International Journal of Climate Change Strategies and Management

1079

Received 19 May 2025
Revised 9 August 2025
Accepted 2 October 2025

Climate change and smallholder farmers in Northwest Syria: perceptions, impacts and the promise of climate-smart agriculture

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Abstract

Purpose – This study focuses on the climate changes affecting the livelihoods of smallholder farmers in the Northwest Syria (NWS), a largely overlooked topic to date. It aims to assess the impact of climate change and examine adaptation strategies, of which climate-smart agriculture (CSA) practices, in particular.

Design/methodology/approach – The study uses a mixed-methods approach, integrating primary data from 19 key informant interviews, a structured survey and three focus group discussions with farmers and relevant locals, with an analysis of 44 years of rainfall and temperature data, to assess climatic trends.

Findings – The study reveals a reduction of approximately 20 mm in precipitation and an increase of 0.5°C in temperature per decade, intensifying water scarcity and agricultural losses. Testimonies relating to climate change confirm severe economic impacts, including crop losses, reduced agriculture employment opportunities (particularly for women) and diminishing social solidarity. It also reveals little knowledge of CSA amongst farmers who are largely unaware of its objectives. Obstacles to CSA implementation include a lack of supportive policies, due to the conflict, limited access to climate-resilient technologies and insufficient communication channels.

Originality/value – To the best of the authors' knowledge, this study is the first comprehensive assessment of climate change in NWS, a context of conflict, with a weak institutional structure and no climate-focused agricultural extension services. It highlights the complex relationship between farmers' perceptions and climatic datasets by triangulating primary data with secondary climate data, emphasizing the urgent need to raise awareness of climate change and CSA practices and for additional studies and related policies.

Keywords NWS, Adaptation, Climate change, Small-scale farmer perception, CSA, Conflict

Paper type Research paper

1. Introduction

Climate change is among the most pressing global threats, particularly in semiarid and arid regions like the Middle East and North Africa (MENA), where rising temperatures, desertification and erratic rainfall patterns intensify existing vulnerabilities such as water scarcity and fragile governance (García, 2013; FAO, 2015; Elias *et al.*, 2019). These compounded risks undermine food security, disrupt ecosystems and threaten sustainable

International Journal of Climate Change Strategies and Management
Vol. 17 No. 1, 2025
pp. 1079-1096
Emerald Publishing Limited
1756-8692
DOI 10.1108/IJCCSM-05-2025-0139

rural development. The Syrian conflict, now in its postcrisis phase, has triggered the world's largest displacement crisis, with over 12 million forcibly displaced. The February 2023 earthquake further worsened conditions, affecting 8.8 million people and damaging critical infrastructure (OCHA, 2023). Armed conflict has also led to environmental degradation, though its full impact remains underexplored (Alhasan *et al.*, 2023).

Northwest Syria (NWS) faces severe food insecurity, with 3.7 million of 4.7 million people affected (OCHA, 2023). Climate pressures, economic instability and water scarcity, exacerbated by COVID-19 pandemic, heighten vulnerabilities in this agriculturally dependent region (FAO, 2022; IMMAP, 2022; Kelley *et al.*, 2015). Broader studies of the Near East and North Africa highlight that small-scale farmers here are highly vulnerable due to poor resource management, limited technology access and weak market engagement, resulting in low adaptive capacity (Marzin *et al.*, 2017; Szaboova, 2023).

Climate-smart agriculture (CSA) introduced by FAO in 2010, provides a framework balancing productivity, resilience and mitigation to address climate risks (FAO, 2015; World Bank, 2016; CGIAR, 2021; CCAFS, 2020; Läderach *et al.*, 2022; Jonathan *et al.*, 2022). While global CSA strategies emphasize context-specific approaches, their implementation in fragile, conflict-affected settings remains limited. Gender-responsive CSA is particularly important, as women farmers often face barriers such as limited access to land, credit and inputs, hindering their adoption of climate-smart practices. Addressing these barriers is essential for equitable and effective agricultural adaptation (FAO, World Bank and IFAD, 2015).

Most studies on climate change and agriculture rely on secondary data for modeling (Breisinger *et al.*, 2011; Al-Riffai *et al.*, 2012) or to assess its impacts on agriculture and social conflict (Ulker *et al.*, 2018; Gleick, 2014). Previous climate change-related research on Syria has explored the climate-conflict link related to migration (Abel *et al.*, 2019; Dinc and Eklund, 2023) whereas that on CSA has focused on conservation agriculture in Central Syria (Lalani *et al.*, 2018), and the effects of drought on irrigation in NWS (Atik *et al.*, 2024) but has not focused specifically on understanding smallholder farmers' perceptions of climate change and their awareness of CSA, particularly in conflict-affected areas like NWS.

This study addresses critical gaps by using a mixed-methods approach that integrates primary data from smallholder farmers and key informants with secondary climate data. It provides the first comprehensive assessment of climate change impacts and adaptation strategies among smallholders in NWS's conflict-affected context. The research tackles the urgent global challenge of climate change, which significantly affects ecosystems and key sectors, aligning with global efforts to transform agrifood systems toward sustainable development (FAO, 2020; Crippa *et al.*, 2021). The focus on Syria is due to its unique combination of water scarcity, droughts, economic deterioration and internal displacement, as documented in conflict studies (Gleick, 2014; Kelley *et al.*, 2015; Daoudy, 2020). Rapid population growth, unemployment and inequality further complicate the situation and contribute to political unrest. Smallholder farmers in developing countries like Syria are particularly vulnerable due to their dependence on agriculture and climate change impacts (FAO, 2022).

Previous research highlights the need for transformative approaches that address sociopolitical factors affecting CSA adoption (Chandra *et al.*, 2017; Ogunyiola *et al.*, 2022; Singh *et al.*, 2019; Ekpa *et al.*, 2021). Although global CSA studies offer valuable insights (FAO, 2021), few have specifically addressed the unique challenges faced by conflict-affected smallholder farmers in the MENA region. While existing research from Yemen and Sudan (CARPO, 2025; Elmakki, 2024) highlights institutional barriers, this study contributes empirical insights by presenting a comprehensive assessment of climate impacts on small-scale farmers in NWS and offering actionable guidance for inclusive, participatory adaptation policies urgently needed in areas where rain-fed agriculture and livelihoods remain highly vulnerable (Mesquita and Milhorance, 2019). It emphasizes on- and off-farm diversification through CSA, as climate threats intensify, and offer critical strategies to strengthen smallholder resilience and promote sustainable agriculture, grounded in the real experiences of farmers in fragile, conflict-affected contexts.

2. Theoretical framework

This study is conceptually grounded in the widely accepted vulnerability framework, which understands climate change impacts as the interaction between exposure, sensitivity and adaptive capacity (Smit and Wandel, 2006). In the context of smallholder farmers in conflict-affected regions like NWS, this framework helps to analyze how external shocks (e.g. climate variability, conflict, economic instability) interact with internal household and community characteristics (e.g. access to information, social capital, resources) to shape adaptive behaviors.

In addition, the study draws on the CSA conceptual framework developed by FAO (2010), which emphasizes the triple objectives of increasing productivity, enhancing resilience and reducing emissions. By assessing farmers' perceptions and implementation barriers, this research contributes to understanding how CSA can be tailored to fragile contexts where institutional and infrastructural support is limited.

3. Research methodology

3.1 Description of the study areas

The study was conducted in Al-Bab and A'zaz, two key agricultural districts of Aleppo Governorate in NWS (see Figure 1), each with distinct agroecological conditions crucial for local farming and livestock. Al-Bab, in Aleppo Governorate, covers 1,673 km^2 with a hot-summer Mediterranean climate; summers range 30–35°C, winters 4–9°C, and annual rainfall averages 300–400 mm, mainly in winter (Central Bureau of Statistics, 2010). Its economy depends heavily on agriculture but faces challenges like water scarcity, frequent droughts and degraded irrigation systems. A'zaz, covering 1,570 km^2, has similar climate conditions with summer temperatures of 32–37°C, winter 6–10°C, and comparable rainfall (Hatahet, 2021). Agriculture and livestock are main income sources, though seasonal water shortages affect productivity. These districts typify key agricultural challenges in NWS, especially water scarcity and climate change, with their postconflict context further intensifying these issues, making them ideal for studying combined climatic and sociopolitical impacts.

3.2 Data collection methods

This study used a mixed-methods approach, integrating both primary and secondary data. Primary data were collected through a structured survey questionnaire using Kobo forms, generating 412 responses from farmers, complemented by 19 key informant interviews (KIIs) with community leaders, meteorologists, academics and local authority representatives, and three focus group discussions (FGDs) in the study areas, with 15–20 stakeholders, including farmers and other local representatives, enabling in-depth insights into adaptation strategies in Al-Bab and A'zaz. The quantitative survey provided data on climate impacts and adaptation, while the qualitative KIIs and FGDs explored socioeconomic and contextual factors. Secondary data was drawn from relevant climatic, demographic and agricultural records. This mixed-methods design was chosen for its ability to comprehensively address the research question (Zachariadis *et al.*, 2013).

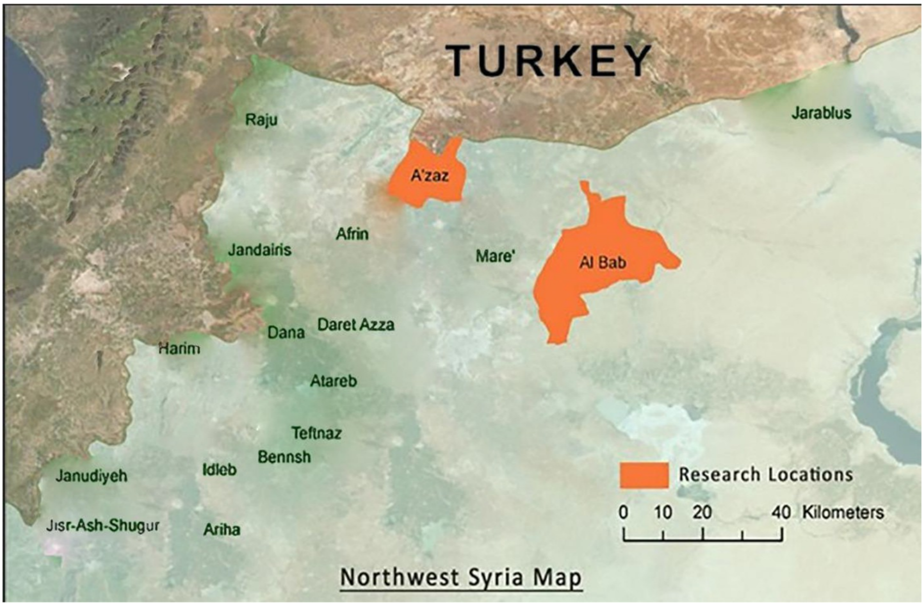


Figure 1. Location map of the research sites in NorthWest Syria (NWS)
Source: Authors' own creation

The survey sample size was determined using the following formula: $S = Z^2 \times P \times (1 - P)/M^2$, where S = required sample size; Z = Z-score corresponding to the desired confidence level (95%, $Z = 1.96$); p = assumed population proportion (50% or 0.5, maximizing sample size for variability); and M = margin of error (5% or 0.05). The 412 survey respondents represent 4.12% of the estimated 10,000 farmers in Al-Bab and A'zaz, ensuring statistical validity with a 95% confidence level and 5% margin of error, an acceptable range for rural social research (Creswell, 2013).

The primary data collection tools included open-ended questions on weather changes, extreme events (e.g. droughts, floods), crop production shifts, socioeconomic impacts, coping strategies and adaptation barriers, as well as local authorities' and stakeholders' policies. Farmers' perceptions on climate change were compared with secondary climatic data on rainfall and temperature gathered monthly, from 1979 to 2022, by the International Center for Agricultural Research in the Dry Areas (ICARDA).

The survey methodology required farmers to complete questionnaires, supported by trained data collectors, both male and female agricultural engineers from local communities, to maintain trust and ensure safety.

Given the conflict context, it is also important to consider that potential recall bias or respondent hesitancy may affect data quality, as has been noted in similar postconflict research (e.g. Moreno-Serra *et al.*, 2022).

3.2.1 Ethical considerations. The research adhered to ethical standards for studies in conflict-affected areas (Groves-Williams *et al.*, 2021), prioritizing participant safety and well-being. Ethical approval was granted by the University of Lincoln (Ethics Reference: UoL2022_10849), and informed consent was obtained after a clear explanation of the study's purpose and procedures, as well as notification of the right to withdraw at any time.

Anonymity and confidentiality were assured. Given the conflict context, some recall bias or respondent hesitancy may affect data quality, as noted in similar postconflict research (e.g. Moreno-Serra *et al.*, 2022).

3.3 Characteristics of the smallholder survey sample

Although the study aimed to sample a diverse group of male and female farmers to ensure broad representation and reliable findings, the final gender ratio was 89.9% male to 10.2% female, indicating a significant gender asymmetry in agricultural engagement in the study areas (Table 1). This disparity appears to be influenced by cultural norms prevalent in the region, which may limit women's involvement in agriculture and related practices. Respondents' ages varied, with 11.5% under 30 years, 56.5% ranging from 31 to 50 years of age and 32% aged 50 years or older.

3.4 Data analysis

The analysis integrated farmers' perceptions with climate data, enabling a comprehensive understanding of climate change impacts and adaptation responses in NWS.

A thematic ethnographic approach was adopted for the KII qualitative data to identify emerging themes linked to interviewees' perceptions of adaptive responses to climate change (Goodman, 2018). Initial inductive coding allowed themes to emerge from the data, which were subsequently refined and categorized using a CSA-based thematic framework, aligning with the analytical methods used in other adaptation-related literature. JMP and Microsoft Excel were used for the quantitative survey data, with frequency distributions visualized through histograms. This mixed-methods approach

Table 1. Sociodemographic characteristics of questionnaire respondents (n = 412)

Demographic characteristics percent of participants (n = 412)	No.	% of participants
Age		
Less than 30	46	11.5
Between 31 and 50	229	56.5
More than 50	137	32.0
Total	*412*	*100*
Education		
Illiterate	60	14.6
Primary	167	40.5
Elementary	101	24.5
Secondary	68	16.5
Higher education	16	3.9
Total	*412*	*100*
Gender		
Male	370	89.8
Female	42	10.2
Total	*412*	*100*
Residence type		
Host community	363	88.11
IDPs	49	11.89
Total	*412*	*100*

Source(s): Authors' own creation

allowed triangulation (Ebel *et al.*, 2018) to enhance the credibility and breadth of the study findings.

The Mann–Kendall test (Abghari *et al.*, 2012), a robust nonparametric method unaffected by missing data or outliers, was used for the ICARDA data set, which spanned from 1979 to 2022, to assess temperature and precipitation trends.

4. Results and discussion

This section presents the study findings through a CSA lens and vulnerability framework with the following six core components: exposure, sensitivity, adaptive capacity, productivity, resilience and mitigation.

4.1 Climate change exposure and sensitivity

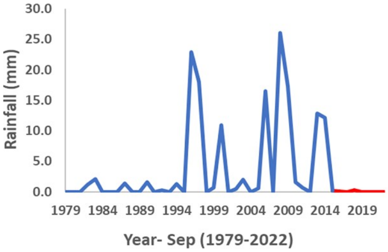
4.1.1 Farmers' perceptions of climate change. To assess interviewees' awareness of climate change, they were asked about significant weather changes observed over the past five years. As shown in Table 2, most reported irregular precipitation, decreased annual rainfall (99%), increased drought frequency (96%) and rising temperatures (73%). Secondary data confirmed the link between these observations and regional climate trends. Similar studies (Tesfaye and Seifu, 2016; Zeleke *et al.*, 2022) report comparable findings despite geographic differences. The majority of farmers who participated in the FGDs agreed that rising temperatures and reduced rainfall have harmed agriculture, with many groundwater depletion and worsening water scarcity. This has made weather predictions increasingly difficult. As noted by a female farmer from Al-Bab "The unpredictability of local weather has led to significant agricultural losses" which was echoed by a farmer from A'zaz "Current weather conditions are incomprehensible, and we hope someone can explain the cause of these losses."

4.1.2 Temperature and rainfall trends. The impact of climate change in NWS is increasingly evident through both local perceptions and long-term climatic data, yet uncertainties remain due to data scarcity and contextual factors. To address this, we compared primary data from KIIs, surveys and FGDs with ICARDA's historical climate records (1979–2022). Figure 2(a)–(d) illustrates marked shifts in seasonal precipitation patterns, particularly a decline in rainfall during the critical wheat and barley planting season (September–November), especially in October and November. Conversely, December shows a mild increase in rain, signaling a temporal shift in precipitation. Figure 2(e) further confirms this trend, showing a decline in annual rainfall from 365.9 mm in 1972 to 313.6 mm in 2022, a loss of approximately 20 mm per decade.

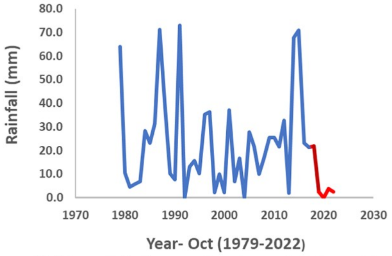
Table 2. Farmers' perception of climate change indicators in Northwest Syria

Farmers' perception of climate change	%
Irregular precipitation distribution	99
Decreasing annual precipitation	99
Increasing occurrence of drought	96
Increasing temperature above the general average	73
Increased occurrence of frost	49
Increasing storms	14
Dust storms	10
Floods	2

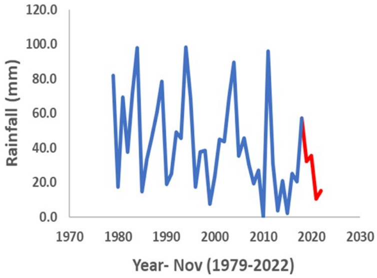
Source(s): Authors' own creation



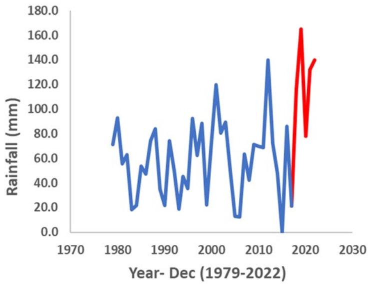
(a) Rainfall during Sep from 1979 to 2022



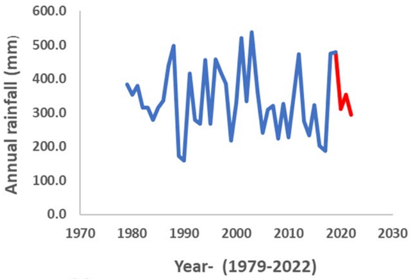
(b) Rainfall during Oct from 1979 to 2022



(c) Rainfall during Nov from 1979 to 2022



(d) Rainfall during Dec from 1979 to 2022

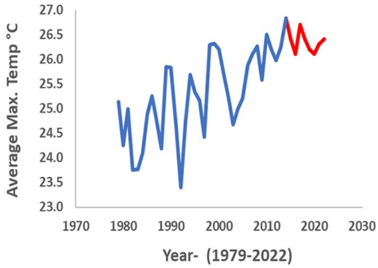


(e) Annual rainfall from 1979 to 2022

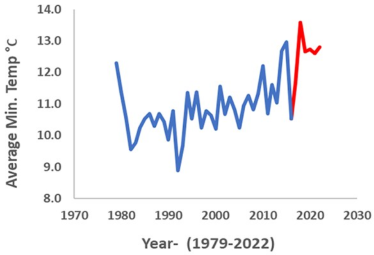
Figure 2. Analysis of annual rainfall trends based on ICARDA data (1979–2022)
Source: Authors' own creation

The results show that over the last four decades, the average annual temperature increased from 17.6°C in the early 1980s to 19.2°C in 2022, aligning with a regional warming trend. Figures 3(a)–(c) support this, showing a consistent rise in maximum, minimum and overall annual average temperatures.

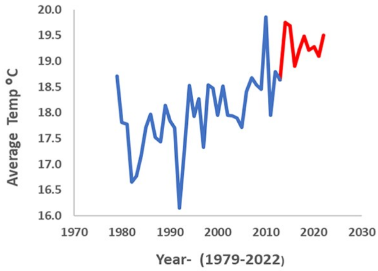
To further quantify these observed changes, we applied the Mann–Kendall test and Sen's slope estimates (Table 3). The results show statistically significant trends in both temperature and rainfall. Kendall's tau values of 0.552 and 0.463 for maximum and minimum temperatures, respectively, suggest robust upward trends. Sen's slope reveals a warming trend of +0.050°C/year (or 0.5°C per decade), while annual rainfall shows a negative slope of −2.085 mm/year, confirming long-term drying conditions. These findings align with global trends in semiarid regions (IPCC, 2019).



(a) Average Max temperature from 1979 to 2022



(b) Average Min temperature from 1979 to 2022



(c) Average annual temperature from 1979 to 2022

Figure 3. Trends in average maximum, minimum and annual temperatures (1979–2022)
Source: Authors' own creation

Table 3. Trends in temperature and rainfall based on Mann–Kendall test results

Climate parameters	Min.	Max.	Mean	SD	Kendall's tau	*p*-value	Sen's slope
Average max. temp °C	23.41	26.83	25.47	0.88	0.552	<0.0001**	0.050
Min. temp °C	8.89	13.58	11.08	1.03	0.463	<0.0001**	0.052
Avg. temp °C	16.15	19.86	18.25	0.85	0.567	<0.0001**	0.048
Annual rainfall mm/year	188.40	537.60	331.11	82.47	−0.258	0.014*	−2.085

Source(s): Authors' own creation

Farmers' perceptions closely align with actual climate data in NWS (Table 4). Most reported irregular precipitation (99%) and decreasing annual rainfall (99%), matching observed seasonal shifts and a long-term decline of about 20 mm per decade. Increased drought frequency (96%) and rising temperatures (73%) also correspond with recorded trends. Perceptions of frost, storms, dust storms and floods lack sufficient support from current data, mainly due to limited meteorological stations and climate monitoring, highlighting the need for enhanced data collection systems.

In the wider MENA region context, FAO (2022) projects a 1.7°C to 2.6°C temperature rise by 2100, with more severe warming (up to 4.8°C) in specific areas. Precipitation is expected to decline further, coupled with rising seasonal variability and an anticipated 150% increase in drought frequency by 2070. These predicted changes resonate with the study farmers' current perceptions (Table 2).

Table 4. Farmers' perceptions of climate change indicators compared to actual climate data in NorthWest Syria

Climate indicator	Farmers' perception (%)	Actual climate data	Notes
Irregular precipitation	99	Significant shifts in seasonal rainfall patterns (Sep–Nov), with decreases in Oct and Nov and slight increase in Dec	Strong alignment between perception and data
Decreasing annual precipitation	99	Annual rainfall declined from 365.9 mm (1972) to 313.6 mm (2022), approximately 20 mm loss per decade	High agreement
Increasing drought frequency	96	Supported by increased variability and long-term drying trends in rainfall	Confirmed by rainfall data
Rising temperatures	73	Average temperature increased by 0.5°C per decade (17.6°C in 1980s to 19.2°C in 2022)	Strong correlation between perception and data
Increased occurrence of frost	49	No precise data available in current study	Further investigation needed
Increasing storms	14	No clear evidence in available climate data	Possibly localized or intermittent events
Dust storms	10	No specific data reported	Unconfirmed
Floods	2	Not observed as a major phenomenon in climate data	Unconfirmed

Source(s): Authors' own creation

It is important to note that participants' perceptions may be influenced by recall bias (Moreno-Serra *et al.*, 2022) and sociopolitical factors arising from prolonged conflict (Atik *et al.*, 2024), which have also affected agricultural practices and contributed to traumatic experiences. Despite these challenges, the strong alignment between lived experiences and empirical data suggests that farmers can differentiate between conflict- and climate-driven environmental changes, providing valuable insights into the exposure and sensitivity components of vulnerability.

These findings underscore the urgent need for robust adaptation strategies in the agriculture sector of NWS. However, future research should address the current lack of local meteorological stations. The observed shifts in rainfall and temperature emphasize the high exposure and sensitivity of smallholder farmers, whose limited adaptive capacity, exacerbated by ongoing conflict and institutional fragility, directly impacts agricultural productivity and resilience, which are key aspects of the CSA framework.

4.1.3 Socioeconomic impacts on small-scale farmers. Rapid climate shifts in NWS have triggered serious economic and social repercussions for smallholder farmers. Respondents reported a decline in agricultural productivity and a rise in crop diseases, including fungal and insect infestations. These challenges have reduced yields and increased local food prices, adding financial pressure on already vulnerable farming households. Many Syrian families engaged in agriculture now face severe economic insecurity. According to FAO (2022), climate change has accelerated the country's economic collapse, notably through reduced wheat and barley yields. Some livestock breeders have been forced to sell their animals, while land degradation has led to widespread unemployment and migration in search of alternative livelihoods. FGDs reinforced these observations. Farmers cited recurring debt and heavy crop losses due to unusual frost events. A 30 year old farmer from A'zaz stated: "The frost in April caused a total loss of vegetable crops. Adapting to climate change requires costly changes to modern irrigation, different crops, or replanting." FGDs also revealed a perceived link between climatic changes and Syria's broader economic decline. The findings align with IMMAP (2022), which highlights climate change as a predominant and escalating challenge in the region over the past several decades, significantly affecting agricultural productivity and livelihoods.

Beyond economic impacts, the social fabric of farming communities has deteriorated. Declining employment, especially for women, has reduced household income and weakened traditional social solidarity. Internally displaced persons are particularly affected. A female farmer from Al-Bab shared: "I can no longer work due to the lack of agricultural jobs where I used to participate in harvest seasons." Similarly, a 55 year old woman from A'zaz explained: "We used to support one another, but poverty has made that impossible." These intertwined economic and social challenges reflect high exposure and sensitivity within the vulnerability framework, compounded by limited adaptive capacity due to ongoing conflict and institutional fragility. The observed impacts directly undermine agricultural productivity and community resilience, highlighting the urgent need for climate-resilient interventions that are gender-sensitive and tailored to the realities of smallholder farmers in NWS.

4.2 Adaptive capacity and resilience strategies

4.2.1 Sources of climate information. Access to reliable climatic information is essential for developing effective adaptation strategies in NWS. Findings indicate that most farmers rely on local authorities, NGOs, social media and agricultural associations for weather updates. However, the lack of advanced meteorological infrastructure and official communication platforms, such as radio poses significant barriers. Individual experts play a critical role, often depending on data from neighboring countries like Turkey. One expert explained: "We rely on the Adana balloon for data and share information with farmers via personal Facebook pages, without external support." This reliance on informal sources mirrors patterns observed in other low-resource settings, where weak infrastructure and limited institutional support hinder access to accurate climate services (Tazeze *et al.*, 2012; Zeleke *et al.*, 2022). Sedtha *et al.* (2023) similarly found that 88.2% of respondents depended on multiple channels for climate information. These findings emphasize the need to invest in structured, context-sensitive communication systems. Establishing official platforms such as radio broadcasts or mobile alerts would enhance the dissemination of forecasts, early warnings and agricultural advice, enabling farmers to implement timely and effective adaptation strategies.

4.2.2 Local adaptation strategies. To assess the relevance and effectiveness of current adaptive strategies among smallholder farmers in the two study subdistricts, we analyzed primary data against environmental challenges, revealing a diverse range of adaptation measures being used to address the challenges posed by climate change (see Figure 4), with farmers drawing on indigenous knowledge and practical experience.

Survey results show that 85% of farmers had modified their planting schedules to mitigate the impacts of delayed rainfall and extended droughts, and to enhance sustainability in water use. These included the adoption of water harvesting techniques (80%), the use of greywater for irrigation (75%), the deepening of wells (75%) and, for the few who were able to afford it, the adoption of solar-powered irrigation systems (20%). Many farmers also reported the selection of climate-resilient crop varieties to reduce production risks and pest pressures, and to improve stability of yields. While strategies such as the deepening of wells and use of grey

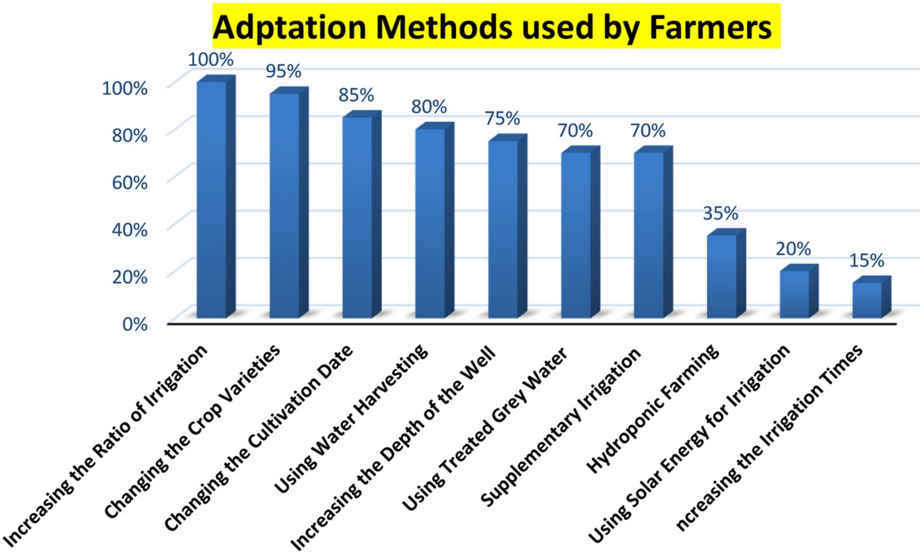


Figure 4. Climate change adaptation strategy
Source: Authors' own creation

water might be beneficial in the short term, they would contribute to groundwater depletion and potential environmental contamination, if not properly managed.

These measures reflect farmers' efforts to align their agricultural practices with environmental realities. Despite little or no formal knowledge of CSA, farmers are instinctively adopted CSA practices, a finding that aligns with similar research from Eastern Ethiopia (Zeleke *et al.*, 2022) and South Asia (Wang *et al.*, 2017).

While some adaptive responses have increased resilience, others may be considered maladaptive, requiring technical support and guidance to avoid long-term harm. However, limited access to technical knowledge and financial resources hinders the formal widespread adoption of CSA in NWS. Crucially, the loss of agricultural extension services in NWS and the broader knowledge economy, due to the protracted conflict, has severely undermined the dissemination of CSA innovations and the capacity of farmers to adopt new practices. While relatively small farmers reported benefiting from NGO-led training programs, many others have abandoned or leased their lands, and in some cases migrated to urban areas.

4.3 Barriers to the adoption of climate-smart agriculture practices

Findings indicate that farmers would likely be willing to adopt climate adaptation practices, many of which reflect their indigenous practices, but lack institutional financial and other support. As illustrated in Figure 5, nearly 90% of smallholder farmers surveyed reported no awareness of CSA or its core principles, including agriculture's role in greenhouse gas emissions and the importance of mitigation. In addition, 60% of respondents lacked basic knowledge of climate change itself, indicating a broader deficit in environmental literacy. Similarly, 90% of farmers reported no access to awareness-raising campaigns or agricultural extension services. Local authority representatives interviewed, confirmed this, citing persistent funding limitations and a shortage of qualified staff in climate and environmental sciences. One remarked: "I have not received any training on this approach [CSA], and there

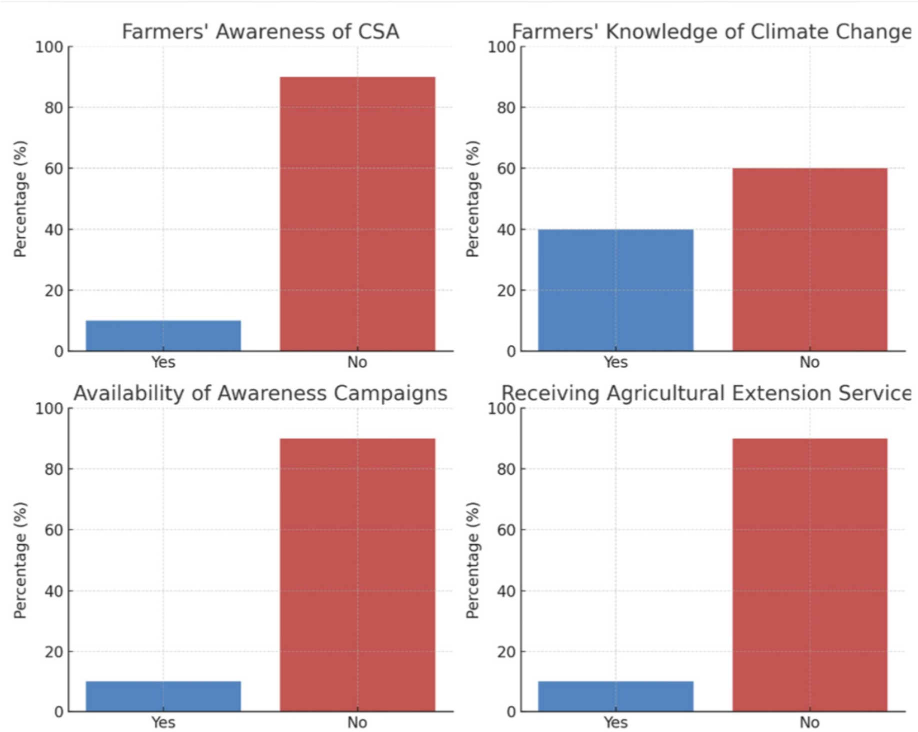


Figure 5. Barriers to adopting climate-smart agriculture (CSA) practices
Source: Author's own creation

are no academic or official institutions specializing in it […] our knowledge about this approach is almost non-existent." About 95% of farmers also stated that they had never received specialized training on climate risk management nor resilience-building, leaving them vulnerable to extreme weather events and without institutional support.

These challenges are compounded by the lack of local climate policies, early warning systems and dedicated climate institutions, gaps rooted in years of instability, shifting donor priorities and limited human and financial capacity. These challenges align with previous studies on comparable countries (Zeleke *et al.*, 2022; Sanga *et al.*, 2013; Waithaka *et al.*, 2007; Nyasimi *et al.*, 2017), which highlight that adoption of CSA practices is shaped by several interrelated factors: perceived benefits; access to information and technical skills; and ability to address implementation challenges, e.g. labor and capital.

The institutional gaps identified in NWS are deeply rooted in the prolonged conflict in Syria, which has severely damaged agricultural infrastructure, weakened extension services and disrupted the dissemination of agricultural knowledge and innovation, thereby significantly limiting the capacity of farmers to adopt and implement CSA practices (FAO, 2017).

5. Conclusion

This study assessed the effects of climate change on agriculture in NWS and smallholder farmers in Al-Bab and A'zaz subdistricts, combining primary data from interviews, a survey and FGDs, with long-term climatic data. Analysis of four decades of temperature and precipitation records shows a consistent rise in annual temperatures and a decline in rainfall during key cropping seasons. Analysis of the primary data demonstrated a broad awareness of long-term climate trends, albeit a limited understanding of its longer-term impact and the most effective adaptation strategies.

Although the majority of farmers commonly attributed increased plant diseases, declining yields and rising commodity prices to climate change, these were also linked to the ongoing conflict, which has severely damaged or destroyed critical infrastructure, reducing access to agricultural inputs and disrupted markets. This overlap highlights the difficulty of disentangling the impacts of climate change from those of the conflict. Nevertheless, it is crucial for farmers to build their understanding of climate-related risks, as sustainable adaptation will be integral to addressing both climate pressures and the structural challenges caused by years of instability.

Despite the challenges faced, including the absence of meteorological stations and weather reports, with farmers having to rely on social media and other informal sources of expertise, they have demonstrated their resilience through a range of adaptation strategies, although limited by constrained financial resources and a lack of local institutional support. Efforts to support the widespread adoption of CSA in NWS, face considerable barriers, not least due to the foundational CSA-related knowledge gaps amongst smallholder farmers in terms of the concept and its objectives, but the wider lack of awareness amongst local authorities that should be the drivers of awareness-raising campaigns and training programs.

These contextual realities, that include a weak local government, and consequent lack of centralized climate-related policies, inadequate access to modern technologies and the lack of formal communication systems, through which to access weather information, continue to confound the formal adoption of CSA in the two study areas.

The study findings have important implications for public policy and donor engagement. Integrating CSA strategies into local and national policies can help to enhance adoption of CSA practices, boosting resilience and reducing climate risks. The role of coordinated donor support and improved governance is critical to overcoming fragmented efforts and limited resources.

The study recommends that authorities coordinate efforts with agricultural institutions and international partners. Priority actions include establishing meteorological stations, investing in advanced climate-monitoring systems and the development and delivery of awareness-raising campaigns and training programs, initiatives that will both inform and empower smallholder farmers, as well as promote sustainable agriculture and build rural livelihood resilience in the region. Strengthening institutional capacities and investing in digital advisory platforms and extension services will also enable farmers to access timely and accurate climate information, fostering informed decision-making. This underscores the urgent need for targeted policy frameworks, enhanced data collection and institutional support to enable effective adaptation and mitigation in NWS.

Special emphasis should be placed on gender-inclusive adaptation approaches to empower women farmers, who are disproportionately affected by climate change and economic hardships. Evidence shows that gender-responsive climate action can strengthen community resilience and contribute to sustaining peace and stability, thereby reducing the risk of climate-induced displacement (UN Women, 2020).

Further investigation is essential to explore the socioeconomic consequences of climate change on vulnerable groups, particularly women in agriculture, to inform more effective and equitable policy responses. These should explore in greater depth the socioeconomic and gender dimensions to inform adaptation policies, strategies to improve the quality of life for smallholders and social cohesion in general. Addressing maladaptive practices, driven by the conflict, such as excessive reliance on greywater irrigation, is another area for further research and targeted interventions to ensure sustainable water management.

Acknowledgements

This research was supported by Cara (the Council for At-Risk Academics, http://www.cara.ngo), a UK charity, via a grant made through its Syria Programme. The authors would like to sincerely thank Cara staff, led by Mrs. Kate Robertson, for their unwavering support and insightful feedback. Special thanks are extended to Dr. Jonathan W. Bridge, Department of the Natural and Built Environment, Sheffield Hallam University, UK, for his expert guidance, invaluable advice, and continuous mentorship. We also thank the field research team for their dedication in collecting the data across northwest Syria, which was essential for this study.

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