



From Dry Fields To Smart Resilience: Climate-Smart Agriculture, Digital Early-Warning Systems And Household Food Security In Chivi District, Zimbabwe

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Abstract: This paper examines how climate-smart agriculture (CSA) and digital early-warning systems can jointly support household food-security resilience in Chivi District, a drought-prone area of south-eastern Zimbabwe dominated by rain-fed smallholder agriculture. Using a structured qualitative evidence synthesis with a district-centred case orientation, the study reviews 47 academic, policy and institutional sources published from 2021 to 14 September 2026. The study prioritises direct Chivi evidence, while using Zimbabwean, southern African, and wider African evidence comparatively where district-specific studies are limited. The synthesis identifies six interrelated themes concerning climate shocks, CSA adoption, small grains and water management, digital early warning, gender and institutional capacity, and integrated resilience. The findings indicate that CSA can strengthen food security when extension, inputs, finance, and markets support conservation agriculture, crop diversification, small grains, soil-fertility management, and water harvesting. However, digital early-warning information contributes to resilience only when it is timely, trusted, localised and translated into feasible action. Accordingly, the paper's principal contribution is an integrated smart-resilience framework centred on an information-to-action pathway: climate information can influence household food-security resilience only when farmers have viable adaptation options and the material, social and institutional capacity to act. The paper therefore treats digital information, agronomic adaptation, gender, household resources and local institutions as interdependent rather than separate interventions.

Keywords: Climate-Smart Agriculture, Digital Early-Warning Systems, Household Food Security, Small Grains, Chivi District, Zimbabwe, Sustainable Development Goals (SDGs)

1. Introduction

Climate change has become an everyday livelihood issue affecting rural households in semi-arid Zimbabwe and is no longer a distant environmental concern. Climate stress affects farming families in districts like Chivi as seasons shorten, dry spells occur within seasons, water availability declines, livestock are lost, crop yields become unstable, and dependence on food assistance increases. Southern Africa is a region highly vulnerable to rising temperatures, rainfall variability, and drought risks (IPCC, 2021, 2022), and global food-security assessments indicate a growing interaction between climate shocks and poverty, market volatility, and underinvestment in rural systems, which increases the probability of worsening food insecurity (FAO, 2023; FAO et al., 2024). Chivi District's geography in Zimbabwe's semi-arid production landscape, where rural livelihoods largely depend on rain-fed agriculture, makes it a strong case for studying rural climate resilience. The district relies heavily on rain-fed agriculture and small livestock, as well as remittances, casual labour, and local food markets. A study on climate adaptation in Chivi revealed that socio-economic status, gender, agricultural training, club membership, access to and control of land, and differential access to extension services, especially for female-headed households, influence climate adaptation (Belle, Mapingure and Owolabi, 2024). This makes Chivi a climate-risk site and a site for examining how technology, agriculture, gender, and local institutions influence household food security.

The need was further highlighted after the 2023/2024 El Niño seasonal drought, which significantly affected food production at national and subnational levels and strained food-security systems. Households in rural districts were particularly vulnerable during the drought because they depend on their own cereal production, with Zimbabwean livelihood assessments and international humanitarian reports signalling decreased food availability, lower household purchasing power, and increased demand for targeted assistance (ZimLAC, 2024; FEWS NET, 2024; UN OCHA, 2024; WFP, 2025). These conditions point to the importance of moving beyond short-term relief towards resilience strategies that help households anticipate, absorb and adapt to climate shocks (World Bank, 2024b). One such approach gaining traction is climate-smart agriculture (CSA), which seeks to increase productivity, build adaptive capacity and, where feasible, reduce emissions. Research conducted in Zimbabwe indicates that CSA practices can have positive effects on household welfare and food security; however, adoption does not occur automatically and depends on the availability of labour, land, knowledge, inputs, finance, extension support, and households' ability to combine practices in ways suited to local conditions (Mujeyi, Mudhara and Mutenje, 2021; Mujeyi, Mudhara and Mutenje, 2022; Kombat, Sarfatti and Fatunbi, 2021). For Chivi, this means CSA cannot be seen merely as a package imposed from outside, but as a series of flexible practices that need to be adapted to drought-prone terrain, household resources, and food cultures.

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Meanwhile, the concept of smart resilience is growing in relevance with the use of digital technologies, climate services, mobile platforms and early-warning systems to assist farmers' decision-making. Evidence from Africa indicates that climate information services are most effective when they are accessible, trusted, localised and coupled with practical advisory services that can guide farmers on the timing, type and management of crops and other farm activities, and help protect livestock during dry spells (AfDB, 2023; Nyoni et al., 2024; WMO, 2024). More recent Zimbabwe-focused work similarly stresses that digital tools deliver stronger benefits when they are embedded within supportive institutional ecosystems rather than deployed as isolated technologies (Choruma et al., 2026). Digital tools therefore need to be accompanied by extension officers, farmer groups, local-language communication, indigenous knowledge, and access to seeds, water and markets. Accordingly, this paper examines the relationship among climate-smart agriculture, digital early-warning systems and household food-security resilience in Chivi District. Rather than assuming that climate information or agricultural technologies generate resilience independently, the study focuses on the conditions under which households can convert information into feasible action. The overarching research question is therefore: How, and under what enabling conditions, can climate-smart agriculture and digital early-warning systems jointly enhance household food-security resilience in Chivi District, Zimbabwe? By addressing this question, the paper connects technology, agricultural adaptation, social inclusion and institutional capacity within a district-centred analytical framework (UN DESA, 2024; Government of Zimbabwe, 2021a; Government of Zimbabwe, 2024).

Existing Zimbabwean scholarship commonly examines CSA adoption, climate-information services, gendered adaptation, small-grain production and food-security monitoring as related but analytically separate areas. Moreover, direct Chivi-specific evidence remains fragmented: recent studies provide important insights into gendered adaptation constraints and millet-based livelihoods, yet they do not explain how digital early-warning information interacts with feasible agricultural responses and households' material capacity to act (Belle, Mapingure and Owolabi, 2024; Mabhandu and Sibanda, 2025). Therefore, this study's novelty lies in developing a district-level smart-resilience framework that integrates CSA and digital early-warning systems through an information-to-action pathway. Specifically, the framework explains that timely climate information can contribute to household food-security resilience only when farmers have viable adaptation options and the material, social, and institutional capacity to implement them. This integration moves beyond treating technology, agronomy, gender and institutions as parallel themes and instead specifies how they interact in the production of resilience. The overarching question is operationalised through three sub-questions. RQ1: What does recent evidence indicate about the contribution and limitations of climate-smart agriculture for household food-security resilience in drought-prone Chivi? RQ2: Through what information-to-action conditions can digital early-warning and climate-information services influence farm decision-making and household food-security resilience? RQ3: How do gender relations, household assets, extension access, markets, and institutional capacity condition households' ability to convert climate information and CSA options into action, and what integrated district-level resilience framework follows from this evidence?

2. Literature Review

2.1. Climate Stress, Rural Livelihoods and Household Food Security

Availability, access, utilisation, and stability all determine food security and are influenced by climate change. Drought affects crop and livestock yields, heat stress affects crops and livestock, water scarcity limits gardens and household consumption, and market shocks can make food unaffordable even when it is physically available. Globally, evidence shows rising losses from climate-related disasters in agriculture, while food-security reports link climate extremes to undernourishment, lost livelihoods, and reduced access to healthy diets (FAO, 2023; FAO et al., 2024; IPCC, 2022). These stresses are compounded in Zimbabwe, which is heavily dependent on rain-fed farming and maize as a staple food. Food security is a key climate-development issue in the World Bank's Zimbabwe climate analysis, given the country's reliance on maize, which is at risk under hotter, drier conditions, particularly in the southern lowveld (World Bank, 2024a). Districts like Chivi, which suffer from frequent drought, also have agriculture, water, livelihood and disaster risk management as priority areas for adaptation, as stated in the National Adaptation Plan (Government of Zimbabwe, 2024).

Low rainfall is not the sole driver of food insecurity in semi-arid Zimbabwe because poverty, inequitable access to productive assets, weak markets, input costs and limited livelihood diversification can compound household vulnerability. A study in Mwenzezi, another drought-prone district in southern Zimbabwe, shows that climate change affects household food security through crop failure, declining livestock condition and reduced capacity to maintain food security without adaptation and innovation (Muzerengi, Gandidzanwa and Chirubvu, 2023). The findings are relevant to Chivi because the two districts face comparable agro-ecological and livelihood stresses, although results should be transferred with caution. Results from the 2024 and 2025 rural livelihoods assessments show that drought and other shocks continue to exacerbate rural vulnerabilities and that emergency support needs to be combined with longer-term measures that build resilient livelihoods in Zimbabwe (ZimLAC, 2024; ZimLAC, 2025). These assessments are important because they refocus attention on climate as a household food-security and livelihood risk rather than only as a physical hazard.

2.2 Climate-Smart Agriculture and Resilient Smallholder Production

Climate-smart agriculture generally seeks to improve agricultural productivity sustainably, build adaptation and resilience, and, where feasible, minimise or avoid greenhouse-gas emissions. The adaptation and food-security dimensions are typically the most immediate in smallholder dryland farming systems because farmers are directly threatened by crop failure, declining pasture and water stress. Recent CSA studies show that, beyond technical knowledge, supportive institutions, finance, extension services, and farmer-centred scaling strategies are necessary for successful adoption (Kombat, Sarfatti and Fatunbi, 2021; Azadi et al., 2021; FAO, 2021). Evidence from Zimbabwe suggests that CSA can contribute to household welfare when farmers can implement suitable combinations of practices. Mujeyi, Mudhara and Mutenje (2021) found that CSA adoption in integrated crop-livestock systems is associated with improved household welfare, while adoption patterns vary by household type, with better-resourced farmers more able to adopt practices such as crop rotation and minimum tillage (Mujeyi, Mudhara and Mutenje, 2022). More recent national evidence also finds that CSA adoption and access to weather information can each improve food-security outcomes, while the intensity and combination of practices matter (Kairiza, Kembo and Chigusiwa, 2026). This evidence is relevant to Chivi because it cautions against assuming that all households can implement CSA in the same way.

CSA in Chivi should therefore be understood as a livelihood pathway rather than a set of narrowly defined technologies. Practices such as conservation agriculture, crop diversification, manure use, mulching, small grains, water harvesting, climate-smart livestock management and garden-based nutrition interventions may contribute to resilience, but they require labour, knowledge, inputs, land and timely advice (Mhlanga et al., 2022; Makuchete et al., 2024; Madzivanzira et al., 2024). Without these enabling conditions, CSA risks becoming a policy slogan rather than an effective pathway to household food security. The adoption issue is also political and social. Evidence from studies conducted in sub-Saharan Africa shows that CSA adoption is influenced by land tenure, access to incentives, extension-service quality, income, education, farmer networks and trust in institutions (Jellason, Conway and Baines, 2021; Shittu et al., 2021; Ngoma et al., 2021). For Chivi, this means resilience interventions need to consider who owns land, who receives training, who can afford seed, and who has the labour and time required for labour-intensive interventions.

2.3. Small Grains, Rainwater Management and Indigenous Knowledge

One of the central debates in Zimbabwe's dryland food-security policy is the continued reliance on maize in regions where rainfall is becoming increasingly unreliable. Maize is less well adapted to dry conditions than small grains such as sorghum, pearl millet and finger millet, which can also be culturally and nutritionally important. Recent literature has highlighted the potential of sorghum and pearl millet as climate-resilient crops for food and nutrition security in drylands; however, their success depends on seed systems, processing, markets and consumer acceptance (Chaturvedi et al., 2023; Madzivanzira et al., 2024; Makuchete et al., 2024). Chivi-specific evidence published in 2025 further reports that millet production can contribute to household food security and livelihoods, while labour intensity and input constraints remain important barriers (Mabhandu and Sibanda, 2025). Field evidence from Zimbabwe indicates that rainwater management, improved soil fertility and small-grain production can offer important advantages. Makuchete et al. (2024) demonstrate that in-field rainwater management can increase the productivity and economic returns of sorghum and millets, particularly on more productive soils, while degraded soils remain a major constraint. An important lesson for Chivi is that the benefits of crop diversification will be limited if small-grain promotion is not combined with soil-fertility management, water retention, and agronomic support.

Mechanisation and post-harvest systems are also important. Traditional grains can be labour-intensive to plant, weed, harvest, thresh and process, which may deter uptake, particularly among women and elderly household heads. Smallholder-appropriate mechanisation, processing, storage and labour-saving technologies should therefore be considered within resilience planning in Zimbabwe and sub-Saharan Africa, alongside production-focused interventions (Madzivanzira et al., 2024). Indigenous knowledge also remains important for dryland adaptation. Farmers often use local signs and knowledge of soil, livestock behaviour, crop history, and community memory to gauge seasonal risk, and these should not be treated as obsolete systems. Recent climate-services literature increasingly argues that scientific forecasts should be combined with local knowledge and participatory interpretation to make information relevant to farm decisions (Nyoni et al., 2024; Ofoegbu and New, 2022; Government of Zimbabwe, 2024).

2.4. Digital Early-Warning Systems and Climate Information Services

In agriculture, digital early-warning systems are becoming increasingly significant because they can translate climate data into information on dry spells, pests, food-security risk, heat stress, floods and rainfall onset. When used effectively, these systems can support early decisions on land preparation, crop selection, planting dates, input application, livestock movement and household food planning. Global and African climate-service reports emphasise that early warnings should be people-centred, impact-based and linked to action rather than limited to technical forecasts (WMO, 2024; UNDRR, 2023; FAO, 2023). Digital climate adaptation is especially relevant to Zimbabwe because mobile phones, radio, extension services, meteorological services, and humanitarian monitoring systems can fill information gaps in rural districts. SMS platforms, weather advisories and mapping tools can support climate-related agricultural decision-making (AfDB, 2023). Recent Zimbabwe-focused policy analysis also highlights mobile advisory platforms, climate-information services and digital financial services, while warning that low connectivity, affordability and digital literacy can reproduce existing inequalities if digitalisation is not deliberately inclusive (Choruma et al., 2026). These tools are of limited value unless they reach the appropriate people at the appropriate time and farmers have the means to act on the recommendations.

Systematic evidence from Africa indicates that human, social, physical, natural and financial capital influence access to climate information services. Access to and use of climate information are more likely among better-educated farmers, those with access to networks and phones, and those receiving agricultural support and possessing financial resources; vulnerable groups can therefore be left out when services assume literacy, connectivity or purchasing power (Nyoni et al., 2024; Khatibu et al., 2025). This is especially important in Chivi because households most vulnerable to drought may also be least able to access or act on digital information. Climate-risk information also needs to be linked to food-security monitoring within early-warning systems. New research on real-time food-security estimation points to the potential of combining mobile-phone data and face-to-face surveys to produce finer spatial estimates in Zimbabwe, while broader forecasting research illustrates the potential of real-time data to support anticipatory action before a food crisis worsens (Ishida et al., 2025; Herteux et al., 2024). This suggests that farmer advisories and district food-security surveillance should be considered together rather than as separate interventions.

2.5. Gender, Institutions and Inclusive Resilience

Climate vulnerability is gendered because men and women often have differential access to land, livestock, credit, extension services, phones, markets and decision-making power. In Chivi, evidence indicates that women's adoption of climate-change adaptation measures is shaped by age, marital status, agricultural training, membership in agricultural clubs and farm size, alongside gaps in extension services and socio-cultural barriers (Belle, Mapingure and Owolabi, 2024). This indicates that CSA interventions in Chivi need to be gender-responsive. The gender dimension matters because women often manage food production, water collection, care activities, and small-scale production, yet may have less access to land, income, and technology. Studies on CSA extension and gender gaps show that women can be disadvantaged when extension services, training programmes, and resources are geared toward male farmers or better-resourced farming households (Duffy et al., 2021; Delavallade et al., 2025). In Chivi, this means women, in particular, need direct access to digital early-warning information and trusted community-based communication channels. Whether adaptation is achieved also depends on the institutional setting. Climate-resilient agriculture, water management, disaster-risk reduction, and inclusive development are key

components of Zimbabwe's NDC, National Development Strategy, and National Adaptation Plan; however, implementation depends on district capacity, coordination, and finance (Government of Zimbabwe, 2021a; Government of Zimbabwe, 2021b; Government of Zimbabwe, 2024). Chivi therefore requires policy alignment alongside visible support through extension officers, local farmer groups, seed systems, boreholes, irrigation schemes and markets for resilient crops.

2.6. Critical Synthesis and Research-Gap Mapping

Across the literature, three tensions are evident. First, CSA studies report welfare and production benefits, but adoption research consistently shows that these benefits are conditional on assets, labour, finance, extension and institutional support. Second, climate-information studies demonstrate the potential of timely forecasts, yet last-mile barriers and the inability to act on information can neutralise that potential. Third, small-grain and gender studies show that technically suitable adaptations can still fail when markets, processing burdens, land access and decision-making power are ignored. The literature therefore supports neither a technology-only explanation nor an agriculture-only explanation of resilience. The gap is strongest at the district scale. Chivi-specific studies provide important evidence on women's adaptation decisions and, more recently, on millet production, but little work jointly examines CSA, digital early warning, household food security, gendered capacity, and district institutions. This paper addresses that gap through synthesis rather than primary-data claims: it asks how these evidence streams fit together and where the connections remain empirically untested in Chivi.

2.7. Theoretical Framework and Research Propositions

The guiding framework combines climate-smart agriculture, livelihood resilience and people-centred early-warning thinking within an explicit information-to-action logic. Household food-security resilience is understood as an outcome of interactions among climate exposure, livelihood vulnerability, adaptive options and the systems that enable or constrain action. In this formulation, neither information nor technology is sufficient on its own. Rather, resilience depends on whether ecological, technological, livelihood and institutional resources can be combined in ways that allow households to anticipate, absorb and adapt to climate stress (IPCC, 2022; FAO, 2023; World Bank, 2024a). The central theoretical mechanism is converting information into feasible action. Climate forecasts can shape decisions only when households understand and trust the information, perceive it as locally relevant, and have access to realistic response options. For example, a rainfall warning has limited practical value when a household lacks suitable seed, labour, water, finance or extension support. Consequently, co-production, local-language communication, farmer networks, extension linkages, and tailoring advisories to household resources are not peripheral delivery issues; they are mechanisms through which climate information becomes actionable (Nyoni et al., 2024; Ofoegbu and New, 2022; Khatibu et al., 2025).

Accordingly, the framework can be represented as a conditional pathway: climate hazards and livelihood vulnerability create food-security exposure; digital early-warning systems provide risk and timing information; households interpret that information through trust, experience and local knowledge; CSA provides a set of possible adaptation responses; and household assets, gender relations, extension, markets and institutions determine whether those responses are feasible. Food-security resilience is therefore expected to emerge from successfully converting credible information into timely and materially feasible action. This mechanism constitutes the principal theoretical link between digital early warning and CSA in the present study. Proposition 1: The adverse effect of climate shocks on household food security in Chivi is expected to be greater where households have lower adaptive capacity, including limited access to water, productive assets, livelihood diversification and institutional support (Muzerengi, Gandidzanwa and Chirubvu, 2023; ZimLAC, 2024; World Bank, 2024a).

Proposition 2: The contribution of CSA to household food-security resilience is conditional on households' ability to access complementary resources, particularly training, appropriate inputs, finance, water management, extension and viable markets (Mujeyi, Mudhara and Mutenje, 2021; Mujeyi, Mudhara and Mutenje, 2022; Kombat, Sarfatti and Fatunbi, 2021). Proposition 3: Digital early-warning systems influence household food-security resilience indirectly through an information-to-action mechanism; their contribution is expected to be stronger when advisories are timely, trusted, localised and linked to feasible household response options (AfDB, 2023; WMO, 2024; Nyoni et al., 2024; Choruma et al., 2026). Proposition 4: Gender relations, age, land access, farmer-group membership, digital literacy, household assets and extension access condition the information-to-action pathway by shaping both access to climate information and the capacity to implement recommended responses (Belle, Mapingure and Owolabi, 2024; Duffy et al., 2021; Nyoni et al., 2024). Proposition 5: District-level resilience is expected to be stronger when climate information, indigenous knowledge, extension, farmer organisations, CSA options, water systems, markets and social protection are institutionally coordinated than when these interventions operate in isolation (Government of Zimbabwe, 2024a; World Bank, 2024a; WMO, 2024).

3. Research Method

3.1. Research Design

This study employed a structured qualitative evidence synthesis with a district-centred case orientation. The purpose was not to estimate household food-security outcomes from new survey data, but to integrate recent academic and institutional evidence on the interaction among climate risk, agricultural adaptation, digital early warning, gender, and institutional capacity in Chivi. This designation is used deliberately because the manuscript does not claim to constitute a primary empirical case study; instead, Chivi functions as the focal analytical context through which heterogeneous secondary evidence is interpreted (Creswell and Creswell, 2023; Morgan, 2022). Chivi District was selected because it represents a drought-prone, rain-fed smallholder setting where climate risk, food insecurity, small-grain production, gendered adaptation, and institutional constraints intersect. Direct Chivi-specific studies were given the greatest contextual weight. However, because the district-level evidence base is limited, Zimbabwean studies and evidence from comparable southern African and wider African dryland settings were used to interpret mechanisms and contextual possibilities rather than to claim direct measurement of Chivi households (Belle, Mapingure and Owolabi, 2024; Mabhandu and Sibanda, 2025; Government of Zimbabwe, 2024; World Bank, 2024a).

3.2. Sources, Search Period And Eligibility Criteria

The evidence base comprised peer-reviewed journal articles, systematic reviews, international reports, Zimbabwean policy documents, climate-service studies, food-security assessments and development-agency publications published from January

2021 to 14 September 2026. Sources were eligible when they addressed one or more of the following: climate change or drought in Zimbabwe and comparable southern African drylands; climate-smart agriculture; digital early-warning systems or climate-information services; household food security; small grains or dryland farming; gender and adaptation; extension and digital inclusion; or Zimbabwean resilience policy. We prioritised direct evidence from Chivi District where available, followed by Zimbabwe-specific evidence, then regional comparative evidence. The final synthesis included 47 sources. Sources were excluded when they were published before 2021, duplicated another record, lacked a verifiable publication source, focused on contexts with weak analytical relevance to semi-arid smallholder farming, or did not contribute evidence to the research questions. We retained recent methodological sources where needed to explain qualitative document analysis and thematic synthesis. The post-2021 recency criterion was adopted to keep the review aligned with the rapidly changing climate, policy and digital-agriculture context; however, this decision also limits engagement with older foundational literature and is therefore treated as a methodological limitation rather than as evidence of comprehensiveness.

3.3. Search Strategy And Screening Procedure

The search was updated on 14 September 2026. Electronic searching used OpenAlex and Crossref-linked publisher records and was supplemented by targeted searches of official repositories and websites of the Government of Zimbabwe, Food and Nutrition Council/ZimLAC, FAO, WMO, UNDRR, World Bank and other development agencies. Search terms were combined in different forms and included: "Chivi District", "Masvingo", "Zimbabwe", "climate-smart agriculture", "climate resilient agriculture", "drought", "food security", "small grains", "sorghum", "millet", "rainwater harvesting", "digital early warning", "climate information services", "weather information", "gender", "extension" and "digital literacy". Screening proceeded through duplicate removal, title/abstract or executive-summary assessment, and full-text or full-record assessment against the eligibility criteria, followed by reference-list checking. Because the search record available for this synthesis did not retain complete numerical counts for each interim screening stage, no PRISMA-style flow numbers are reported; therefore, interpret the review as a structured qualitative synthesis rather than a systematic review claiming exhaustive retrieval. This limitation is made explicit to avoid overstating methodological reproducibility.

Table 1: Structured desk-review search and screening protocol

Review element	Procedure used in the manuscript
Search platforms	OpenAlex; Crossref-linked publisher records; targeted official repositories/websites of Government of Zimbabwe, Food and Nutrition Council/ZimLAC, FAO, WMO, UNDRR, World Bank and development agencies.
Search period	January 2021 to 14 September 2026.
Core search concepts	Chivi District/Masvingo/Zimbabwe combined with climate-smart agriculture, drought, food security, small grains, sorghum, millet, rainwater harvesting, digital early warning, climate information, weather information, gender, extension and digital literacy.
Inclusion	Recent peer-reviewed studies, systematic reviews, official policy documents and institutional assessments directly relevant to Chivi, Zimbabwe or comparable southern African dryland smallholder systems.
Exclusion	Duplicates; pre-2021 sources; unverifiable publications; sources with weak relevance to the research questions or semi-arid smallholder conditions.
Screening	Duplicate removal; title/abstract or executive-summary screening; full-text/full-record relevance assessment; final citation-reference reconciliation.
Final corpus	47 sources.
Coding	Six deductive theme families followed by inductive sub-theme development and triangulation across academic, policy and assessment sources.

Source: by the author

3.4. Data Analysis And Thematic Coding

We analysed the documents using thematic synthesis. First, we examined each source for evidence relevant to the research questions. Second, evidence was coded deductively under six initial categories: (1) climate shocks and household food security; (2) CSA practices, adoption and enabling conditions; (3) small grains, soil fertility and rainwater management; (4) digital early-warning and climate-information services; (5) gender, inclusion and institutional capacity; and (6) integrated resilience and policy coordination. Third, we developed recurring sub-themes inductively within these categories, including information trust, actionability, resource constraints, last-mile communication, labour burdens, market access, and institutional coordination. Finally, the study compared convergence, contradiction, and contextual differences across sources before linking themes to the research questions and the proposed framework. Thus, the six reporting themes were informed by the initial coding structure but were interpreted through cross-source comparison rather than treated as predetermined findings (Braun and Clarke, 2022; Morgan, 2022).

We prioritised triangulation across source types during analysis. Claims about drought and food insecurity were checked against climate reports, Zimbabwean livelihood assessments and food-security literature; claims about CSA were compared across Zimbabwean empirical studies, Chivi-specific studies and broader sub-Saharan African reviews; and claims about digital early warning were checked against climate-services research and technology-focused institutional reports (Mujeyi, Mudhara and Mutenje, 2021; AfDB, 2023; Nyoni et al., 2024; ZimLAC, 2024; ZimLAC, 2025; Choruma et al., 2026). Evidence was not treated as equivalent merely because it appeared in the corpus. Instead, direct Chivi evidence received the greatest weight for district-specific claims; Zimbabwean evidence was used for national contextual inference; regional evidence was used comparatively; and global or institutional evidence was used primarily for conceptual and policy support.

3.5. Evidence Hierarchy, Source Appraisal and Transferability

To strengthen interpretive transparency, the synthesis applied a contextual evidence hierarchy rather than a numerical quality score. Direct Chivi studies were treated as the strongest basis for claims about district conditions; Zimbabwe-specific empirical and policy evidence provided national contextual support; evidence from comparable southern African and wider African dryland settings was used to examine mechanisms and transferability; and global or multilateral sources were used to support

broader climate, food-security and early-warning principles. Peer-reviewed empirical studies and systematic reviews were prioritised for causal or behavioural claims, while policy and institutional reports were used primarily for current conditions, programme context and policy direction. Consequently, regional or global findings are not presented as direct observations of Chivi households unless district-specific evidence corroborates them.

Table 2: Contextual evidence hierarchy and transferability framework

Evidence level	Primary role in synthesis	Use for Chivi-specific claims	Interpretive caution
Direct Chivi evidence	District-specific empirical or contextual evidence	Primary basis	Limited number of recent studies; does not cover all wards or household groups
Zimbabwe-specific evidence	National empirical, policy and food-security context	Contextual support and plausible mechanisms	Not treated as direct measurement of Chivi households
Southern African / African comparative evidence	Comparison of CSA, climate-information and inclusion mechanisms	Transferability assessment	Contextual differences in institutions, markets and agro-ecology must be considered
Global / multilateral evidence	Conceptual principles, climate risk and policy guidance	Framework and policy support	Used cautiously for local inference

Source: the author

4. Findings

The findings below report cross-source analytical patterns rather than a second narrative summary of the literature. Each theme is interpreted according to the evidence hierarchy described above, with direct Chivi evidence distinguished from national and comparative evidence. Across the corpus, six interrelated patterns were identified: drought functions as a multidimensional household food-security shock; CSA offers practical adaptation options but remains resource-dependent; small grains and rainwater management are central to dryland adaptation but require agronomic and market support; digital early-warning systems are useful only when information becomes actionable; gendered and institutional inequalities shape the capacity to act; and these relationships converge in an integrated smart-resilience model. The findings therefore focus on conditions and mechanisms that connect information, adaptation options and household capacity rather than simply restating whether each intervention is beneficial (Mujeyi, Mudhara and Mutenje, 2021; Belle, Mapingure and Owolabi, 2024; Nyoni et al., 2024; ZimLAC, 2024).

4.1. Drought Is A Household Food-Security and Livelihood Shock

The first finding is that drought should be understood as a multidimensional household food-security shock rather than only as a precipitation deficit. Direct Chivi evidence on the full range of household responses remains limited; therefore, this interpretation combines district-specific adaptation evidence with Zimbabwean livelihood assessments and broader climate-risk evidence. Planting decisions, crop establishment, pasture availability, livestock health, access to water, casual labour and food prices can all be affected by climate stress, although the magnitude of these effects may vary across Chivi wards and household types (IPCC, 2022; IPCC, 2023; Belle, Mapingure and Owolabi, 2024). The 2024 and 2025 rural livelihoods assessments and humanitarian reporting show that drought and other shocks placed substantial pressure on food security in Zimbabwe, especially among rural households with low production potential and purchasing power (ZimLAC, 2024; ZimLAC, 2025; UN OCHA, 2024; WFP, 2025). For a drought-prone district such as Chivi, a failed maize season can plausibly reduce household food availability and increase reliance on remittances, asset sales or assistance; however, the desk-based design does not permit direct measurement of the scale of these responses within Chivi households. The literature also shows that structural vulnerability can exacerbate the impact of climate shocks. Poor households may be aware of the risk-reduction potential of small grains, mulching or water harvesting but still lack seed, labour, draught power, manure, cash, secure land or extension advice. The evidence therefore supports the broader proposition that food insecurity reflects an interaction between climate hazards and limited adaptive capacity rather than climate change alone (Muzerengi, Gandizanza and Chirubvu, 2023; World Bank, 2024a; Government of Zimbabwe, 2024).

4.2. CSA Offers Resilience, But Adoption Remains Uneven

The second finding is that CSA has clear resilience potential, but the reviewed evidence does not support treating its benefits as uniform across households. Zimbabwean studies provide the strongest empirical basis for the association between CSA adoption, welfare and food-security outcomes, while direct Chivi evidence is more limited. Accordingly, the district-level inference is conditional: CSA is most plausibly beneficial when households can assemble suitable combinations of practices and complementary resources rather than when a single practice is promoted in isolation (Mujeyi, Mudhara and Mutenje, 2021; Mujeyi, Mudhara and Mutenje, 2022; Kairiza, Kembo and Chigusiwa, 2026). For Chivi, the evidence suggests that resilience programmes should not be designed around a homogeneous farmer. A household with cattle, labour, land, a phone, extension contact and savings has a wider set of feasible adaptation options than a resource-poor, female-headed or elderly household with limited labour and poor access to inputs. Studies from sub-Saharan Africa report similar patterns, with CSA adoption linked to information, incentives, social networks, income, and institutional support (Kombat, Sarfatti and Fatunbi, 2021; Jellason, Conway and Baines, 2021; Shittu et al., 2021). The evidence also calls into question one-off input-distribution models. Seed packs and demonstrations may be insufficient if farmers lack markets, pest control, timely advice during dry periods or the means to maintain soil fertility. Across the reviewed sources, CSA performs more convincingly as a system of practices connected to finance, extension, water, markets and local knowledge than as a stand-alone technology package (FAO, 2021; Mhlanga et al., 2022; World Bank, 2024a).

4.3. Small Grains and Rainwater Management are Central to Dryland Resilience

The third finding is that small grains constitute an important, although not self-sufficient, component of dryland resilience. This theme is supported by both Zimbabwean agronomic evidence and direct Chivi-specific evidence on millet-based livelihoods. Sorghum, pearl millet and finger millet are generally more drought-tolerant than maize and can support dietary diversification; however, their contribution to household food security depends on seed access, labour, processing, soil fertility, water management, market opportunities and consumer acceptance (Chaturvedi et al., 2023; Makuchete et al., 2024; Mabhandu and Sibanda, 2025). The evidence also indicates that small grains are not a stand-alone solution to food insecurity. Their productivity depends on soil fertility, rainwater management, pest control, seed quality and farmers' knowledge. Makuchete et al. (2024) show that in-field rainwater management can boost sorghum and millet yields, while poor soils remain a constraint. The reviewed evidence therefore supports combining small-grain promotion with soil restoration, water harvesting and agronomic support. Small grains also need improved post-harvest and market systems. When maize does not perform well under drought, farmers may still prefer it if they cannot adopt labour-saving processing technologies, have no reliable buyers, or are offered no attractive prices. This is because mechanisation and value chain development are not just commercial challenges, but integral to climate resilience (Madzivanzira et al., 2024; FAO, 2022).

4.4. Digital Early-Warning Systems Can Support Farm Decisions But Face Last-Mile Barriers

The fourth finding is that digital early-warning systems can support resilience only when information is converted into decisions that households can realistically implement. Direct evidence evaluating digital early-warning effectiveness specifically in Chivi is scarce; therefore, this finding is principally a mechanism inferred from Zimbabwe-focused digital-agriculture analysis and African climate-services research. A useful warning must move beyond general forecasts and provide local, timely and actionable guidance, such as implications for planting dates, crop choice, water conservation, livestock protection or supplementary feeding (UNDRR, 2023; WMO, 2024; Nyoni et al., 2024; Choruma et al., 2026). Media for disseminating digital climate information in Zimbabwe include SMS, WhatsApp groups, radio, extension, community information centres, farmer groups, and district disaster-risk structures. The AfDB profile of Zimbabwe points to the potential of digital tools for climate adaptation, and African reviews indicate that digital tools are best integrated into the work of human agents – individuals like extension officers, farmer leaders and trusted local institutions (Nyoni et al., 2024; Ofoegbu and New, 2022; AfDB, 2023).

The so-called last-mile problem remains significant. Some households may lack smartphones, reliable network coverage or affordable airtime; language barriers can reduce comprehension; and messages may not be trusted when they conflict with local experience. Even when climate information arrives on time, farmers may be unable to act because they lack seed, water, labour or credit. Recent Zimbabwe-focused analysis similarly warns that low digital literacy, rural connectivity and affordability can constrain inclusive digital adoption (Ahmad, 2026; Ahmad, 2026; Adeel & Batool, 2026; Choruma et al., 2026). The evidence therefore links effective digital communication to material and institutional capacity (Nyoni et al., 2024; Khatibu et al., 2025; WMO, 2024). The reviewed literature also indicates potential for linking early-warning systems with food-security monitoring. Mobile and face-to-face data can support finer-grained food-security estimates in Zimbabwe, while forecasting research highlights the value of anticipatory action before conditions reach crisis levels (Ishida et al., 2025; Herteux et al., 2024). For district-level planning, this supports linking climate advisories, household-vulnerability mapping, and social-protection triggers, although the effectiveness of such integration in Chivi requires empirical testing.

4.5. Gender And Institutional Inequalities Shape Resilience Outcomes

The fifth finding is that social and institutional conditions strongly differentiate resilience outcomes. Here, Chivi-specific evidence is particularly important because it demonstrates that adaptation decisions among female-headed households are associated with training, age, marital status, club membership and farm size. When read alongside the broader gender and climate-services literature, this evidence suggests that access to information and the capacity to act on it are unevenly distributed across households (Belle, Mapingure and Owolabi, 2024; Duffy et al., 2021; Delavallade et al., 2025). Gender-responsive resilience requires more than making space for women in training activities. The reviewed evidence highlights the importance of direct access to climate information, appropriate training times, support for women's farmer groups, recognition of care burdens, and access to land, finance, and markets. Wider evidence on gender and CSA extension indicates that climate-smart systems can reproduce existing inequalities unless they are designed explicitly for women and poorer households (Duffy et al., 2021; Delavallade et al., 2025). Institutional coordination is another barrier. Zimbabwe has policies addressing climate change, development, and adaptation; however, at district level, limited budgets, staffing, and programme capacity, together with weak links between agriculture, meteorology, water, social welfare, and disaster-risk management, can constrain implementation. This policy-to-practice gap is recognised in wider climate-development planning literature and policy analysis (Government of Zimbabwe, 2021a; Government of Zimbabwe, 2024; World Bank, 2024a).

4.6. Towards An Integrated Smart-Resilience Model For Chivi

The sixth and final finding is an integrative inference rather than a directly tested district intervention. Across the reviewed evidence, resilience appears strongest conceptually when seasonal forecasts, indigenous knowledge, extension advice, farmer groups, drought-tolerant seed, soil-fertility management, water harvesting, livestock support, markets and social protection are connected rather than implemented as isolated measures. This synthesis therefore culminates in a smart-resilience model in which information must be translated into feasible action through material and institutional support (FAO, 2023; WMO, 2024; World Bank, 2024a). At a conceptual level, the model could be organised around ward-level climate and food-security platforms in which meteorological warnings are translated into Shona and locally relevant action messages; extension officers and lead farmers provide options; farmer clubs support peer learning; local authorities identify highly vulnerable households; and social-protection systems trigger action before productive assets are sold. This proposal draws on the reviewed evidence and is not presented as an empirically tested Chivi intervention. It aligns with people-centred early-warning principles, CSA scaling approaches, and Zimbabwe's adaptation-policy direction (Nyoni et al., 2024; UNDRR, 2023; Government of Zimbabwe, 2024).

5. Discussion

5.1. Interpretation In Relation to the Research Questions

In relation to RQ1, the synthesis indicates that CSA can contribute to household food-security resilience, but only under resource and institutional conditions that make adoption feasible. In relation to RQ2, digital early warning should not be understood as a substitute for farmers' knowledge or as a stand-alone technological intervention. Rather, its contribution depends on whether farmers trust scientific climate information, interpret it locally, and connect it to practical response options. In relation to RQ3, gender relations, household assets, extension access, markets and institutions condition this conversion process by shaping who receives information, who controls resources and who can implement recommended responses. Taken together, the three research questions converge on a single analytical mechanism: resilience depends on converting credible information into feasible action (Ofoegbu and New, 2022; Nyoni et al., 2024; Khatibu et al., 2025; Choruma et al., 2026). Regarding the first and second research questions, the evidence supports joint planning for CSA and digital early warning. CSA provides households with practical adaptation options, while early-warning systems can inform when and how to use those options. Forecast information about delayed planting is more useful when farmers can access short-season seed; dry-spell warnings are more useful when farmers know moisture-conservation techniques; and livestock warnings are more useful when households can access fodder, water points or veterinary services (Mujeyi, Mudhara and Mutenje, 2021; Makuchete et al., 2024; AfDB, 2023). Kairiza, Kembo and Chigusiwa (2026) similarly show at national level that CSA and weather information each contribute to food-security outcomes, reinforcing the value of analysing them together rather than separately.

A key theoretical implication is that climate-smart agriculture should be analysed through an inequality lens. The reviewed literature indicates that better-resourced households are generally more able to adopt CSA and use climate-information services, while poorer households may be expected to adapt without the resources required to act. The third research question therefore draws attention to who is included, who is excluded and what differentiated support is required for resilience (Belle, Mapingure and Owolabi, 2024; Nyoni et al., 2024; Delavallade et al., 2025). The evidence also highlights small grains as both a technical and socio-economic resilience resource. Sorghum and millets are better adapted than maize to many drought-prone environments, but their promotion also depends on taste, processing, labour, markets, seed access and social identity. In Chivi specifically, the 2025 millet study strengthens the case for treating small grains as part of household livelihood strategy rather than only as an agronomic substitution (Mabhandu and Sibanda, 2025). This supports an integrated approach that combines agronomy, value-chain development, and food-culture considerations (Chaturvedi et al., 2023; Madzivanzira et al., 2024; Makuchete et al., 2024).

5.2. Theoretical Contribution

The principal theoretical contribution is specifying smart resilience as a conditional information-to-action pathway. Existing CSA research explains the importance of adaptive practices, while climate-services research emphasises access, timeliness, trust and communication. This study connects these domains by proposing that digital early warning affects resilience through a sequence of interpretation and feasible response: climate information is received and interpreted; households assess its relevance and credibility; CSA or other livelihood responses provide possible actions; and household resources, gender relations, extension, markets and institutions determine whether those actions can be implemented. Thus, digital information does not directly produce resilience, and CSA does not automatically generate resilience. Their effects are interdependent and contingent on the social and material conditions that permit action. This mechanism provides a more specific explanation for why technically appropriate information or practices may fail to improve food security among resource-constrained households. From a policy perspective, this framework also clarifies the distinction between national policy alignment and district-level implementation. Zimbabwe's adaptation documents recognise climate-resilient agriculture, water management and early-warning systems; nevertheless, implementation depends on whether ward- and household-level actors receive locally relevant advisories, effective extension support, appropriate inputs, water infrastructure and targeted social protection (Government of Zimbabwe, 2021b; Government of Zimbabwe, 2024; World Bank, 2024a). The Chivi-specific contribution of the synthesis is therefore not a claim that the proposed interventions have already been proven locally. Instead, it integrates the available Chivi evidence on gender and small-grain livelihoods with national and regional evidence on CSA, climate information and digital agriculture to derive a testable district-level framework.

5.3. Practical and Policy Implications

The practical implications follow directly from the information-to-action pathway. First, district agricultural and meteorological actors should translate seasonal and short-term climate information into locally relevant farm options rather than distributing forecasts without decision guidance. Second, extension services and farmer organisations should assess whether households have the seed, labour, water, finance, and market access needed to implement recommended CSA responses; without these resources, information alone is unlikely to change outcomes. Third, digital delivery should be combined with radio, extension officers, farmer groups and local-language communication so that households with limited connectivity or digital literacy are not systematically excluded (Nyoni et al., 2024; Ofoegbu and New, 2022; Choruma et al., 2026). Finally, the framework has implications for cross-sector coordination. Agriculture, meteorology, water, disaster-risk management and social-protection actors should treat early warning as a trigger for coordinated anticipatory action rather than as a communication product alone. Such coordination could also support progress toward SDG 1, SDG 2, SDG 5, SDG 6, SDG 13 and SDG 15; however, the manuscript treats these SDG linkages as policy relevance rather than as outcomes directly measured by the present synthesis (UN DESA, 2024; FAO et al., 2024; Government of Zimbabwe, 2024). Furthermore, gender-responsive implementation should address access to land, information, training, finance and decision-making rather than treating women's attendance at training as sufficient inclusion. Small-grain promotion should similarly be linked to soil-fertility management, water harvesting, labour-saving processing, storage and viable markets. These measures matter because evidence shows that technically appropriate adaptations can remain unattractive or infeasible when labour burdens and value-chain constraints are ignored (Belle, Mapingure and Owolabi, 2024; Madzivanzira et al., 2024; Makuchete et al., 2024).

6. Limitations and Future Research

This study does not report new interviews, household survey data or direct observations from Chivi and is therefore limited by its reliance on secondary evidence. Household food security, digital access and CSA adoption may vary substantially between

wards, villages and household types. In addition, the corpus combines peer-reviewed studies, policy documents and institutional reports with different evidentiary purposes and levels of methodological detail. Although the analysis applied a contextual evidence hierarchy, it did not conduct a formal risk-of-bias score or meta-analysis. The post-2021 publication restriction may also exclude influential foundational studies, while the search approach may be affected by database coverage, publication availability and language or indexing bias. Furthermore, the authors did not report complete numerical counts for each interim screening stage, which limits reproducibility compared with a fully systematic review. The synthesis should therefore be interpreted as a structured, literature-based case analysis and conceptual contribution rather than as direct measurement of household outcomes or an exhaustive systematic review of Chivi (Creswell and Creswell, 2023; Morgan, 2022).

Future research should test the five propositions and the integrated smart-resilience framework using primary data. Specific priorities include: a ward-comparative household survey of CSA adoption, food-security outcomes and early-warning access; focus groups examining trust, indigenous knowledge and local-language communication; key-informant interviews with extension, meteorological, social-protection and local-government actors; gender-disaggregated analysis of device ownership, land access and decision-making; and longitudinal or quasi-experimental evaluation of whether timely climate advisories change farm decisions and food-security outcomes. Participatory mapping could also identify where early-warning communication channels fail within Chivi (Braun and Clarke, 2022; Belle, Mapingure and Owolabi, 2024).

7. Conclusions

This paper examined how recent evidence connects climate-smart agriculture and digital early-warning systems with household food-security resilience in Chivi District. The synthesis indicates that CSA can provide feasible adaptation options through small grains, conservation agriculture, rainwater management, and soil-fertility improvement, but their effectiveness depends on extension, inputs, finance, water, and markets. Likewise, digital early-warning systems can support farm decision-making only when information is timely, trusted, localised, and linked to actions that households can materially implement. Because the study is based on heterogeneous secondary evidence, these conclusions are evidence-informed propositions rather than direct measurements of Chivi households. The main contribution is therefore theoretical and integrative: the proposed smart-resilience framework explains resilience through an information-to-action pathway in which climate information, interpretation, feasible CSA responses, household resources, gender relations, extension, markets and institutions operate as interdependent components. This formulation also clarifies why access to information alone is insufficient when households lack the capacity to act. Future primary research in Chivi should test the framework across wards and household types, with particular attention to whether access to early warnings changes farm decisions, how gender and resource inequalities affect the ability to act, and which combinations of CSA, market, water and social-protection support produce measurable food-security gains.

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References

- African Development Bank. (2023). *Digital climate adaptation in agriculture profile for Zimbabwe*. African Development Bank.
- Azadi, H., Movahhed Moghaddam, S., Burkart, S., Mahmoudi, H., Van Passel, S., Kurban, A., & Lopez-Carr, D. (2021). Rethinking resilient agriculture: From climate-smart agriculture to vulnerable-smart agriculture. *Journal of Cleaner Production*, 319, 128602. <https://doi.org/10.1016/j.jclepro.2021.128602>
- Ahmad, I. (2026). How CSR Shapes Reputation: A Culture-Moderated, Multi-Mediation Model of Image, Knowledge Creation, and Stakeholder Engagement in IT Firms. *Innovation Management Frontiers*, 1(1), 17-28. <https://doi.org/10.36923/imf.v1i1.401>
- Ahmad, I. (2026). Advancing Strategic Management Research in the Generative AI Era: A Human-AI Strategic Capability Framework. *Innovation Management Frontiers*, 1(1), 47-55. <https://doi.org/10.36923/imf.v1i1.413>
- Belle, J., Mapingure, T., & Owolabi, S. T. (2024). Factors influencing rural women's adoption of climate change adaptation strategies: Evidence from the Chivi District of Zimbabwe. *Climate*, 12(11), 191. <https://doi.org/10.3390/cli12110191>
- Braun, V., & Clarke, V. (2022). *Thematic analysis: A practical guide*. SAGE Publications. <https://doi.org/10.53841/bpsqmp.2022.1.33.46>
- Batool, S., & Adeel, A. (2026). Leading the Human-AI Paradox: Paradoxical Leadership, Human-AI Complementarity, Responsible AI Agency, and Employee Innovation. *Innovation Management Frontiers*, 1(1), 47-55. <https://doi.org/10.36923/imf.v1i1.432>
- Chaturvedi, P., Govindaraj, M., Govind, G., Bhargava, A., & Bassinello, P. Z. (2023). Editorial: Sorghum and pearl millet as climate-resilient crops for food and nutrition security. *Frontiers in Plant Science*, 14, 1170103. <https://doi.org/10.3389/fpls.2023.1170103>

- Choruma, D., Dirwai, T. L., Mugiyo, H., Chitsungo, B., Jafarzadeh, S., Madani, K., Jiri, O., Masuka, A. J., & Mabhaudhi, T. (2026). *Digital agriculture and AI for climate-resilient smallholder farming in Zimbabwe*. United Nations University Institute for Water, Environment and Health. <https://doi.org/10.53328/INR26PTM002>
- Creswell, J. W., & Creswell, J. D. (2023). *Research design: Qualitative, quantitative, and mixed methods approaches* (6th ed.). SAGE Publications.
- Delavallade, C., Dizon, F., Hill, R. V., & Petraud, J. P. (2025). *Women and climate adaptation in rural Sub-Saharan Africa*. World Bank. <https://doi.org/10.1596/1813-9450-11095>
- Duffy, C., Toth, G., Cullinan, J., Murray, U., & Spillane, C. (2021). Climate smart agriculture extension: Gender disparities in agroforestry knowledge acquisition. *Climate and Development*, 13(1), 21-33. <https://doi.org/10.1080/17565529.2020.1715912>
- FAO, IFAD, UNICEF, WFP, & WHO. (2024). *The state of food security and nutrition in the world 2024: Financing to end hunger, food insecurity and malnutrition in all its forms*. FAO.
- FAO. (2021). *Climate-smart agriculture case studies 2021: Projects from around the world*. Food and Agriculture Organization of the United Nations.
- FAO. (2022). *The state of food and agriculture 2022: Leveraging automation in agriculture for transforming agrifood systems*. Food and Agriculture Organization of the United Nations.
- FAO. (2023). *The impact of disasters on agriculture and food security 2023*. Food and Agriculture Organization of the United Nations.
- FEWS NET. (2024). *Zimbabwe food security outlook, October 2024 to May 2025*. Famine Early Warning Systems Network.
- Government of Zimbabwe. (2021a). *National Development Strategy 1: January 2021–December 2025*. Government of Zimbabwe.
- Government of Zimbabwe. (2021b). *Zimbabwe revised nationally determined contribution 2021*. Ministry of Environment, Climate, Tourism and Hospitality Industry.
- Government of Zimbabwe. (2024). *Zimbabwe's climate change national adaptation plan 2024–2030*. Government of Zimbabwe.
- Herteux, J., Raeth, C., Martini, G., Baha, A., Koupparis, K., Lauzana, I., & Piovani, D. (2024). Forecasting trends in food security with real time data. *Communications Earth & Environment*, 5, 611. <https://doi.org/10.1038/s43247-024-01698-9>
- IPCC. (2021). *Climate change 2021: The physical science basis*. Cambridge University Press.
- IPCC. (2022). *Climate change 2022: Impacts, adaptation and vulnerability*. Cambridge University Press.
- IPCC. (2023). *Climate change 2023: Synthesis report*. Intergovernmental Panel on Climate Change.
- Ishida, S., Howes, A., Bradley, V., Semenova, E., Rashid, T., Dzumbunu, S., Bajaj, S., Singhal, G., Sejdinovic, D., Zvirere, H., Piovani, D., Passeri, S., Hachhethu, K., Husain, A., Kembo, G. D., Kairiza, T., & Flaxman, S. (2025). *Real-time small area estimation of food security in Zimbabwe: Integrating mobile-phone and face-to-face surveys using joint multilevel regression and poststratification*. arXiv. <https://arxiv.org/abs/2505.03517>
- Jellason, N. P., Conway, J. S., & Baines, R. N. (2021). Understanding impacts and barriers to adoption of climate-smart agriculture practices in North-Western Nigerian drylands. *The Journal of Agricultural Education and Extension*, 27(1), 55-72. <https://doi.org/10.1080/1389224X.2020.1793787>
- Kairiza, T., Kembo, G., & Chigusiwa, L. (2026). The role of climate-smart agriculture in improving food security in rural Zimbabwe in instances of weather information deprivation. *The Journal of Development Studies*, 62(5), 797-815. <https://doi.org/10.1080/00220388.2025.2595050>
- Khatibu, S., Malisa, M., Mwangoka, M., & Mlozi, M. (2025). Effectiveness of climate information services in Sub-Saharan Africa: A systematic review. *Frontiers in Climate*, 7, 1616691. <https://doi.org/10.3389/fclim.2025.1616691>
- Kombat, R., Sarfatti, P., & Fatunbi, O. A. (2021). A review of climate-smart agriculture technology adoption by farming households in sub-Saharan Africa. *Sustainability*, 13(21), 12130. <https://doi.org/10.3390/su132112130>
- Mabhandu, W., & Sibanda, K. (2025). Examining the role of millet entrepreneurial production in improving food security and nutrition in Chivi Rural District. *Jurnal Ekonomi dan Bisnis Airlangga*, 35(1), 105-128. <https://doi.org/10.20473/jeba.V35I12025.105-128>
- Madzivanzira, T., Mvumi, B. M., Nazare, R. M., Nyakudya, E., Mtambanengwe, F., & Mapfumo, P. (2024). A review of appropriate mechanisation systems for sustainable traditional grain production by smallholder farmers in sub-Saharan Africa with particular reference to Zimbabwe. *Heliyon*, 10(17), e36695. <https://doi.org/10.1016/j.heliyon.2024.e36695>
- Makuchete, L., Hove, A., Nezomba, H., Rurinda, J., Mbanyele, V., Mlambo, S., Nyakudya, E., Mtambanengwe, F., & Mapfumo, P. (2024). Productivity of sorghum and millets under different in-field rainwater management options on soils of varying fertility status in Zimbabwe. *Frontiers in Agronomy*, 6, 1378339. <https://doi.org/10.3389/fagro.2024.1378339>
- Mhlanga, B., Pellegrino, E., Thierfelder, C., & Ercoli, L. (2022). Conservation agriculture practices drive maize yield by regulating soil nutrient availability, arbuscular mycorrhizas, and plant nutrient uptake. *Field Crops Research*, 277, 108403. <https://doi.org/10.1016/j.fcr.2021.108403>
- Morgan, H. (2022). Conducting a qualitative document analysis. *The Qualitative Report*, 27(1), 64-77. <https://doi.org/10.46743/2160-3715/2022.5044>
- Mujeyi, A., Mudhara, M., & Mutenje, M. J. (2021). The impact of climate smart agriculture on household welfare in smallholder integrated crop-livestock farming systems: Evidence from Zimbabwe. *Agriculture and Food Security*, 10(1), 4. <https://doi.org/10.1186/s40066-020-00277-3>
- Mujeyi, A., Mudhara, M., & Mutenje, M. J. (2022). Adoption patterns of climate-smart agriculture in integrated crop-livestock smallholder farming systems of Zimbabwe. *Climate and Development*, 14(5), 399-408. <https://doi.org/10.1080/17565529.2021.1930507>
- Muzerengi, F., Gandidzanwa, C. P., & Chirubvu, L. (2023). Impacts of climate change on household food security in Matande communal lands, Mwenezi district in Zimbabwe. *Jamba: Journal of Disaster Risk Studies*, 15(1), a1499. <https://doi.org/10.4102/jamba.v15i1.1499>

- Ngoma, H., Pelletier, J., Mulenga, B. P., & Subakanya, M. (2021). Climate-smart agriculture, cropland expansion and deforestation in Zambia: Linkages, processes and drivers. *Land Use Policy*, 107, 105482. <https://doi.org/10.1016/j.landusepol.2021.105482>
- Nyoni, R. S., Bruelle, G., Chikowo, R., & Andrieu, N. (2024). Targeting smallholder farmers for climate information services adoption in Africa: A systematic literature review. *Climate Services*, 34, 100450. <https://doi.org/10.1016/j.cliser.2024.100450>
- Ofoegbu, C., & New, M. (2022). Evaluating the effectiveness and efficiency of climate information communication in the African agricultural sector: A systematic analysis of climate services. *Agriculture*, 12(2), 160. <https://doi.org/10.3390/agriculture12020160>
- Shittu, A. M., Kehinde, M. O., Adeyonu, A. G., & Ojo, O. T. (2021). Willingness to accept incentives for a shift to climate-smart agriculture among smallholder farmers in Nigeria. *Journal of Agricultural and Applied Economics*, 53(4), 531-551. <https://doi.org/10.1017/aae.2021.19>
- UN DESA. (2024). *The sustainable development goals report 2024*. United Nations Department of Economic and Social Affairs.
- UN OCHA. (2024). *Zimbabwe flash appeal: May 2024–April 2025*. United Nations Office for the Coordination of Humanitarian Affairs.
- UNDRR. (2023). *Global status of multi-hazard early warning systems 2023*. United Nations Office for Disaster Risk Reduction and World Meteorological Organization.
- WFP. (2025). *Zimbabwe annual country report 2024*. World Food Programme.
- WMO. (2024). *State of climate services 2024*. World Meteorological Organization.
- World Bank. (2024a). *Zimbabwe country climate and development report*. World Bank.
- World Bank. (2024b). *Zimbabwe economic update 2024: Improving resilience to weather shocks and climate change*. World Bank.
- ZimLAC. (2024). *2024 rural livelihoods assessment report*. Zimbabwe Livelihoods Assessment Committee.
- ZimLAC. (2025). *2025 rural livelihoods assessment report*. Zimbabwe Livelihoods Assessment Committee.

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