effective action at the local level (RGC 2025; Theang & Thuon 2025).

At the global and national levels, interest in strengthening Weather-Water-Climate-Services (WWCS) has increased due to their potential to generate socio-economic and environmental benefits (WMO 2024; Suckall & Soares 2022). However, improving agricultural decision-making requires weather and climate information that is accurate, context-specific, and trusted (Kumar et al. 2020). In particular, there is the need in WWCS to address the “last-mile” gap, as meaningful impacts on smallholder farmers through advisory services can only be achieved when information is effectively delivered, understood, adopted and tailor-made for the specific local need (FAO 2021; Zwahlen et al. n.d.).

1.1 Knowledge gap and relevancy

A wide range of existing literature highlights the potential of agrometeorological services (WWCS for the agricultural sector) to support farming decision-making, enhance climate change resilience, and boost agricultural incomes (Paparrizos et al. 2022; Suckall & Soares 2022). However, significant challenges remain in closing the gap between the production of weather and climate information and its effective dissemination and use by smallholder farmers in the Global South (Tarchiani & Grey 2025). Given Cambodia’s high

vulnerability to climate change, particularly in northwestern regions where the impacts of climate-related hazards are expected to disproportionately affect smallholder farmers (Appendix A), WWCS represent a potentially promising approach to cope with these challenges (Paparrizos et al. 2022). Despite this potential and the international interest in WWCS (FAO 2021; WMO 2024), there is limited published research on the implementation and use of WWCS in Cambodia specifically focused on the agricultural applications. This highlights a clear regional and sectoral knowledge gap and underscores the need to investigate how such services could be strengthened and adapted to the context of northwestern Cambodia. More specifically, this thesis aims to assess the current availability and use of weather and climate information in the agricultural sector of northwestern Cambodia, explore the potential of different WWCS to strengthen CCA and DRR, and identify social, cultural, institutional, economic, and technical factors that enable or constrain their effective implementation.

1.2 Research questions

Against the background of the identified knowledge gaps, this thesis is structured around the following research questions:

- What is the current availability and use of weather and climate information in the agricultural sector of northwestern Cambodia?
- Which key farmer decision-making needs could be supported by WWCS for agriculture to strengthen CCA and DRR among smallholder farmers in northwestern Cambodia?
- Which social, cultural, economic, institutional, and technical aspects act as enabling conditions or limitations for effective implementation and uptake of WWCS for agriculture in northwestern Cambodia?

To address these research questions from an NGO perspective, the thesis adopts a comparative case study approach. This approach contrasts an established type of WWCS application in Cambodia (EWS1294, see Subsection 2.5.1) with a conceptualised WWCS approach (Subsection 2.5.2), allowing for an exploration of both the potential and limitations of WWCS in the context of northwestern Cambodia (further details are provided in Chapter 3). While the thesis does not focus on the technical feasibility or system development aspects of specific WWCS, selected technical considerations of a general nature are incorporated into the analytical reflections and explored through in-depth interviews with key stakeholders.

2 Context and conceptual framework

This thesis is grounded in a conceptual framework that positions WWCS as an approach for addressing climate change impacts through CCA and DRR (Fig. 1). It builds on the interlinkages between climate change impacts, CCA, DRR, and WWCS in strengthening climate resilience, with a particular focus on smallholder farmers in northwestern Cambodia. The research is therefore aligned with Sustainable Development Goal (SDG) target 13.1, which aims to strengthen resilience and adaptive capacity to climate-related hazards and disasters (UN n.d.) as well as the Sendai Framework for DRR (UNDDR 2015). The components of the conceptual framework, embedded in the local context, are further described in the sections of Chapter 2.

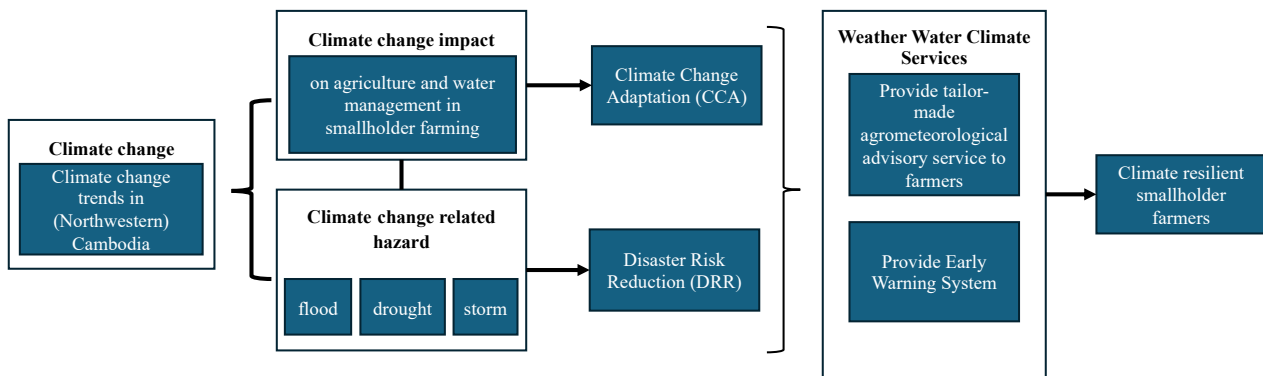


Figure 1 Conceptual framework showing the interlinkages between climate change – WWCS – climate resilience (source author's own visualization)

2.1 Demographic and socioeconomic context

Cambodia's population reached over 17.3 million in 2024, with rural households (approximately 2.1 million) still outnumbering urban households (1.6 million), despite ongoing urbanisation. Northwestern region accounts approximately 15% of the national population (NIS 2025a).

Educational attainment has improved over recent decades, with a national literacy rate of 85.5% (83% in rural areas) among younger cohorts; however, literacy remains lower among older populations, and 40.8% of the population (45.5% in rural areas) has not completed primary education (NIS 2025a). The economically active population represents 62.9% of the total population. While Cambodia has undergone a gradual structural shift towards secondary and tertiary sectors, agriculture, forestry, and fisheries remain central to rural livelihoods (NIS 2022). Although employment in agriculture declined from 54.7% of the active population in 2019 (75.9% in rural areas) to 34.5% in 2024 (48.6% in rural areas), it continues to play a critical role in the rural economy (NIS 2022; NIS 2025b).

2.2 Climate change impact

Cambodia is highly vulnerable to climate change, with elevated risk primarily driven by limited adaptive capacity and low socioeconomic readiness. Both the INFORM Climate Change Risk Index and the ND-GAIN Index identify Cambodia alongside Myanmar as among the most climate-vulnerable and least prepared countries in Southeast Asia, ranking 161 out of 187 countries worldwide in 2023, with pronounced vulnerability in the food and water sectors where moderate climate exposure intersects with weak coping capacity (Thow et al. 2022; ND-GAIN 2026). Climate projections indicate increasing frequency and intensity of floods and droughts, partly driven by ENSO variability, with the population exposed to flooding expected to rise by around 20% by mid-century (WBG & ADB 2021; WBG 2024; Winsemius et al. 2015).

Climate-related hazards already affect a large share of the population: 39.2% of villages have been exposed to flooding and 47.6% to drought at least once over a five-year period (NIS 2025b), posing substantial risks to agricultural livelihoods (Monin 2021; WBG 2024). Floods and storms account for the majority of internal displacement nationally (IOM 2024). In northwestern Cambodia, climate-related factors (including crop failure,

food insecurity, and climate-hazard disasters) account for 45% of household migration, suggesting that migration in the region is largely driven by survival needs (Jacobson et al. 2018). The region is further assessed as facing severe to extreme drought risk under the Cambodian National Plan for Drought Management and Adaptation (MOWRAM 2025). Under a high-emissions scenario (RCP8.5), simulations project yield declines of approximately 10% for rice and other crops, such as maize, by 2050 relative to 2024 (Appendix B). Beyond staple crops, increasing water and heat stress are also expected to adversely affect vegetable production, including tomato and yard-long bean cultivation (Alvar-Beltrán et al. 2022).

2.3 Climate change adaptation and disaster risk reduction

The common understanding among CCA and DRR is that the frequency and intensity of climate-related hazard will increase in the future. To reduce both disaster and climate change risk, exposure needs to be minimized, vulnerability reduced, and capacities for resilience strengthened (Turnbull 2013) (Fig. 2).

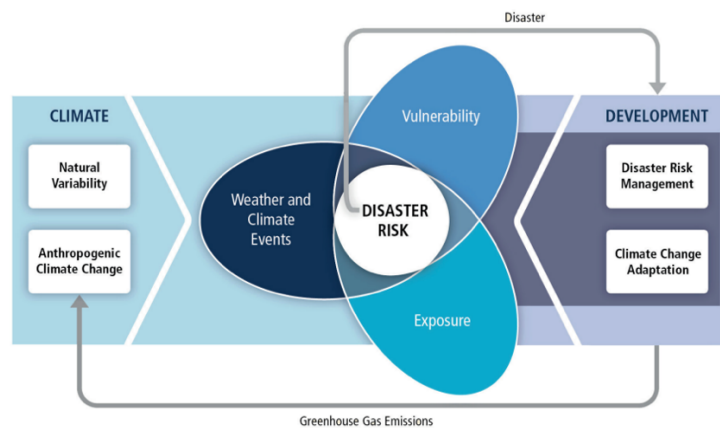


Figure 2 IPCC disaster risk framework defines the risk as the overlapping of weather and climate related hazard, the exposure and the vulnerability (source: IPCC 2012)

CCA and DRR in Cambodia are closely linked to structural drivers of climate risk, including land-use change, irrigation infrastructure conditions, and the increasing frequency of extreme weather events (Phy et al. 2022). Adaptive capacity at the community level is shaped by the availability and diversity of livelihood assets (human, physical, social, natural, and financial capital), making capacity strengthening a central component of both CCA and DRR, particularly in addressing climate-related migration pressures (Khavarian-Garmsir et al. 2025; Jacobson et al. 2018). CCA measures in Cambodia have the potential to reduce crop yield losses and halve the negative impacts of climate change on GDP (Appendix C). In northwestern Cambodia, projected climate change impacts require farmers to adopt adaptive strategies to reduce vulnerability and limit negative effects on crop yields (Touch et al. 2016). Common adaptation measures include improved fertilizer management and optimized irrigation management (Touch et al. 2016). Evidence from Banteay Meanchey province, located in the northwestern region, shows that supplementary irrigation is the most commonly adopted CCA practice in rice production to cope with drought conditions (Thangrak et al. 2020). However, national statistics indicate that only 14.6% of agricultural land is irrigated, leaving most production systems highly dependent on rainfall and exposed to climate variability (NIS 2025b). The adoption of adaptation practices is closely linked to farmers'

behavioural change. Evidence suggests that farmers who receive agricultural extension services, are risk-averse, or have experienced severe crop losses or negative climate-related impacts are more likely to adopt new techniques (Brown 2025). Farmers' perceptions of climate change are further shaped by recent experiences of extreme events (Ha et al. 2023), as well as by structural factors such as farm size, age, and farming experience. In this regard, larger-scale farmers tend to exhibit higher awareness of climate risks and a greater propensity to adopt adaptation options than smallholder farmers (Thangrak et al. 2020). Awareness of climate change and uptake of adaptation practices are closely associated with access to weather and climate information (Chetri et al. 2024). In this context, strengthening access to and effective use of WWCS is particularly relevant for smallholder farmers in northwestern Cambodia, where high climate exposure and limited resources constrain adaptive responses.

2.4 National policy and strategies on climate change adaption and disaster risk reduction

Although the Cambodian Constitution does not explicitly reference CCA or DRR (Bernard & Scott 2020), the country has progressively developed a comprehensive policy framework to address climate-related risks. The Cambodia Climate Change Strategic Plan (CCCSP) 2014 – 2023 provided the first overarching national framework, aiming to engage public and private sectors, civil society organisations, and development partners in addressing the causes and impacts of climate change, with a particular focus on reducing the vulnerability of the most vulnerable population groups and socio-ecological systems (RGC 2013). The CCCSP 2014 – 2023 explicitly promoted the development of early warning system (EWS) and the improvement of reliable weather services as key instruments for strengthening adaptive capacity, subsequently operationalised through sectoral strategies led by institutions such as the Ministry of Water Resources and Meteorology (MOWRAM), the Ministry of Agriculture, Forestry and Fisheries (MAFF), the Ministry of Rural Development (MRD), and the National Committee for Disaster Management (NCDM).

Building on this foundation, the CCCSP 2024 – 2033 reinforces the national commitment to strengthening adaptive capacity, with specific outcomes targeting: DRR, community preparedness and recovery (Outcome 2.2), resilience strengthening of vulnerable groups (Outcome 2.4), and the promotion of climate-smart technologies and sustainable agricultural practices across food value chains (Outcome 2.5) (RGC 2025). These priorities align with broader policy frameworks, including the UN Sustainable Development Cooperation Framework for Cambodia 2024–2028 (Output 3.4) (UN Cambodia 2023) and the Pentagonal Strategy for Cambodia Vision 2050, which emphasises climate-resilient agriculture and sustainable natural resource management (RGC 2023).

Within the agricultural sector, the National Agriculture Development Policy 2022–2030 articulates the ambition of developing a competitive, inclusive, resilient, and sustainable agricultural system, explicitly recognising CCA as essential to improving farmers' incomes and overall wellbeing (RGC 2022). At the subnational level, improved access to weather and climate information to support adaptive crop cycle management is identified as an opportunity to strengthen CCA and DRR (NCDDS 2018), while the Cambodian National Plan for Drought

Management and Adaptation underscores the need to strengthen drought EWS and risk communication (MOWRAM 2025). Despite these policy commitments, persistent gaps in disaster preparedness and coordination indicate the need to further strengthen public awareness, local governance, and coordination to improve disaster management and ensure long-term climate change resilience (Theang & Thuon 2025).

2.5 Weather-Water-Climate-Services

“Local actors’ ability to access and generate information on climate change impacts and solutions to address climate risks are prerequisites for awareness and informed planning and decision-making” (IBRD & WBG 2024) making WWCS, also called hydrometeorological or climate services, essential tools for building local climate resilience. In general, WWCS *“help protect lives and livelihoods from hydrometeorological and related environmental hazards and achieve beneficial socioeconomic and environmental outcomes in weather-, water- and climate sensitive sectors”* (WMO 2024). In practical terms, WWCS are tools that use water, weather and climate data to assist users’ decision-making in building adaptive capacity or protection from climate change impacts (WMO 2024). When applied to agriculture (also commonly referred to as agrometeorological services) WWCS can generate multiple benefits (Table 1), including reduced crop losses and damages and enhanced resilience to climate variability and extreme events (Simelton et al. 2019). Climate services constitute a broad category of interventions that strengthen farmers’ adaptive capacity by improving weather forecasts and EWS, while also enabling farm-level adaptation measures related to water, soil, and pest management (FAO & UNFCCC 2024). The scope of WWCS varies across temporal and spatial scales, ranging from national to farm level (Appendix D). According to the Global Framework for Climate Services (WMO 2011), functional climate services consist of six components: (i) basic systems and information; (ii) research, modelling and prediction; (iii) climate service information system; (iv) user engagement; (v) capacity development; and (vi) governance (Appendix E).

Table 1 Socio-economic and environmental benefits linked to WWCS (source: Suckall & Soares 2022)

Economic	1. Reduced cost of cultivation and agricultural inputs, including labour
	2. Increased farm production/avoidance of crop loss
	3. Avoidance of loss of property from flood damage
	4. Avoidance of accrued debt
Social	5. Protection of human life, including physical and mental health
	6. Increased preparedness for emergencies and increased awareness of threats
	7. Household decision-making for women
Environment	8. Reduced irrigation
	9. Efficient use of pesticide and fertiliser

Despite the potential benefits of WWCS, reaching the “last-mile” in smallholder farming contexts remains a challenge (Tarchiani & Grey 2025). In Southeast Asia, key barriers include difficulties in translating climate information into actionable agronomic decisions and limited communication channels for effective dissemination (FAO 2021). Recommended strategies to address these constraints include the use of digital communication technologies and the provision of crop-specific, user-friendly agrometeorological information

(FAO 2021). In Cambodia, the development and operationalisation of WWCS face significant institutional and resource constraints (Donovan et al. 2024). There is no specific legislation regulating the Department of Meteorology (DoM) within MOWRAM, and limited funding and policy support restrict access to broader weather and climate data networks. A recent assessment of the national hydrometeorological service reported *“less than basic capacity for climate services provision”* and the absence of a formal national framework for climate services (Donovan et al. 2024). These constraints persist despite the prioritisation of strengthening the capacity for climate data collection, analysis, modelling, and dissemination to various end-users being part of the CCCSP 2013–2023 (RGC 2013).

2.5.1 The case of EWS1294 in Cambodia

In response to Cambodia’s high flood risk, the NGO People in Need (PIN) implemented a pilot project in 2013 to strengthen the country’s pre-existing EWS, which was at that time managed by MOWRAM with limited capacity and unable to meet stakeholder needs (Dutta et al. 2015; Ket et al. 2024). The system has since been upgraded and is now recognised as Cambodia’s official multi-hazard early warning system (MHEWS), known as EWS1294 (Fig. 3), and is owned and managed at the national level by the NCDM. EWS1294 operates through a network of 54 river water-level sensors and currently serves more than 800,000 subscribers (PIN 2026). In addition to flood warnings, the platform can be used to disseminate alerts for droughts, storms, and air quality hazards; however, these alerts are generated from external data sources rather than the sensor network itself. EWS1294 is widely cited as a successful example of an operational WWCS in Cambodia (WMO 2024; UNDRR & WMO 2025; UN-OHRLLS & UNDRR 2024; Zwahlen et al. n.d.). Intermediate users of the system include national and subnational disaster management authorities (NCDM and provincial level PCDM), who monitor flood conditions via Tepmachcha sensors and disseminate warnings to local populations (the end-users) through multiple channels, including village loudspeakers, radio, voice messages, social media, and the EWS1294 website (PIN 2022a).

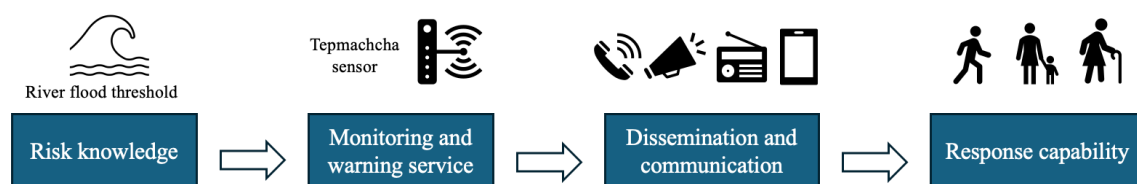


Figure 3 EWS1294 represented on the four pillar framework of the Early Warning for All (EWS4All) initiative adapted from UNDRR & WMO 2025 (source: author's representation)

2.5.2 The new case: conceptual WWCS with tailor-made advisory for smallholder farmers

The proposed conceptual WWCS is based on a system implemented by the NGO Caritas Switzerland in Tajikistan¹, where a dense network of local weather stations supports the delivery of tailored agrometeorological

¹ An initial small-scale pilot using the same technology was conducted under the Nurture Project in Cambodia between June and September 2025; however, while it inspired the conceptual development of this study, the pilot results are not included in the thesis analysis.

services for farmers’ decision-making, including guidance on optimal timing for land preparation, sowing, irrigation scheduling, and harvesting to reduce yield losses, in addition to an EWS providing cold- and heatwave warnings (Kassam et al. n.d.). In this context, locally generated weather data were used to provide user-oriented services aligned with specific agronomic needs, with initial field observations indicating yield increases among participating farmers (Bellprat 2022). Using irrigation scheduling as an illustrative example, the conceptual WWCS integrates locally observed weather parameters with soil- and crop-specific information to generate plot-level recommendations on daily crop water requirements, which are communicated directly to farmers via messaging application (Fig. 4). User feedback is incorporated to iteratively refine calculations of subsequent water requirements, with the objective of improving water use efficiency (WUE). Comparable smart irrigation applications for rice cultivation have been documented in the literature (Mallareddy et al. 2023). By translating complex weather and climate data into clear, actionable agronomic advice, the service aims to address the “last-mile” gap in converting climate information into practical decision-support for farmers.

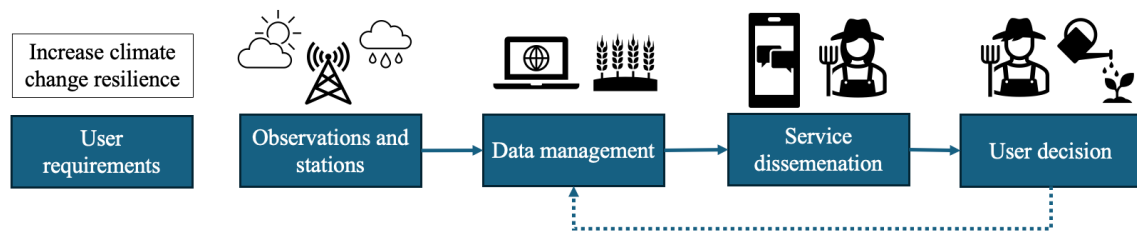


Figure 4 Steps of the conceptual WWCS tailor-made for individual farmer decision-making represented using an adapted version of the GFCS framework based on Zwahlen et. al (n.d.) (source: author's own representation)

3 Methodology

The research questions of this thesis were investigated by using an exploratory research approach, applying a mix of qualitative methods: comparative case study, primary data collection through selected stakeholders interviews, and secondary literature analysis, to explore potential and limitations of a tailor-made WWCS approach for smallholder farmers in northwestern Cambodia.

3.1 Study Area

While the geographical research focus of this thesis encompasses northwestern Cambodia as a whole, Oddar Meanchey (OMC) was selected as proxy for the provinces of Bantaey Meanchey, Battambang, Siem Reap, and Preah Vihear, which are located on the upper Tonlé Sap Lake area. OMC, located along the border with Thailand, is characterised by an annual precipitation of 1,317.78 mm, compared to a national average of 1,836 mm. September is the wettest month (253.22 mm), while January is the driest (2.70 mm). April is the hottest month, with a mean temperature of 30.25°C, and December the coolest, with a mean temperature of 25.12°C. Under projected climate change scenarios over the next decades, the annual High Heat Index (number of days with $T_{max} > 35^{\circ}\text{C}$) is expected to increase from 120.64 days during the period 2020 – 2039 to 176.31 days during 2040 – 2059 (WBG 2024). The majority of households (66%) in OMC live in rural areas (NIS 2025a).

Approximately 142,000 hectares of agricultural land are cultivated, predominantly with rice, which is grown by 77% of farming households, followed by cassava (NIS 2025b). Horticulture also plays an important role in income generation, with locally produced vegetables accounting for 42% of the market in 2020 (Lim & Hem n.d.).

3.2 Data collection & analysis

Comparative case study

The research adopts a comparative case study approach, analysing one empirical and one conceptual case. The EWS1294 system (Section 2.5.1) was selected as an example of a WWCS for DRR that has been successfully scaled up at the national level in Cambodia. In contrast, a conceptual WWCS tailored to agricultural decision-making (Section 2.5.2) was investigated as an approach with a stronger focus on CCA. Although the two cases are not directly comparable in terms of service scope, the analysis of the key success factors and implementation challenges of EWS1294, combined with insights from stakeholder interviews, enables an exploration of the broader potential, drivers, and challenges for implementing a farmer-oriented WWCS within the same local context.

KIIs and FGDs

Given the existing geographical knowledge gap on the research topic, primary qualitative data collection was essential to understand the local social, cultural and institutional context. An initial stakeholder mapping (not included in this thesis) was conducted to identify relevant actors for WWCS, following the suggested stakeholders categories in Papparizos et al. (2023). In line with the subnational focus of the study, national-level actors were identified but not included in the primary data collection. Contact with selected stakeholders was facilitated through the Nurture Project (<https://nurtureproject.org/>). Primary data were collected between 27 and 31 October 2025 through semi-structured key informant interviews (KIIs) and two focus group discussions (FGDs) with representatives of Farmer Water User Community (FWUC) Committees (Appendix F). Interviews conducted in the study region were facilitated by the author in English and translated into Khmer, while online KIIs were conducted exclusively in English. Tailored interview guides (Appendix G) and a list of discussion topics for FGDs were used (Appendix H), with follow-up questions introduced as needed. In some cases, author-developed visual materials were used to facilitate discussions on existing service providers and potential WWCS needs. Given the diversity of stakeholders interviewed and the exploratory nature of the research, the author chose not to apply formal qualitative coding to the interview transcripts. Thus, the thesis does not report direct quotations but uses primary data to support, triangulate, and validate findings from the literature, as well as to explore stakeholder perspectives in a context where empirical evidence remains limited.

Desk review

The desk review comprised academic literature and publicly available grey literature, including reports from NGOs, multilateral organisations and other development partners. It was used to map the current landscape of weather and climate information in Cambodia and to identify key drivers and challenges related to the implementation of WWCS in Cambodia and additional contexts. The Digital Village Initiative Knowledge

Exchange (DVI-KE) Databank (FAO 2025) was initially accessed to map current digital solutions providing WWCS. The desk review complemented the primary data collection by providing contextual background and supporting the interpretation and triangulation of interview findings.

3.3 Methods limitations

Northwestern Cambodia covers an extended geographical area; therefore, the selected study area and interviewed stakeholders may not fully represent conditions and perspectives across all other provinces. Although FGDs were conducted with representatives of farmer communities, the qualitative data cannot substitute for a statistically representative farmer survey. In particular, the study did not systematically differentiate between farmer categories, nor did it explicitly include women and vulnerable groups. Moreover, interviews with farmer community representatives focused exclusively on rice production systems through FWUC Committees. While rice is the dominant crop in the region, other production systems, such as vegetable farming, are also relevant for assessing the broader applicability of WWCS. In addition, the study did not address the detailed technical feasibility of WWCS implementation, which would be required for an intervention-oriented system design and could not be adequately assessed through a conceptual case study. Limited availability of policy documentation in English, particularly at the subnational level, also constrained the depth of policy analysis. Consequently, the findings should be interpreted as exploratory for the topic in the study region, providing an initial foundation for further, more comprehensive research.

4 Results and Discussion

The information reported in this chapter are a mix of primary collected information through KIIs and FGDs, and secondary literature (see Section 3.2).

4.1 Current situation of weather and climate information

Current offer of weather and climate information for Cambodian agricultural sector

The mapping of existing WWCS providers in Cambodia reveals a diverse landscape of services varying in target users, providers, dissemination channels, and scope (Fig. 5); for additional details and individual references see Appendix I). Some solutions specifically target agriculture, while others provide general weather forecasts for the broader population. Despite not being specifically designed for agricultural decision-making, MOWRAM forecasts, selected free commercial platforms, and the EWS1294 system were identified by OMC interviewed stakeholders as the most widely recognized sources of weather information.

Across the mapped solutions, information is predominantly disseminated via smartphone applications and dedicated websites. However, according to both representatives of FWUC Committees and provincial authorities, social media platforms (including public and private groups on messaging applications) are the primary information source for many farmers. National data indicate high mobile phone ownership among rural households (95.5%) but low access to radios (18.3%) and computers (6.1%), while affordable internet enables 84.8% of rural populations to connect online (NIS 2025a). Consequently, WWCS that rely on internet

connectivity and smartphones as dissemination channels should, at least in theory, be accessible to a large share of potential end-users.

The mapped solutions follow different commercialization pathways, reflecting the typology proposed by Paparrizos et al. (2023) (Appendix J). These include horizontal integration with the National Hydrometeorological Service (NHMS), as in the case of the MOWRAM weather forecast and EWS1294; vertical integration within private companies (e.g. Tonle Sap); and mixed integration models combining public and private actors, such as the Chamka App. Overall, the landscape includes private sector initiatives, public-private partnerships, NHMS-based services, public-NGO collaborations (notably EWS1294), small-scale NGO initiatives, and other (non-agriculture-specific) freely available public and commercial services. Private sector solutions often target agribusinesses in addition to farmers, embedding weather forecasts as a secondary feature alongside market and agronomic advice. This configuration suggests that the primary value proposition of such platforms is often market-oriented. An example of functional interoperability between services is provided by the Khmer Smart Farming platform, which integrates EWS1294 alerts to enhance public early warning dissemination, illustrating the potential for collaboration and information sharing across different WWCS initiatives.

Despite the variety of available solutions, most focused on providing short-term weather forecasts without translating this information into actionable agricultural advices for farmers, maintaining the “last-mile” gap. Only a limited number of initiatives (Chamka App and SESAME) provide agrometeorological bulletins. Seasonal climate bulletins, which could support strategic decisions such as crop selection and planting calendars (Jayasiri et al. 2025), are rarely available and generally require substantial climatic and agronomic knowledge to be effectively utilised. Beyond the solutions presented in Fig. 5, two large initiatives attempt to address this “last-mile” gap. The Partnerships for Ecologically Sound Agriculture and Resilient Livelihoods in the Northern Tonle Sap Basin (PEARL) project seeks to improve the availability and access to agrometeorological advisory services tailored to specific crop value chains (FAO 2022b). Within this framework, the Chamka App has been upgraded to disseminate recommended farm activities based on weather and climate forecasts across multiple time horizons (10-day, monthly, and seasonal) through both website and mobile app (CAS 2026). However, crop-specific advisories remain limited; in OMC, for example, only mango cultivation is targeted, despite rice being the dominant crop in the province (KII4, 28.10.2025). Similarly, the Climate Adaptive Irrigation and Sustainable Agriculture for Resilience (CAISAR) project, which will focus on the lower Tonle Sap region, aims to provide timely and locally tailored weather information to improve irrigation efficiency and enhance resilience to climate-related hazards (AIIB 2025).

No mapped services currently integrate weather-indexed crop insurance, although NGOs (KII 6, 30.10.2025) and private companies (KII 8, 31.10.2025) are exploring WWCS as an add-on for insurance subscribers.

Overall, despite the growing diversity of WWCS initiatives, no existing provider delivers a service comparable to the conceptual WWCS proposed in this thesis, which aims to close the “last-mile” gap by offering tailored, simple, decision-oriented recommendations for smallholder farmers. This suggests an existing potential for the conceptual WWCS to address the gap in providing various services as presented in Section 4.2.

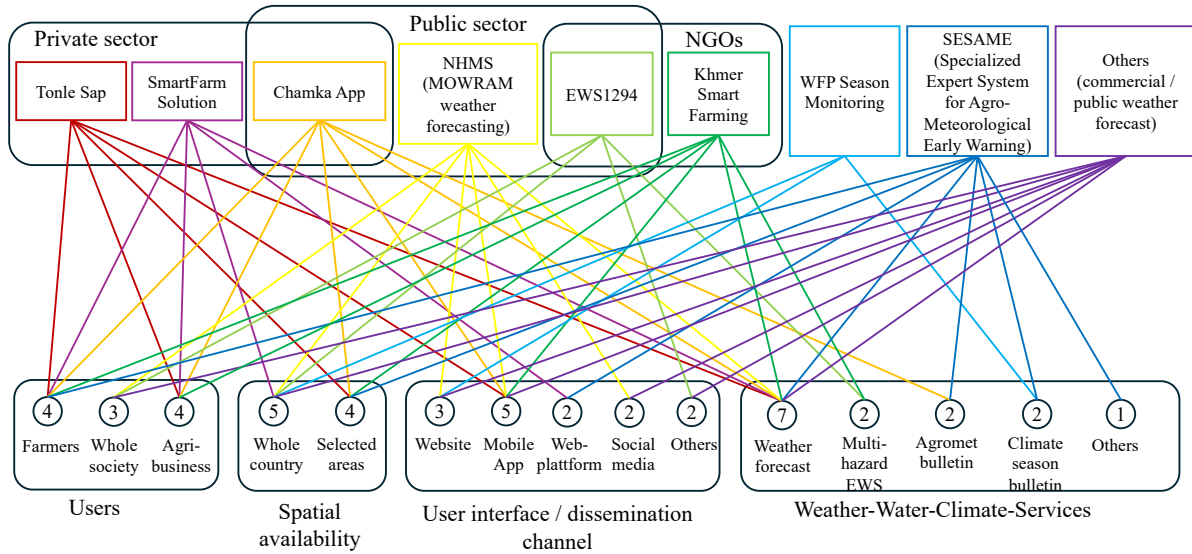


Figure 5 Mapping of current providers of weather and climate information in Cambodia (source: author's own visualization)

Accessibility and use of weather and climate information in northwestern Cambodia agricultural sector

Systematic national data on the accessibility and use of weather and climate information by farmers in Cambodia are absent, as neither the NHMS nor other public institutions routinely monitor usage; a gap also confirmed by provincial authorities in OMC. Existing evidence therefore relies on localized studies and qualitative insights. Although not representative of northwestern Cambodia, a study from southern regions found that 56% of respondents had access to weather and climate information, with floods and droughts identified as major drivers of crop losses in the region (Thav et al. 2023). In OMC, interviews and a previous assessment (Sevea 2022) suggest that farmers generally have basic access to weather information, primarily through social media and a limited number of smartphone-based commercial forecasting applications. However, the content is often perceived as difficult to interpret or insufficiently specific to local conditions, limiting its practical usefulness for agricultural decision-making. In response, the Provincial Department of Water and Meteorology (PDWRAM) disseminates simplified weather bulletins at the provincial level, while public agricultural extension services are not systematically involved in weather or climate information dissemination. Instead, FWUC Committee members reported that information is often shared informally among farmers, but that limited or no actions on crop production are taken based on that information. Despite these limitations, participants in the FGDs expressed the general perception that currently available weather information is useful and reasonably accurate. At the same time, there was broad consensus among farmers representatives and authorities on the need for more locally specific, timely, and practical information. This highlights a gap between information availability and its relevance and applicability for farm-level decision-making.

The EWS1294 system, together with official NHMS forecasts, is likely to be among the most used weather-related service in the study area, reflecting its successful national upscaling. Nonetheless, a observed lack of awareness among one FWUC Committee points to uneven uptake at the community level. Without targeted training and sustained awareness-raising, local adoption is likely to remain limited. Extension representatives

further emphasised the need to strengthen outreach and promote active registration and use of EWS1294 (KII 3, 28.10.2025). Despite its relevance for DRR, EWS1294 offers limited added value for agricultural decision-making, as flood and drought warnings are issued shortly before the event. Consequently, farmers' response options are limited to minor adjustments, such as small shifts in planting or harvesting schedules and selected post-harvest activities (KII 4, 28.10.2025). Consequently, EWS1294 does not effectively address the “last-mile” gap for smallholder farmers.

4.2 Potential contribution of WWCS to CCA and DRR in northwestern Cambodia

The development of WWCS in Cambodia has so far been strongly shaped by the need to address the country's high vulnerability to floods. Within this context, EWS1294 emerged as a comparatively straightforward and widely accepted response to an urgent and clearly defined need (Fig. 6), facilitating a shared understanding among institutional and local stakeholders. Over time, the system has progressively expanded into a MHEWS, incorporating alerts for additional risks such as droughts and storms (Chowdhary n.d.; PIN 2022a). In OMC, the system has also been used to disseminate information related to non-climatic societal risks, such as during the COVID-19 pandemic (KII 2, 27.10.2025). Available impact assessments indicate that communities perceive EWS1294 as beneficial and that its use contributes to increased flood preparedness at the local level (PIN 2022b; UNDP 2020a). However, interviews suggest that the system's potential has not yet been fully exploited. Discussions are ongoing regarding further technical upgrades, such as the inclusion of flash flood forecasting alongside river flood monitoring (KII 7, 30.10.2025). This stepwise approach to scaling and extending services points towards opportunities for integrated future solutions with services, as suggested in the conceptual WWCS, to support agricultural decision-making. The following paragraph presents the types of needs and consequently services that could be part of the conceptual WWCS.

WWCS to support farmers decision-making needs

KIIs and FGDs confirmed that crop production in OMC is exposed to multiple climate-related hazards, including floods, droughts, storms, and pest and disease outbreaks, all of which negatively affect crop yields. Agricultural extension officers highlighted the potential role of WWCS in supporting decisions related to pest management, fertilizer application, and water management, while planting and harvesting dates were described as being strongly shaped by farmers' experience and traditional practices. Representatives from PDWRAM similarly emphasised the need for improved information on fertiliser and pest management, while FWUC Committee members expressed interest in services supporting optimized use of agricultural inputs, and less in WWCS-supported irrigation scheduling, given that (in their view) the issues are more linked to water availability, particularly in the absence of reliable irrigation infrastructure, rather than to water management. Projected climate change impacts are expected to increase the need to improve crop WUE and adjust planting calendars to cope with intensified climate hazards (Alvar-Beltrán et al. 2022). This underscores the relevance of WWCS-supported irrigation scheduling, as demonstrated in previous assessments with rice farmers in the Mekong Delta region (Nguyen et al. 2023). There remains a lack of crop planning based on seasonal climate

information, which could help reduce agricultural vulnerability to climate variability and extremes (RGC 2022). In rice production, supplementary irrigation systems, which are often based on private wells and ponds, play a critical role in coping with climate stress, yet farmers typically rely on traditional practices and lack knowledge of crop-specific water requirements (Sok et al. 2022).

The relevance of WWCS-informed advisories is further reinforced by their potential economic benefits for farmers (Paparrizos et al. 2022). While irrigation costs account for only a marginal share of total production costs (around 0.3% or less), expenditures on fertilizers and plant protection products can represent up to one third of total crop production costs in Cambodia (NIS 2025b). Up to 70% of farming households use mineral fertilizers, with slightly lower shares applying pesticides and other plant protection products (NIS 2025b). More precise and timely weather- and climate-informed recommendations could therefore contribute to reducing input-related risks and inefficiencies, with benefits for a large proportion of rural households.

Crops with high WWCS relevance

Although rice remains the dominant staple crop (NIS 2025b), vegetable production plays an important role in household consumption and income diversification in OMC (Sevea 2022), suggesting strong potential demand for crop-specific WWCS targeting both rice and vegetables. Evidence from studies on weather-based irrigation scheduling for leafy vegetables in Cambodia demonstrates that the use of climate data can substantially improve WUE, highlighting the untapped potential of WWCS to support both CCA and DRR through enhanced farm-level decision-making (McPhee et al. 2022). Furthermore, farmer survey evidence indicates that improved access to weather information can increase farmers' readiness to adopt climate-smart practices such as intercropping, underscoring the importance of information and perception in shaping adaptive behaviour for adoption of CCA practices in agriculture (Ha et al. 2024), suggesting that WWCS can be used as tool to support alternatives to rice monocropping.

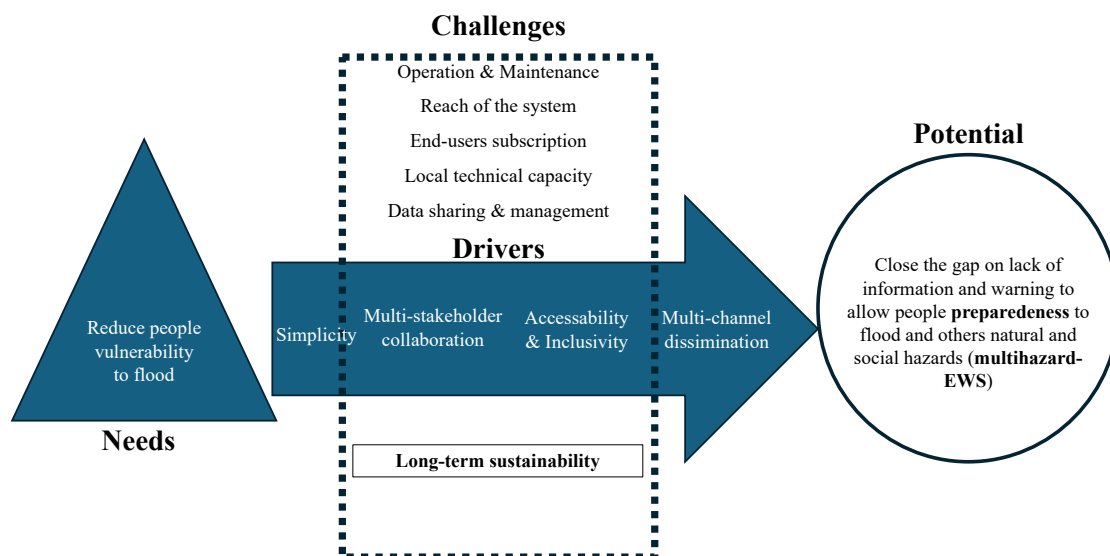


Figure 6 Summary of the needs, potential, challenges, and enabling factors associated with the implementation of EWS1294, and their implications for successful upscaling. (source: author's own visualization)

4.3 Challenges and barriers to implement WWCS in northwestern Cambodia

The insights from the EWS1294 experience provide a useful entry point for understanding the constraints to implementing WWCS in the local context. Reported challenges in operationalizing EWS1294 in Cambodia included (Fig. 6): lack of local technical capacity for operation and maintenance of the system, coordination among multi-stakeholders and data sharing among different actors, lack of community engagement in addition to an initial lack of focus on the dissemination, which limited the reach and end-user subscriptions (PIN 2022a; WMO, 2024). While the remaining challenges are mostly linked to the long-term sustainability of the intervention that despite being handed over to NCDM, still requires technical support from PIN (UNDP 2020a). Long-term sustainability of WWCS requires co-production processes involving farmers and relevant stakeholders, rather than one-way information delivery (Paparrizzos et al. 2024). Currently EWS1294 is a unilateral communication meant to disseminate information, PCDM representatives highlighted the need to have a system that allows more interaction with the users. This confirms the recommendation of FAO (2021) to “*establish an effective two-way communication and timely data collection and sharing between information providers and users*”. Longterm sustainability would be a concern for the implementation of the conceptual WWCS, whose implementation in northwestern Cambodia may be limited by several challenges.

Social challenges

Low educational attainment in the older population and illiteracy among parts of the rural population of southern Cambodia have been identified as key barriers limiting the adoption of new CCA technologies despite farmers directly experiencing climate impacts on crop production (Thav et al. 2023). Limited digital literacy in using ICT-based tools, such as smartphone applications, further hinders access to weather and climate information (Chetri et al. 2024). Field evidence from OMC indicates that farmers often face difficulties in using smartphone applications and interpreting weather information, even when access is available. FWUC Committee members reported widespread mistrust towards digital services, including SMS- and voice-based systems, due to the prevalence of cyber scams, which has also affected user engagement with EWS1294 alerts (KII 1, 27.10.2025; KII 2, 27.10.2025). Language constitutes an additional barrier: only Khmer-language solutions have realistic uptake potential, as 94.3% of the population in OMC speaks only the national language (NIS 2020). Even basic interactions with digital platforms, such as logging into applications, were reported as challenging for many farmers, increasing the implementation and follow-up costs for service providers (KII 6, 30.10.2025).

Cultural challenges

Farmers’ reluctance to adopt new CCA practices has been previously documented in northwestern Cambodia, where traditional knowledge and experience-based decision-making remain dominant (Touch et al. 2016). Adoption is strongly influenced by perceived usefulness and awareness of adaptation options, while limited understanding of climate change and its implications constrains behavioural change (Ha et al. 2023). FWUC Committee representatives also noted that some farmers are unlikely to change long-standing practices regardless of new information and services that would be available. Weather and climate data are often perceived as abstract or “scientific” information, weakly linked to everyday farming practices, reinforcing resistance to

change (KII 5, 30.10.2025). Similar patterns of mistrust toward digital services, due to widespread cybercrime, and low digital literacy have been identified in studies on farmers' acceptance of e-commerce in Cambodia (Chan et al. 2020), indicating broader structural challenges that generally hinder the uptake of digital solutions in the Cambodian farming communities (Ratha et al. 2025). These findings highlight the central role of agricultural extension in awareness building and the role trusted intermediaries in providing WWCS that could effectively be accepted by farmers.

Economic challenges

Economic constraints limit both the supply and demand sides of WWCS. Crop insurance schemes, which could potentially be bundled with WWCS, remain uncommon among smallholder farmers in OMC (KII 1, 27.10.2025; KII 3, 28.10.2025), reflecting their novelty in Cambodia and limited trust in such models (Ty 2023; Wang et al. 2022). Given that borrowing for agricultural activities already accounts for around 15% of household debt (NIS 2023), farmers are unlikely to invest additional resources in subscription-based climate services (KII 1, 27.10.2025; KII 3, 28.10.2025), or only if a clear financial benefit will be generated (FGDs 28.10.2025; KII 5, 30.10.2025). This aligns with evidence that low output prices and market constraints are key barriers to the adoption of new agricultural technologies in northwestern Cambodia (Nickens et al. 2023). Private sector WWCS solutions are perceived as poorly suited to smallholder contexts due to profit-driven models, while NGOs and public institutions remain heavily dependent on donor funding (KII 4, 28.10.2025; KII 6, 30.10.2025). Limited public-sector financial capacity further constrains the initiation and scaling of WWCS (KII 5, 30.10.2025). Public sector resources to initiate and sustain WWCS would need strong support from NGOs (KII 1, 27.10.2025), leaving uncertainty about the long-term sustainability of the approach.

Institutional challenges

Institutional fragmentation represents a major constraint to the effective implementation of WWCS. At the national level, there is no clear regulatory framework governing the provision of WWCS (KII 4, 28.10.2025), potentially hindering access for private sector initiatives. Although national strategies emphasize climate information for CCA and DRR (RGC 2013; MOWRAM 2025), implementation at subnational level remains limited and siloed. In OMC, responsibilities are distributed across multiple institutions with limited integration: PDAFF focuses primarily on technical extension, water access, market access; PDWRAM disseminates weather forecasts; PCDM manages flood sensors and warning dissemination; and PCRD is responsible for groundwater monitoring for drought alerts. Moreover, agricultural extension services in the region are strongly delivered by NGOs, increasing the risk of misalignment, duplication, and uneven coverage (Nickens et al. 2023).

Technical challenges

In the case of EWS1294, the development of additional hazard alerts, such as drought warnings, requires context-specific trigger thresholds and modelling expertise that are limited within local authorities, necessitating continued external technical support (KII 7, 30.10.2025). The maintenance and operation of infrastructure and software, including weather stations and sensors, remain an ongoing challenge due to funding and capacity constraints of NGOs (KII 6, 30.10.2025). Public sector institutions face limited human and financial

resources to initiate and sustain such systems independently (KII 8, 31.10.2025). These technical challenges underline the importance of long-term local capacity development for WWCS implementation.

4.4 Drivers to implement WWCS in northwestern Cambodia

The EWS1294's major key factor of success is the simplicity of the system that relies on sensors and platform for the authorities to be used in an easy way, ensuring a technology take-over. Simplicity is also essential for the end-users and to ensure broader upscaling (Chowdhary n.d.). The successful national upscaling of EWS1294 demonstrates that WWCS can be institutionalised in Cambodia through (Fig. 6): a simple solution that ensures inclusive accessibility, collaboration and active involvement of different stakeholders at national and subnational level, and the multi-channel dissemination that takes into consideration the low digital literacy (PIN 2022a). A successful implementation of the conceptual WWCS should benefit from following drivers.

Social drivers

Local collective structures, such as FWUCs and Agriculture Cooperatives (ACs), can play an important role in facilitating collective action for CCA, as farmers tend to adopt only practices they perceive as feasible and beneficial (Sam & Ouch 2015). FGDs indicate that limited access to agricultural extension services constrains farmers' ability to adapt beyond traditional practices, reinforcing the need for simple, tailored advisory services embedded within WWCS. Strengthening farmers' digital literacy is therefore a key social driver to enhance uptake and effective use of climate information (KII 5, 30.10.2025; KII 6, 30.10.2025). Inclusive co-production and multi-stakeholder collaboration, as initiated under PEARL, further support social acceptance of WWCS (Libanda et al. 2026; Gbangou et al. 2020). If farmers are actively engaged in the co-development of the WWCS there are higher chances of a wider acceptance of the technology (Gbangou et al. 2020).

Cultural drivers

Cultural factors strongly influence farmers' willingness to engage with WWCS. While reliance on traditional knowledge remains prevalent, interviews with agricultural extension officers and FWUC Committees suggest that farmers show willingness to change practices when benefits are clearly demonstrated. Demonstration farms, learning laboratories, and peer-to-peer learning through champion farmers are therefore important drivers for behavioural change, and well-known practices in the local context (KII 5, 30.10.2025; KII 6, 30.10.2025). Trust is central to cultural acceptance. FGDs participants consistently expressed higher trust in information disseminated by NGOs, particularly when these collaborate with local authorities, compared to private sector actors. This finding mirrors earlier evidence on farmers' trust in intermediaries and digital services in Cambodia (Chan et al. 2020) and in private providers of crop insurance (Lay et al. 2023). The EWS1294 experience confirms that NGO involvement can be decisive in building credibility during early implementation phases, especially because authorities see NGOs as reliable partners with technical know-how (KII 4, 28.10.2025).

Economic drivers

Economic considerations provide a strong incentive for WWCS adoption. Farmers in OMC face rising production costs, particularly related to fertilizers and plant protection products, and interviews indicate significant interest in services that could optimise input use and reduce inefficiencies. KIIs suggest that while

smallholder farmers are generally reluctant to pay for climate services, larger or more commercially oriented farmers may be willing to invest, potentially enabling spill-over benefits for neighbouring smallholders (KII 3, 28.10.2025; KII 6, 30.10.2025). ACs could also be enablers to facilitate the initial investment and provide the services to their members (KII 6, 30.10.2025). Partnerships with private sector was also seen as promising in further strengthening the EWS through additional service delivery (UNDP 2020b). There is also interest in linking WWCS to improve product quality and market access. If climate-informed decision-making leads to higher-quality yields, buyers and private sector actors may become engaged, creating economic incentives for farmers and increasing willingness to pay for services (KII 5, 30.10.2025). Evidence from Bangladesh shows that farmers' willingness to pay for tailored WWCS increased when they were involved in co-development and received training on the services (Paparrizos et al. 2021).

Institutional drivers

The EWS1294 case demonstrates that strong institutional ownership, combined with NGO support and development partner engagement, can enable legitimacy and scalable climate service provision.

Despite lacking a specific national framework on WWCS, its implementation indirectly aligns with Cambodia's existing policy framework to strengthen climate resilience in agriculture (see Section 2.4). Additionally, although climate services are not explicitly emphasized, the National Agriculture Development Policy promotes modern agricultural techniques, digital support systems for extension services, strengthened farm productivity, improved WUE, and enhanced climate resilience; all areas directly supported by WWCS (RGC 2022). Institutional interest in climate-informed agricultural decision-making was already articulated in the Climate Change Priorities Action Plan for the Agriculture, Forestry and Fisheries Sector 2014 – 2018 (MAFF 2014) and this interest was confirmed through an assessment of the climate services need within MAFF (Soksophors et al. n.d). Current national initiatives that involved large international donors and national partners, the PEARL and CAISAR projects (see Section 4.1), also offer further opportunities to integrate future additional WWCS to this ongoing progress on the provision of weather and climate information and advisories for farmers. At the subnational level, Commune Agriculture Officers (CAOs) could potentially be key facilitators of WWCS uptake, provided their mandate and capacities are strengthened to support implementation and follow-up with farmers on climate services adoption (KII 3, 28.10.2025; KII 5, 30.10.2025).

Technical drivers

From a technical perspective, it is consistently emphasized the need for climate information that is simple, location-specific, and directly actionable, reflecting limited technical capacity and familiarity with smartphone-based applications (KII 3, 27.10.2025). The stepwise development of EWS1294 illustrates the effectiveness of gradually expanding service functionality towards MHEWS, which is an approach that should be also applied for other WWCS by starting with initial small-scale pilots (KII 8, 31.10.2025). Broader trends, including increasing internet subscriptions (Kim 2025) and national plans to promote ICT-based agricultural extension, further support the feasibility of digital WWCS implementation (MAFF 2015). Building on existing digital platforms used by public authorities and NGOs can reduce entry barriers and enhance interoperability. Finally, limitations of EWS1294, particularly the lack of systematic feedback mechanisms (KII 2, 27.10.2025), highlight a key

opportunity for conceptual WWCS as designed. Integrating two-way communication would enable better validation of field conditions and improve the relevance of advisories for both CCA and DRR objectives.

5 Conclusion and recommendations

This study is an exploratory assessment to understand the current contextual enabling environment before implementing an intervention involving a tailored WWCS for individual smallholder farmers in northwestern Cambodia. While multiple barriers to implementation persist, the identified potential for strengthening CCA and DRR, together with the presence of supportive drivers, suggest that the proposed conceptual WWCS could deliver tangible benefits for smallholder farmers in the region. The identified challenges and enabling factors, as well as the comparison with the successful implementation of EWS1294 (despite its primary focus on DRR rather than agriculture) indicate that a horizontal integration approach (Appendix J) represents the most viable pathway for its development. Such an approach would rely on strong partnerships between NGOs and public institutions, complemented by targeted collaboration with private sector actors, for example as service providers or to stimulate through the market opportunities the technology uptake within farming communities.

Based on the findings, the following recommendations for implementing NGOs and policymakers are formulated adopting the FAO framework for effective climate services provision (FAO 2021).

- **Data collection and monitoring**

Data infrastructure and systems should be developed through the sharing of infrastructure and data with existing initiatives. Emphasis should be placed on simple infrastructure and targeted actions to enhance local capacity to ensure long-term local technical expertise outside the implementing NGO.

- **Information products**

WWCS products should be accurate, locally and crop specific, and designed to be simple and accessible to support farmer decision-making. Clear current gaps in existing agrometeorological initiatives, especially including PEARL and CAISAR initiatives and the upgrade of the Chamka App, should be identified. The focus should be on finding synergies and sharing data to help close the “last-mile” gap. The overarching objective should be the development of an integrated solution that jointly addresses CCA and DRR through an integration of the successful existing solutions, such as EWS1294.

- **Co-production of WWCS**

A user-driven design approach should be adopted. In this regard, the practical checklist developed by the Swiss Federal Office of Meteorology and Climatology (MeteoSwiss 2018) may serve as a useful reference. The co-production includes following components:

- **Multidisciplinary working groups**

Close collaboration with policymakers and other development partners is required to address the current absence of a specific national framework for climate services. Aligning this process with the recommendations of the

Global Framework for Climate Services could help establish a supportive policy environment that enables sustainable implementation and encourages greater private sector engagement.

- **Communication**

Appropriate communication channels should be selected to address farmers' concerns regarding trust and to ensure two-way communication, which is not only an essential component in the designed conceptual WWCS but also enables continuous feedback and improvement of advisory services. User interfaces should remain simple and intuitive, ensuring inclusive access. NGOs can also play a key role in supporting farmers' digital literacy through collaboration with other local organisations, while also advocating for increased policy prioritisation of digital literacy in rural areas.

- **Climate-informed decision**

Behavioural change represents a critical factor of a successful WWCS uptake and should be addressed through suitable frameworks and a participatory process. Agricultural extension services, including public (PDFAFF & CAO), NGO, and private actors, should be actively involved in supporting the adoption of WWCS and in linking climate information use to broader CCA practices. This includes the potential use of weather and climate information to support diversification strategies and shifts away from rice monocropping.

- **Participatory engagement**

A deeper understanding of farmers' needs is essential and should be pursued through participatory approaches to co-design the service portfolio. Broader assessments of needs and acceptance are necessary to build trust in the technology. The involvement of demonstration farmers is identified as a key factor in fostering uptake and credibility within farming communities.

Finally, it is important to acknowledge that this exploratory research is subject to important limitations and should not be considered fully representative of the entire region or farming population. A follow-up study is therefore recommended, incorporating a larger and more representative sample of stakeholders and explicitly assessing the technical feasibility of the proposed conceptual WWCS. In addition, funding mechanisms were not directly addressed in this study and should be examined in future research to ensure long-term financial sustainability and to reduce reliance on donor-dependent funding models.

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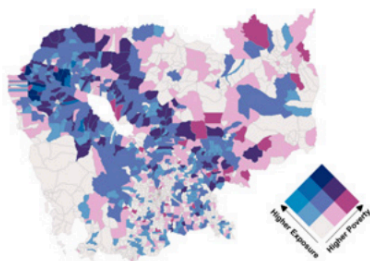
Declaration of use of use of AI-based tools

AI-Based Tool	Use Case	Scope
ChatGPT(GPT-5.2), OpenAI (free version) Last date of access: 15.01.2026	Revision of text for grammatical and stilistics mistakes and conciseness rephrasing	Entire work

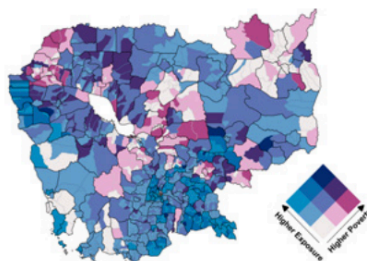
7 Appendices

Appendix A: Overlap between poverty and exposure to extreme weather events in Cambodia

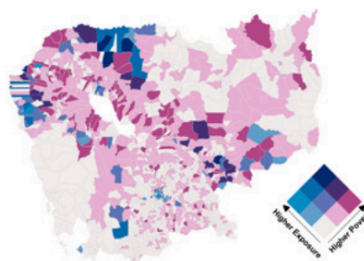
a) Exposure of poor households to agricultural losses from floods



b) Exposure of poor households to agricultural losses from droughts



c) Exposure of poor households to heat stress

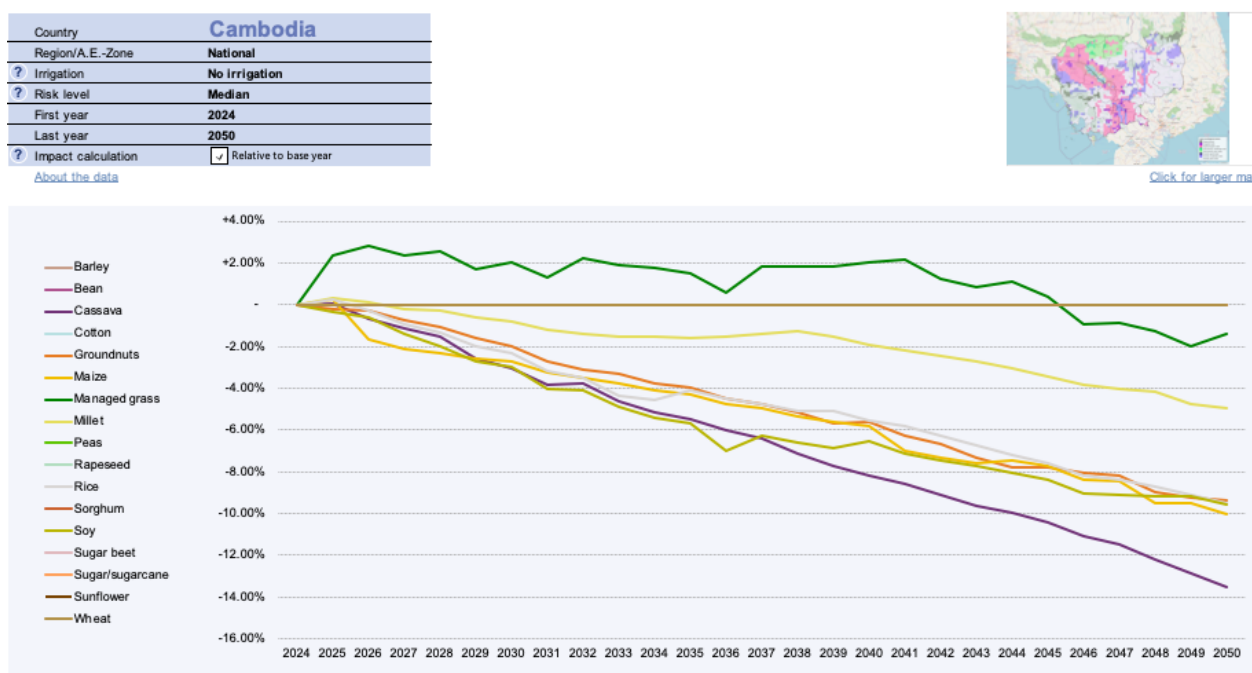


Source: Essenfelder et al. (2022). The authors calculated the expected exposure of agricultural land and population to floods, drought, and heat stress by overlaying population and agriculture maps with the Fathom probabilistic flood data set (Fathom, 2023), the FAO's Agricultural Stress Index (FAO, 2023), and VITO's extreme heat probabilistic data set (Fraser, 2017). Then, they overlaid the resulting maps with poverty maps from the National Institute of Statistics (2022).

Source: World Bank Group WBG (2023) Cambodia: Country Climate and Development Report,

<https://documents1.worldbank.org/curated/en/099092823045083987/pdf/P17887106c6c2d0e909aa1090f3e10505c1.pdf>

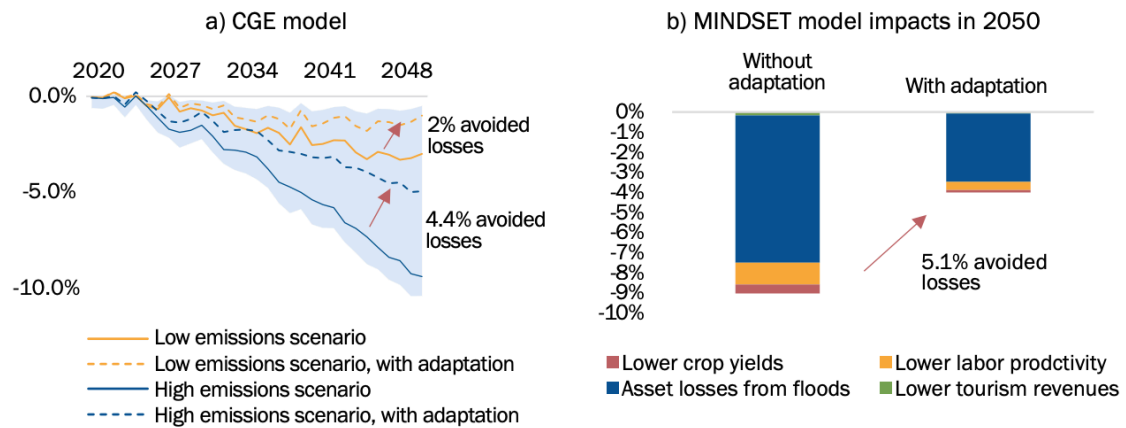
Appendix B: Simulation on the impact of climate change on the yield of non-irrigated crops in Cambodia in the timeframe of 2024-2025 conducted using the IFAD Climate Adaptation in Rural Development Assessment CARD Tool (Author's own simulation conducted on 04.01.2026)



Source: International Fund for Agricultural Development IFAD (2019) Climate Adaption in Rural Development CARD Assessment Tool – User Guide, accessible online: https://www.ifad.org/documents/48415603/49790217/Card_usermanual_W.pdf/ea60e97b-ccd3-ca7b-3f4c-f613a93471db?t=1764086699167 (last visited on 04.01.2026)

Appendix C: Impact of climate change on GDP relative to a no-climate change baseline, with and without adaptation (%)

Impacts of climate change on GDP relative to a no-climate change baseline, with and without adaptation (%)

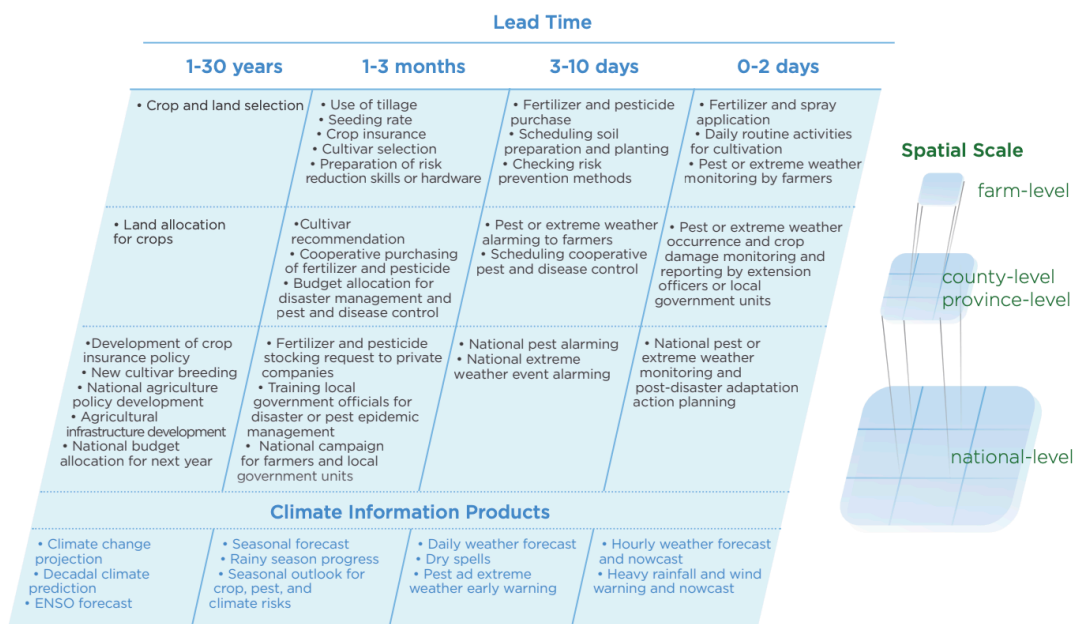


Note: Panels a) and b) include asset losses from floods, impacts of heat on labor productivity, impacts of climate change on tourism, and impacts of climate change on agriculture crop yield losses, without adaptation measures. In panel a), asset losses are the average. In panel b), asset losses are based on losses from a 1 in 10-year flood, excluding supply chain effects. Adaptation measures include risk-informed land-use planning, resilient transport infrastructure, climate-smart agriculture, and air conditioning.

Source: World Bank Group WBG (2023) Cambodia: Country Climate and Development Report,

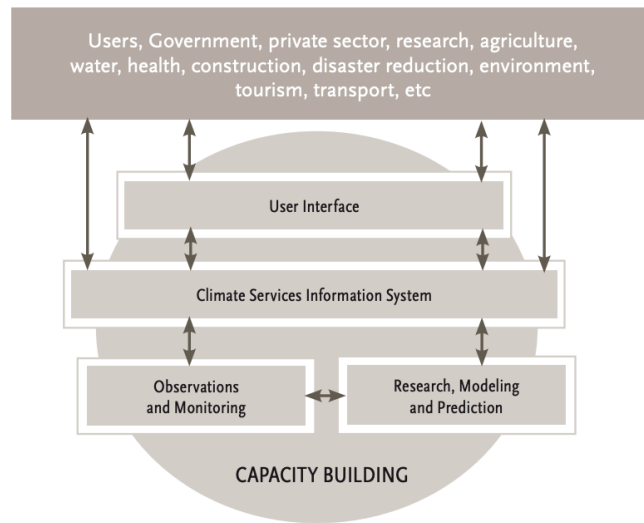
<https://documents1.worldbank.org/curated/en/099092823045083987/pdf/P17887106c6c2d0e909aa1090f3e10505c1.pdf>

Appendix D: Example of agricultural decisions based on temporal and spatial scales of climate information products



Source: Food and Agriculture Organisation of the United Nations FAO (2021) National agrometeorological services and pest and disease early warning in Asia and the Pacific, <https://doi.org/10.4060/cb6537en>

Appendix E: Pillars of a functional WWCS according to the Global Framework for Climate Services



Source: WMO (2016)

From WMO 2016 (page 14.)

User needs are met by each of the pillars as follows:

- *user Interface Platform (users can make their voices heard through the Platform and make sure climate services are relevant to their needs);*
- *climate Services Information System (the production and distribution system for climate data and information products that address user needs);*
- *observations and monitoring (the essential infrastructure for generating the necessary climate data);*
- *research, modelling and prediction (to advance the science needed for improved climate services that meet user needs);*
- *capacity development (to support the systematic development of the institutions, infrastructure and human resources needed for effective climate services).*

Source: World Meteorological Organization WMO (2016) Climate Services for Supporting Climate Change Adaptation Supplement to the Technical Guidelines for The National Adaptation Plan Process,

https://unfccc.int/sites/default/files/resource/WMO_Climate_Services_for_Supporting_CCA.pdf

Appendix F: List of Key Informant Interviews (KIIs) and Focus Group Discussions (FGDs)

	Date	Type	Who
1	27.10.2025	KII	Director Provincial Department for Agriculture Forestry and Fisheries (PDAFF) in Oddar Meanchey
2	27.10.2025	KII	Representative Provincial Department for Disaster Management (PCDM) in Oddar Meanchey
3	28.10.2025	KII	Commune Agriculture Officer (CAO) Beng Commune (Oddar Meanchey Province)
4	28.10.2025	KII	Representative Provincial Department Water Resource and Meteorology (PDWRAM) in Oddar Meanchey
5	30.10.2025	KII – online	Representative NGO that piloted ICT weather-climate-based solution for farmers in Cambodia
6	30.10.2025	KII – online	Representative NGO that piloted ICT weather-climate-based solution with crop insurance company in Cambodia
7	30.10.2025	KII - online	Representative NGO that implemented EWS1294 in Cambodia
8	31.10.2025	KII - online	Representative private company that is currently developing WWCS solution combined with weather index crop insurance model in Cambodia
A	28.10.2025	FGD	6 members of Farmer Water User Community (FWUC) Committees in Beng Commune (Oddar Meanchey Province)
B	28.10.2025	FGD	5 members of Farmer Water User Community (FWUC) Committees in Ou'Angkong Commune (Oddar Meanchey Province)

Appendix G: Summary of semi-structured interview guides* for KIIs

KII 1	PDAFF
Weather- and climate-related hazards and challenges for agriculture in the OMC province - What are the major climate-related hazards to the agriculture in this region? What are the consequences of these hazards for the farmers? Weather information current practices - Which types of weather information and services are available in this region? Do farmers use this information? Are they able to understand it? - Does PDAFF play a role in disseminating weather information? (for example, does it support farmers in understanding the information in relation to agricultural activities?) - Do you know of any of these apps? Examples include the MOWRAM Weather App, the Tonle Sap App, the Chamka App, the Khmer Smart Farm App, etc. (see the printed pictograms.) Potential WWCS - In your opinion, do you see any need to improve weather service to support farmers decision making on crop cultivation? - What is the benefit of EWS1294 for farmers? Challenges WWCS - In your opinion would farmers pay for having access to precise weather information and specific recommendations for their crop production? - Do farmers use crop insurance? Collaboration around WWCS - Who are other key actors? What should be their roles?	
KII 2	PCDM
Weather- and climate-related hazards and challenges for the OMC province	

	- What are the major climate-related hazards affecting people in this region? What consequences do these hazards have for farmers? Weather information current practices - Which types of weather information and services are available in this region? EWS1294 - benefit - What are the benefits of EWS1294? When people receive an alert, what actions can they take? - What factors contributed to the successful implementation? EWS1294- challenges - What are the remaining challenges for EWS 1294? (e.g., financial, technical, behavioral change)? Future potential EWS - What other types of hazards do you think could be integrated into the EWS1294 system or addressed using a similar approach? Sustainability of the approach - What are the challenges for PCDM to ensure long-term operation of EWS1294? - What can be the role of other actors?
KII 3	CAO
	Weather- and climate-related hazards and challenges for agriculture in the OMC province - What are the major climate-related hazards to the agriculture in this region? What are the consequences of these hazards for the farmers? Weather information current practices - Which types of weather information and services are available in this region? Do farmers use this information? Are they able to understand it? - Does CAO have a role in disseminating weather information? - Do you know of any of these apps? Examples include the MOWRAM Weather App, the Tonle Sap App, the Chamka App, the Khmer Smart Farm App, etc. (see the printed pictograms.) Potential WWCS - In your opinion, is there a need to improve the weather service for farmers? - What decisions and activities of farmers could be supported by WWCS? What should good services look like? Challenges WWCS - What may be the challenges and risks linked to new WWCS for farmers? - In your opinion would farmers pay for having access to precise weather information and specific recommendations for their crop production? Collaboration around WWCS - What could be your role as CAO in the further implementation of WWCS?
KII 4	PDWRAM
	General information PDWRAM and weather forecasting - What is the role of PDWRAM in disseminating weather information? - Which national and subnational regulations regulate provision of the weather services? Weather- and climate-related hazards and challenges for agriculture in the OMC province - What are the major climate-related hazards to the agriculture in this region? Weather information current availability and use - Which types of weather information and services are available in this region? Do farmers use this information? Are they able to understand it? - Do you know of any of these apps? Examples include the MOWRAM Weather App, the Tonle Sap App, the Chamka App, the Khmer Smart Farm App, etc. (see the printed pictograms.) Potential WWCS - What types of hazards could be addressed by improving existing services? Which types of WWCS would be useful for agriculture? Challenges WWCS - What are the current challenges linked to the weather information? Collaboration around WWCS - Who are key actors that should be involved in WWCS? What should be their roles?

Longterm sustainability of the approach	
Which actors would be better suited to carrying out a WWCS in the long term?	
KII 5	NGO – Piloted weather-climate services
- Could you explain how did your pilot with weather stations work? - In your intervention with weather stations, where were the major challenges? - What would you identify as key success factors? - Which actors were involved in the project? - Which farmer activities could be supported through WWCS? - What should be needed to ensure long-term sustainability of such an approach?	
KII 6	NGO – Piloted climate services with crop insurance company
- In your intervention with weather stations, where were the major challenges? - What would you identify as key success factors? - Which actors were involved in the project? - Which farmer activities could be supported through WWCS? - What should be needed to ensure long-term sustainability of such an approach?	
KII 7	NGO – EWS1294 implementer
- EWS-1294 is reported to be a successful example of the implementation of the WWCS to address a natural hazard. Could you explain the factors that contributed to this achievement? - EWS1294 began with flood hazards, and now, in some provinces, they use it to monitor drought and storm hazards with weather forecasting. What additional types of hazards could it cover? - What are the remaining challenges? - How can long-term ownership of such an approach be ensured?	
KII 8	Private company – developing climate services with weather indexed crop insurance
- Could you explain how the technology you are currently developing will work? - What are the challenges that you are facing? - Which actors were involved in the project? - How have you assessed the farmer activities could be supported through WWCS? - What is the long-term perspective of the solution?	

**Note that these are only guiding questions. Follow-up questions were asked during the semi-structured interview.*

Appendix H: Summary of key topics* (and related sub-topics) for the moderation of FGDs

FGD A	FWUC Committee Beng Commune
FGD B	FWUC Committee in Ou'Angkong Commune
Climate Hazards Affecting Agriculture Key weather- and climate-related hazards impacting agricultural production in the FWUC area.	
Current Use of Weather Information - Access to weather information and services. - Level of trust in weather information and ease of application in farming practices. - Awareness and use of existing digital tools (e.g. Tonlé Sap, Chamka App, Khmer Smart Farm).	
Potential of Weather–Water–Climate Services (WWCS) - Additional hazards for which farmers need better information. - Farming activities that could benefit from weather-based, tailored recommendations. - Existing use of crop insurance among farmers.	
Barriers and Enabling Factors for WWCS Adoption - Willingness to pay for precise, farm-specific weather information and recommendations. - Readiness to change farming practices (e.g. irrigation scheduling) based on new technologies. - Key factors needed to build farmers' trust in weather-related technologies.	

**Note that these are only guiding topics. Follow-up questions were asked during the discussion.*

Appendix I: Mapping of current weather and climate services related to the agricultural sector available in Cambodia

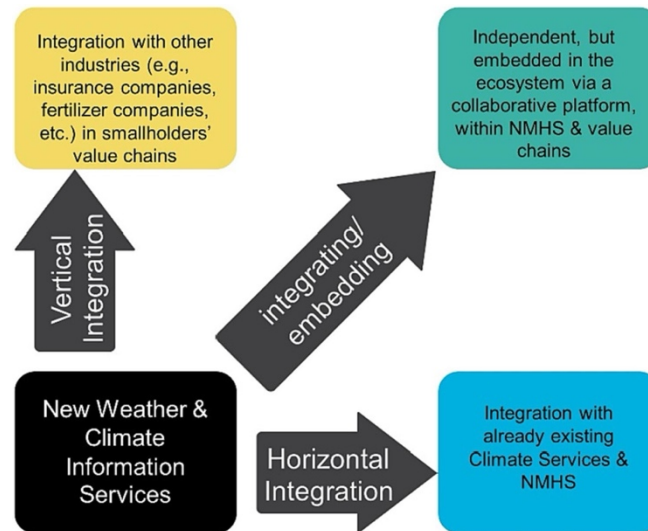
Name	Service type	Supplier category	Supplier Name	Primary users	Geographic scope	Deliver type	Data Source	Development stage	References*
MOWRAM Weather	Weather forecast	National Government	MOWRAM	Broad publicum (not sector specific)	National	Website; Mobile App; Social media	National weather stations network & weather radar	Broad use possible	1;2;3
EWS1294	Early Warning System	National Government & INGO	NCDM PIN ActionAid	Broad publicum (not sector specific)	National	Urban speaker; Radio; Voice call; SMS service; (Mobile App without alert)	Flood sensor & diverse source for other hazards	Broad use possible	4;5
Chamka App	- Agricultural technical knowledge; - Extension and technical support chat; - Virtual marketplace; - Weather forecasting; - Agromet bulletin	National Government & private sector	MAFF Bronx technology	Farmers; Agribusiness	Selected locations in Cambodia	Mobile App	National weather stations network	Broad use possible	6;7;8;9
Khmer Smart Farming	- Agricultural technical knowledge; - EWS1294; - Weather forecast;	INGO	DanChurchAid	Farmers; Agribusiness	Selected locations in Cambodia	Mobile App	NA	Broad use possible; limited functionality	10;11
SESAME	- Weather forecast; - Climate seasonal outlook; - Agromet bulletin; - Crop pest alert	Inter-governmental institution	Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES)	Farmers	National (Agromet bulletin only selected locations)	Web based platform; (Mobile App)	NA	Web based platform with restricted access; (Mobile App not available)	12;13;14
SmartFarm Solution	- Farm process data management; - Weather forecast;	Private sector (agritech company)	CropIn Technologies	Farmers; Agribusiness	National (in Cambodia and other 20 countries)	Web based platform;	Satellite data	Commercial stage (need subscription)	15;16
Tonle Sap	- Agricultural technical knowledge; - Market information; - Access to loans; - Input-supplier connections; - Weather forecast	Private sector (financial institution)	AMK Microfinance Institution Plc.	Farmers; Agribusiness	Selected locations in Cambodia	Mobile App	NA	Commercial stage (broad use, use locally)	17;18
WFP Seasonal Monitoring	Monthly weather and climate bulletin	Multilateral Organization	WFP	Development partners in agriculture sector	National	Website	Remote sensing data	Available	19

***References to the mapping on climate services**

	Source	Link	Last visited
1	GooglePlay – MOWRAM Weather (CamMob)	https://play.google.com/store/apps/details?id=com.cammob.weather.mowram&hl=en	04.01.2026
2	Facebook – MOWRAM Weather	https://www.facebook.com/mowramcambodia/	04.01.2026
3	MOWRAM Weather	http://www.cambodiameteo.com/map?menu=3&lang=en	04.01.2026
4	PIN EWS1294	https://resources.peopleinneed.net/documents/1055-1.pdf	04.01.2026
5	EWS1294	https://ews1294.org/	04.01.2026
6	FAO DVI Databank – Digital Solution	https://dvi-ke.fao.org/digital_solutions_details.php?id=306	04.01.2026
7	Growth Asia Digital Directory - Chamka	https://directory.growasia.org/chamka/	04.01.2026
8	GooglePlay – Chamka (BRONX Technology)	https://play.google.com/store/apps/details?id=com.bronx.chamka&hl=en&gl=US	04.01.2026
9	Chamka App	https://appchamka.com/#	04.01.2026
10	FAO DVI Databank – Digital Solution	https://dvi-ke.fao.org/digital_solutions_details.php?id=300	04.01.2026
11	AppStore – Khmer Smart Farming (Folkenkirkens Noedhjaelp)	https://apps.apple.com/us/app/khmer-smart-farming/id1478873113	04.01.2026
12	FAO DVI Databank – Digital Solution	https://dvi-ke.fao.org/digital_solutions_details.php?id=466	04.01.2026
13	RIMES (2020) Specialized Expert System for Agro-Meteorological Early Warning (SESAME) – Expert User Guide	https://www.adaptation-undp.org/sites/default/files/resources/5_annex_4_sesame_guide_for_cambodia.pdf	04.01.2026
14	RIMES - Specialized Expert System for Agro-Meteorological Early Warning (SESAME)	https://rimes.int/specialized-expert-system-agro-meteorological-early-warning-climate-resilient	04.01.2026
15	FAO DVI Databank – Digital Solution	https://dvi-ke.fao.org/digital_solutions_details.php?id=310	04.01.2026
16	AppStore – SmartFarm (CropIn Technology Solutions Private Limited)	https://apps.apple.com/us/app/cropin-smartfarm/id1458577484	04.01.2026
17	FAO DVI Databank – Digital Solution	https://dvi-ke.fao.org/digital_solutions_details.php?id=302	04.01.2026
18	GooglePlay - Tonlesap App (AMK Microfinance Institution Plc)	https://play.google.com/store/apps/details?id=com.tonlesap.cambodia&hl=en	04.01.2026
19	World Food Programme – Seasonal Monitoring in Cambodia	https://www.wfp.org/publications/seasonal-monitoring-cambodia	04.01.2026

Additional to the above-mentioned services and solutions common commercial weather forecast providers that can be access through web or as (pre-installed) app on the smartphone are available in Cambodia. Available in Khmer language, however, is only one app called “Khmer Weather Forecast” (<https://play.google.com/store/apps/details?id=com.kode4u.khmerweather&hl=en>, last visited on 04.01.2026).

Appendix J: Potential commercialization pathways for climate services for smallholder farmers in the Global South according to Paparrizos et al. (2023):



“Three main potential commercialization pathways came forward:

- **Horizontal integration:** integration of the Weather and Climate Information Services (WCIS) projects that are being developed with already existing weather and climate information services and/or NMHS. This is a collaboration/integration with other WCIS/partners who offer climate and weather information.
- **Vertical integration:** integration of WCIS projects with other industries. This includes integration with partners in the value chains of smallholder farmers. Potential partners include insurance companies, banks, fertilizer companies, but also potentially the middleman/buyer of crops. This is a collaboration/integration with other actors offering products and services to smallholder farmers.
- **Mix:** a mix of the two scenarios described above where the developed service becomes an independent company and seeks integration with NMHS and the value chain, without becoming dependent on either. In this scenario, the WCIS would be embedded in the eco-system in such way that it fits the specific context of a certain region.”

Source: Paparrizos S., Baggen Y., van Dalen M., Ploum L., Ludwig F. (2023) Commercialization pathways for climate services for small holder farmers in the global South, *Climate Services* 30, <https://doi.org/10.1016/j.cliser.2023.100354>