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Evidence-based analysis for integrating improved and multifunctional paddy water management into policy frameworks in **Zambia**

Socioeconomic profiles, risk perceptions and
practice preferences of smallholder paddy farmers



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by

Eva Pek and Maher Salman

Land and Water Division, Food and Agriculture Organization of the United Nations

Imre Ferto and Zoltan Bakucs

HUN-REN Centre for Economic and Regional Studies, Hungary

Mweshi Mukanga

Zambia Agriculture Research Institute, Zambia

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Foreword

As the demand for food continues to grow and climate variability intensifies across sub-Saharan Africa, strengthening the efficiency and resilience of agricultural water management has never been more essential. Rice, though a relatively new crop in Zambia's agricultural landscape, has rapidly become a strategic crop for diversification, income generation and rural development. Yet the country's vast land and water resources are yet to be fully and sustainably utilized to build resilient livelihoods.

Smallholder farmers form the backbone of Zambia's rice sector. They cultivate in challenging and diverse agroecological settings, often with minimal resources and limited access to technologies and knowledge that could unlock higher productivity. Despite these constraints, the sector shows clear signs of dynamism and potential. By investing in improved water management and supporting the multifunctional roles of paddy fields, Zambia can reduce its reliance on imports and create new market opportunities. Such progress requires integrated approaches that embed irrigation development into the rice value chain.

Funded by the Government of Japan, the project "Promoting productive water use and efficient water management in paddy fields" is implemented by the Land and Water Division of the Food and Agriculture Organization of the United Nations (FAO) in collaboration with international partners and national institutions in Sri Lanka and Zambia. The project piloted enhanced water-use efficiency and water productivity approaches in paddy fields with a particular focus on their multifunctional and value-added roles in the target countries. To assess the potential for widespread adoption of these practices, FAO conducted a rigorous and crucial socioeconomic analysis to examine farmers' ability and willingness to adopt the technology.

This report offers insights from that analysis, which can be used to formulate future policy recommendations. It draws on the findings of a comprehensive socioeconomic assessment conducted among smallholder rice farmers across three provinces in Zambia. It provides a detailed analysis of farmer profiles, production systems, perceptions of climate risk and preferences for irrigation development. By identifying the factors that enable or constrain the adoption of improved water management, the study offers evidence that can support policymakers in interventions for the rice sector in Zambia.



Li Lifeng
Director, Land and Water Division, FAO

Abbreviations

CC	Chitambo in Central Province
FAO	Food and Agriculture Organization of the United Nations
LASSO	least absolute shrinkage and selection operator
NM	Mungwi in Northern Province
USD	United States dollar
WM	Mongu in Western Province
WTA	willingness to adopt
ZMW	Zambian kwacha

Executive summary

The rice sector in Zambia continues to face structural gaps that constrain its contribution to agricultural diversification, household income generation and national food security. Average yields remain at 1.0–1.1 tonnes per hectare compared to the estimated break-even yield of 1.6–2 tonnes per hectare, despite the availability of extensive floodplains and dambos suitable for paddy production. Production is largely rainfed, with only a small fraction of farmers accessing irrigation. Input use rates are among the lowest in the region, and certified seed production is inconsistent as farmers rely heavily on recycled seed. Even small-scale mechanization is minimal and limited to land preparation, leaving most households dependent on labour-intensive methods that constrain the scale and efficiency of production. Overall, the vast heterogeneity of production practices is the result of the lack of established practices and isolated interventions. The Government of Zambia has been investing in the rice sector to systematize the development efforts, and the irrigation sector development has been gaining momentum. As a recognition of interdependence, aligning irrigation development strategies is fundamental to maximizing the potential of rice sector development.

Globally, rice sector development is critically dependent on irrigation development in the face of increasing climate variability. Rice farmers in Zambia are exposed to recurrent drought events, floods and dry spells which erode yields, while a dry year can turn the rice farm profitability negative. Piloting optimal agronomic and irrigation practices showed that controlled irrigation can increase profits by 50 percent over uncontrolled irrigation using the same production conditions and yield four to five times more profit than rainfed methods. While irrigation offers significant productivity gains, evidence shows that adoption depends not only on infrastructure but on capacities. The regression analysis carried out proved that interventions to address the low pace of irrigation uptake should rely on two pillars: capacity building in irrigation management with emphasis on targeted training for women farmers, and integration of climate information and early warning systems.

The recommendations of this study therefore call for irrigation development to be designed as an integrated programme, not as infrastructure delivery alone, that pairs construction with structured capacity building, demonstration plots, women-focused training modules, and connections to seasonal climate forecasts and early warning services.

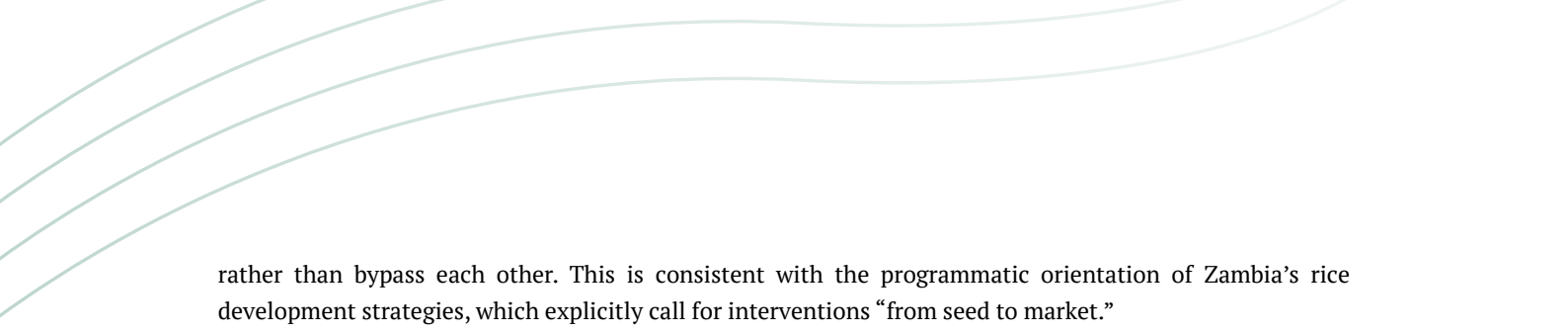
The analysis also shows that farmers typically have a limited understanding of irrigation and its functions due to the lack of experience and locally available demonstration sites. Although irrigation is repeatedly emphasized in national strategies, including the National Rice Development Strategy, as essential for rice sector development, the survey results show that smallholders seldom link irrigation to either increased yield or enhanced resilience. Awareness of irrigation benefits is low, and knowledge about system management, water use and maintenance requires further development. Willingness to adopt irrigation is strongly conditioned by education and disaster exposure, showing that awareness and capacity are the decisive enablers of uptake. Without targeted training, starting with awareness-raising, irrigation infrastructure alone will not result in adoption or sustained use.

The development of multifunctional paddies is fundamentally constrained by weak water control infrastructure and farmers' risk-averse attitudes. While communities express willingness to adopt practices that increase revenues, the lack of irrigation facilities, inadequate on-farm structures, such as bunds and levelling, and minimal adoption of even simple techniques, like mulching, limit the ability to exploit water's full potential. Evidence shows that interventions must go beyond infrastructure provision to address behavioural and technical barriers as even low-cost, low-risk practices remain underutilized without targeted support. Small-scale measures yet require awareness-raising and technical guidance. Aligning rice sector growth with Zambia's Integrated Water Resources Management Strategy creates an opportunity to embed these solutions within national priorities, where investment in water infrastructure, capacity building, and farmer support can amplify the gains of paddy rice production. Multifunctional practices such as fish–rice farming demonstrate how integrated approaches can diversify incomes and strengthen resilience, provided that infrastructure and programmatic development advance in tandem.

Beyond the technical barriers, the challenges in rice production are also institutional and socioeconomic. Agricultural support policies remain strongly skewed towards maize, with the central support programme rarely covering rice. Extension officers have limited rice-specific expertise, and farmer awareness of good agronomic practices for rice remains low. Regarding the socioeconomic barriers, gender disparities are particularly acute. Although women provide a substantial share of labour and are the backbone of Zambia's agriculture sector, they face restricted access to resources. This reduces their willingness and capacity to adopt irrigation. Socioeconomic backgrounds vary widely, making it difficult to identify production drivers and patterns. To address the inter- and intra-regional heterogeneity, the assessment of rice production challenges and needs should rely on a kaleidoscope approach that can map out the mosaic-type production structure. In this context, instead of constructing policies at the regional level, the development should first be parallel at the national and community levels. National-level interventions are required to address the structural and institutional problems through comprehensive and umbrella programmes that apply to all contexts, including input market organization, capacity building, alignment of irrigation and rice sectors, and market access facilitation. At the community level, farmer associations integrating technical services should be supported to enable a bottom–up development process from local production practices to joint market participation.

Gender equity must be a deliberate priority within this two-tier framework: women provide the majority of agricultural labour in Zambia yet face systemic barriers that reduce their willingness and capacity to adopt irrigation even under repeated drought events, and targeted, women-focused training within irrigation programmes is essential to expand the productive base of the sector.

Closing Zambia's rice yield gap requires a value chain approach that links input supply, production and markets. Current interventions are fragmented, focusing on specific parts of the production chain. To support a more systematic and overarching development process, certified seeds, fertilizers, mechanization and irrigation must be integrated with post-harvest infrastructure such as drying, milling and storage facilities. Currently, production practices compromise the rest of the cycle, such as grain quality being impaired by milling practices. Value chain coordination is essential for reducing losses during the production and post-harvest phases; improving quality standards; and ensuring that productivity gains are translated into higher incomes. The study's recommendation is for policies to guarantee reliable input access (e.g. certified seed, fertilizer and mechanization) while rebalancing subsidies away from a maize-dominant system and tying incentives directly to value chain participation, so that input support and market improvements reinforce



rather than bypass each other. This is consistent with the programmatic orientation of Zambia's rice development strategies, which explicitly call for interventions "from seed to market."

Market issues remain one of the most critical constraints. While 70–85 percent of rice produced by the surveyed smallholders is marketed, the bulk is sold as unmilled paddy at low farmgate prices. The absence of structured markets, a guaranteed floor price for rice and quality certification systems prevents farmers from accessing higher-value outlets. Recognizing rice as a cash crop and investing in marketing systems, particularly milling and branding of aromatic varieties such as Supa-Mg and Kilombero, are vital if Zambia is to reduce import dependence and position rice as a driver of rural incomes. Strengthening market positions is also aligned with the ambition to consider rice as a cash crop for smallholders. It can mitigate the business risk of shifting away from the low-cost and subsidized maize production to rice production which has substantially higher cost and a more complex agrotechnology requirement.

Introduction

Despite the high potential, rice yields remain low in Zambia, keeping the country dependent on imports. Average yields stand at only 1.0–1.1 tonnes per hectare, well below the estimated break-even yield of 1.6–2 tonnes per hectare, despite the country’s extensive floodplains and dambos suitable for paddy cultivation. Rice occupies an important position within Zambia’s agricultural development agenda. It is classified as a cash crop with the capacity to contribute to multiple policy objectives, including crop diversification, poverty alleviation, and the improvement of the national trade balance. Unlike many staple crops, rice production in Zambia is predominantly market-oriented rather than subsistence-based. However, structural inefficiencies within the value chain constrain its profitability. Smallholder farmers, who dominate production, typically sell the bulk of their harvest as unmilled paddy at low farmgate prices, retaining only 30–35 percent for household consumption. This marketing pattern limits household food security benefits while reducing the potential for value addition and higher income generation. Consequently, most smallholders operate at subsistence or marginally commercial levels, which restricts the capacity of domestic production to meet the rapidly growing national demand for rice.

The growing recognition of rice's strategic importance highlights the need for structured investments throughout the entire value chain and the empowerment of communities. The profile of Zambia’s rice farmers is characterized by resource-constrained smallholders who are central to national output but face systemic barriers to modernization and competitiveness. These barriers include limited access to improved seed varieties, inadequate irrigation and mechanization, weak extension services, and poorly developed market linkages. To address these challenges, the Government of Zambia is investing in sector development through programmatic approaches that span the entire value chain, from input availability to marketing (Third National Rice Development Strategy, 2022; AnChiCon Limited et al., 2023; Japan International Cooperation Agency, 2022). The project “Promoting productive water use and efficient water management in paddy fields” implemented by the Food and Agriculture Organization of the United Nations (FAO) in collaboration with the Government of Zambia, was aimed at piloting innovative approaches for enhancing water use efficiency and water productivity in paddy cultivation. Beyond improving irrigation practices, the project emphasized the multifunctional and value-added roles of paddy fields, recognizing their contribution not only to crop production but also to broader ecosystem services. Through its structured objective framework, the initiative sought to strengthen water management systems while leveraging the multiple functions of paddy ecosystems. The project aligns with and directly contributes to Zambia’s agricultural policy agenda, which prioritizes increased productivity and profitability in rice production. Its interventions span both technical innovations, such as improved irrigation and agronomic practices, and policy-oriented measures aimed at creating an enabling environment for sustainable sector growth.

Multiple, large-scale programmes have been implemented in Zambia in support of the rice sector development, but results are not yet scaled out and linked to irrigation development projects. Several programmes and projects have been implemented to strengthen Zambia’s rice sector, integrating interventions in irrigation, seed systems and market development. The National Rice Development Strategies have established ambitious targets to expand production areas, raise yields, improve grain quality,

and enhance linkages among value chain actors. While these strategies have contributed to growth in overall output and modest yield improvements, significant productivity gaps remain. Complementary initiatives have been introduced by international partners, including financial institutions and technical agencies, which have supported capacity building, small-scale research, commercialization and input market development. Japan-financed programmes, in particular, have focused on irrigation infrastructure, such as the construction of community-based weirs for crop production, as well as value chain-oriented approaches to improve rice grain quality, processing and marketing. Despite these efforts, systemic challenges persist. Programmes often operate in parallel rather than in a coordinated manner, with irrigation projects insufficiently linked to rice-specific initiatives. This lack of integration reduces opportunities to leverage synergies across interventions and undermines the potential for a systematized, sector-wide development process. The persistence of these coordination gaps highlights the need for stronger institutional mechanisms to align objectives, harmonize interventions and maximize the impact of investments in Zambia's rice sector.

Low productivity is attributed to gaps across many parts of the value chain, but the lack of irrigation is among the most acute, given weather variability. Low productivity is attributed to several factors throughout the production cycle, including the widespread use of recycled seed, unsuitable seeding practices, low levels of inputs and machinery use, and dependence on rainfall. Key challenges to boosting productivity involve the limited availability of irrigated or water-equipped land among smallholder farms, which makes them vulnerable to rainfall variability and other environmental factors. Many farmers do not have access to water storage facilities or infrastructure to capture excess water from rain or river runoff, leaving them exposed to climate extremes. Even farmers with existing irrigation systems struggle to maximize their potential because their management practices do not meet the specific requirements for effective rice irrigation. The high initial costs of setting up irrigation systems also deter adoption or expansion, particularly in regions where comprehensive suitability assessments have not been conducted.

Rice production practices in Zambia are diverse, fragmented and non-standardized, varying widely across regions, farmer profiles and agroclimatic zones, thus requiring a kaleidoscope approach for the socioeconomic assessment. Some farmers cultivate in dambos and floodplains with limited access to irrigation, while others rely entirely on rainfed uplands. Planting methods vary from traditional broadcasting using recycled seeds to modern, albeit limited, transplanting systems. There are significant differences in fertilizer use, mechanization and post-harvest handling as well. Due to this diversity, no single, standardized narrative can adequately represent the socioeconomic backgrounds. A comprehensive analysis must take a kaleidoscope approach, carefully disaggregating practices and conditions to identify specific opportunities and constraints.

The socioeconomic baseline for rice sector development has yet to be completed, which is necessary to understand what drives the consistent adoption of production practices, including irrigation. The programmes aimed at developing the rice sector in Zambia are predominantly technical, concentrating on agrotechnology and market access. However, it is crucial to understand beneficiaries' capacities and challenges to effectively tailor and target interventions. This report begins with profiling rice-producing communities, covering both established and emerging farmers. Its objective is to evaluate farmer preferences, constraints and opportunities for rice sector development in Zambia, focusing on irrigation as a key driver for productivity and resilience. The report utilizes a range of statistical and econometric analyses to establish a baseline regarding the socioeconomic conditions of farmers, assess their exposure to climate risks, identify conditions conducive to farm improvement, and delineate enablers for irrigation development. To provide

a comprehensive overview of the analysis and its implications for policy recommendations, the report is structured into three main chapters.

- The first chapter analyses the socioeconomic conditions and risk perceptions of farmers. It begins with an overview of the rice sector, followed by pilot results from the project that inform the analysis. This chapter details the socioeconomic characteristics and production practices of farmers, illustrating the actual conditions they encounter. It also investigates farmers' perceptions of risks and the role of irrigation in mitigating these risks at the farm level. By employing cluster and factor analyses, the chapter distinguishes different farmer groups based on their exposure to climate risk and identifies factors that affect their farming practices and outcomes. Finally, it includes a regression analysis to explore how underlying factors influence perceptions of climate risk.
- The second chapter outlines the methodology for logit regression aimed at understanding the factors that affect the willingness to adopt irrigation. Recommendations for evidence-based policymaking are developed based on this analysis.
- The third chapter compiles and synthesizes the key findings from the report.

THE APPROACH

Since paddy-producing regions are dispersed in pocket areas across the country, resulting in inherently diverse farmer communities, research methods should be chosen to effectively capture the socioeconomic factors behind the varying levels of production intensity. Since rice production in Zambia is predominantly rainfall-dependent and strongly influenced by local agroecological conditions, both intra- and interannual variability shape the composition of farming households, which complicates the assessment of their socioeconomic status. To account for this heterogeneity, this study employed a random sampling strategy rather than focusing on a single community with relatively uniform production patterns. Random sampling also facilitates the systematic measurement of external influences and targeted interventions, including climate-related risks. The survey was conducted among paddy farmers in three major rice-producing areas: Chitambo in Central Province (CC), Mungwi in Northern Province (NM), and Mongu in Western Province (WM). These provinces, designated by Ministry of Agriculture officials as high-potential rice zones, differ in production intensity, levels of mechanization and access to equipment. In each province, a rapid screening exercise was undertaken to identify paddy farmers, and local authorities supported the selection of representative communities. A total of 300 farmers were surveyed between January and February 2025, with the sample evenly distributed across the three provinces. This design ensured comparability across regions while capturing the diversity of production systems and socioeconomic conditions.

The standardized questionnaire consisted of four blocks:

- **socioeconomic characteristics:** age, education, household composition, off-farm income and farmer association membership;
- **production activities:** rice production volume, input usage, land cultivated and irrigation practices;
- **costs and investments:** expenditures on land preparation, labour, harvesting and transport;
- **risk perceptions and experiences:** historical frequency of drought events and floods, perceived future risks, and coping measures (e.g. early warning systems, irrigation management).

Three methodologies were applied simultaneously to obtain a comprehensive overview of the socioeconomic conditions and risk perceptions of farmers:

- **Cluster analysis:** A k-median cluster analysis was undertaken to categorize farmers by historical experiences (drought and flood events) and perceived future climate risk.
- **Factor analysis:** The analysis was employed to identify underlying dimensions behind production scale, land ownership, irrigation practices, and production objective or orientation.
- **Econometric models:** Regression techniques were applied to identify and evaluate predictors of climate risk perception and farmers' willingness to adopt irrigation, incorporating socioeconomic, environmental and institutional variables. Regression analysis was also applied to select the variables with the strongest explanatory power.

LIMITATIONS

The early stage of rice sector development and the variability in adoption trajectories lead to several assumptions that must be considered in socioeconomic assessments, including the definition of rice-producing farmers, the expected level of farming techniques and practices related to irrigation, and the biophysical suitability of production areas. Rice production in Zambia does not yet have a sufficiently established history to support the development of standardized practices and policies. This absence complicates the identification of consistent production patterns and renders recommendations from the socioeconomic analysis contingent on certain assumptions rather than definitive claims. The recommendations derived from this assessment therefore emphasize the identification of development trajectories that can inform the enabling conditions required for the consolidation of the rice sector. In this sense, the report prioritizes recommendations that highlight potential sectoral development pathways through socioeconomic enablers at the community level rather than prescribing a rice-specific roadmap. The following set of criteria is established to frame the applicability of the resulting recommendations:

- Rice production in Zambia is highly dependent on rainfall variability, which renders the definition of rice-producing communities permeable. Although this assessment focuses on rice-producing farmers, rice is not always a permanent crop choice. Periods of drought or prolonged dry spells often compel farmers to shift temporarily to alternative crops. The survey, therefore, targeted farmers who primarily cultivate rice while acknowledging that insufficient precipitation may occasionally necessitate crop substitution. All surveyed farmers possessed years of experience in rice production, ensuring the relevance of their perspectives to the study.
- Rice-growing areas in Zambia are predominantly rainfed, with only limited access to supplemental irrigation. Consequently, the assessment requires a contextualized definition of irrigation that reflects these production realities. As the majority of farmers lack access to reliable water sources, rice cultivation remains largely dependent on rainfall. This constraint narrows the scope of water management analysis to the relatively few irrigated sites and on-farm practices related to green water management.
- Rice production practices are not yet fully established, and farmers apply general crop production methods to rice cultivation. The survey design considered that globally recognized rice production practices are not necessarily present in the Zambian context. Direct comparison of farmers' practices to international benchmarks is therefore not applicable. Instead, this assessment evaluates production practices in relation to local conditions, with the aim of contextual understanding rather than generalization.

- The existing biophysical analyses for rice production require updating through more localized experimentation in Zambia, which involves assumptions on potential yields and production practices. In the absence of a finalized and officially endorsed biophysical suitability map for rice production, this assessment focuses on identifying general enabling factors that can be applied in areas deemed suitable for cultivation.

In summary, the evidence-based policy recommendations should be presented exclusively within the policy chapters and framed explicitly around the underlying assumptions. These recommendations are therefore structured as follows:

- Broadly defined interventions should be articulated while their specific implementation modalities require further assessment and contextual adaptation.
- National-level scaling is essential; however, interventions at the subnational and community levels must be tailored to local conditions and needs.
- A multisectoral approach is required, ensuring alignment across policies related to rice production, water management, irrigation, food security and poverty alleviation.



1. Socioeconomic conditions and water management implications

Zambia's rice sector is dominated by small-scale farmers, typically cultivating a few hectares of rice alongside maize and other crops, but majority lack established production practices. Farmers often rely on rudimentary practices that are derived from maize production. In the context of Zambia, small-scale farmers are more often referred to in terms of their socioeconomic and resource-related characteristics than in relation to their land tenure structure (United Nations Development Programme, 2025). Land availability is not as constraining to rice production as the availability and accessibility of production inputs such as water, quality seeds, fertilizers and others.

Rice is increasingly recognized as a strategic crop with significant benefits such as improving trade balance, diversification and household income increase, the production challenges hinder the development pace. Government-endorsed strategies emphasize the importance of gradually shifting from maize monocropping to include rice. There are multiple incentives for households to produce rice and for decision-makers to promote the rice sector. Rice demand is rising swiftly in Zambia's urban areas, but domestic production only partly meets consumption needs, leading to expensive imports. Expanding rice farming could cut import costs, diversify farmers' incomes, and improve household food and nutrition security. Rice

cultivation is well suited to wetlands and dambos that are less suitable for maize, offering a climate-smart diversification opportunity. Still, farmers face significant challenges along the value chain. While shifting towards rice holds strong potential for income improvement, these benefits depend on investments in better seed systems, irrigation infrastructure, mechanization, extension services and stronger market links.

Traditional crop production patterns and the associated policy framework are among the significant constraints that hold back rice production expansion. In Zambia, agriculture-related policy frameworks have long favoured maize through subsidy schemes and institutional support, partially limiting the diversification into alternatives like rice. For example, with the Farmer Input Support Programme, which accounts for about two-thirds of public agricultural expenditure, most inputs are directed towards maize production, with low allocation for crops such as rice. Such policies create strong incentives to continue maize cultivation despite maize yields having stagnated and broader food system resilience remaining weak. As a result, strategic efforts to promote rice lag behind the existing cropping systems. A shift towards rice production, therefore, requires not only support for rice-specific infrastructure and value chains but also policy reforms to rebalance public spending, diversify subsidies and reduce maize dependency.

Aside from the maize-favouring subsidy system, the socioeconomic background and path dependence of smallholders make transitioning into crop diversification conditional upon incentives and capacity building. Zambian farmers are resource-poor, so changes in production require careful planning to minimize risk. Maize production is not only the economic backbone of rural communities; it also contributes to household-level food security. Moreover, maize has established production practices, providing a predictable income. Policy reforms require a better understanding of the socioeconomic conditions to tailor interventions to the unique structure of rice-producing areas in Zambia.

1.1. OUTLOOK AND PROGRESS ON THE RICE SECTOR DEVELOPMENT

Rice sector development is driven by the growing urban food demand and the promising income generated at the farm level. FAO (2022) published the report titled “Efficient agricultural water use and management in paddy fields in Zambia.” The report provides an outlook on the development prospects of the rice sector in Zambia, synthesizing the challenges and objectives set by policymakers. There are promising initiatives where production areas have been established, especially in the Chambeshi floodplain, the Upper Luangwa valley and the Zambezi floodplain, where it is widely grown under rainfed conditions. The inclusion of rice in the national food balance sheet reflects its growing importance as urban demand rises. Yet, per capita consumption, though increasing from 1.49 kg per year to 4.11 kg per year between 2011 and 2021, remains far lower than maize consumption (cca. 105 kg per year). This underscores both the growing role of rice and the continued dominance of maize in diets.

Production levels are falling behind the rising demand due to problems with the quantity and quality of domestic output, leaving importers with untapped economic potential. Consumer surveys reveal strong local preference for aromatic varieties such as Supa-Mg and Kilombero, branded regionally as Mongu, Nakonde and Chama rice. However, the limited scale of domestic production keeps local rice less competitive, both in quality and price, relative to imports. Between 2017 and 2021, Zambia produced about 42 315 tonnes annually but imported nearly 15 800 tonnes at an average cost of USD 27.9 million, while exporting only 645 tonnes per year. This widening supply-demand gap highlights a missed economic opportunity. Without productivity and quality improvements, Zambia will remain import-dependent despite its favourable agro-ecological potential.

While national efforts have already shown progress in the production performance, irrigation remains a substantial constraint for further productivity increase. The Second National Rice Development Strategy (2016–2020) aimed to make Zambia’s rice subsector more competitive, food-secure and employment-generating by increasing production by 50 percent through higher yields, expanded area, better quality, stronger knowledge systems and improved value chain coordination. Implementation, focused on lowland and upland rainfed ecologies, with interventions in seed systems, extension, agribusiness and marketing. By 2021, rice area, production volumes and yields had grown significantly, although average productivity remained modest. Support for irrigation was relatively limited, focusing on the rehabilitation of facilities, rainwater harvesting and the adoption of appropriate technologies, which left most rice production still highly dependent on rainfall.

Climate change and the partial implementation of water policy-related targets hinder the pace of rice sector development in Zambia. Climate change makes rice sector development vulnerable as the country already experiences higher temperatures, more frequent drought events, dry spells and floods. Although Zambia has adopted several adaptation frameworks, including the National Adaptation Programme of Action (2007), the National Policy on Climate Change (2016), and its Nationally Determined Contribution (2015), the uptake of climate-smart agriculture among smallholders remains limited. Rice farmers, who rely on an almost entirely rainfed production process, are especially vulnerable despite the available adaptation practices. The government has also promoted Integrated Water Resources Management since 2000 through programmes like the Water Resources Action Programme and the World Bank–supported Water Resources Development Project to improve water governance and strengthen resilience. However, effective monitoring of water use in crop production remains weak. The Ministry of Agriculture monitors rice production, seed availability and yields, but there are no robust systems to measure water use efficiency at the irrigation scheme level, leaving a critical gap for planning under climate stress.

The development of the rice sector is not solely an economic goal but also impacts social progress, including gender equality and youth engagement in agriculture. The sector faces significant social inclusion challenges, especially regarding gender, youth and disability. Women constitute 64 percent of Zambia’s rural population and 80 percent of food producers, yet they encounter obstacles in accessing land, credit, technology and extension services, which leaves men in greater control of cash crops like rice. Although the youth are innovative and adaptable, they are limited by poor access to finance, land tenure and agribusiness training, often viewing agriculture as a last-resort livelihood. Recognizing these inequalities, the Government of Zambia has started to incorporate gender equality and youth participation into agricultural policies, while community organizations assist women and vulnerable groups in accessing seeds, inputs and microcredits. Nonetheless, without stronger structural support, these groups remain marginalized.

1.2. CHARACTERISTICS OF FARMERS AND PRODUCTION CONDITIONS

Understanding stakeholder heterogeneity across distinct agroclimatic and environmental conditions helps define the patterns that inform policies. This section provides an in-depth look at the socioeconomic characteristics, production outcomes and input use among surveyed farmers across the three regions. The analysis utilizes descriptive statistics and comparative testing to highlight the heterogeneity in farmer profiles, offering insights crucial for policymakers aiming to design targeted interventions for livelihood enhancement and resilience building. Comparing farmers across regions is essential to understanding how agroclimatic and environmental conditions influence farming methods. This analysis involves comparing socioeconomic factors across different regions. These conditions often restrict the choice and cultivation of crops, and local variations add to the complexity, creating a varying composition of factors that shape farming practices.

1.2.1. The relatively short experience and former education characterize the smallholder rice producers in Zambia.

The surveyed farmers differ in age, gender, family composition, experience and membership in organizations. Farmers differ in terms of social conditions, thus requiring differentiated approaches for knowledge transfer. Table 1 presents the mean values and statistical significance tests for the socioeconomic variables.

TABLE 1. Socioeconomic characteristics of rice farmers by region, reporting the mean values

	CC	NM	WM	Total	Test
Age	45.8	43.9	51.7	47.2	<0.001
Gender (male-0, female-1)	0.28	0.24	0.57	0.36	<0.001
Number of adults	3.9	3.3	3.5	3.6	0.078
Number of children	4.8	3.7	3.0	3.8	<0.001
Education (without-0, primary-1, secondary-2, advanced-3)	0.93	0.87	1.03	0.94	0.302
Experience (years)	6.9	12.5	19.4	13.0	<0.001
Number of family workforce	4.2	3.2	3.4	3.6	<0.001
Off-farm income (ZMW/year)	5 123	4 707	5 359	5 061	0.884
Mobile phone (no-0, yes-1)	0.93	0.91	0.92	0.92	0.869
Extension service (no-0, yes-1)	0.96	1.00	0.89	0.91	0.002
Membership of farmer association (no-0, yes-1)	0.89	0.85	0.69	0.81	<0.001
Number of observations	100	100	104	304	

Notes: P-values from pooled t-tests, whereas the statistical significance is decided based on the P-values displayed in the test column: $p < 0.05$ suggests a statistically significant result, and $p > 0.05$ suggests the result is not statistically significant; CC = Chitambo in Central Province, NM = Mungwi in Northern Province, and WM = Mongu in Western Province.

Source: Authors' own elaboration.

The differences in farming experience are the most consequential. Even communities with the longest experience are considered relatively new compared to the global baseline. Across Zambia, the average farming experience is 13 years, but communities in CC have as little as 7 years of experience. Meanwhile, farmers in WM have around 19 years of experience. However, this time frame is not long enough to establish and transfer effective farming practices. Given the frequency of disasters, such timeline does not allow for the development of pioneering resilience practices. With farmers having an average primary school education and limited access to farmer associations, a lack of experience is one of the most significant social factors affecting productivity.

Gender, household composition and age differ significantly among the regions, defining the intervention approaches. Women make up the majority of the agricultural workforce in Zambia, being responsible for land preparation, planting and harvesting, while men are responsible for marketing. However, their rights are restricted by cultural norms, crowding them out of critical decision making. Despite the 1996 Land Act allowing women to own land, customary law largely restricts ownership to men, leaving women

with only access and user rights through male relatives. Barriers, such as the need for bank certification and accessibility of services, among others, further disadvantage women, especially those in rural or informal sectors. As a result, women receive far less land and remain marginalized. Age also contributes to the relatively slow process of improving paddy farming practices. WM has the highest average age at 52 years, while the other two regions have significantly younger farmers. Youth inclusion in the rice sector is essential for maintaining a skilled workforce for the labour-intensive rice production, but even regions with relatively younger farmers must further advocate for youth programmes.

Membership in farmer organizations and extension service is relatively high, but the potential of supporting community-led programmes falls short. In some regions, farmer association membership or access to extension service is almost universal. Farmers nurture the culture of community-based organizations, but such organizations have not yet integrated technical services. As rice-producing communities are scattered, the production area boundaries are rather flexible based on the annual cropping pattern. Against this baseline, supporting community-led programmes for the establishment of basic infrastructure and services is an effective strategy to expedite the development.

1.2.2. Production levels fall below the potential despite land resource endowment.

Land resources are not a limiting factor in Zambia; however, production volumes and productivity levels are low, resulting in the underutilization of agricultural potential. The agricultural potential of Zambia is far from being exploited, as only a share of the cultivable area is used for agriculture. While agricultural expansion and diversification are strategic directions, productivity levels are not sufficiently addressed in the rice sector. Despite the land available, the farm outputs, such as yield and income, are lower than those in similar countries in sub-Saharan Africa (Table 2).

TABLE 2.	Rice production levels by region, reporting the mean values				
	CC	NM	WM	Total	Test
Total rice output/year (kg)	2 586	3 122	2 031	2 573	0.030
Household consumption (kg)	341	284	330	318	0.516
Selling price (ZMW/kg)	7.26	6.73	9.59	7.88	<0.001
Off-farm income (ZMW/year)	5 123	4 707	5 359	5 061	0.884
Total income rice (ZMW/year)	14 840	20 523	13 164	16 146	0.028
Total land cultivated (acre)	4.8	11.2	4.6	6.8	<0.001
Number of plots	2	1.8	3.1	2.3	<0.001
Number of plots owned	1.7	1.8	2.9	2.1	<0.001
Owner of land (no-0, yes-1)	0.83	1	0.92	0.92	<0.001
Share of rice produced for household consumption (%)	16.88	9.18	20.11	15.45	<0.001
Share of rice produced for selling (%)	83.07	89.45	79.68	84.01	<0.001

Notes: P-values from pooled t-tests, whereas the statistical significance is decided based on the P-values displayed in the test column: $p < 0.05$ suggests a statistically significant result, and $p > 0.05$ suggests the result is not statistically significant; CC = Chitambo in Central Province, NM = Mungwi in Northern Province, and WM = Mongu in Western Province.

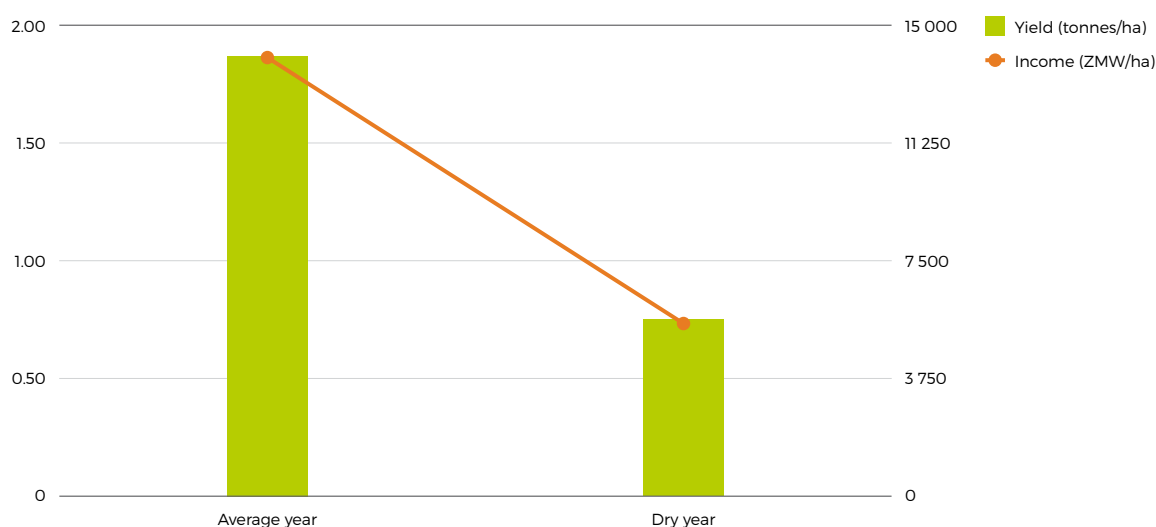
Source: Authors' own elaboration.

Despite land availability, production volumes and profitability are low due to low yield productivity and farmgate prices, but there are large regional differences. The farm sizes in the regions vary from an average of 4.6 acres (cca. 1.86 ha) per household in WM to 11.2 acres (cca. 4.53 ha) per household in NM. The sizes of the sampled farms are slightly bigger than the provincial averages of 0.5–1.5 ha in WM, 1–2 ha in NM and 1–3 ha in areas where mechanization projects have been promoted. Nevertheless, the sampled households still qualify as smallholders. Although this range of land size is sufficient to produce profit, the yields are low, averaging around 0.6–1.1 tonne per hectare. This is well below the break-even yield, which in this context, was determined through community consultation in the Chitambo District. Average production cost in rainfed conditions – assuming traditional practices – was estimated. Based on this, a rough break-even point was set at around 1.6–2 tonnes per hectare. This figure can vary across production areas and markets, as input access and markets can alter the production cost and farmgate prices. Even though the break-even yield is much lower than the potential rice yield of 2–5 tonnes/ha, farmers often do not achieve this level of productivity even under normal weather conditions.

Although the selling price varies across regions, the highest average selling price remains below the achievable market price, resulting in an average rice farm earning less profit than the average national income. WM has the highest average selling price at ZMW 9.6/kg, well above the minimum farmgate price set by the Food Reserve Agency. The minimum farmgate price set by the agency does not equate to the definition of guaranteed floor price. Rice markets function on the “willing seller, willing buyer” principle, allowing buyers full freedom to negotiate prices based on quantity and quality. The lack of floor prices discourages farmers from producing cash crops like rice, which would require taking market risks. Many factors affect farmgate prices, including grain quality, variety and remoteness of the area. In terms of remoteness, as of early 2025, the retail price averaged around ZMW 32/kg, with a wide price range among markets. The difference between the farmgate and retail prices proves the exposure of smallholders to retailers, which is attributed mostly to the lack of direct access to markets. The combination of low productivity and farmgate prices reduces the expected income in most cases. Generally, a household with an average land size of 4–11 acres earns between ZMW 13 000 and ZMW 20 500 annually from rice. Off-farm income accounts for about a quarter of their total yearly earnings. Although rice is regarded as a cash crop, the average income of the sampled farmers remains below the national average, which was reported at ZMW 3 442.9 per month or ZMW 41 314.8 per year in 2022 (Zambia Statistics Agency, 2025). Rice production can only be justified if the expected income is reasonably higher than the national average.

Beyond market risk, production risks like climate disasters threaten annual rice income, potentially leading to negative profits during dry years. Actual field practices were studied to compare the economic performance under different weather conditions in Chitambo, where the community needs assessment was carried out. Although cost–benefit situations are not directly comparable across the country due to different agroclimatic, socioeconomic and market factors, the community consultation highlighted the negative impacts of climate disasters. Dry spells and drought events, which lead to rainfall deficits, can wipe out already low yields. As a result, total revenues may be insufficient to cover production costs, shown in Figure 1. This is one reason why farmers often abandon rice production during dry years. The negative coping strategy confirms that the stability of rice sector performance directly depends on the development of irrigation infrastructure as a resilience-building measure.

FIGURE 1. Comparison of yields and incomes under average and dry weather conditions in Chitambo, based on community consultation



Source: Authors' own elaboration.

Although household consumption varies across the sampled provinces, the average amount of rice consumed remains relatively low, suggesting that farmers produce rice primarily for commercial purposes rather than for household food security. Zambia's population traditionally consumes more maize than any other country, with the highest average maize consumption worldwide at an annual 140–160 kg/person. Rice consumption in Zambia is significantly lower than maize consumption at an annual 4.2 kg/person, even though rice-producing households tend to consume more than the average. The proportion of rice retained for household consumption remains low, at 10–20 percent across the sampled farmers and around 30 percent according to the national statistics. This indicates that rice is primarily viewed as a business venture rather than a dietary choice for farmers. This assumption also implies that profitability levels must be considered if rice is treated as a business.

1.2.3. Rice production development requires a value chain approach to improve productivity levels.

The development of good agricultural practices occurs at the research level while the sector is still awaiting effective adoption at the farm level. Zambia has initiated several comprehensive programmes for rice sector development, including those financed by international donors. These programmes have focused on establishing foundations, including region-specific suitability assessments, piloting various varieties, land preparation, and planting methods. However, the scaling up of input management and practices remains pending. This means that most field practices are ad hoc and based on relatively short experiences in rice production.

Inputs such as labour days, agrochemicals and seed types vary widely across the regions, highlighting the need for standardized practices to mitigate volatility. The input use per land unit differs across regions (Table 3). While NM has the largest land size, inputs are not proportionally higher compared to CC and WM, suggesting heterogeneous production practices. Likewise, seed types and crop establishment differ across regions, with seed types skewed towards recycled, farmer-produced seeds.

TABLE 3. Production inputs by region, reporting the mean values

	CC	NM	WM	Total	Test
Labour costs of production (ZMW)	3 956	5 217	3 840	4 331	0.080
Total days of family and hired labour (days)	58.5	87.6	61.9	69.3	<0.001
Purchased inputs (ZMW)	2 168	5 156	2 323	3 204	<0.001
Seed type (farmer-produced-0, certified-1)	0	0	0.05	0.19	0.003
Crop establishment (transplanting-0, direct-1)	0	0.000	0.55	0.19	<0.001
Road access (no-0, yes-1)	0.90	0.99	0.96	0.95	0.011

Notes: P-values from pooled t-tests, whereas the statistical significance is decided based on the P-values displayed in the test column: $p < 0.05$ suggests a statistically significant result, and $p > 0.05$ suggests the result is not statistically significant; CC = Chitambo in Central Province, NM = Mungwi in Northern Province, and WM = Mongu in Western Province.

Source: Authors' own elaboration.

The differences in production inputs and reported market prices suggest that rice productivity is limited by multiple factors throughout the entire value chain rather than by a single factor. Unlike in many other countries, practices are random and diverse due to the inaccessibility or unavailability of resources, whether physical input or knowledge. From the availability and accessibility of quality seed to input selection and marketing opportunities, production practices need to be updated comprehensively. While some parts of the value chain can be improved through capacity building and the direct transfer of best practices, others require the development of an enabling environment. For instance, seed availability can be enhanced only if seed-producing entities are established and operated consistently across the country.

Initial and operating expenses of rice production are substantially higher than those of maize, and the profit margin can only justify the investment if total production costs are kept to a minimum. The Japan-funded FAO project set up a pilot field to develop the best agronomic and irrigation practices, using 880 m² production area. The cost structure of the pilot shows that machine- and infrastructure-related costs, including irrigation, are substantially higher than labour costs such as ploughing or harvesting, as displayed by Figure 2. Therefore, locally available resources should be carefully assessed before defining the required degree of mechanization.

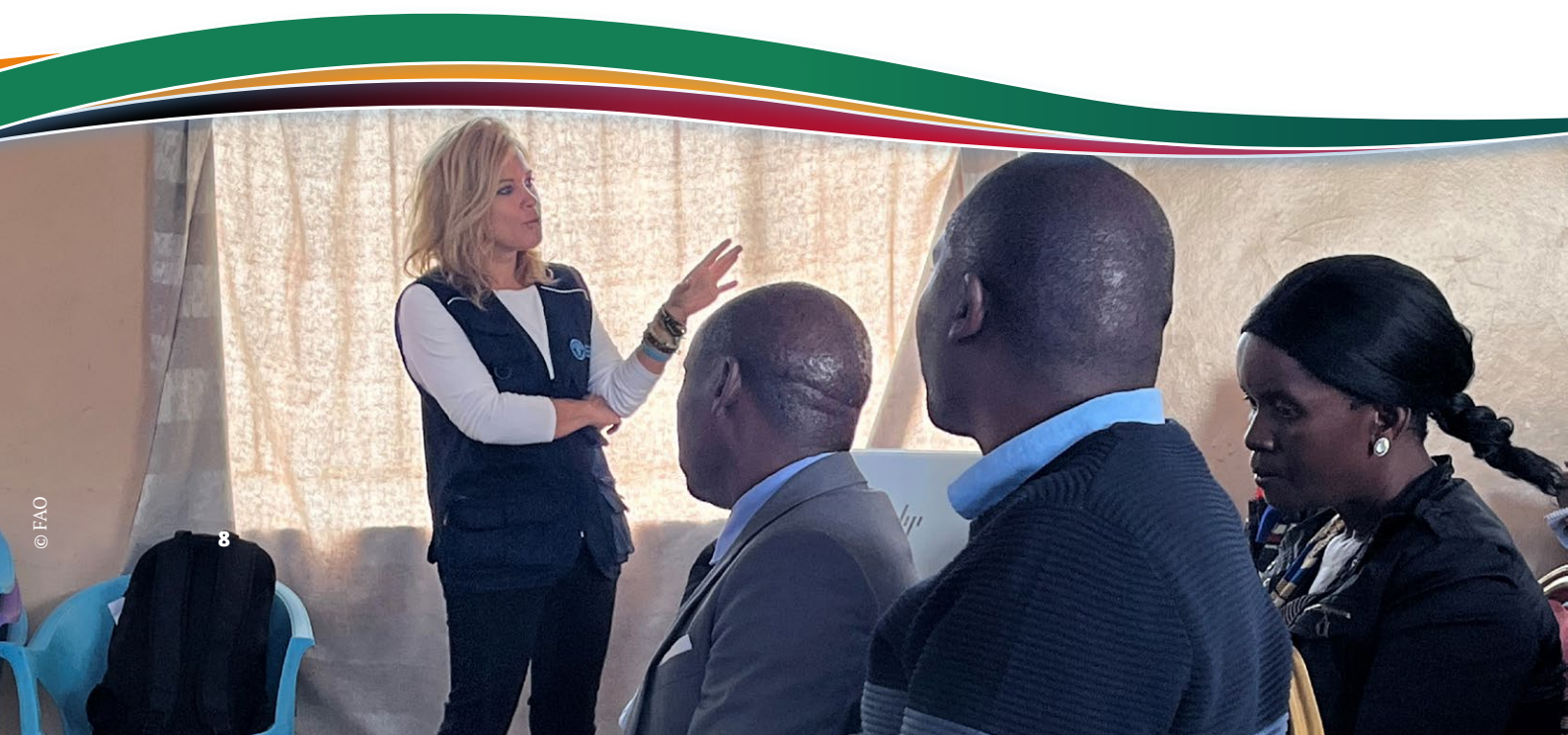
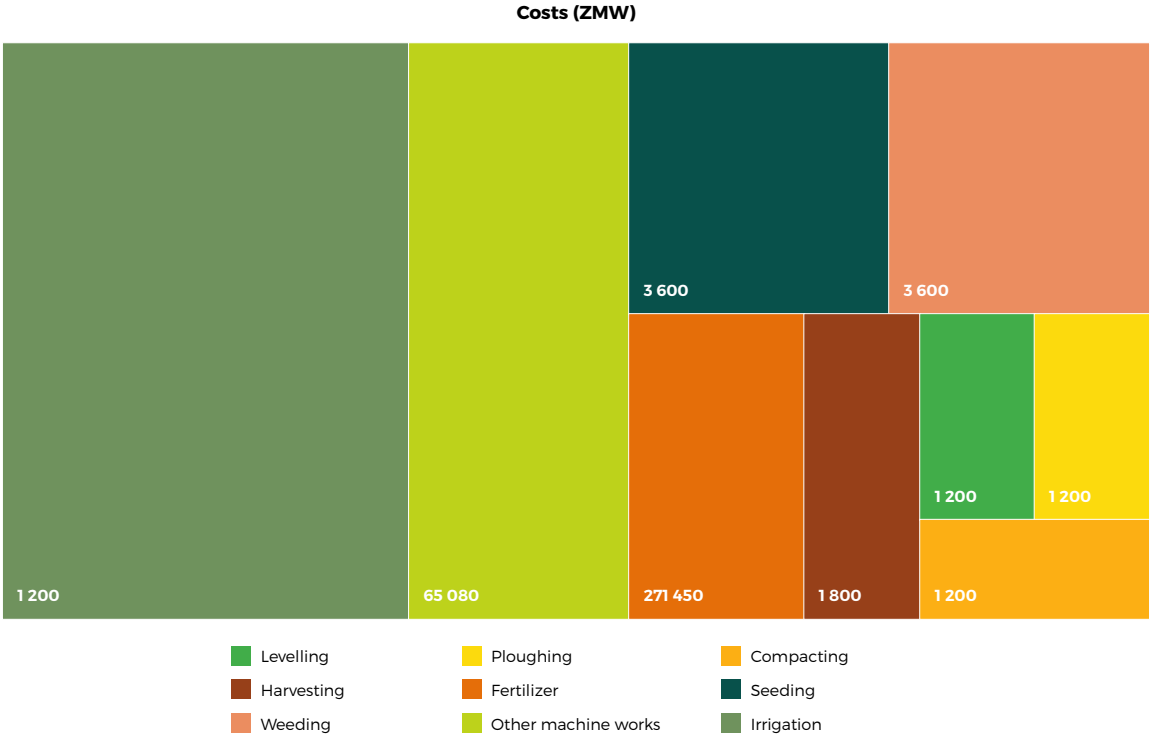


FIGURE 2. Cost structure and cost-benefit analysis of the pilot field

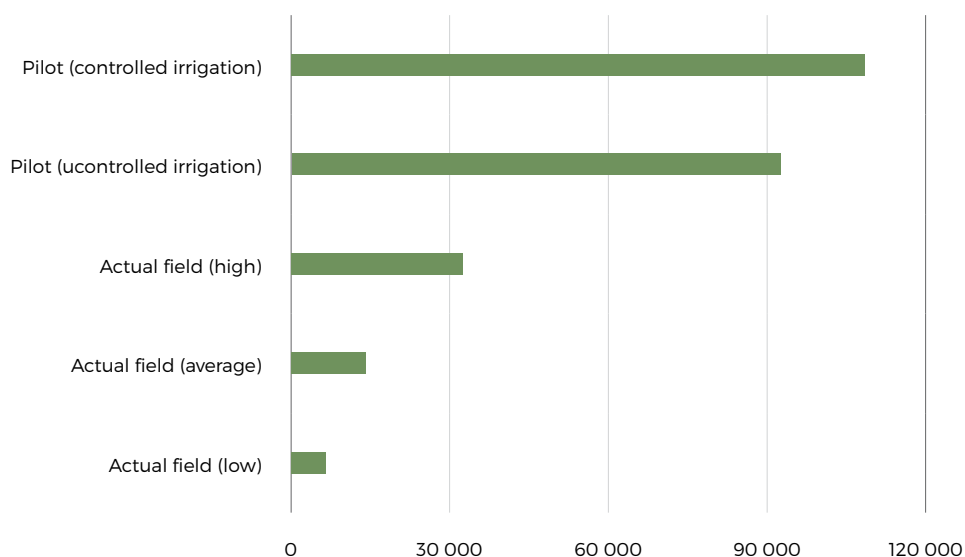


Source: Authors’ own elaboration.

Using best farming and irrigation methods can increase production revenues fivefold by increasing yields, more than covering the extra costs of these practices and resulting in significantly higher profits. Community consultations revealed a significant variation in total revenues among farmers within the same community, ranging from approximately 6 000 to around 35 000 ZMW per hectare under normal weather conditions (Figure 3). When total production costs outweigh low revenues, the farm’s profit can turn negative. Farmers have reported instances where they abandoned rice production to avoid this risk. Although proper agronomic and irrigation practices may incur higher costs, the revenues from increased and higher-quality yields can more than offset them. However, even high revenues still fall far short of the revenues that can be generated through optimal agronomic and irrigation practices. Evidenced by the Japan-funded FAO project, the pilot experimenting controlled and uncontrolled irrigation produced four or five times higher benefits.



FIGURE 3. Comparison of the total revenues under field and pilot conditions (ZMW/ha)



Source: Authors' own elaboration.

The development of Zambia's rice sector requires a comprehensive and value chain approach rather than a narrow focus on farm production. While smallholders register low yields due to the constraining factors along the production cycle, the production risk is compounded by weak post-harvest handling, poor processing infrastructure and inadequate marketing systems. Even if they can enter the market, nearly all smallholders sell unmilled paddy, receiving low prices and leaving processors and traders to capture most of the value. Therefore, interventions must address the entire value chain, from input management to marketing. However, value chain development should consider the mitigation of climatic disasters, as extreme water-related events have been intensifying. Irrigation is a key strategy to increase coping capacities, but the level of uptake is low.

1.2.4. Irrigation infrastructure is a critically missing component of the rice production value chain.

The development of the rice sector must go hand in hand with irrigation development to reduce the reliance on rainfall, which poses the biggest exogenous risk to production levels. Regardless of the proven benefits of irrigating rice, rice farming in Zambia is overwhelmingly dependent on rainfall. Existing irrigation initiatives, such as pilot schemes in Sefula (Western Province) and Chanyanya (Kafue), remain limited in scale and scope. Production is concentrated in lowland floodplains and dambos in Western, Muchinga, Northern and Luapula provinces, which are prone to unpredictable flooding, drought events and seasonal variability, making the crop highly vulnerable to climate shocks. The absence of reliable irrigation infrastructure constrains productivity and threatens the stability of smallholder incomes under increasing climate variability.

Although rice sector development depends on the pace of irrigation infrastructure development, farmers are often unaware of its importance. While paddy rice production requires facilities for controlled irrigation, many communities lack a formal irrigation system. The situation is exacerbated by poor understanding of the link between paddy rice production and irrigation. Community consultations revealed that farmers are unaware of the significance and methods of irrigation and, therefore, do not advocate infrastructure development.

TABLE 4. Irrigation practices by region, reporting the mean values

	CC	NM	WM	Total	Test
Share of plots with direct access to irrigation water (%)	7.4	0	45.9	18.1	<0.001
Land equipped for irrigation (no-0, yes-1)	0.06	0.00	0.48	0.18	<0.001
Water source: (river-1, reservoir-2, groundwater-3)	2.94	2.88	2.17	2.65	<0.001
Ever irrigated land before (no-0, yes-1)	0.03	0.00	0.37	0.13	<0.001
Land connected to water storage facilities (no-0, yes-1)	0.06	0.00	0.21	0.09	<0.001
Membership in water user association or similar (no-0, yes-1)	0.07	0.00	0.19	0.08	<0.001

Notes: P-values from pooled t-tests, whereas the statistical significance is decided based on the P-values displayed in the test column: $p < 0.05$ suggests a statistically significant result, and $p > 0.05$ suggests the result is not statistically significant; CC = Chitambo in Central Province, NM = Mungwi in Northern Province, and WM = Mongu in Western Province

Source: Authors' own elaboration.

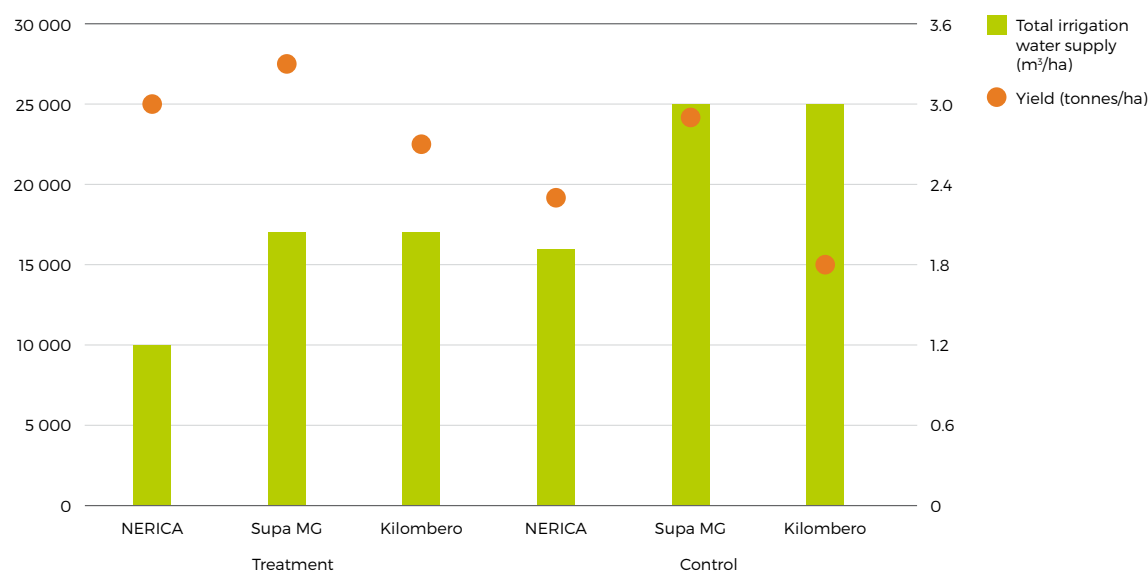
Infrastructure development, including irrigation infrastructure, can succeed only if the knowledge gap of smallholders is systematically addressed. Both paddy production and irrigation development require substantial capacity building. Small-scale farmers in Zambia generally have limited knowledge and skills for managing irrigation systems. Only a segment of smallholders who are already into improved schemes or commercial farming apply more advanced irrigation methods. The majority remains constrained by limited technical knowledge. Most irrigated farms rely mainly on low-cost, labour-intensive methods such as bucket irrigation, treadle pumps and small engine pumps, with some also using furrow or basin irrigation (Japan International Cooperation Agency, 2011). Even larger irrigation projects continue to be hindered by the incomplete understanding of infrastructure operation and maintenance, as well as irrigation management.

Irrigation infrastructure is almost entirely absent for some communities despite the abundant surface water resources and the indispensable role of irrigation in paddy production. The analysis of the sampled communities, included in Table 4, corresponds with the existing baseline studies on irrigation in the paddy sector. Only WM communities have a relatively acceptable level of access to irrigation water; the other regions do not practice irrigation. The distribution of water sources also differs significantly. WM farmers tend to rely more heavily on rivers and reservoirs, reflecting the ecological setting of the Zambezi floodplain. By contrast, groundwater use sparsely appear in CC and NM, though the actual access remains very limited. Access to water storage facilities is again highest in WM and almost absent in CC and NM, underscoring the need for irrigation development in these regions.

Even though paddy sector development is conditional upon the infrastructure development in Zambia, approaches that incentivize the community-driven initiatives can speed up the process. Although there is variation in the involvement of water user associations across regions, the average membership rate remains low. Multiple projects have been implemented with a focus on training smallholders on farmer-led irrigation development. Although the sustainability of low-cost, flexible and small-scale irrigation infrastructure depends on a variety of factors, these temporary infrastructures can serve as a bridge to permanent structures as farmers gain experience (Japan International Cooperation Agency and Sanyu Consultants Inc., 2011). Promoting participatory approaches is, therefore, a powerful approach to expedite paddy rice sector development.

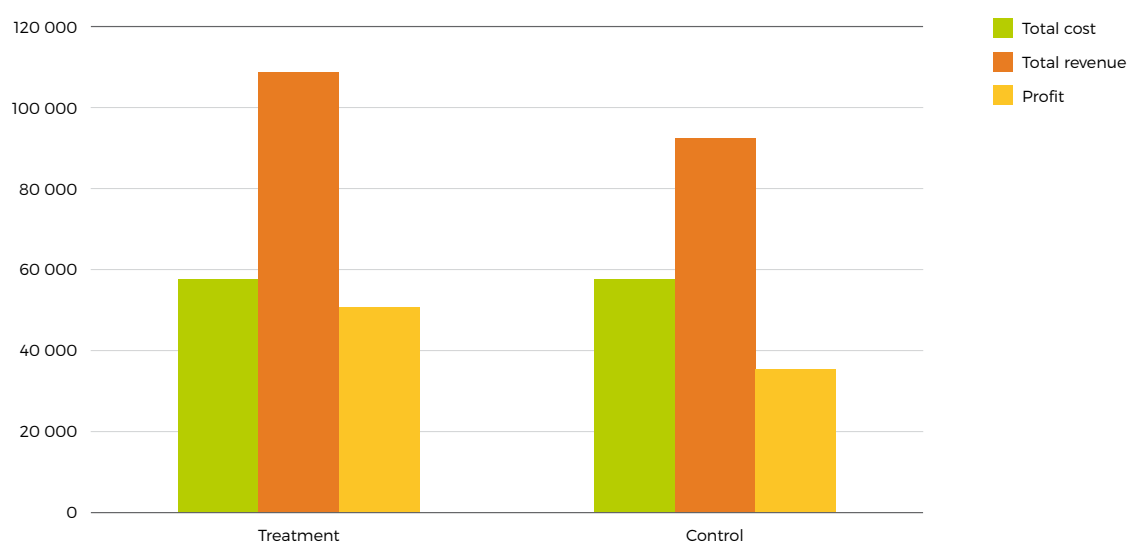
In rice-producing regions, investment in irrigation development should be targeted by using appropriate technical design to maximize productivity benefits. The pilot site used by the Japan-funded FAO project experimented two irrigation management modalities, involving constant flooding (control site) and controlled irrigation (treatment site), illustrated in Figure 4. The results show that controlled irrigation, with a reduced amount of water, can increase yields for both upland and lowland varieties (NERICA, Supa MG and Kilombero). This implies that irrigation development in rice areas should be designed in line with the required water management practices for paddy cultivation.

FIGURE 4. Comparison of water supply and yield indicators under different irrigation practices



Source: Authors' own elaboration.

FIGURE 5. Comparison of the costs, revenues and profits of rice production under different irrigation practices (ZMW/ha)



Source: Authors' own elaboration.

Implementing irrigation schemes can bring numerous benefits, including increased farm income through higher productivity, greater resilience to climate-related disasters, and the potential for double-cropping, provided that the scope of irrigation development goes beyond infrastructure to the establishment of suitable irrigation types and practices. On one hand, the yield increase directly leads to higher income as rising domestic demand can absorb the additional production. The marketable yield of the pilot farm with controlled irrigation generated almost 50 percent higher profit than the flooded farm (Figure 5). This is because controlled irrigation practices do not involve higher costs, but they can increase yield productivity, generating higher revenues at the same unit production cost. On the other hand, irrigation, recognized as an effective adaptation measure, can improve capacities to cope with the impacts of dry spells and drought events. Finally, year-round access to irrigation water can facilitate production during the dry season. As most farmers rely on rainfall, double-cropping has not yet been practised in Zambia despite the biophysical potential of irrigated agriculture. It confirms that simply developing irrigation infrastructure is not enough to improve rice production performance, as irrigation type and capacity building in proper irrigation practices are also necessary.

1.2.5. The multifunctional roles of paddies can be exploited only under predictable water management conditions.

The willingness to adopt technology has not translated into actual field activities yet, and this restricts the ability to exploit the multiple functions of water use. The community consultation revealed that there is an interest in revenue-increasing configurations of paddies, but the technology requirements are far from sufficient. The low level of technology use in rice production highlights the risk-averse behaviour of farmers. The development of multifunctional paddies should address the infrastructure deficiencies and farmers' risk-taking attitude simultaneously.

Studies show that small-scale practices such as mulching with paddy straw can activate additional functions of water, but even such practices require awareness-raising. Analyses have proven that mulching with paddy straw can increase soil water retention, even in rainfed areas, by reducing runoff and evaporation. Residual soil moisture, in turn, can increase the yield and conserve the topsoil. Despite its simplicity, low labour requirement, no-risk and proven benefits, mulching is not practiced widely. This exemplifies that even small-scale practices require technical support to promote adoption.

The multifunctional roles of paddies, including their ecosystem, economic and social functions, depend on water control infrastructure. Water infrastructure is a prerequisite for exploiting the multifunctional roles of paddies. The surveyed communities have low access to irrigation facilities, restricting the variety of additional roles. Even irrigating communities use low-complexity irrigation systems without control devices. The level of irrigation infrastructure is one of the major barriers to maximizing the benefits of water. Beyond the lack of system-level infrastructure, on-farm infrastructure is inappropriate for water retention, as rice farms are too large in size, and farmers do not construct paddy bunds. The consequences are multiple. Runoff is high on unlevel lands, decreasing water-use efficiency. Furthermore, the higher-grade lands are more prone to dry up, and agrochemicals are leached to downstream farms. Even with small-scale interventions, such as levelling and bund construction, farmers could start benefiting from more available and controlled water.

Aligning the development of the rice and irrigation sectors with Zambia's Integrated Water Resources Management (IWRM) Strategy and Implementation Plan is a unique opportunity to strengthen synergies, and exploiting the multifunctional roles is a pragmatic approach. Zambia's IWRM

Strategy and Implementation Plan sets four strategic focal areas: water resources management; water infrastructure development; water supply and sanitation; and monitoring, evaluation and capacity building. It emphasizes the efficient and equitable management of water resources. Exploiting the economic potential of water by amplifying its unit monetary benefit is in line with the plan's principles. Multifunctional roles, such as fish–rice farming, can help achieve this objective while responding to the priority interventions on investing in water infrastructure.

1.2.6. Rice production is vulnerable to multiple water-related disasters.

Rice production depends on rainfall and river flow regimes in floodplains, making it vulnerable to water- and weather-related disasters such as floods and drought events. Without formal irrigation systems, farmers must rely on rainfall or the hydrological behaviour of natural streams. The situation is further complicated by a lack of farm equipment to retain water in the paddies. Given the increasing frequency of climate disasters, including dry spells, drought events, and floods, it is essential that rice sector development incorporates resilience measures to protect and stabilize production.

TABLE 5. Climate risk variables by region, reporting the mean values

	CC	NM	WM	Total	Test
Number of drought events in the past decade	1.55	2.15	2.21	1.97	<0.001
Number of flood events in the past decade	1.84	1.53	2.80	2.06	<0.001
Future drought risk perceived (no-0, yes-1)	0.91	0.40	0.93	0.75	<0.001
Future flood risk perceived (no-0, yes-1)	0.79	0.43	0.78	0.67	<0.001
Weather service or early warning (no-0, yes-1)	0.86	0.01	0.91	0.59	<0.001

Notes: P-values from pooled t-tests, whereas the statistical significance is decided based on the P-values displayed in the test column: $p < 0.05$ suggests a statistically significant result, and $p > 0.05$ suggests the result is not statistically significant; CC = Chitambo in Central Province, NM = Mungwi in Northern Province, and WM = Mongu in Western Province.

Source: Authors' own elaboration.



While Zambia faces drought events and floods simultaneously, the agroecological zones influence how farmers perceive the risk. On average, farmers have reported two major flood and drought events over the past decade, with notable regional variations (Table 5). Western Province has seen the most drought and flood events; Central Province has had the fewest drought events; and Northern Province has had the fewest flood events. The disaster experience corresponds to the agroecological setting of the production areas, with the Zambezi floodplain more prone to flood events and is most at-risk for drought, according to the combined drought indicator for Zambia (Southern Africa Drought Resilience Initiative, 2025).

Perceptions of drought and flood risk vary greatly, regardless of disaster experience. Farmers in CC and WM have high risk perceptions, particularly regarding drought, which is widely agreed upon. In contrast, farmers in NM are less concerned about future events, with fewer than half considering drought events and floods to be persistent risks. The risk perceptions align with most disaster vulnerability assessments; however, the unpredictability of future events requires resilience-building measures.

Access to early warning systems is imbalanced among the regions, downplaying the role of weather information in crop production. Even if some areas experience fewer disasters, early warning systems are still useful for managing rainwater more effectively. Farmers with access to information can plan crop production methods and set up irrigation practices.

1.3. CLIMATE-RESILIENCE TYPOLOGIES OF RICE-PRODUCING FARMERS

A detailed understanding of climate risk exposure and adaptive responses among smallholder rice farmers in Zambia requires not only a national overview but also a nuanced, regionally disaggregated analysis that helps identify farmer typologies. The extended analysis focuses on cluster characteristics, socioeconomic correlates, resource use and irrigation modalities. Rather than treating producers as a homogenous entity, this method groups them according to shared characteristics across socioeconomic, production and resource-use variables. This is particularly useful for the Western Province, where diverse environmental conditions of the Zambezi catchment, socioeconomic factors and institutional context generate distinct risk profiles. This approach helps reveal patterns in how farmers access land, labour, irrigation, information and markets while shedding light on the ways these factors interact with climate risks and livelihood strategies. Social dimensions further complicate the picture. Women, youth and people with disabilities face specific barriers that shape their participation and productivity. These overlapping variations create a kaleidoscope of rice production practices, making it challenging to draw simple typologies. By applying cluster analysis, it becomes possible to move beyond averages and instead capture the distinct profiles and dynamics shaping decisions. This provides a stronger foundation for developing interventions and policies that are better aligned with the specific conditions and needs of different categories of rice producers.

While climate-related disasters do not affect every part of the country in the same way, all farmers, particularly those managing rainfed systems, face a certain degree of risk, which can serve as a trigger for investing in rice farming. While socioeconomic conditions and production practices vary widely across regions and farmer groups, virtually all producers share vulnerability to drought events, floods or erratic rainfall. These shocks not only disrupt yields but also amplify existing inequalities as farmers without irrigation or weather information are less prepared. Negative coping capacities, such as abandoning rice production, are widely observed among farmers in dry years. At the macroeconomic level, reduced harvested

area and production volumes can be associated with climate risks, too. By anchoring the analysis in disaster risk, one can identify how socioeconomic and production practices differ across farmer groups. In a context where patterns and typologies are blurred by heterogeneity, disaster experience becomes a unifying entry point. It provides a logical foundation for building farmer profiles and designing tailored resilience strategies.

Rice-producing farmers are heterogeneous not only across but within regions, thus requiring region and typology-specific policies. The initial cluster analysis employs the Calinski-Harabasz pseudo-F test to determine the optimal number of climate risk-differentiated groups among farmers, both nationally and within WM (Table 6). While a three-cluster solution provides the best overall fit, the pseudo-F value is notably higher in the Western Province (296.21) compared to the national sample (275.16), indicating that intraprovincial heterogeneity is at least as pronounced as regional variation.

TABLE 6. Calinski/Harabasz pseudo-F statistics for different cluster solutions

Number of clusters	National sample	Western province
2	213.93	210.49
3	275.16	296.21
4	232.53	220.19
5	215.40	201.12

Source: Authors' own elaboration.



TABLE 7. Results of the cluster analysis and the disaster-differentiated clusters								
Variable	Cluster 1	Cluster 2	Cluster 3	P-value	Western cluster 1	Western cluster 2	Western cluster 3	P-value
Number of drought events	2.97	2.62	1.55	<0.001	2.67	2.05	1.94	<0.001
Number of flood events	3.19	5.83	0.97	<0.001	5.76	2.68	0.09	<0.001
Future drought risk perceived	0.93	1.00	0.65	<0.001	1.00	0.87	0.94	0.078
Future flood risk perceived	0.95	0.93	0.54	<0.001	0.91	0.84	0.62	0.009

Notes: P-values from pooled t-tests, whereas the statistical significance is decided based on the P-values displayed in the test column: $p < 0.05$ suggests a statistically significant result, and $p > 0.05$ suggests the result is not statistically significant.

Source: Authors' own elaboration.

The cluster analysis highlights marked differences in disaster exposure and risk perception among rice-farming households. Across the full sample, cluster 1 experienced the highest number of drought events (2.97) and cluster 2 the highest number of flood events (5.83), while cluster 3 reported far fewer shocks of either kind (1.55 for drought and 0.97 for flood), as displayed in Table 7. These patterns are statistically significant and suggest that disaster histories are strongly differentiated across farmer groups. Perceptions of future risk mirror these experiences. Clusters 1 and 2 report near-universal concern over future drought events and floods (above 0.9), while cluster 3 shows far lower perceived risk (0.65 for drought and 0.54 for flood).

Western Province farmers differ because their production system is tied to the Zambezi floodplain and dambos, where rice depends directly on seasonal flooding, thus splitting farmers into distinct typologies. The reliance on the Zambezi's hydrology means farmers are exposed to multiple extremes, including climatic and hydrological variability. They experience both recurrent floods and periods of insufficient water. As the data show, they report a much higher number of flood events than farmers elsewhere, and their risk perceptions are shaped by the historical experience. Disaster risk is, therefore, two-sided. Floods are more frequent and damaging, yet the absence of floods is also a risk because it disrupts the natural production cycle. This paradox makes Western Province farmers' experience of disasters more pronounced, complex and different from regions. Results from Western Province follow a similar pattern to the aggregate typologies, though with sharper contrasts in flood exposure. Cluster 1 reports nearly six flood events on average in the past decade, compared to 2.7 in cluster 2 and virtually none in cluster 3.

1.3.1. Farmer typologies range from climate-vulnerable to resilient and irrigating groups. Farmer typologies can be defined as climate-resilient and experienced; climate-neutral and less-equipped; and diverse and climate-exposed groups, whereas climate risk perception is directly associated with information resources and available infrastructure. The differences among farmer groups relate to their levels of disaster risk, access to irrigation and information resources (Table 8). Interestingly, farmers with higher disaster exposure and risk perception are more equipped with irrigation and have more experience and access to information. The community consultation revealed that this discrepancy is the direct result of poor awareness. Communities without access to irrigation have a limited understanding of resilience-building measures such as irrigation, and so the association of irrigation and climate resilience is not yet a common perception.

TABLE 8. Cross-validation of cluster analysis with the variables

	Cluster 1	Cluster 2	Cluster 2	P-value
Number of drought events in the past decade	2.97	2.62	1.55	<0.001
Number of flood events in the past decade	3.19	5.83	0.97	<0.001
Future drought risk perceived (no-0, yes-1)	0.93	1.00	0.65	<0.001
Future flood risk perceived (no-0, yes-1)	0.95	0.93	0.54	<0.001
Ever irrigated land (no-0, yes-1)	0.12	0.38	0.09	<0.00
Number of plots	3.05	2.57	2.07	<0.001
Number of plots owned	2.92	2.14	1.92	<0.001
Weather service or early warning (no-0, yes-1)	0.59	0.93	0.53	<0.001
Experience (years)	14.10	17.70	11.76	0.00
Water source (river-1, reservoir-2, groundwater-3)	2.41	2.57	2.75	0.00
Land equipped for irrigation (no-0, yes-1)	0.14	0.38	0.16	0.00
Selling price (ZMW/kg)	8.30	8.35	7.66	0.03
Share of rice produced for household consumption (%)	12.82	19.39	15.41	0.03
Share of plots with direct access to irrigation water (%)	15.42	31.14	16.22	0.04
Total land cultivated (acre)	7.98	4.55	7.01	0.06
Membership in water user association or similar (no-0, yes-1)	0.12	0.17	0.06	0.07
Mobile phone (no-0, yes-1)	0.88	1.00	0.92	0.08
Share of rice produced for selling (%)	86.43	80.60	84.02	0.10
Extension service (no-0, yes-1)	0.90	0.98	0.96	0.10
Total days of family and hired labour (days)	56.95	74.66	71.88	0.12
Seed type (farmer-produced -0, certified-1)	0.05	0.02	0.01	0.13
Road access (no-0, yes-1)	1.00	0.93	0.94	0.14
Purchased inputs (ZMW)	3.92	2.10	3.22	0.15
Education (without-0, primary-1, secondary-2, advanced-3)	0.90	1.14	0.92	0.17
Number of adults	4.02	3.57	3.50	0.18
Household consumption (kg)	282	243	345	0.19
Total rice output (kg/year)	2.39	1.94	2.75	0.23
Off-farm income (ZMW/year)	4.04	7.32	4.93	0.27
Age	45.86	50.00	47.04	0.27
Gender (male-0, female-1)	0.37	0.45	0.35	0.45
Number of family workforce	3.36	3.64	3.70	0.48
Total income from rice (ZMW/year)	14 498	13 656	17 146	0.48

TABLE 8. Cross-validation of cluster analysis with the variables (continued)

	Cluster 1	Cluster 2	Cluster 2	P-value
Membership in farmer association (no-0, yes-1)	0.85	0.76	0.81	0.56
Land connected to water storage facilities (no-0, yes-1)	0.07	0.07	0.10	0.62
Labour costs of production (ZMW)	4.73	4.154	4.253	0.77
Owner of land (no-0, yes-1)	0.93	0.93	0.91	0.84
Crop establishment (transplanting-0, direct-1)	0.17	0.21	0.19	0.85
Number of children	3.75	3.69	3.89	0.87

Notes: P-values from pooled t-tests, whereas the statistical significance is decided based on the p-values displayed in the test column: $p < 0.05$ suggests a statistically significant result, and $p > 0.05$ suggests the result is not statistically significant.

Source: Authors' own elaboration.

The cluster analysis demonstrates that differences in irrigation access and equipment correspond closely to farmers' disaster experiences and risk perceptions. Farmers in cluster 2, with the highest share of irrigated plots (38 percent – ever irrigated, 31 percent – direct access, 38 percent – equipped), are concentrated in floodplain ecologies where floods are naturally more frequent. This explains why they reported the highest number of flood events (5.83) and why nearly all perceive both drought and flood risks as future threats. By contrast, clusters 1 and 3, with much lower irrigation coverage (12 percent – ever irrigated; 14 percent – direct access, 16 percent – equipped), operate mainly in rainfed systems where drought events are the predominant hazard. Cluster 1 recognizes this strongly, perceiving high risks of both drought (0.93) and flood (0.95), whereas cluster 3 perceives considerably lower risks (0.65 and 0.54), despite also being rainfed. Furthermore, farmers in cluster 2 are often better connected to weather and early warning services, which make them more aware of climate risks. Irrigation and information access differentiate farmer groups by situating them in distinct ecological zones and shaping their levels of climate awareness and preparedness. Intervention strategies focused on irrigation development should aim not only to establish the necessary infrastructure but also to ensure that the design and practices align accurately with the specific crop types.

Climate risk perception and preparedness are associated with experience and knowledge, thus mitigating disaster vulnerability. Although not statistically significant, farmers in cluster 2 are older and slightly more educated than the other groups, while their farming experience is significantly longer. These attributes shape their relationship with climate risk. Long farming experience provides direct exposure to multiple drought and flood events, which explains their near-universal perception of future risks. Typically, longer experience and access to knowledge resources, such as education or early warning systems, would imply lower disaster exposure and risk perception as farmers are better equipped to identify and implement resilience measures. However, this is not the case in Zambia, where there is a very low understanding of the causal link between water-related disasters and rice production. This is partly due to the relatively short experience in rice production, the absence of established production practices, and the lack of expertise in irrigation. This is why policies addressing water management and rice production in Zambia should prioritize capacity building, from awareness-raising to technical expertise.

1.3.2. Variation of farmer profiles is high even within the same region.

Farmers with the highest access to irrigation in the same region display diverse profiles regarding irrigation levels, disaster risk, knowledge resources and production purposes. Those with irrigation access are almost exclusively located in WM, within the Zambezi catchment. Although farms in the western part have been strategic priorities in Zambia's rice sector development and several projects have been implemented in there, production practices are still not standardized. This results in a wide variation in profiles, as shown in Table 9.

TABLE 9. Cross-validation of cluster analysis with the variables in the WM

	WM Cluster 1	WM Cluster 2	WM Cluster 3	P-value
Number of drought events in the past decade	2.67	2.05	1.94	<0.001
Number of flood events in the past decade	5.76	2.68	0.09	<0.001
Education (without-0, primary-1, secondary-2, advanced-3)	1.49	0.81	0.82	<0.001
Mobile phone (no-0, yes-1)	1.00	0.78	1.00	<0.001
Labour costs of production (ZMW)	3 473	5 581	2 302	<0.001
Purchased inputs (ZMW)	1 869	3 732	1 231	<0.001
Crop establishment (transplanting-0, direct-1)	0.30	0.51	0.85	<0.001
Share of plots with direct access to irrigation water (%)	42.36	26.41	70.59	<0.001
Water source (river-1, reservoir-2, groundwater-3)	2.46	1.78	2.32	<0.001
Total rice output (kg/year)	1 714	2 666	1 650	0.001
Number of plots owned	2.12	3.81	2.74	0.001
Extension service (no-0, yes-1)	0.97	0.76	0.97	0.003
Land connected to water storage facilities (no-0, yes-1)	0.06	0.19	0.38	0.004
Age	52.85	46.65	56.29	0.006
Total days of family and hired labour (days)	85.49	52.41	49.24	0.006
Future flood risk perceived (no-0, yes-1)	0.91	0.84	0.62	0.009
Number of plots	2.52	4.03	2.79	0.011
Number of family workforce	3.52	4.03	2.77	0.012
Share of rice produced for household consumption (%)	19.04	15.72	25.94	0.017
Household consumption (kg)	261	395	329	0.024
Selling price (ZMW/kg)	8.82	10.40	9.46	0.024
Share of rice produced for selling (%)	80.93	83.74	74.06	0.024
Membership in farmer association (no-0, yes-1)	0.76	0.78	0.53	0.042
Land equipped for irrigation (no-0, yes-1)	0.52	0.32	0.62	0.042
Future drought risk perceived (no-0, yes-1)	1.00	0.87	0.94	0.078

TABLE 9. Cross-validation of cluster analysis with the variables in the WM (continued)

	WM Cluster 1	WM Cluster 2	WM Cluster 3	P-value
Total land cultivated (acre)	3.84	5.68	4.20	0.080
Number of adults	3.36	4.00	3.27	0.118
Ever irrigated land (no-0, yes-1)	0.52	0.32	0.29	0.130
Experience (years)	22.50	17.72	18.21	0.139
Road access (no-0, yes-1)	0.91	0.97	1.00	0.142
Off-farm income (ZMW/year)	7 694	2 068	6 744	0.159
Seed type (farmer-produced -0, certified-1)	0.03	0.11	0.03	0.267
Weather service or early warning (no-0, yes-1)	0.88	0.89	0.97	0.353
Gender (male-0, female-1)	0.49	0.60	0.65	0.398
Total income from rice (ZMW/year)	12 502	14 242	12 668	0.688
Number of children	2.94	2.89	3.24	0.708
Membership in water user association or similar (no-0, yes-1)	0.21	0.22	0.15	0.722
Owner of land (no-0, yes-1)	0.94	0.92	0.91	0.910

Notes: P-values from pooled t-tests, whereas the statistical significance is decided based on the P-values displayed in the test column: $p < 0.05$ suggests a statistically significant result, and $p > 0.05$ suggests the result is not statistically significant.

Source: Authors' own elaboration.

Flood and drought risks differentiate groups, with some farmers experiencing water-related disasters almost every year due to the unique hydrology of the Zambezi, but irrigation is not yet deployed widely to build resilience. Farmers in WM cluster 1 experienced more than five flood events and almost three drought events, on average, in the past decade. Despite the high degree of exposure, only around half of the farmers are equipped and have direct access to irrigation. This assumes that although irrigation is used as a resilience-building strategy to some degree, it is still not regarded as a universal solution for all farmers.



Farmer typologies show sharp contrasts in production practices and input use, highlighting the lack of established practices even within the same region. WM cluster 2 farmers are the most input- and labour-intensive, investing heavily in purchased inputs and hired labour, and using direct seeding more often, which helps them achieve the highest yields. WM cluster 3 farmers rely on traditional transplanting and have the strongest irrigation access; yet, their very low input spending and smaller workforce result in the lowest output, indicating inefficiency despite better water access. WM cluster 1 farmers adopt a moderate approach, utilizing limited inputs and irrigation, and consequently record modest yields. In short, WM cluster 2 represents a more commercialized, input-driven model, while WM cluster 1 and WM cluster 3 remain constrained by low or inefficient input use despite different levels of irrigation. In conclusion, access to inputs and resources is not sufficient to improve the yield productivity, but establishing good practices can significantly increase the input efficiency and productivity.

Farmers with varying levels of disaster exposure and access to irrigation differ in socioeconomic background. WM cluster 1 farmers are older, better educated and have near-universal access to mobile phones and extension services, combined with moderate irrigation and the highest reported flood events. WM cluster 2 farmers are younger, with larger households and more family workforce, lower education, and weaker access to phones and extension. They face moderate flood events and the lowest irrigation access. WM cluster 3 farmers are the oldest, with smaller households, fewer family workers, weaker farmer association membership but the highest irrigation access and the lowest reported flood events.

1.4. FACTORS AFFECTING FARMERS' DISASTER RISK MANAGEMENT APPROACHES

Given the high heterogeneity among rice farmers across socioeconomic, production, irrigation and disaster-related variables, factor analysis offers a useful tool to reduce complexity and identify the underlying dimensions that structure this diversity. Farmers differ not only in age, education and household composition but also in their access to irrigation, labour use, input spending, market orientation, and exposure to floods and drought events. This huge variation creates diversity, where patterns are difficult to discern from single indicators alone. By grouping correlated variables into broader factors, factor analysis enables clearer capture of the main drivers of difference. This approach supports a more systematic understanding of farmer typologies and strengthens the analysis by highlighting the structural dimensions of paddy farmers in Zambia.

Although socioeconomic characteristics are challenging or difficult to influence, production and irrigation-related characteristics can be addressed, which limits the need for factor analysis in these aspects. Factor analysis is conducted to identify the dynamics or patterns that influence disaster risk perception, which informs risk management strategies. However, only the meaningful factors can be addressed or influenced through policies or interventions. As socioeconomic characteristics, including age or experience, cannot be altered, the factor analysis focuses on production and irrigation-related characteristics that can indicate policy directions.

1.4.1. Production scale and land characteristics define farmers' decisions.

The factor analysis reveals that rice production among smallholder farmers in Zambia is structured around two broad and complementary dimensions: the scale of production and land structure. The scale of production (factorcost 1) and land structure (factorcost 2) indicate that rice farming outcomes are not driven by a single variable but by the interaction of resource intensity and structural conditions (Table 10). Policies aiming to improve rice production should first define the desired economic scale of production at the farm level and the availability of land and water resources. Such cost-related factors can be managed through on-farm interventions and policies that address individual farmers.

TABLE 10. Results of factor analysis with production cost and input variables

Variables	factorcost1	factorcost2	factorcost2
Total rice output (kg/year)	0.9564		0.0820
Household consumption (kg)	0.4195		0.8109
Total income rice (ZMW/year)	0.9225		0.1482
Total land cultivated (acre)	0.7959		0.3661
Labour costs of production (ZMW)	0.7527		0.4047
Purchased inputs (ZMW)	0.6926		0.5202
Crop establishment (transplanting-0, direct-1)		0.4580	0.7533
Number of plots		0.8992	0.1840
Number of plots owned		0.9071	0.1640
Share of plots with direct access to irrigation water (%)		0.4514	0.7405

Notes: Factor loadings range from –1 to 1 and indicate the strength and direction of a variable's association with a factor; values closer to ±1 suggest a stronger relationship. Uniqueness reflects the proportion of variance not explained by the factors: lower values indicate better explanatory power.

Source: Authors' own elaboration.

The scale of production is defined by the resource efficiency and productivity of rice farming. The scale of production (factorcost 1) reflects the scale and efficiency of farming operations. This factor is defined by high loadings (indicated in the right column), on rice output, income, land cultivated, labour costs and purchased inputs. This shows that farmers who have more resources tend to achieve higher levels of productivity and income. It highlights the importance of resource intensity and market access as key drivers of performance in the rice sector.

Land structure is composed of the land size, tenure and access to irrigation water as critical production factors. The number of plots, ownership and access to irrigation water are crucial for efficient rice production. Although land availability is generally not a limiting production factor in Zambia, it defines the volume of rice production. This is partly because farmers do not allocate all plots to rice production. On the other hand, equipping land with irrigation access requires a certain scale of land availability.





1.4.2. Rural and water infrastructures influence rice production dynamics.

The factor analysis indicates that rice production decisions are structured around three key and complementary dimensions: water, rural infrastructure and market orientation. Farming outcomes are shaped by the interaction of rural infrastructure, water resources and markets, as shown in Table 11. Such factors are interconnected by nature, as the availability of water determines the feasibility of irrigation development, and the rural road network improves access to markets. While cost-related factors are grouped around on-farm management, such as input and resource use, this set of factors is more structural and related to off-farm aspects. Therefore, addressing these factors largely depends on policies and strategies at the community or larger level.

TABLE 11. Results of factor analysis with irrigation practices and management

Variables	Factor1	Factor2	Factor3	Factor4	Uniqueness
Weather service or early warning (no-0, yes-1)			0.4334		0.5487
Road access (no-0, yes-1)				0.9688	0.0598
Ever irrigated land (no-0, yes-1)	0.9107				0.1706
Land equipped for irrigation (no-0, yes-1)	0.8705				0.1906
Water source (river-1, reservoir-2, groundwater-3)			-0.8215		0.3080
Land connected to water storage facilities (no-0, yes-1)			0.7956		0.3518
Membership in farmer association (no-0, yes-1)	0.7930				0.3484
Share of rice produced for household consumption (%)		0.9636			0.0642
Share of rice produced for selling (%)		-0.9587			0.0790

Notes: Factor loadings range from -1 to 1 and indicate the strength and direction of a variable's association with a factor; values closer to ± 1 suggest a stronger relationship. Uniqueness reflects the proportion of variance not explained by the factors: lower values indicate better explanatory power.

Source: Authors' own elaboration.

Water infrastructure, including access to water, irrigation equipment, and less obvious but still important weather services, influence the pace of rice sector development. Two decisive factors for rice sector development are the level of irrigation equipment (factor 1) and access to water (factor 3), especially access to river water. Weather services do not load very strongly, yet these are identified as a complementary variable in the infrastructure-related conditions. Although previous analysis showed that irrigation alone increases but does not maximize production volume unless it is well managed, it is still necessary for sector development.

Market orientation is a fundamental decision that separates smallholder rice producers. Smallholders' household consumption of rice remains lower than that in urban areas. Even among farmers with the highest share of household use, it is clear that rice production is not solely driven by subsistence needs. The ratio of retained rice to household size indicates that rice is primarily produced as a cash crop rather than for meeting household food demands. Despite relatively low household consumption, the analysis indicates that market orientation (factor 2) continues to play a significant role in farmers' engagement and investment in rice production. Supporting smallholders in market access is a strategic intervention that could incentivize farmers to increase their production volume.

Lack of access to good all-season roads is a significant obstacle to the productivity and competitiveness of smallholders, as it isolates them from larger markets and restricts their selling opportunities to local markets where maize remains the dietary preference. Zambia has an extensive road network of about 68 000 km, but the quality and accessibility of rural roads remain weak, limiting agricultural productivity and market integration. Only a small share of rural households lives within close reach of all-season roads, which raises transport costs, reduces access to inputs and services, and leads to post-harvest losses. Recognizing this bottleneck, the Government of Zambia and its partners have launched initiatives such as the Farm-to-Market Compact and the Improved Rural Connectivity Project, which aim to rehabilitate feeder roads, expand access to all-season infrastructure, and lower transport costs for smallholder farmers. These interventions are seen as critical for improving market accessibility, stabilizing farm incomes, and enhancing the competitiveness of agriculture in line with national development goals (Foster and Dominguez, 2010; World Bank, 2024). Road accessibility (factor 4) is fundamental for rice sector development, as dietary preferences of rural households are still skewed towards maize. Households in rural areas that eat maize reduce the marketing opportunities for the increased volume of rice produced.

1.5. IMPACTS OF DECISION-MAKING FACTORS ON CLIMATE RISK PERCEPTIONS

Although factors such as production scale, land structure, water and rural infrastructures, and market orientation can influence decision-making, the way and extent they are applied depend on how farmers associate them with perceived risks or expected benefits. The factor analysis identified the drivers that essentially define the dynamics of rice farm development, but whether farmers consider them as opportunities depends on their risk perceptions. In rainfed systems, one of the key risks is weather variability, which is particularly salient in Zambia, where a dry year can result in negative profits. So, the first step in understanding the potential of these factors in decision-making is to assess their impact on climate risk perceptions. For this reason, the analysis applies logistic regression in the next step to measure and understand the impact of the factors on farmers' perceptions of future drought and flood risks. The analysis includes regional controls, using dummy variables for WM and NM to determine whether being based in the province systematically affects the baseline probability of risk perception (Table 12).

TABLE 12. Results of the logistic regression measuring the impact of the factors on risk perceptions

	Future drought risk perceived (no-0, yes-1)	Future flood risk perceived (no-0, yes-1)	Future drought risk perceived, regional (no-0, yes-1)	Future flood risk perceived, regional (no-0, yes-1)
factorcost1	-0.19	-0.22	-0.19*	-0.19*
factorcost2	-0.75***	-0.33	-0.83***	-0.39**
factor1	1.10***	0.31	0.27	-0.19
factor2	0.40**	-0.22*	-0.36**	-0.73***
factor3	1.73***	0.75***	0.34	0.08
factor4	0.10	0.16	0.09	0.16
WM Province			-3.02***	-2.27***
NM Province			0.75	0.55
constant	1.77***	0.82***	2.47***	1.44***
Number	303	303	303	303

Notes: Coefficients represent the direction and strength of the association between each factor and the outcome variable. Positive values indicate a higher likelihood or count; negative values indicate a lower one.

Asterisks denote statistical significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Source: Authors' own elaboration.

The perception of drought risk is reduced by increasing land size, especially when combined with direct access to irrigation, as larger farms are viewed as more resilient due to their higher production volumes. The number and ownership of plots connected to irrigation water mitigate the perception of drought risk. Although land size itself is not typically considered a drought mitigation strategy, farmers in Zambia consider larger holdings more resilient. This can be attributed to the fact that reduced unit productivity can be offset by a larger production scale. Nevertheless, such perception does not provide a sustainable and long-term strategy to mitigate drought risk.

Farmers reserving more rice for household consumption tend to be less cautious about flood risk, likely because food security buffers can enhance resilience in areas where disasters are frequent, such as the Western Province. Household reserves are seen as a coping mechanism for repeated flood events, and farmers in more flood-prone regions like the Zambezi catchment feel even less at risk when their stocked volumes are higher. Even if the average rice retention is below the required calorie intake of a household, it can be a mitigating factor for disasters that have localized and mobility-restricting impacts, such as floods (Japan International Cooperation Agency, 2011).

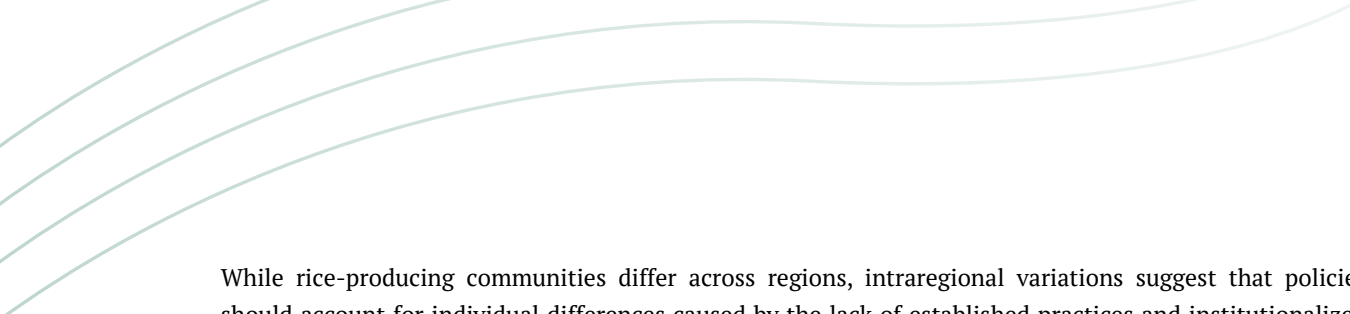
As an ambivalent perception, awareness of drought risk increases with the presence of water infrastructure, but this effect is mainly regional. Factors related to water infrastructure (factors 1 and 2) consistently show a positive and significant association with drought risk perception in the base model. This suggests that farmers with greater involvement in irrigation infrastructure and associations are more aware of drought threats. However, these associations diminish with the inclusion of regional dummies, indicating that much of the observed effect is regionally concentrated. Since most irrigating farmers are in

WM and their drought risk perception does not increase with the irrigation facilities, the main reason for the negative correlation in the overall model is likely due to a poor understanding of the concept and function of irrigation. Consequently – and as previously reiterated – irrigation development in Zambia is not only about infrastructure development but also about comprehensive and programmatic capacity building, starting with awareness-raising.

1.6. RECOMMENDATIONS FOR ENGAGING SMALLHOLDERS IN IMPROVING PADDY RICE FARMING

The results of the analyses allow for the definition of some recommendations that can support the sustainable engagement of smallholders in paddy production:

- **Rice sector development requires a comprehensive, value chain approach:** Improving Zambia's paddy rice sector requires embedding input systems and incentives into the wider value chain. Farmers currently operate with recycled seed, low fertilizer use and minimal mechanization, which limits productivity. To address this, policies should guarantee the reliable provision of inputs while also offering incentives that can rebalance the maize-dominant subsidy system. These incentives should not be isolated but directly linked to value chain development, encouraging farmers to adopt improved practices. By aligning input support with value chain improvements, farmers gain both the means and the motivation to modernize their production.
- **The dependence of the rice sector on irrigation development must be recognized:** The alignment of rice and irrigation development strategies is critical for stabilizing and increasing rice yields and reducing dependence on rainfall. Given the spatial diversity and scattered production pattern, irrigation suitability should first be assessed to define the best system configurations for the paddy-producing areas. Beyond infrastructure, the focus must be on building farmers' capacity in water-use efficiency, controlled irrigation methods and system maintenance. Demonstration plots and participatory training can highlight how controlled irrigation increases yields without additional costs. Strengthening water user associations can institutionalize irrigation management, enabling community-based initiatives.
- **Climate-related disasters should be recognized as major production risks to prompt resilience measures:** Addressing climate risk requires interventions that go beyond irrigation. Farmers face recurring drought events and floods that threaten to decimate their harvests and income, yet they often fail to identify and adopt risk mitigation measures. As a result, they choose negative coping strategies, such as abandoning rice production and reverting to maize. Policies should expand access to information and provide comprehensive capacity building on climate risks and early warning systems.
- **Market access must be facilitated through community-based development to mitigate the market risk:** Market integration should be pursued as a distinct but complementary goal. Investments are needed in improving production practices to enhance quality. Supporting the production of high-demand aromatic varieties, such as Supa-Mg and Kilombero, aligns smallholder output with consumer preferences, increasing competitiveness against imports. As a next step, communities should be empowered to enable marketing at scale and increase their negotiation power. Finally, small-scale post-harvest machines and storage facilities should be established to counterbalance the effect of remoteness on market potential.



While rice-producing communities differ across regions, intraregional variations suggest that policies should account for individual differences caused by the lack of established practices and institutionalized development. Therefore, this set of policy recommendations offers broad interventions that should be implemented at the national level before targeting region-specific characteristics. At the same time, results inferred from the regional analysis should be addressed through community-led approaches to facilitate the parallel development of the sector.



2. Farmers' preferences for irrigation development

The link between improving rice production and developing irrigation is acknowledged by policymakers but has not yet influenced farmers to adopt irrigation practices. The analysis shows that while irrigation has the potential to significantly increase rice farm productivity and profits, farmers remain unaware of its benefits and functions. The lack of irrigation and water control facilities limits the possibility to use paddies for multiple purposes. Without community interest, irrigation development programmes risk underutilizing their potential advantages. The next step is to identify what prompts smallholders involved in paddy farming to be willing to adopt irrigation.

The analysis showed that irrigation is closely linked to an understanding of its roles and functions; therefore, assessing the willingness to adopt (WTA) irrigation considers education level as a proxy of awareness. Awareness typically depends on access to knowledge, making education a key factor in adopting technologies like irrigation. The surveyed farmers generally have low education levels, indicating they need support from specialized knowledge centres, such as extension services. Therefore, the assessment of the WTA should attempt to identify the degree of relationships between irrigation and education levels.

2.1. MEASURING THE WILLINGNESS TO ADOPT IRRIGATION AMONG RICE PRODUCERS

Not all non-irrigation farmers are open to adopting irrigation, so explanatory factors must be identified to understand the dynamics. To measure WTA, data were collected from 262 smallholder rice farmers who were involved in the original farmers dataset and were not currently irrigating their fields. Willingness was defined as perceiving a future drought risk. Of these, 190 farmers (73 percent) reported willingness if given the opportunity, while 72 (27 percent) did not. All 190 willing farmers were non-irrigators who perceived a future drought risk, while the 72 unwilling farmers neither irrigated nor perceived such a risk (Table 13).

TABLE 13. Construction of the "willingness to adopt" variable

	Have you ever irrigated your land before =0, Future drought risk perceived =1	Have you ever irrigated your land before =0, Future drought risk perceived =0	Total
WTA = 1 (yes)	190	0	190
WTA = 0 (no)	0	72	72
Total	190	72	262

Notes: WTA = willingness to adopt

Source: Authors' own elaboration.



2.1.1. Gender, education, farm input management, location and disasters are among the most influential factors for irrigation management.

Given the large number of variables, the analysis should be limited to those that are considered to have the strongest explanatory power. To identify the strongest predictors of WTA, least absolute shrinkage and selection operator (LASSO) models were employed, using 29 possible explanatory variables, including demographics, production characteristics, risk perceptions, input use and region, which are particularly suitable when dealing with a relatively high number of potential predictors compared to the sample size. The adaptive LASSO model selected eight variables as most predictive: gender, education level, purchased input value, seed type (certified or farmer-saved), share of plots with irrigation access, NM region, number of drought events in the past decade, and perceived flood risk (Table 14).

TABLE 14. LASSO-selected variables and coefficients (post-selection)

Variable	Coefficient	Interpretation
Gender (male-0, female-1)	-5.15	Lower willingness for female farmers
Education (without-0, primary-1, secondary-2, advanced-3)	+1.74	Increased willingness for farmers with higher education
Purchased inputs (ZMW)	-0.00	Slightly negative and small magnitude willingness with input purchase
Seed type (farmer-produced -0, certified-1)	-4.61	Lower willingness with certified seeds
Share of plots with direct access to irrigation water (%)	+0.05	Increased willingness with higher irrigation access
NM Province dummy	-5.33	Lower willingness in NM
Number of drought events in the past decade	+2.47	Increased willingness with more historical drought events
Future flood risk perceived (no-0, yes-1)	+8.88	Increased willingness with higher perceived flood risk

Notes: LASSO = least absolute shrinkage and selection operator

Source: Authors' own elaboration.



TABLE 15. Results on willingness to adopt irrigation and the comparison across models

	Logit	Probit	Semiparametric
Future flood risk perceived (no-0, yes-1)	2.48***	1.34***	1.17***
Gender (male-0, female-1)	-5.19***	-2.83***	-2.72***
Education (without-0, primary-1, secondary-2, advanced-3)	1.75**	0.98**	0.74***
Purchased inputs (ZMW)	-0.00***	-0.00**	-0.00***
Seed type (farmer-produced -0, certified-1)	-4.63***	-2.47***	-2.54***
Share of plots with direct access to irrigation water (%)	0.05**	0.02***	0.02*
NM Province dummy	-5.36***	-2.82***	-2.95***
Number of drought events in the past decade	8.88***	4.64***	5.46***
Number	262	262	262

Notes: Coefficients represent the direction and strength of the association between each factor and the outcome variable. Positive values indicate a higher likelihood or count; negative values indicate a lower one.

Asterisks denote statistical significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Source: Authors' own elaboration.

Gender, seeding practices and regional differences are negatively associated with WTA, while education, access to irrigation water, historical drought events and flood risk perception increase WTA. The LASSO variable-reducing technique highlights that the most significant variables of reduced WTA are the gender, seed type and the location – more specifically, farmers in NM – with a low magnitude effect of purchased inputs. In turn, education, access to irrigation water, drought events and flood risk perceptions increase the WTA but from different perspectives. The LASSO results are validated through three estimation approaches simultaneously conducted (logit, probit and semiparametric), displayed in Table 15. The results show a high degree of consistency in both the direction and significance of the estimated marginal effects.

Climate exposure, including historical drought events and flood risk, has a strong, positive and significant effect on the willingness to adopt irrigation. Water-related uncertainty acts as a critical driver for adoption. Farmers perceiving higher flood risk are substantially more likely to consider irrigation, with the largest marginal effect observed in the logit model. As floods are less likely to pose a physical threat to rice farms, the willingness might be the result of the unutilized opportunity of periodic excess water. Inundations and flood water are already being used for agricultural production in the floodplains, but due to the lack of water storage and water control infrastructure, farmers are unable to make better use of the naturally recurring excess water. However, it is the experience of drought that has the strongest positive effect among all predictors. This highlights how direct exposure to water scarcity acts as a powerful driver, potentially overriding financial or informational barriers.

Seed type, irrigation access and input use have an impact on irrigation adoption but the impact is shown in different ways: farming practices still define further development. Seeding practices, potential access to irrigation water and spending on inputs are significant drivers of WTA. This implies that farmers with already established practices or technologies have a stronger stake in whether they are ready to take more. Still,

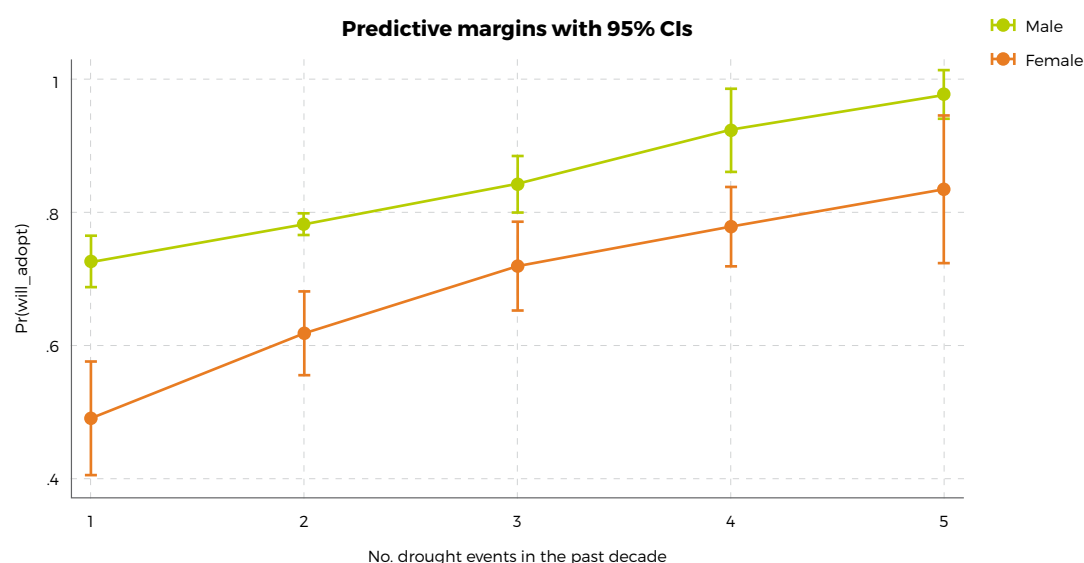
even if these farmers have made a definite decision, they are not necessarily prepared to adopt irrigation. For example, although the number of farmers with certified seeds is too low to make general conclusions, they are less likely to develop irrigation even if certified seeds have higher productivity potential.

Regional differences emerge as a predictor of irrigation development, possibly due to the level of information and awareness. Farmers in NM are consistently less likely to adopt irrigation, with a strong and significant negative effect across all models, highlighting spatial heterogeneity. Regional differences indicate not only the need for intervention but also the method. The lack of demonstration sites, established good practices, or available information hinders the technology transfer across regions. Given the vast distances in Zambia, interregional knowledge transfer must be facilitated to achieve a regionally balanced level of information availability.

2.1.2. Women are less willing to adopt irrigation even in the light of intensifying drought events.

Female farmers are more conservative in irrigation uptake, although women are traditionally responsible for agricultural production in Zambia. Women demonstrate lower willingness to adopt irrigation compared to men, largely due to limited access to resources and technologies. The analysis of drought exposure shows that while the probability of adopting irrigation rises with the number of drought events for both genders, men consistently exhibit higher adoption likelihood. To verify this, the marginal effect of the drought event count was assessed on the WTA (Figure 6). The assessment shows that the probability of adopting irrigation increases with the number of drought events experienced in the past decade for both men and women. However, the probability is consistently higher for men across all drought levels. For example, after experiencing five drought events, the predicted probability of adoption approaches 1.0 for men, while it remains below 0.9 for women. This indicates that although drought experience is a strong motivator, women face persistent structural and informational barriers that constrain adoption. Recognizing these gendered disparities is critical, as women remain central to Zambian agriculture, making targeted support for their production efforts a strategic priority.

FIGURE 6. Marginal effects of perceived number of drought events by gender

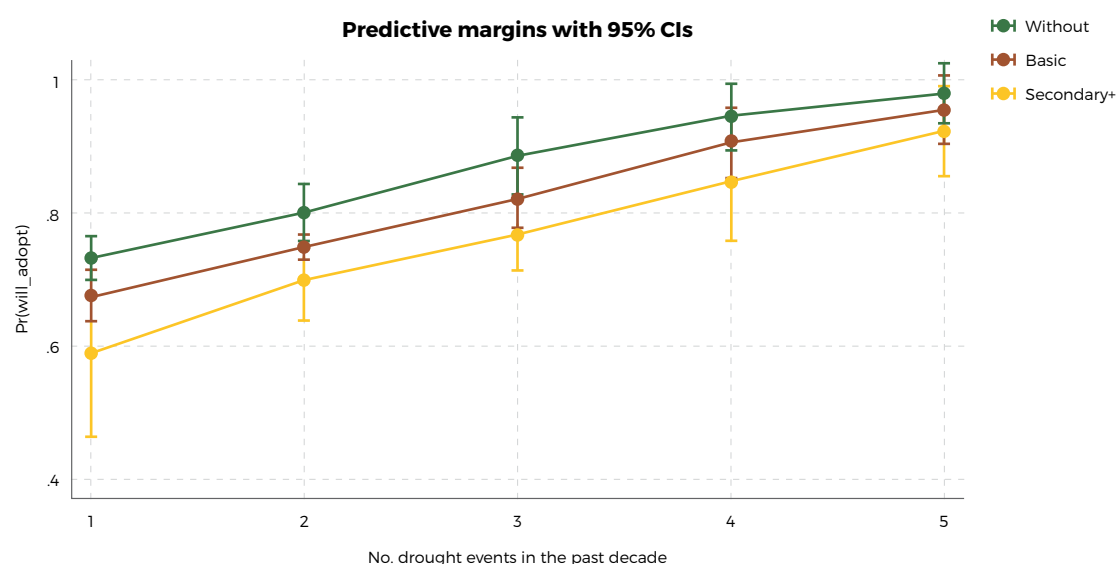


Source: Authors' own elaboration.

2.1.3. Education helps assess disaster exposure, boosting the willingness to adopt irrigation.

Education has a positive and significant impact on WTA, indicating that farmers with higher education levels are better at assessing the advantages of irrigation technologies and accessing related information and support. The assessment of the marginal effect of drought on WTA, displayed in Figure 7, highlights the interaction between education and drought frequency. Farmers with secondary or higher education consistently show the highest predicted probability of adoption across all drought levels, followed by those with basic education, while those without formal education lag behind. Moreover, the probability of adoption rises sharply with increased drought experience across all education groups, approaching near-universal adoption after five drought events for more educated farmers. This pattern indicates that education not only enhances awareness and perceived benefits of irrigation but also amplifies adaptive responses.

FIGURE 7. Marginal effects of perceived number of drought events by education level



Source: Authors' own elaboration.



2.2. RECOMMENDATIONS FOR ENGAGING SMALLHOLDERS IN IRRIGATION DEVELOPMENT

Although investment in irrigation is usually centrally coordinated due to its scale and impacts, the assessment of farmers' commitment is necessary to create an enabling environment. The following conclusions can be used to formulate policy recommendations on irrigation development:

- **There is a need for programmatic, knowledge-enhancing irrigation development beyond mere water infrastructure development.** While farmers remain reliant on rainfall, those with access to irrigation consistently achieve higher yields and greater resilience to climate variability. Policies should, therefore, prioritize a coordinated approach that combines infrastructure investment with institutional support. This means scaling up efforts in irrigation development and integrating them into Zambia's broader rice development strategies. Irrigation expansion must be designed not just as infrastructure delivery but as an integrated programme that connects farmers with technical support services. A central part of this strategy is capacity building. Farmers lack technical knowledge on irrigation management – from controlled water use to system maintenance. Even when infrastructure is available, these knowledge gaps often limit productivity gains. By embedding training and farmer organization into irrigation programmes, adoption can be more effective and sustainable.
- **Women, as the engine of the agriculture sector, should be empowered to access irrigation programmes.** Women's empowerment must be a deliberate focus of irrigation development to improve their production performance. Women provide the majority of agricultural labour in Zambia but face systemic barriers. Evidence shows that women are less willing to adopt irrigation, even in areas of repeated drought, largely due to resource constraints. Policies should, therefore, create women-focused irrigation programmes that provide targeted training. Ensuring that women farmers are fully integrated into irrigation initiatives will not only promote equity but also expand the sector's productive base.
- **The role of climate exposure in shaping irrigation adoption must be explicitly recognized in policy design.** Farmers who have experienced drought events and floods are significantly more willing to consider irrigation as a coping strategy. This shows that climate risk perception can act as a trigger for technology uptake. Policies should therefore integrate climate information systems into irrigation programmes, linking early warning systems, seasonal forecasts and risk awareness campaigns. By framing irrigation as both a productivity enhancer and a resilience strategy, farmers are more likely to invest in and sustain its use.

Irrigation development is a prerequisite for a high-performing rice sector. Despite their joint potential, neither irrigation nor rice production is high on the farmers' investment agenda. Adopting these irrigation-related recommendations at the policy level should be done alongside the implementation of the rice sector development strategies. This can ensure that production risks related to climate disasters are mitigated and the production potential, in terms of yield productivity and profitability, is exploited.



3. Conclusions

Zambia's rice sector faces a structural gap between its strong potential and current performance. Productivity levels remain low even compared to the continental level. The conducted survey and econometric analysis underline that these constraints are not primarily biophysical but rooted in systemic weaknesses along the production cycle. These findings directly align with the priority areas set out in the Second National Rice Development Strategy (2016–2020) and the Third National Rice Development Strategy (2022–2026), which emphasize improved input systems, expansion of irrigation, stronger extension and enhanced value chain coordination.

To address these weaknesses, the study advances four priority recommendations: a comprehensive, value chain approach to input and market development; programmatic, knowledge-embedded irrigation expansion; climate risk recognition and early warning integration; and targeted market access measures for rural communities, including support for high-demand aromatic rice varieties.

Irrigation remains the critical missing link in Zambia's rice development agenda. National strategies already identify irrigation as indispensable for reducing rainfall dependency and stabilizing production, yet implementation has been partial and largely limited to infrastructure development. The analysis of farmers' preferences reinforces this policy direction by showing that climate exposure strongly increases the likelihood of adopting irrigation, but knowledge gaps and gender constraints hinder uptake. This implies that irrigation must be advanced programmatically, combining infrastructure with targeted capacity building and inclusive governance mechanisms. In this respect, the results complement the objectives of the National Policy on Climate Change (2016) and the Nationally Determined Contribution (2015), which both emphasize climate-resilient agriculture but extend them with concrete farmer-level evidence on how climate risk perceptions shape technology adoption.

Specifically, irrigation programmes should integrate three mutually reinforcing actions: embedding capacity building, from awareness-raising to technical training in controlled water use and system maintenance, directly into infrastructure delivery; establishing women-focused training as a non-negotiable component, given that women face persistent structural barriers that suppress adoption even under repeated drought events; and linking irrigation expansion to climate information systems and seasonal early warning services to activate risk-driven uptake.

Rice production analysis should take a kaleidoscope approach, which emphasizes the heterogeneity of farmer responses and the need for umbrella policy interventions that can cover the largely varying production levels and needs. Irrigation adoption among rice farmers in Zambia is shaped by education, gender and climate experience, making uniform policies ineffective. Because production practices vary widely, policies must be adaptive and tailored to local contexts. Women, in particular, are less likely to adopt irrigation even under drought stress, highlighting the need for gender-responsive programmes. Aligning irrigation development with such approaches supports Zambia's broader agricultural goals of equity and inclusion, as outlined in the National Agriculture Investment Plan.

In practice, this calls for a two-tier structure: national umbrella programmes that address structural and institutional barriers (e.g. input market organization, irrigation–rice sector alignment, capacity building and market access facilitation), complemented by community-led farmer associations that embed technical services and enable a bottom–up pathway from local production practices to joint market participation.

The emphasis on value chain integration directly supports the government's programmatic approach to rice development, which stresses interventions from seed to market. Zambian rice farmers mainly grow rice for sale but face low farmgate prices, highlighting that productivity gains alone are insufficient. National strategies must therefore emphasize investments in milling, quality management and market access as essential complements to on-farm productivity improvements. These findings validate the country's comprehensive, value chain-based approach to rice sector development.

Annex

DESCRIPTION OF THE LEAST ABSOLUTE SHRINKAGE AND SELECTION OPERATOR (LASSO) MODEL

Advanced statistical tools, such as adaptive LASSO logistic regression, are used to examine many possible factors that may influence whether small farmers are willing to adopt irrigation. These methods helped focus only on the most important drivers while avoiding the risk of overcomplicating the analysis. By doing so, a clear and reliable model was built that shows which social, economic, environmental and regional factors matter most. This approach ensures that the results are both trustworthy and easy to interpret, giving practical insights into what shapes farmers' decisions.

LASSO applies a penalty to the size of the regression coefficients, shrinking less relevant ones towards zero, thereby performing variable selection and regularization simultaneously. This approach is advantageous in behavioural adoption studies where many socioeconomic and perception-based variables may exhibit multicollinearity or weak predictive power. In this case, an adaptive LASSO logistic regression with 10-fold cross-validation is used to identify the most relevant predictors of willingness to adopt (WTA) from a pool of 29 explanatory variables. Post-selection inference was then applied to obtain unbiased coefficient estimates and robust standard errors for the selected predictors.

In addition, elastic net regularization was tested as a complementary approach, combining the penalties of both LASSO and ridge regression. This method is particularly useful when highly correlated predictors are present because it allows for the selection of grouped variables rather than arbitrarily choosing one. The elastic net model, also tuned via cross-validation, confirmed the robustness of the adaptive LASSO results, with a largely overlapping set of selected predictors. Finally, a post-LASSO inference framework was employed to conduct valid statistical inference on key covariates of interest while ensuring that the model maintained predictive stability. These regularization-based methods ensured that our analysis avoided overfitting and yielded a parsimonious, interpretable model that identified the main socioeconomic, environmental and regional factors driving smallholders' willingness to adopt irrigation technologies.

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