TECHNICAL REPORT

Cost-Benefit Analysis of Drought Risk Reduction Anticipatory Action in the Western Province of Zambia

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Front cover photo: Drip irrigation in Zambia. Adam Öjdahl/IWMI
Back cover photo: 2024 Zambian drought in Lusaka. Icem4k/Wikimedia Commons

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Acronyms

AA	Anticipatory Action
CBA	Cost-benefit Analysis
BCR	Benefit-Cost Ratio
CGIAR	Global Research Partnership for a Food Secure Future
DR	Discount Rate
DT	Drought Tolerant
FAO	Food and Agriculture Organization of the United Nations
GBP	British Pound Sterling
GDP	Gross Domestic Product
IFAD	International Fund for Agricultural Development
IFRC	International Federation of Red Cross and Red Crescent Societies
IPCC	Intergovernmental Panel on Climate Change
IRI	Irrigation
IRR	Internal Rate of Return
IWMI	International Water Management Institute
MT	Metric Ton
NPV	Net Present Value
RCCC	Red Cross Red Crescent Climate Centre
SADC	Southern African Development Community
SADRI	Southern Africa Drought Resilience Initiative
US	United States
USD	United States Dollar
WFP	World Food Programme
ZAM	Zambia (Country Code, used in datasets)
Zamstats	Zambia Statistics Agency

Executive Summary

Frequent droughts and floods in Zambia raise the question of whether taking anticipatory action based on information from early warning systems could mitigate the amount of damage from such events. This issue has strong policy relevance due to its potentially significant impact on resource allocation before the climatic event. A powerful example is the 2018 drought endured by the Western and Southern provinces, which was recorded as one of the worst in recent history. The lack of large-scale anticipatory measures led to widespread hardship, particularly among farming communities and those whose livelihoods depended heavily on agriculture. It can be argued that in such cases, carefully planned and implemented anticipatory action could have limited the negative impacts of the drought. While this may be the case, policymakers often wonder whether the costs of such advance/pre-disaster actions can be justified with the benefits that they produce. Thus, an ex-ante analysis of the costs and potential benefits of each anticipatory action can be useful.

This study evaluated the economic viability of different anticipatory action specifically, province-wide, farmer-led small-scale irrigation, state-sponsored adoption of drought-tolerant crop varieties, and a combination of both in mitigating the impacts of drought in Zambia's Western Province. This region is highly vulnerable to recurrent droughts and other crises that threaten agricultural productivity, contributing to food insecurity and high food price inflation. Irrigation and the choice of crop species, particularly drought-tolerant varieties, play a critical role in enhancing resilience to such conditions, as these species can significantly reduce crop failure risks and improve yields in arid environments, thus ensuring more stable food supplies and economic outcomes. However, the use of irrigation in reducing the impact of drought also faces challenges, including potential groundwater depletion with irrigation, water scarcity, water quality deterioration, and soil erosion. Similarly, for drought-tolerant varieties, possible negative challenges include possible high trade-off between yields and risk reduction, social norms and diet preferences that favour other non-drought-tolerant crops, e.g., maize vs. millet for food. This implies that a careful combination of both may minimize the negative impacts of each.

The study employed program appraisal methods, including benefit-cost ratios, internal rates of return, net present values, costs of avoided damages for each action per hectare, costs of avoided relief per district and province to assess their economic viability. The results clearly show that these measures can be effective as anticipatory strategies. However, relying solely on drought-tolerant crop varieties is the least effective option of the three measures considered. The best outcomes are achieved when the adoption of drought-tolerant varieties is combined with irrigation-scaling efforts. This should, however, be executed such that drought-tolerant varieties are used where irrigation potential is low. The second better Anticipatory Action (AA) is the irrigation-only option.

The benefit-cost ratios for all scenarios exceed one at the provincial level and at the districts level, indicating strong economic viability. The net present values, along with the relief costs saved by adopting these anticipatory measures, amount to tens of millions of US dollars. Building on positive results, Zambia could attract investors to help fund these agricultural transformations. Beyond private financial viability, these investments would significantly enhance resilience. Irrigation infrastructure would provide long-term benefits, supporting multiple growing seasons, while the technical knowledge gained by farmers in using irrigation technologies and drought-tolerant crops would continue to offer advantages well beyond a single season, further strengthening the sector's resilience to future climate shocks.

The government and other stakeholders should continue to provide information on drought-tolerant seed varieties and facilitate farmers' access to them through short-term, well-targeted support mechanisms—such as revolving seed banks, public–private seed distribution partnerships or temporary subsidies designed to encourage adoption. They should also advise farmers on and promote the cultivation of crop species that perform well under low-rainfall conditions (e.g., cassava and sweet potato), while simultaneously supporting the use of high-yielding varieties in areas with adequate water. This integrated, mixed-cropping approach can harness the dual benefits of high productivity and drought resilience, while avoiding long-term dependency or market distortions. More importantly, there is a need to eliminate non-tariff barriers to trade on irrigation equipment, especially those that can be accessed by small and medium farmers, including fuel/solar systems for motorized systems to reduce production costs and enable them to expand and maintain production during dry spells. Again, creating awareness among farmers about the availability of affordable and reliable irrigation equipment, as well as building capacity in the use of such equipment, to minimise operational costs and increase use efficiency, are important factors for scaling irrigation utilization. As the economics of anticipatory action is an emerging field, it is important that research in this area be intensified for stakeholders to be apprised of which actions may be worthwhile depending on their own specific contexts.

1. Introduction

1.1 Food Production and Climate Variability

Agriculture in Southern Africa is increasingly exposed to climate variability, with droughts and floods posing recurring threats to food security and livelihoods. The Intergovernmental Panel on Climate Change (IPCC 2021; 2023) projects that extreme temperature and rainfall events will become more frequent and intense across Sub-Saharan Africa, leading to shorter growing seasons, higher evapotranspiration rates, and greater production uncertainty. In Zambia, mean annual temperatures are expected to rise by 1.5 to 3.0°C by mid-century under moderate emission scenarios (World Bank 2022), while the frequency of moderate to severe droughts may double by 2050 (SADC Secretariat 2023). These shifts are likely to further amplify the vulnerability of farming systems, particularly in the Western and Southern provinces, where production already depends heavily on rainfed agriculture.

Zambia remains an important contributor to the Southern African Development Community food basket, yet agricultural output continues to face setbacks caused by recurrent dry spells and erratic rainfall. The Southern, Eastern, and Central provinces together produce more than half of the country's cereals, while the Western Province, despite its vast land area and significant potential—accounts for only about 8% of total planted area and less than 4% of national cereal production. This imbalance reflects both structural constraints and climate-related stress. Droughts recorded in 1987/88, 1991/92, 1994/95, 1997/98, 2001/03, 2004/05, 2011/12, 2015/16, 2018/2019, and 2023/2024 (SADRI 2021) have occurred at an average interval of four to five years. The 2018/2019 drought alone reduced output in the Western Province by nearly 80% (Zamstats 2023), affecting the livelihoods of more than 2.3 million people nationwide (FAO 2019).

Table 1 illustrates Zambia's substantial but underutilized land and water resources. The country's low population density and extensive arable land provide opportunities for agricultural transformation, if effective risk management and climate adaptation strategies are implemented.

Table 1. Land and population statistics for Zambia and the Western Province.

	Zambia (national)	Western Province
Total land on cereals (ha)	1,243,883 (Trading Economics 2024)	~70,000 (average)
Total area under irrigation (ha)	155,912	2,600 (1, 7%)
Total irrigable land area (ha)	2.75 million	~165,000 ha (Western Province's irrigable land area is estimated proportionally using its approximate 6% share of Zambia's cultivated agricultural land, resulting in an indicative potential of about 165,000 ha)
Total land on legumes (ha)	Groundnut = 192,246 (Tembo et al. 2023) Soybean = 375,000 (USDA, 2024) Mixed beans = 84,566 (Simfukwe et al. 2022)	Groundnut = 7,143 Soybean = 597 Mixed beans = 4,164
Total population	17,000,000	1,363,520
Total households	4,054,603	288,000

Note: All figures are reported by Zamstats (2023), unless otherwise noted.

Agricultural production in Zambia thus faces persistent exposure to drought and erratic rainfall, with the Western Province among the hardest hit. Strengthening preparedness and early response through anticipatory measures could significantly reduce the economic and humanitarian losses that recur with each drought cycle.

1.2 Anticipatory action and Their Role in Disaster Risk Reduction

In the context of disaster risk reduction (DRR), anticipatory action can be considered as falling into two categories namely, short-term and medium to long-term. Short-term anticipatory action may include those actions which can be taken quickly within a narrow window of opportunity (usually 6 months in the case of Zambia) between the disaster warnings and the time of disaster impact (examples would be arrangements for portable water provision, borehole drillings, drought-tolerant seeds procurement, small scale irrigation equipment deployment, among others). On the other hand, actions including large-scale irrigation canals construction, consumption behavioural change interventions, etc., may be considered as medium- to long-term anticipatory action.

When disasters strike, stakeholders typically focus on responding to limit the damage rather than on preventive measures. Although this is important, in many cases, it is too costly and often falls short of demand. Furthermore, such efforts rarely create medium to long-term resilience of communities, and in some cases, they create dependency. Organizations such as the World Food Programme (WFP), UNHCR (United Nations High Commissioner for Refugees), various civil society groups, and the affected governments often shift their attention to immediate damage control, prioritizing actions that mitigate harm to livelihoods. These actions are useful as they can minimize vulnerabilities and disaster risks and avoid or limit the adverse impacts of hazards (Pichon 2019). During these response periods, key considerations for success include the timing, nature and target population of the intervention.

Regardless of the disaster's nature, effective response strategies require a thorough understanding of the disaster's dynamics before, during and after it occurs. Such emphasis on reactive measures, rather than proactive prevention, highlights a tendency to address consequences rather than reduce risks beforehand. In some cases, such reactive approaches may be less effective in reducing damage and necessarily call for advance action that could minimize the negative impacts of the disaster from occurring. For example, to enhance the targeting of response efforts during droughts, stakeholders could act more effectively if they had access to information about the sizes and locations of the affected populations.

Prevention of negative impacts of climate events is often far better than curative measures. Thus, knowing in advance which interventions would be most effective and cost-efficient, as well as identifying key windows of opportunity for action, would lead to better prevention. Therefore, proactive planning for disaster risk reduction could give society a significant advantage in minimizing loss of livelihoods and mitigate deteriorated conditions for those affected. Engaging in anticipatory action following information about a looming disaster may be more effective and to the extent that some anticipatory action may seek to build long-term resilience of households, they may be preferable as both short, medium and long-term measures of disaster risk reduction. To reduce negative impacts from disasters significantly, it is useful to adopt approaches that emphasize both mitigation and impact reduction (Aghaei et al. 2018).

Anticipatory action (AA) are the set of actions implemented to prevent or mitigate a potential disaster before severe impacts are felt (Schindler et al. 2023). The emphasis here is on the prevention of the occurrence of the negative impacts. Thus, AA to minimize the impacts of disasters involve proactive measures designed to prepare for and reduce the effects of a disaster before it fully unfolds and can therefore be very useful in this respect (Schindler et al. 2023). By taking early action before a disaster occurs, AA have the potential to protect already realized gains from development and promote resilience building (Kurdi and Ruckstuhl 2023). Anticipatory action can fall into several categories, namely, those applicable before the disaster strikes, those that should take place during the onset of the disaster and those that should continue beyond the disaster to proof the future against similar disasters. Anticipatory action can also save lives and livelihoods (WFP 2020) for example in Bangladesh in 2017 and 2020, recipients of anticipatory cash were more likely to evacuate their families and livestock before floods (Gros et al. 2019). Similarly, the International Federation of Red Cross and Red Crescent Societies (IFRC 2019) estimates that the cost of doing nothing about disaster preparedness could lead to as many as 200 million people every year requiring international humanitarian aid, due to impacts of climate-related disasters and the socioeconomic impacts of climate change. Inaction would also mean that future costs of avoiding these impacts would be as high as USD 20 billion (IFRC 2019).

In the context of proofing the livelihoods against disasters within the agri-food systems, many of these anticipatory action include improving agriculture related infrastructure and equipment for improved resilience, agronomic practices and livelihood diversification, improved drought-tolerant varieties and species as well as some risk reduction strategies for livestock, early relief programs and risk transfers (see FAO 2017). Owing to its potential to minimize the negative impact of disasters on communities, AA is a growing area of action in the domain of climate and disaster risk management and should progressively be embedded in disaster risk reduction (DRR) frameworks. AA emphasizes the use of climate services and risk analyses to predict where crises might strike, identify what their potential impacts may be and enable preventive action before disasters occur (de la Poterie et al. 2023).

The specific types of AA that may be applicable within a particular context depend on the nature of risk a community is facing. For drought risk, as the one frequently faced by communities in Zambia, a number of anticipatory action may be useful. Some of these actions include water conservation and efficiency measures, drought-tolerant crop varieties, water storage and management infrastructures, drought monitoring and early warning systems, irrigation, drought insurance and any combination of these options. If some of these strategies can be chosen carefully and implemented, communities can build resilience to droughts, reduce vulnerability and minimize the adverse impacts of drought on agriculture, ecosystems and livelihoods.

2.2.1 Success Factors for Anticipatory action

For AA to be effective, early information about impending drought is required. This is the case for many AA. For example, forecast-based financing is gaining importance due to its benefits which include enhanced capacity for risk monitoring, development of contingency plans, anticipation and mobilization for interventions, improved financial and procurement structures and increased coordination with other stakeholders. These factors demonstrate that investing in capacity building for anticipatory action leads to systemic improvements in overall organizational capacity. Such enhanced capacity is crucial for realizing other potential benefits, such as scaling up and expanding anticipatory action (Clatworthy 2023). Similarly, early information on impending disasters received between 6–8 months in advance can trigger investment in AA including borehole drilling for irrigation, deployment of motorized solar pumps for small-scale irrigation, as well as distribution of drought-tolerant seeds.

2.2.2. Application of AA in Practice to Various Settings

Initial investments in AA can also develop key partnerships and facilitate later scaling-up by other organizations. From a humanitarian perspective, anticipatory (humanitarian) action has emerged as a risk mitigation strategy that attempts to bridge the gap between development, longer-term disaster risk reduction, and post-disaster humanitarian response (De la Poterie et al. 2023). For example, beyond money, De la Poterie et al. (2023) found that through investments in planning, preparedness, training, coordination and simulation, AA programs often affect positive changes that go beyond AA. These co-benefits of developing AA systems, include fostering a more proactive approach to DRR, expedited funding and response, better collaboration with partners and gradual progress toward the institutionalization and scaling up of AA.

AA can also be taken by the government, civil society, private sector and development partners in isolation or in unison for better results. For example, the government can consider replenishment of Cereal Banks' reserves, cash transfer (vouchers) as well as distribution of forage for livestock as AA for drought, building on information obtained through climate information services (Hansen et al. 2022) to forecast extreme events and their impacts and to facilitate action. Within the humanitarian circles, AA pre-defines triggers and actions and allocates funding automatically when thresholds are reached. When an extreme event is forecasted, AA systems fund the implementation of actions in the window between the forecast and the predicted disaster with the aim of preventing or reducing a hazard's impact on people's health, livelihoods and property (Coughlan de Perez et al. 2014).

2.2.3. The Paucity of AA Research in Zambia and the Need for Context Specific Evidence

While good predictions from early warning systems of dry spells and below normal rainfall were available in Zambia during 2018–2019 between 6–8 months in advance, they were not taken advantage of, in the sense of mounting a well-coordinated and significant suit of AA to minimize the inevitable negative effects of the predicted droughts. The lack of advance action by authorities at the time may be explained by several factors including that the concept of AA is relatively new and not yet properly internalized by policy implementers. It may also be related to many other reasons, including the confidence with which authorities hold the predictions and the limited funding for implementing such actions.

As there are often many possible courses of action that any decision maker can take in response to a disaster, the question about the effectiveness of any one or more strategies becomes pertinent. Policymakers would desire to pursue policy actions that have high returns on investments and save more lives, hence justifying the advance investments that they must make. It is thus important to study and document what sort of AA they should have implemented and document the resulting benefits from those actions. Further as there are many possible AA strategies that can be implemented by different partners, it is important to understand which ones would be more effective for different settings, as well as their associated costs and whether such costs would be justified by the losses/benefits of those AA. Unfortunately, such information around AA is presently limited due to the absence of recent studies on these issues in Zambia.

1.3 Study Objectives

This study thus set out to examine the following for the 2018/2019 drought in Zambia:

i) To understand the economic viability of the following strategies as Anticipatory action (AA) that could have been implemented to minimize drought risk in 2018/2019 in Western Zambia:

- Investing in simple farmer-led irrigation, upon knowledge of the impending drought in drought-prone areas. As drought information was available at least 6–8 months before the sowing period, certain types of irrigation would have been possible;
- Adoption of drought-tolerant varieties in drought-prone areas; and
- An option that combines both irrigation and drought-tolerant crop varieties.

ii) To estimate how much of the production losses experienced in 2018/2019 would have been averted, had the government and stakeholders implemented the most effective combination of AA listed in i).

iii) To understand which options would have been more economically viable.

iv) Recommend a set of AA for the government to consider in mitigating future drought-related disasters in Western Zambia.

2. Irrigation and Drought Tolerant Crops as Anticipatory action in the Face of Drought

Upscaling irrigation as well as drought-tolerant crops can serve as important anticipatory action in cases of drought risk. Where one or both strategies are chosen as the right AA, concerned communities would need to roll out irrigation investments as well as drought-tolerant crops. Each of these cases have associated costs and from an analytical perspective, it is useful to understand if such costs can be recoverable by the realized benefits. The sections that follow present studies from both Zambia and outside Zambia to help elucidate the economic viability of irrigation and drought-tolerant crops and crop varieties. As this is an under studied area in the context of Zambia, we make use of lessons drawn from studies elsewhere, which is a standard practice. For example, it is acceptable to transfer cost and benefit parameters from other locations and apply them to new locations (benefit transfer process) (Brouwer and Bateman 2005).

Planting drought-tolerant crop species, such as cassava, millet, and sorghum, is a proactive and cost-effective adaptation strategy to ensure food security and dietary diversity during drought periods (Baudoin et al 2017; Grobicki et al. 2015). These crops are resilient to water scarcity and offer a reliable food supply for vulnerable communities. However, their adoption is often hindered by limited access to improved seeds, which may be either unavailable or cost-prohibitive for smallholder farmers (FAO 2023; Grobicki et al 2015).

There have been attempts in different settings to study the costs of early action as well as the benefits associated with implementation of such actions in the context of disaster risk management, to understand if the costs of such AA actions can be justified. For example, benefit-cost ratios of often lower than 1.7 for Zambia were reported for smallholder irrigation, but higher ones of around 4 were reported for large-scale irrigation based on the already existing dams (You 2008). In settings similar to Zambia, some studies have found that for irrigation, investment costs of USD 600 per ha and associated operation and maintenance costs of USD 25 per ha, may be reasonable for smallholder farmer-led irrigation projects (You 2008) as the resulting gains usually surpass the costs. Some of the studies by You (2008), carried out in developing countries similar to Zambia within Africa, showed that many of the irrigation projects studied had benefit-cost ratios that varied between around 27 in Niger to 1 in Lesotho, implying that irrigation upscaling had the potential to provide better returns on investment.

Equally, analyses by IFAD (2000, 2001) also showed that many of the irrigation projects studied were profitable, but that the profitability depended on the type of irrigation and who implemented them, because the cost structures partly depended on these parameters. Table 2 shows that some water management techniques including water harvesting, flood recession, river diversions and motorized pumps cost from as low as around USD 600 to as high as USD 8,000 per hectare.

Table 2. Typology and unit costs of small-scale irrigation.

	Examples	Average cost per hectare (USD)
Traditional community-based	Water harvesting, flood recession and swamp irrigation	**USD 600 to USD 1,000**
Individual	Pumps and other small lift systems (e.g., treadle, motorized, with and without sprinklers)	**USD 1,500 to USD 3,000**
Intercommunity	River diversions, small dams and deep tubewells	**USD 3,000 to USD 8,000**

Source: Kay (2001)

The benefits of AA should also be evaluated, not only from a perspective of just the costs of providing the AA compared to the revenue that flows from it, but more importantly to consider the benefits in terms of the costs that are prevented as a result of AA working and reducing damage. The evidence of economic viability of AA is not readily available for Zambia, but studies focusing on countries within Africa are informative and discussed herein. In other settings, including Kenya where aid and relief agencies reported that over USD 427.4 million was used in relief efforts in Kenya in 2011 to fight the impacts of drought that affected 3.75 million people. The amounts of relief aid provided to Kenya in 2009, 2006 and 2004 were USD 432 million, USD 197 million, and USD 219 million, respectively (Republic of Kenya 2012). These figures underscore the huge costs that come with relief programs, and which would be avoided with a carefully planned suite of AA.

Indeed, the cost of a drought for example can be in the form of spending by donors and governments as they intervene, food deficits that may not be met by interventions, negative copping strategies by households that costs they more later, the value of per hectare-level losses, as well as costs of early action implemented to avert the losses. Thus, by implication, the benefits of AA that seeks to reduce the impacts of droughts or any climate event include direct cost savings by donors for the avoided damages, reduced food deficits, avoided negative coping strategies and avoided losses per unit of land of livestock herd or any such unit as the case may be (see Venton 2017). For example, a DFID (Department for International Development, United Kingdom) study, in Ethiopia found that household food deficits decreased by 15% on average by receiving early transfers, which is a significant gain.

In Ethiopia, for every GBP 1 that the Start Network spent on AA ahead of drought, recipients realized an average of GBP 2.58 (USD 3.25) more benefits from maintained income and the health of their stock (Atkinson 2018). Again, investment in building the resilience of communities to cope with risk in disaster-prone regions was found to be more cost effective than relying on humanitarian response, however Venton et al. (2012) found little reliable evidence to support these conclusions (Venton et al. 2012).

Venton et al (2012) modeled the total deficit under a humanitarian response for households in Southern Ethiopia and Wajir Grasslands in Northern Kenya valued in metric tonnes (MT) of food required and then multiplied this by the cost per MT to deliver food aid as estimated by the World Food Programme (WFP) for each country (USD 845 Ethiopia, USD 889 Kenya), to estimate the total cost of response. The goal of this analysis was to understand the cost of filling household deficits totally.

Similarly, the Kenya Post Disaster Needs Assessment (PDNA) assessed the Kenya drought from 2008–2011 and found that food aid over the four years accounted for 60–80% of the total cost of response. Therefore, food aid estimates are inflated by 25% (conservative) to reflect the additional cost of non-food aid that is normally provided in a humanitarian response (e.g., water, nutrition, health, etc.) (Republic of Kenya 2012). In practice, aid is not the only cost incurred in a drought — numerous other losses such as lives, livestock, milk and meat production, health impacts and economic activity, all add to the total economic burden. The value of these losses can be hard to measure but are significant, as once a family gets past the initial stage of relief, they have to recover their livelihoods and asset base, rebuild their herds, etc. (Republic of Kenya 2012).

3. Background of the Study Area in Zambia

This section provides a summarized account of Zambia's agroclimatic zones and the common agricultural production systems. It serves to provide the context in which climate-related disasters affect livelihoods to provide an understanding of the underlying climate-related risks and hazards in Zambia. The last subsection focuses on Western Zambia where this study was implemented.

Agroecological zones and soils

Zambia is divided into three major agroecological regions (Regions I, II and III) which are primarily based on the amount of rainfall but also incorporate soils and other climatic characteristics (Jain 2007).

Semi-arid Region I includes areas of southern, eastern and western Zambia. Zambia's valleys at 300–800 m altitude mostly lie in this region. The mean annual rainfall ranges from 600 to 800 mm (Jain 2007). The growing season is relatively short (80–120 days) and risky for crop production, as rainfall is poorly distributed, resulting in frequent dry spells (Chikowo 2024). The region contains a variety of soil types, ranging from slightly acidic, loamy, clayey soils with loam topsoil to acidic sandy soils. Characteristics of these soils include erosion, limited soil depth in hilly and escarpment areas, and poor physical properties, which impose significant constraints on crop production and make tillage difficult, especially on cracking clay soils, crusting, and low water-holding capacity in sandy soils (Chikowo 2024).

Region II includes much of central Zambia, with most of Central, Western, Southern, Eastern and Lusaka provinces. It contains the most fertile soils and most of the country's commercial farms (Jain, 2007). Annual rainfall in Region II averages 800–1,000 mm, and the growing season is 100–140 days long (Chikowo 2024). Distribution of rainfall is not as erratic as in Region I, but dry spells are common and reduce crop yields, especially on the sandier soils. Average mean daily temperatures range from 23–26°C in the hottest month of October to 16–20°C in the coldest months of June and July. The most common soils in Region II are red to brown clayey to loamy soil types that are moderately to strongly leached. Physical characteristics of the soils that affect crop production include low water holding capacity, shallow rooting depth, and topsoil prone to rapid deterioration and erosion. These soils also have low nutrient reserves and retention capacity, are acidic, have low organic matter and nitrogen content and are phosphorus-deficient.

Region III, the high-rainfall area, lies in a band across northern Zambia, including the Northern Luapula Copper belt, north-western provinces, and some parts of the Central Province (Jain 2007). This region receives over 1,000 mm of precipitation each year, and the growing season ranges from 120–150 days (Chikowo 2024). Soils in Region III are highly weathered and leached and characterized by extreme acidity. Consequently, the soils have few nutrients available for plant growth, and are high in exchangeable aluminium and manganese, both of which are toxic to most crops unless soils are limed to increase their pH (Chikowo 2024).

Major cropping systems

In Zambia, maize is the principal cash crop (> 65% of cropped land) and the main staple crop. Per capita maize consumption is estimated at 105 kg annually. Other important crops include soybean, cotton, sugarcane, sunflower, wheat, sorghum, pearl millet, cassava, tobacco and various vegetable and fruit crops (Chikowo 2024). Maize is the dominant staple crop in Zambia and forms the backbone of the country's agricultural sector. Maize is often intercropped with other crops, including beans and groundnuts, vegetables and other cash crops (Jain 2007).

Region I has predominantly small-scale farmers in the major valley systems. In the Luangwa Valley, sorghum, finger millet and maize are the major starchy food crops, while groundnuts, cowpeas and pumpkins are also grown. Farmers use hand hoes for cultivation. Farm households commonly keep goats and chickens, and some farmers have a few cattle. Other areas of the region mainly produce bulrush millet, sorghum and cassava.

Figure 1 shows that changes in agricultural GDP tend to move in the same direction as rainfall variability, although the statistical association is weak (Pearson's $r = 0.27$, $p = 0.094$). This pattern is consistent with the structure of Zambia's agricultural sector, where most production is rainfed and therefore remains sensitive to fluctuations in seasonal rainfall, even if the aggregate GDP measure does not fully capture the strength of this relationship.

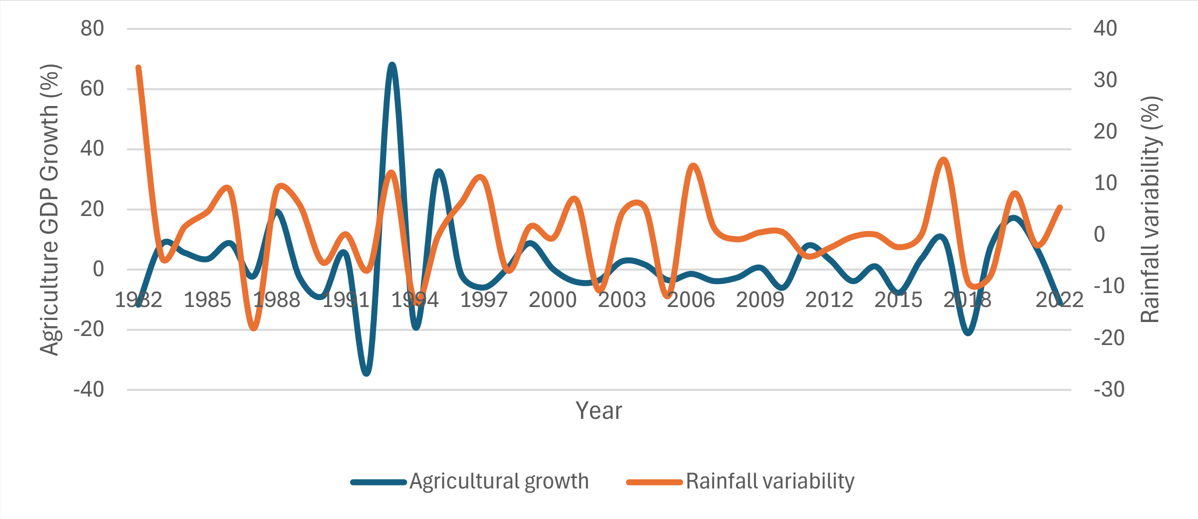

Figure 1: Rainfall variability and agricultural growth in Zambia

Source: Zamstats (2024) and World Bank (2024)

The Western Province

The Western Province is the largest administrative region in Zambia with a total land area of 126,386 square kilometres (Government of Zambia nd). Mongu is the provincial headquarters and borders Angola to the west and Namibia to the south. Internally, the province is bordered to the east by the Central Province, to the north by the North-Western Province and to the southeast by the Southern Province. The Zambezi flood plain extends from the confluence of the Zambezi with the Lungwebungu and Kabompo rivers at the northern border of the province, to a point below Senanga and above the Ngonye Falls in the south (Government of Zambia nd). This floodplain is inundated from December to June. It is fed by other rivers with their own floodplains and serves as a vast reservoir storing the waters of the Zambezi (Government of Zambia nd). Seasonal flooding is very important to agriculture in the province, providing natural irrigation for the grasslands on which vast herds of cattle depend, and bringing water to the settlements along the edges of the plain.

The flood plain comprises Bulozi flood plains, Lower Luena Basin, Luampa-Lui watershed, the Northeast watershed in Lukulu district and Nyengo plain in Kalabo district, while the upper land comprises Kaoma, Mongu and Silowana terrace (Government of Zambia nd).

Western Province experiences variable rainfall patterns, with the rainy season typically occurring from November to April (Brigadier et al. 2015). However, rainfall amounts are often insufficient and unpredictable, leading to frequent droughts and water shortages. Climate change is exacerbating rainfall variability, contributing to more frequent and intense drought events in the region. The erratic rainfall affects all sectors of agriculture, causing crop failure, livestock deaths and low productivity of livestock, forestry, crops and fish. This is so because droughts have profound impacts on agricultural production in Western Province, affecting crop yields, livestock health, and pasture availability. Maize, the staple food crop, is particularly vulnerable to drought stress, leading to reduced yields and food insecurity among rural households (Brigadier et al. 2015). These have further socio-economic impacts including increased poverty, migration, displacement and increased competition for natural resources for coping.

Agriculture is a significant economic activity in Western Zambia, playing a vital role in the livelihoods of rural communities and contributing to the region's overall economic development (Government of Zambia 2022). A variety of crops, including maize, millet, sorghum, groundnuts, cassava and vegetables characterize the Western Province's agriculture, and there is some presence of both rainfed and irrigated agriculture in different agroecological zones within the region. Livestock production involving cattle, goats, sheep, poultry and pigs remains an integral part of agriculture in Western Zambia. Irrigated agriculture is practiced in Western Zambia, along river valleys and floodplains such as the Barotse Floodplain and the Zambezi River Basin.

There is some presence of small-scale irrigation schemes, including canal systems, furrow irrigation and small reservoirs. These are used to supplement rainfall and extend the growing season for rice, vegetables and horticultural crops. Nevertheless, irrigation adoption rates in the province are low, owing to limited access to irrigation infrastructure and water management. Agriculture in the region is thus challenged by the negative effects of climate variability, including frequent droughts, flash floods, pests and diseases, limited input access, low coverage of extension services, low investments in irrigation and general high levels of poverty. Being more rural and less developed than urban centers, Western Zambia has a lower income per capita, with high poverty rates that have not changed much since the 1990s (Kapungwe 2004; Zambia Statistics Agency 2023). Muchinga province had the highest proportion of the population living in poverty at 82.6%, followed by Western (79%) and Northern (78%) provinces. Lusaka (27%) and Copperbelt (35.9%) had the lowest poverty levels, although higher than in 2015 (Zambia Statistics Agency 2023).

Irrigation in the Western Province (Ngoma et al. 2017) was much more prevalent among those with 5–20 ha parcels of land, as in the country as a whole. This implies that those with lower land holdings, which may likely be among the vulnerable groups, are less likely to adopt irrigation. The study area in the Western Province of Zambia, which is illustrated in Figure 2.

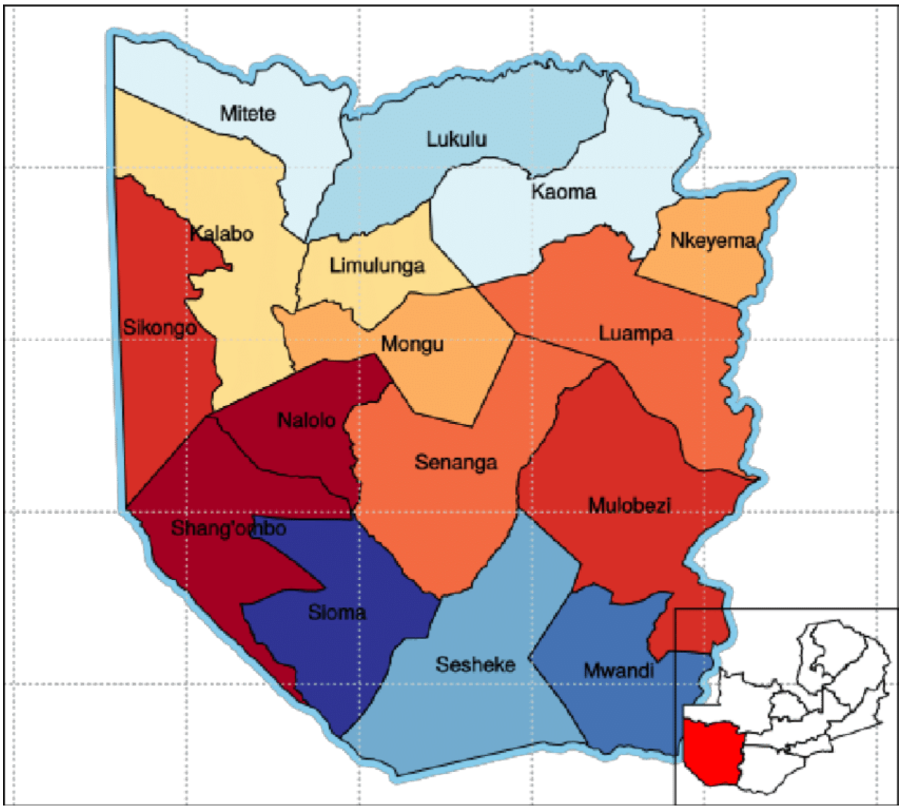

Figure 2. Western Province districts in Zambia.

Source: https://en.m.wikipedia.org/wiki/File:Districts_of_Western_Province_Zambia.svg

For Zambia, maize and cassava are the key staple crops, but maize is vulnerable to drought. Drought-tolerant maize varieties have shown the potential to maintain higher yields or suffer less yield reduction under drought conditions compared to conventional maize varieties. Yield advantages range from 5–20% for drought-tolerant maize varieties in Zambia when there is drought. However, such yield advantages over normal varieties are reduced when rainfall is normal. Sorghum and millet are traditional drought-tolerant crops that can produce reasonable yields under water-limited conditions in Zambia. Sorghum and millet yields can range from 500–2,000 kg/ha or more in drought-prone areas of Zambia. Cowpea yields in Zambia range from 300–1,500 kg/ha, whereas groundnuts yield range from 800–2,000 kg/ha.

Under irrigation, maize performs well and yields can vary depending on factors such as variety, soil fertility, water management and agronomic practices. However, there is evidence that they can range from 6–12 tons/ha (

Zamstats 2023). Similarly rice cultivation under irrigation in Zambia may vary from 4–8 tons/ha (Zamstats 2023). Cotton is also grown under irrigation in Western Zambia for commercial purposes. Yields of irrigated cotton can vary from 1 to 3 tons of lint per hectare.

The main point is that all these crops grown in the Western Province of Zambia, can do better under drought conditions if they are drought-tolerant or are irrigated. If they can be promoted, the impact of climate change on livelihoods may be reduced.

Whether anticipatory action can lead to reduction in damage by climate change events, including drought and floods, does not imply that they have to be pursued at any cost. Ultimately, it is only those anticipatory actions that are cost-effective that may or should be advocated. This is also from a practical point of view because resources constraints are pervasive in Africa and more so in Zambia. Thus, an advanced analysis of costs associated with the implementation of anticipatory action and the benefits thereof compared to non-action or compared to alternatives can be helpful in decision-making around whether to undertake actions and in what way.

4. Methodology

4.1 Benefit–Cost Ratio Analysis

Owing to the nature of the drought that the Western province faced in 2018/19, a host of AA can be considered for evaluation. To the extent that irrigation and drought-tolerant crops uptake is low in Zambia and the Western Province in particular, irrigation and drought-tolerant crops can be considered as AA with un-exploited potential. A third AA that can also be considered is an option that combines irrigation and drought-tolerant crops. To understand if these options are worthwhile from an economic perspective (whether the costs justify the benefits), we perform benefit-Cost Analyses for each of them, for each location, compare their values as well as calculate the associated net present values. We thus followed these steps:

Anticipatory action options

Upon a literature review (Mechler et al. 2008) and consultations focusing on smallholder farmers in the Western Province of Zambia, the following anticipatory action that could have been considered by the government of Zambia to reduce the risk of drought in 2018/2019 were selected for the analysis, namely:

a) supporting operationalization and /or adoption of irrigation-based agriculture (as in Mechler et al. 2008; Kull et al. 2013) to complement and supplement rain-fed agriculture in the Western province;

b) Promoting adoption of drought-tolerant crops/crop varieties (drought-tolerant maize, sorghum, millet; cassava and sweet potatoes) (as in Ng'ang'a et al. 2017); and

c) A combination of drought-tolerant crops on some land and irrigation on other portion of the land. Combined interventions tend to bring higher BCRs than single interventions (e.g. Irrigation plus insurance in Mechler et al. 2008; FAO 2019a).

Some potentially important actions that would be useful to analyse, but are not analysed owing to paucity of readily available information include:

d) Borehole drilling in communities to support water availability for livestock, access to clean drinking water and vegetable production;

e) Forage distribution to support livestock in areas forecast to be heavily affected; and

f) Community level parametric drought insurance to transfer some loss associated with drought to insurers (as in Kull et al. 2013).

In terms of an analytical framework, it is necessary to assess costs and agricultural performance when AA is implemented, comparing them with standard practices under both hazard and non-hazard conditions, where applicable. The analysis in this CBA spans a 15-year period with 2018 as year 1, because some irrigation infrastructure may remain effective for that duration.

The benefits and costs of implementing irrigation systems, as well as the adoption of new technologies in general, include those that arise from the actual activities and outputs flowing from the irrigation or technology adoption activity, as well as those arising from unintended externalities that result from the intervention. For example, a smallholder farmer who installs irrigation equipment on her farm benefits through increased yield and production during drought periods and pays the cost of installation and maintenance. On the other hand, owing to the availability of water on the farm and hence crop residues, animals, including livestock, benefit from increased water and food availability during drought, leading to a reduction in livestock mortality and environmental degradation. In some cases, uncontrolled water withdrawal in irrigation systems could also lead to mosquito prevalence with potential increases in malaria incidences which is a cost for a farmer through loss of labour due to illness, cost of drugs and generally a less productive workforce, and it is also a cost on society. While these are useful for a comprehensive Cost-benefit Analysis, the data demands are high, requiring specific willingness to pay surveys. Owing to resource constraints, these surveys were not carried out and thus, the Cost-benefit Analysis implemented did not consider ecosystem services in the manner implemented in Bekoe et al. (2021). Our methodology is however in line with many others including Kull et al. (2013) as well as Seekao and Pharino (2016). Moreover, our methodology also involves further dimensions, including the costs of relief. Therefore, the analysis is designed to inform the design of AA to drought and climate-related disasters.

4.1.1. Costs Estimates for Each Anticipatory Action

The costs associated with implementation of each AA in the province were calculated for each hectare of land and each sub-district, under assumptions provided in the data section (see the tables below). In general, the costs for irrigation as an AA include those related to the purchases of irrigation equipment (a motorized pump and accessories), maintenance, labour, seeds, fertilizer and pesticide costs per hectare (see Table 4). The costs are calculated as direct costs of production, transportation, purchase or operations and maintenance. Some of these are obtained from literature as well as from assumptions informed by stakeholder consultations.

It should be stated here that irrigation can be implemented in several ways as summarized in Table 2. Indeed, irrigation strategies often utilized by smallholder farmers in Zambia range from simple water harvesting techniques, flood recession, swamp irrigation, pumps and other small lift systems (e.g., treadle, motorized, with and without sprinklers). In some cases, attempts around river diversions, and small dams are implemented. For purposes of this study, we assume that the farmer uses a small pump with or without sprinklers and calculate the costs of installation and operation thereof. Water is sourced from a well sunk for this purpose, or from a river, when water is available. The other irrigation methods are hard to up-scale or not directly applicable for many households. For example, while a motorised pump can be installed anywhere, if ground water or river water is available, flood and river diversion are infeasible or not applicable upland, and so is water harvesting during drought. Similarly, we assume that drought-tolerant varieties for each crop considered are available.

For irrigation costs, for example, *b*aseline assumptions in the literature (You 2008) include on-farm investment costs of USD 600 per hectare and operations and annual maintenance costs of USD 25 per hectare. We deviate from this underestimate but instead embrace the costs in Table 4, which is ten times the figures in You (2008) and are informed by data on Zambia drawn from various sources, including Smith et al. (2014). We further assume that once purchased, a motorized pump must undergo a major pump service of 20% of the cost price every 5 years, and then these costs increase by 5% every five years thereafter. The costs of inputs increase by a modest 1% each year, in each location, but prices across locations also vary with the distance from main markets. With an assumed running cost and repairs of 10% per annum and labour as well as seed costs tabulated in Table 4, per hectare costs of irrigated agriculture amount to approximately USD 7,200, whereas this cost amounts to around USD 600 per hectare for drought-tolerant seeds.

4.1.2. Benefits Calculation

The benefit–cost analysis only focuses on the direct benefits of the AA in focus. Two types of direct benefits should be analysed:

1. **Added benefits**: Early actions determine an increase in agricultural output or an increase in the value of agricultural output; and
2. **Avoided losses**: Early actions prevent or reduce damage and losses caused by hazards on agricultural assets and/or output (these also include avoided relief).

Thus, the key benefits included those at the farm level as approximated by the value of production, using market prices for output. The other components of benefits considered were the value of damage avoided per hectare and relief saved, i.e., the relief avoided due to successful AA limiting damage. Thus, the parameters for calculating benefits of AA in this case include avoided damages or avoided losses that follow from using the AA in the subject as well as avoided costs of relief/aid. Therefore, damages or losses avoided as a result of investing in AA is a benefit. Thus, avoided losses were calculated by comparing the potential loss, without taking preventive measures to the actual loss after implementing those measures. The formula for avoided loss can be expressed as:

$$\text{Avoided Loss} = \text{Potential Loss} - \text{Actual Loss}$$

Alternatively, avoided loss is equivalent to actual production without the measure (known) minus what would be the actual production with the measure (estimate using known parameters).

What would be the actual production with the measure can be estimated by multiplying known yields of the drought-resistant crop under stress with the area that was grown to the crop that was partly damaged. This principle applies similarly to the avoided losses from relief programs and irrigation, as well as drought insurance measures.

For each unit of land, avoided losses during a drought are calculated as the difference between the value of production with the anticipatory measure (irrigation or drought-tolerant seeds and crops) and the value of production without the anticipatory measure. Further, to calculate the relief saved, we calculate production with irrigation, drought-tolerant crops and production without these anticipatory measures for each district. Each of the production quantities for crops is subtracted from district-level required food consumption (expressed in maize equivalent) to obtain food deficit quantities. Research shows that in some cases and neighbouring countries, it takes USD 600 90 per ton to deliver food relief. We thus multiply the deficits with the per-ton costs of delivery under each anticipatory action. Saved relief is then calculated by subtracting relief costs under each anticipatory action, from relief needed in the absence of the anticipatory action. The costs associated with deficit reduction are calculated by aggregating district-level costs associated with production under each AA implemented. These two quantities are then used to calculate the NPVs, as well as the BCRs.

Therefore, at the quantification stage, the benefits were assigned monetary values using various assumptions for those benefits for which an express monetary figure was not available. For example, the value of relief saved was derived using the method of benefit transfer, whereby estimated costs of providing relief from other similar settings within Africa are used in line with the literature.

Owing to time value of money, comparison of benefits and costs utilizes the concept of discounting, in which all values are weighed by a discount rate and a time factor to ensure that future benefits are compared to present costs appropriately as a dollar today is usually worth more than the same dollar in future due to the inevitable uncertainties that govern economies of the future. This is important for AA investments because many of these accrue more benefits in the long run. The discount rate represents a cost of capital or the opportunity cost of using money for one purpose and not another. As such, the key interest rate used by the Central Bank in an economy is often used as a discount rate.

The baseline assumptions underlying the calculations for an irrigation action include a discount rate of 10, 15 and 20%; on-farm investment costs of USD 6,000 per hectare in the year 0, and operations and annual maintenance costs of USD 900 per hectare for smallholder irrigation (see Table 4). For drought-tolerant crops, the costs are around USD 900 per hectare, and in any case (see Table 4), costs vary depending on the combination of crops grown in the district and on a measure of transaction costs for input access, which varies with the distance from the district centre to the main markets. The discount rate accounts for the cost of investment finance. Thus, projects should have rates of return that are higher than the discount rate over the period considered for them to be worthwhile. The interest rate for lending money to banks, as set by the Central Bank of Zambia, has varied from 9% in 2012 to around 13% in 2024 (CountryEconomy 2024), and so, the discount rates chosen to understand the viability of the AA is 10%, 15% and 20%. These are realistic and in line with the cost of borrowing at the time in Zambia.

The benefits include the increase in value of production because of the AA measure, as well as the relief savings realized as a result of implementing the AA measure, thus reducing any need for relief.

The Cost-benefit Analysis of irrigation at the farm level depends on several factors, including the technology chosen or feasible, as well as the commodities being grown, the prices of other inputs and the output produced. The Cost-benefit Analysis in this paper is based on the production of maize, groundnuts, sorghum, sweet potato, millet, rice, cowpeas, Bambara nuts, mixed beans, soybeans, sunflower, Virginia tobacco and cassava. These are chosen because the crop forecast surveys by the Zambia National Statistics provide them sufficient coverage for this purpose, and they account for closer to 95% of crop-based agriculture activities in the Western province.

The benefit-cost ratios were calculated directly by dividing the sum of the discounted benefits by the sum of the discounted costs. A ratio of greater than 1 implies that benefits outweigh the costs, and the anticipatory measure is worthwhile and economically viable. These ratios were compared and the larger ones are to be preferred. A mathematical representation of the benefit-cost ratio (BCR) is provided below for ease of reference.

$$\mathrm{BCR} = \frac{\sum_{t=0}^{t=n} B_t}{(1+r)^t} \Big/ \frac{\sum_{t=0}^{t=n} C_t}{(1+r)^t}$$

Where *t* stands for time, r is the discount rate, and *n* is the total number of years, while *B* and *C* are the benefits and costs for each year (see Seekao and Pharino 2016).

Following the quantification of costs and benefits, net present values (NPVs) for each were calculated by subtracting the discounted costs from the discounted benefits for each AA. This is a measure of economic viability and a positive NPV indicates that the action is economically viable.

By definition, the NPV is calculated by (Seekao and Pharino 2016):

$$\mathrm{NPV} = \frac{\sum_{t=0}^{t=n} B_t}{(1+r)^t} - \frac{\sum_{t=0}^{t=n} C_t}{(1+r)^t}$$

Given that the NPV are calculated, this study also reports an internal rate of return (IRR). The IRR is the theoretical discount rate at which the NPV equals zero (that is, the rate that equalizes the discounted costs and benefits). The IRR, therefore, is an indicator of the strength of a project, and it is the *r* that satisfies the equation below. From a project funds lending/borrowing perspective, a higher IRR than the ruling interest rates is better because it implies that the project is worthwhile, i.e., an investor can borrow money at the r rate and be sure to pay back as the project gives profits at the higher rate of IRR (Seekao and Pharino 2016).

$$\frac{\sum_{t=0}^{t=n} B_t}{(1+r)^t} - \frac{\sum_{t=0}^{t=n} C_t}{(1+r)^t} = 0$$

To assess the robustness of the results, sensitivity analyses were carried out by changing assumptions about the value of investment costs per unit for each of the AA strategies under study, as well as discount rates, benefit estimates or input costs. This is useful for identifying which factors have the most significant impact on the outcomes of the analysis and provides insights into the uncertainty surrounding the results. Such information enables policy makers as they make decisions on investments.

The discount rates chosen for this analysis are 10%, 15% and 20% and are chosen on the basis that the literature cites them, especially in African projects. In addition, the band is wide enough to account for the risk of lending in Africa and allows for short-term investment projects.

4.2 Assumptions and Limitations

The following eight assumptions and limitations applied to the study:

1. The study considers two AA (irrigation with motorized pumps and adoption of drought-tolerant crops). It constructs a third AA by combining irrigation and drought-tolerant crops so that non-irrigable areas are planted with drought-tolerant crops, while irrigable areas are planted with regular high-yielding varieties. While the results show that this leads to even better results, this study does not discuss the other pros and cons of such a combination.
2. The study used a cash flow model over 15 years. A 5–15-year time horizon was applied to investments in irrigation and drought-resistant crops. This would be more applicable for irrigation investments, although it may not be as appropriate for drought-tolerant varieties, which may require shorter time horizons.
3. Commodity prices and other inputs were assumed to remain constant over the period, although sensitivity analyses were conducted (see the section before the conclusions).
4. The AA interventions identified in this study start to generate benefits immediately (for drought-tolerant seeds), although for irrigation, a one-year lag may make sense since the first year may involve equipment installation.
5. Discount rates are assumed to be in line with a developing country's high costs of borrowing. Discount rates of 10–12% were considered a starting point (Harrison 2010), making our choice of 10%, 15%, and 20% realistic.
6. Cropping patterns and output and input prices are assumed constant over 5 years, and if they change, they change uniformly for both inputs and outputs.
7. Yields of maize and other crops increase with irrigation and, particularly for maize, can range from 2–10 t/ha (Bekoe et al. 2021). However, for the analyses of benefits and costs, the yields considered for these crops are set below their maximum potential to ensure results are robust even if yields under the chosen AA is below average or maximum potential.
8. There are spatial differences in input and commodity prices, proportional to each district's distance from main markets, such that inputs become more expensive the further away the locations are from markets, however, outputs become cheaper the further away a location is from key markets.

4.3 Data

The major sources of data for this analysis included the following:

a) **Literature:** Estimates about costs of irrigation per hectare, seeds, discount rates, yields, costs of transportation, potential yields and prices (see Table 4 for specific sources)

b) **Stakeholder consultations:** Primary qualitative data were collected through stakeholder consultations conducted between March and May 2024. These consultations involved officials from the Disaster Management and Mitigation Unit (DMMU), the Ministry of Agriculture, the Zambia Meteorological Department, and the Ministry of Green Economy and Environment, as well as district-level agricultural officers and selected farmer representatives from Mongu, Kaoma and Sesheke. The discussions focused on validating cost assumptions, identifying feasible anticipatory action and contextualizing the data used in the benefit–cost analysis.

c) Zambia Statistics for data from crop forecast surveys to calculate losses, planted areas and yields (Zamstats 2019).

4.3.1. Baseline Data

The following tables present some baseline data, which are useful for carrying out province-wide benefit-cost estimations of AA in Zambia.

Table 3. Yield values for farmland: Rain-fed, irrigated and during drought without irrigation.

	Rain-fed (no-drought)	Irrigated	During drought without irrigation
Yields for cereals	Millet = 1.2 t/ha Maize = 2.4 t/ha Sorghum = 0.8 t/ha Rice = 1.3 t/ha (Zamstats 2023)	Millet => 3 t/ha Maize => 4 t/ha Sorghum => 3 t/ha Rice =>4 t/ha (Zamstats 2023)	Millet = 0-10% reduction (Shrestha et al. 2023) Maize = reduce by 30-90% Széles et al. 2023 Sorghum = reduce by 35-55% (Abreha et al. 2021) Rice = reduce by 50% (Esmaeilzadeh-Moridani et al. 2023)
Yields for drought-tolerant cereals	Millet = 1. t/ha Maize = 2. t/ha Sorghum = 0.8 t/ha Rice =1.3 t/ha	Millet = 1.0 t/ha Maize = 2 t/ha Sorghum = 0.7 t/ha Rice = 1.0 t/ha	Millet = 1.0 t/ha Maize = 2 t/ha Sorghum = 0.7 t/ha Rice = 1. 0 t/ha
Yields for legumes	**Groundnuts** = 0.730 t/ha (Tembo et al. 2023) Soybean = 1.3 t/ha (USDA 2024) Mixedbeans = 0.3 t/ha	**Groundnuts** => 1 t/ha Soybean = 1.8 t/ha (Cornelius and Goldsmith 2019) Mixedbeans = >0.5t/ha	**Groundnuts** = reduced by up to 80% (Matchaya et al. 2022) Soybean = reduced by 34% (Matchaya et al. 2022) Mixed beans = reduce by 22% (Matchaya et al. 2022)
Yields for drought-tolerant legumes	**Groundnuts** => 1 t/ha Soybean = 1.8 t/ha (Cornelius and Goldsmith 2019) Mixedbeans => 0.5t/ha	**Groundnuts** => 1 t/ha Soybean = 1.8 t/ha (Margaret Cornelius and Peter Goldsmith 2019) Mixedbeans => 0.5 t/ha	**Groundnuts** => 1 t/ha Soybean = 1.8 t/ha (Cornelius and Goldsmith 2019) Mixedbeans => 0.5 t/ha
Yields for sweet potato	15t/ha	20t/ha	Reduced by 25% (Motsa et al. 2015)
Yields for Irish potato	13 t/ha (Chilipa et al. 2020)	18 t/ha (Enviro-Flor Ltd and HZPC 2013)	Reduced by 50% (Nasir and Toth 2022)
Cassava	5.8 t/ha (Tembo et al. 2017)	8 t/ha	4 t/ha

Source: Zamstats (2024) except where another source is expressly stated.

Table 4. Indicative costs for inputs per hectare and per ton of relief food**.**

	Zambia	Western Province
Irrigation motorized pump cost including installation/ha (Maximum) (Smith et al. 2014)	USD 6,000	USD 6,000
Running costs of irrigation equipment/ha e.g., energy (Smith et al. 2014)	USD 600	USD 600
Land costs and others (USD) (Smith et al. 2014)	USD 400	USD 400

Cost of seeds per ha **Maize seed = 20 kg/ha**	Maize; USD 67/ha	USD 67/ha
Cost of seed distribution per household/ha (World Bank 2012)	USD 0.11 per MT/km	USD 0.11 per MT/km
Labour costs per ha (Vroegindewey and Crawford. 2015)	USD 145/ha for maize	USD 145/ha
Costs of relief program per MT	USD 889 /MT as reported by Venton et al (2012)	USD 889 /MT as reported by Venton et al (2012)

The following parameters are important, and data thereof were organized to understand sectoral losses.

4.4 Data Requirements for Damage and Loss Assessment in Crops

To quantify the economic impacts of drought and evaluate the benefits of AA, the analysis required detailed crop-level information on the production, damage and losses. These data were essential for estimating avoided losses, avoided relief needs and the overall benefit-cost ratios of different AA scenarios.

The specific data requirements included:

- Number of hectares of crops damaged and/or destroyed by disasters, disaggregated by the type of crop
- Expected yield reduction in partially affected plot areas (t/ha) by crop
- Average yield (t/ha) by crop
- Types of cultivated crops per area
- Hectares of planted crops by crop type.

Relief programs are also considered as a cost and covered as avoided loss and added to other avoided losses. For example, the food requirements are known for the Western Province, and for 2018 drought year the food deficit is worked out in metric tons (MT). Food aid then would be needed to cover the deficits, which implies that the costs of relief can be worked out, since a cost of MT food aid is known, e.g., USD 889 per MT in Kenya. Successful anticipatory programs would obviate the need for the costs of food aid, and these avoided losses can be counted as benefits of successful AA.

Note that in some cases, parameters were drawn from experiences in other countries, and therefore reliance on data and studies applying to other parts of Zambia or neighbouring countries where no studies are found for Zambia can be useful. This process/method is termed benefit/cost transfer from the perspective of CBA.

5. Results and Discussion

This section presents statistics on agricultural production, crop damage due to drought and Cost-benefit Analysis of AA, highlighting farm level benefit-cost ratios as well as district and provincial level Cost-benefit Analysis of the AA. The analysis also extends to the amounts of relief aid saved/avoided because of embarking on a particular AA.

Agricultural production shares are relatively low in the Western Province (Table 19). Maize is predominantly grown in the Eastern Province, followed by the Central Province and the Northern Province. The national share of maize grown in the Western Province is around 1.1%. However, within the Western Province, maize accounts for an overwhelming 67% of crop-based agricultural output. Soybean, groundnuts, wheat, sweet potato and cotton also follow as key crops in the region, accounting for at least 2% of production in the province. Nationally, Zambia's key crops include maize, cotton, groundnuts, soybeans, wheat, sunflower and millet, accounting for 36, 11,8,7,6, 4 and 3% of average planted areas, respectively.

Yields are generally low in the Western Province and have varied over time (Figure 3).

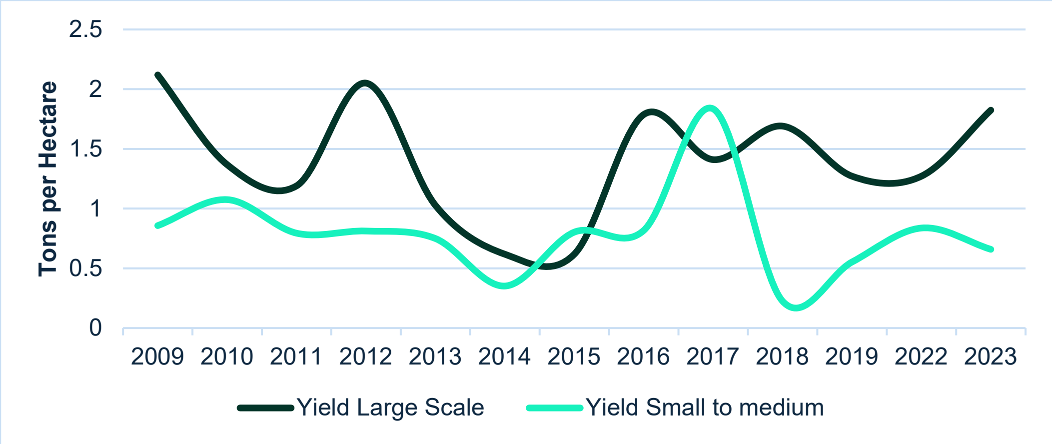

Figure 3. Yield Changes in Western Province over time.

Source: Zamstats (2023)

While the yield for cereals targeted in the African Union's CAADP (Comprehensive Africa Agriculture Development Programme) declaration is 2 tons/ha, it is generally consistently low in Zambia and in the Western Province in particular. This low productivity is related to changes in rainfall amounts, coupled with low investment in irrigation and general agricultural water management (see Figure 1). This provides preliminary evidence that improving drought tolerance of crops or improving water availability through efficient irrigation technologies can reduce the impacts of droughts.

5.1 Economic Analysis

5.1.1 Estimated Damage Costs

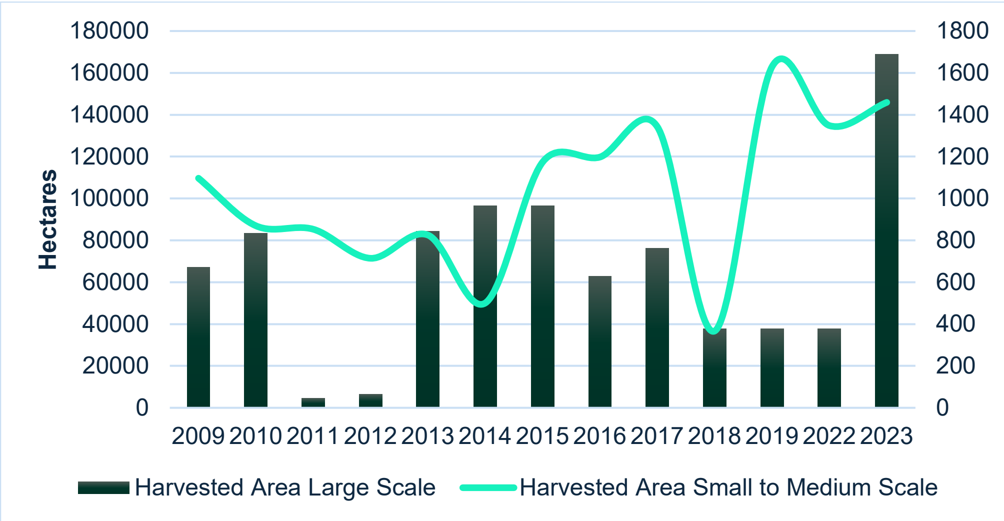

Figure 4. Harvested area in the crops sector in the Western Province over time.

Source: Zambia Statistics (2023).

Note: Based on crop forecast survey data.

In Figure 4, the harvested areas in Zambia are capped at approximately 162,000 ha for smallholder farmers (operating land sizes of 0–5 ha) and at under 1,700 ha for large-scale farmers with land sizes of larger than 5 ha. Thus, agricultural production in Western Zambia is predominantly small-scale.

For both smallholder and large-scale farmers, harvested areas plummeted in 2018 due to the drought, which destroyed crops before their harvest. These data show a drop in the operated area of more than 70% in 2018 compared to 2017. Thus, assuming a long-term yield average of 1.2 MT/ha for all cereals, and given that cereals account for over 70% of cultivated land in the province (Figure 5), there were over 119,000 MT losses in cereals alone, translating to USD 82 million in value (assuming a composite price of USD 0.83/kg for cereal grains). When losses in non-cereal crops, which together account for approximately 30% of total cropped area in the province, are taken into account, total crop-sector losses during the 2018 drought are conservatively estimated to exceed USD

110 million.. See also the right panel for losses in MT for both smallholder and large-scale farmers. Figure 5 presents similar information on production in MT and shows that lost production is around 142,000 MT, amounting to approximately USD 80 million worth of output lost in 2018.

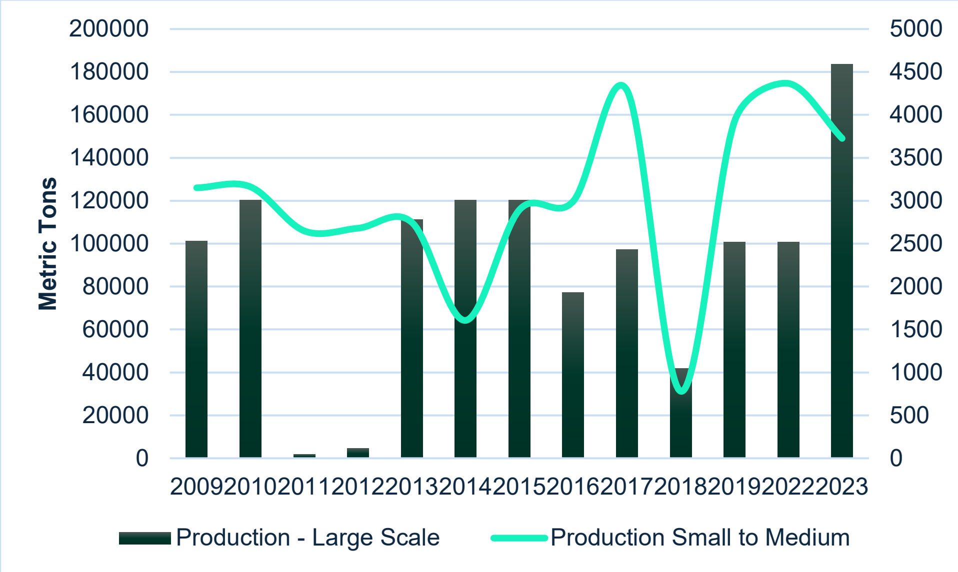

Figure 5. Production in the crops sector in the Western Province**.**

Source: Authors construction using data from Zambia Statistics (2024).

5.2 Cost-benefit Analysis of Anticipatory Action Measures

The assumptions that underpin the results include uniform commodity prices across districts. This, however, is mitigated by the introduction of a transaction-cost parameter that varies directly with distance, thereby increasing the costs of commodities and inputs in each district.

5.2.1. Irrigation as an Anticipatory Action to Reduce Damage from Drought

The share of land allocated to irrigation in Zambia is very low, including in the Western Province; as a result, crop yields are among the lowest. Irrigation is an option for ensuring that the Western Province attains long-term resilience against the adverse effects of climate change, which have recently emanated via frequent droughts and dry spells. From a policy perspective, early action based on drought predictions can help limit damage. While most drought predictions indicated an inevitable drought for the 2018 (RCCC 2024) harvesting season in the Western Province, little early action was undertaken to mitigate the unavoidable crop and livelihood damage. Part of the reason may be the absence of studies that establish the cost-effectiveness or value for money of early action through various strategies. For instance, questions about the value for money for embarking on smallholder farm-led irrigation or adopting drought-resistant varieties remain unanswered for the Western Province. Similarly, whether donors would save money by allocating a portion of their future relief funds to this resilience-building AA also requires study.

However, the Western Province has access to water and fertile land despite its low productivity. The Zambezi and Cuando rivers and their tributaries pass through the area. The province is typically subdivided into floodplains and more arid uplands (RCCC 2024), implying abundant groundwater resources. There is movement of communities between these areas, dependent on water availability. The traditional Kuomboka ceremony which happens annually is about migration and derives its name from this movement (Kabanda and Sikananu 2021; RCCC 2024).

The next section discusses the Cost-benefit Analysis results for crop irrigation in terms of avoided international aid resulting from irrigation adoption. Further on, Cost-benefit Analysis results for drought-resistant cereals are discussed, before considering the offering of boreholes and forage for livestock protection and discussing crop insurance.

Based on maize-equivalent per capita consumption, the Western Province requires around 370,000 MT annually to support a population of approximately 1 million. At present, less than 1% of the more than 100,000 ha of cultivated land is irrigated, owing to limited investment in irrigation infrastructure. The consequence of underinvestment in the province is frequent food deficits. An analysis of production data from the Zambia crop forecast surveys reveals that the average annual maize-equivalent demand for the province often exceeds production, resulting in an average deficit of approximately 260,000 MT (Table 19).

Had there been a deliberate, modest irrigation investment drive for around 7% of the irrigable land in the province, around 50,000 ha would have been under cultivation. At a fixed cost of 6,000 per ha and variable costs for running a motorized pump, training, seeds, labour and pesticides of around USD 900 per ha, the province would reduce its perpetual food deficits by around 190,000 MT. In other words, since dry spells are perpetual in the Western Province, each year can be considered a drought year, and therefore investing in irrigation would lead to avoided losses on the farm, as well as avoided deficits in each district. As explained, avoided values are calculated as the difference between drought loss under no AA and the drought loss under the AA. Similarly, the avoided deficit is the difference between the deficit during drought and without the AA and the deficit during drought and with the AA.

Under the irrigation scenario, many of the districts in the province, led by Nalolo, Sesheke, Sioma, Sikongo and Shangombo, would reduce their deficits by more than 10,000 MT each, i.e., by 23,800 MT, 20,400 MT, 19,000 MT 17,700 MT and 1,700 MT, respectively. The cost-benefit considerations for this strategy are discussed below; however, it should be noted that the approach would also yield avoided costs of relief of over USD 169 million per annum, assuming a WFP aid-delivery cost of around USD 889 per MT. Thus, although the initial investment for this strategy is significant, the long-term benefits justify it.

Given an initial set of prices for commodities in the subject and the costs of inputs, including seeds, fertilizers, a motorized pump, maintenance and training per hectare, and assuming that government, private agencies and development partners facilitate in making such investments, the per-hectare benefit and costs analyses would be as per Table 5.

Table 5. Benefit-cost analyses of irrigation across and within the province.

Year	Discounted Cost (USD)			Discounted Benefit (USD)		
	10%	**15%**	**20%**	**10%**	**15%**	**20%**
0	7390,6	7390,6	7390,6	5712,1	5712,1	5712,1
1	926,2	885,9	849,0	5281,6	5052,0	4841,5
2	844,6	772,7	709,7	4882,2	4466,9	4102,4
3	770,2	674,0	593,2	4511,8	3948,5	3475,2
4	702,3	587,9	495,9	4168,4	3489,3	2943,1
5	1471,7	1178,4	952,5	3850,1	3082,8	2491,9
6	620,0	474,8	367,8	3555,2	2722,9	2109,3
7	565,2	414,1	307,4	3282,1	2404,5	1785,0
8	515,3	361,1	256,9	3029,3	2122,8	1510,2
9	469,8	314,9	214,7	2795,4	1873,7	1277,5
10	945,7	606,3	396,2	2578,9	1653,4	1080,3
11	391,6	240,2	150,4	2378,7	1458,8	913,4
12	357,0	209,4	125,7	2193,6	1286,8	772,1
13	325,5	182,6	105,0	2022,5	1134,8	652,6
14	296,7	159,2	87,8	1864,3	1000,6	551,4
15	270,5	138,9	73,3	1718,2	882,1	465,9
Grand Total	16862,8	14591,1	13076,0	53824,6	42292,0	34684,0
BCRs				**3,19**	**2,90**	**2,65**

Note: BCR = Benefit Cost Ratio.

The BC ratios for investment in irrigation are greater than one for each of the chosen discount rates (10%, 15% and 20%). At the provincial level, therefore, investment in irrigation is worthwhile, and at a minimum, an investment of 1 USD is associated with a benefit of USD 2.50, which is substantive (Table 5). The BCRs are higher at lower discount rates: USD 3.19 for the 10% discount rate, USD 2.90 for the 15% discount rate, and USD 2.65 for the 20% discount rate. Various realistic assumptions drive these results. For example, patterns of crop choices are assumed to be unchanged in terms of type and the shares of land allocated to them, and that irrigation yields are above 4 tons per hectare for cereals, 8 tons per hectare for roots and tubers, and above 2 tons per hectare for legumes such as peanuts, cowpeas, soybeans and Bambara nuts. These assumptions on yields are consistent with the literature and are set at respective minimums for well-organized irrigation systems.

Nevertheless, the fact that investment in irrigation shows a gain does not imply that irrigation is worthwhile as a strategy for AA. To ascertain whether this is the case, we computed the avoided losses per hectare associated with undertaking a massive smallholder-farmer-led irrigation endeavour. The results are tabulated in Table 6.

Table 6. Cost-benefit Analysis for irrigation-driven avoided losses in the Western Province (USD).

YEAR	Discounted Cost_10	Discounted Cost_15	Discounted Cost_20	Discounted Avoided Loss_10	Discounted Av Loss_15	Discounted Av Loss_20
0	7390,6	7390,6	7390,6	4757,1	4757,1	4757,1
1	926,2	885,9	849,0	4292,4	4105,8	3934,7
2	844,6	772,7	709,7	4040,8	3697,0	3395,4
3	770,2	674,0	593,2	3692,1	3231,2	2843,9
4	702,3	587,9	495,9	3441,9	2881,2	2430,2
5	1471,7	1178,4	952,5	3215,2	2574,5	2081,0
6	620	474,8	367,8	2929,1	2243,4	1737,8
7	565,2	414,1	307,4	2684,3	1966,5	1459,9
8	515,3	361,1	256,9	2494,6	1748,1	1243,6
9	469,8	314,9	214,7	2300,0	1541,7	1051,1
10	945,7	606,3	396,2	2071,8	1328,3	867,9
11	391,6	240,2	150,4	1961,2	1202,7	753,1
12	357	209,4	125,7	1805,0	1058,8	635,4
13	325,5	182,6	105,0	1671,2	937,7	539,2
14	296,7	159,2	87,8	1534,1	823,3	453,7
15	270,5	138,9	73,3	1434,0	736,1	388,8
Grand Total	16862,8	14591,1	13076,0	44324,7	34833,3	28572,7
BCRs				2,63	2,39	2,19

Source: Authors.

Note: IRI = irrigation, DT = Drought Tolerant, DR = Discount Rate, BCR = Benefit Cost Ratio.

The avoided losses are calculated as the difference between the losses to drought under the status quo, where irrigation adoption in the province and the country in general is minimal as discussed earlier, and the loss that may occur under irrigation. Since not all land area can be equipped for irrigation owing to differences in water availability, an assumption that 47% of the land can be irrigated is made following literature on irrigation potential for the province. Thus, this assumption also avoids over estimation of the positive impact irrigation may make on provincial-level productivity and production outcomes.

Avoided losses will lie between USD 1,900 (USD 29,000/15) and USD 2,900 (USD 44,000/15 periods) per representative hectare of crops over the lifetime of the investment (15 years) (see Table 6). Given that irrigation is assumed to cover approximately 50,000 ha in the province, this translates to potential avoided losses of about USD 95–147 million per year, particularly if drought frequency increases. Linking these estimates with projected climate scenarios would further strengthen the analysis, as recent projections suggest that droughts in Western Zambia could become more frequent and severe under mid- to high-emission pathways (IPCC 2023; SADC Secretariat 2023). This alignment underscores the growing economic relevance of anticipatory and adaptive investments such as small-scale irrigation.

Since the actual losses under irrigation during a drought (the counterfactual) are not readily observable, we espouse the assumption that only a minimal amount of yield (0.5%) may be lost when compared to irrigation in the absence of a drought. Thus, the avoided losses approximate to the difference between production under irrigation during drought and the production observed in 2018, which we assume to be production without irrigation. The BCRs associated with irrigation as an anticipatory measure for drought, therefore, amount to considering whether the avoided damages/losses arising from irrigation can justify the costs of investing in irrigation over the chosen time horizon.

The Table 6 shows the BCRs to be above one, with the least worthwhile possibility of a BCR of 2.19, which implies that a USD 1 investment in irrigation yields a gain of USD 2.19 at the minimum in terms of avoided losses. Thus, it would be worthwhile to invest in an anticipatory action of irrigation to limit the impacts of drought, as the avoided losses per hectare justify those investments.

Whether with or without investment in irrigation, there are bound to be food deficits in the Western Province owing to its population when evaluated from its production potential and food needs. The question is, however, whether timely irrigation campaigns led to the reduction of food deficits in a manner that would justify such early investment in irrigation. This is an important question, as it weighs the importance of building long-term resilience for populations, versus relying on yearly hand-outs of food through food aid to them as drought hits. In essence, the BCR analysis compares the cost of relief programs during drought, when there is an irrigation undertaking, and when there is no such investment. The difference between the two costs of relief is an avoided relief aid and is considered a benefit for purposes of computation of the BCR. The food deficit is calculated using the population and food demands for each of the 16 districts in the Western Province, and those needs are compared to the production potential. An assumption embraced is that food self-sufficiency depends much on production during these times as the role of trade may be undermined by scarcity and the general lack of purchasing power of households. Table 7 shows the BCR of the avoided costs of relief programs combined with food losses under different Discount Rates (DRs).

Table 7. Levels of costs of relief and avoided relief under irrigation assumption (Million USD).

	Total Cost of Relief IRR	Total Cost of Relief	Total Cost of Relief	Total Avoided Relief	Total Avoided Relief	Total Avoided Relief
YEAR	**DR10**	**DR15**	**DR20**	**DR10**	**DR15**	**DR20**
1	2,7	2,6	2,5	13,6	13,0	12,5
2	2,5	2,3	2,1	12,9	11,8	10,8
3	2,3	2,0	1,8	11,7	10,3	9,0
4	2,1	1,7	1,5	11,0	9,2	7,7
5	4,4	3,5	2,8	10,3	8,2	6,6
6	1,8	1,4	1,1	9,3	7,1	5,5
7	1,7	1,2	0,9	8,5	6,2	4,6
8	1,5	1,1	0,8	7,9	5,6	4,0
9	1,4	0,9	0,6	7,3	4,9	3,3
10	2,8	1,8	1,2	6,5	4,2	2,7
11	1,2	0,7	0,4	6,2	3,8	2,4
12	1,1	0,6	0,4	5,7	3,4	2,0
13	1,0	0,5	0,3	5,3	3,0	1,7
14	0,9	0,5	0,3	4,9	2,6	1,4
15	0,8	0,4	0,2	4,5	2,3	1,2
Total	49,9	43,2	38,7	140,9	110,8	91,0
Annual	3,1	2,7	2,4	8,8	6,9	5,7
BCRs				**2,8**	**2,6**	**2,3**

Source: Authors

Note: IRI = irrigation, DT = Drought Tolerant, DR = Discount Rate, BCR = Benefit Cost Ratio.

The costs used in this calculation are the total costs of producing the avoided deficits calculated for the province that result from early action in the form of investments in irrigation (Table 7). The avoided relief is computed by multiplying the avoided deficit in metric tons of food by the cost of delivery of such food per metric ton, which is assumed to be USD 889 per MT in line with figures reported by WFP and other organizations in the literature as discussed previously.

The BC ratios are above 1 implying that for the province and each district in the province, irrigation investments can limit losses through reduced burden on relief programs. In other words, early action in irrigation could save donor aid. For each USD 1 invested in irrigation, donors could save between USD 2.3 and 2.8 because the need for food aid will decline. In fact, if early action involved irrigation, under the current assumptions, the average annual avoided losses from saved relief costs and production would surpass USD 140 million at a discount rate of 10%, over the 15-year horizon. This is similar to the Government of Zambia's 2024 estimate of USD 6 million plus for each of the

84 districts affected (Government of Zambia 2024). These figures are an underestimation because they do not account for the positive effect that irrigation action brings to the livestock sector. Livestock production is likely to be advantaged by the availability of water as well as the availability of crop residues that become feed for livestock after harvest. These would reduce livestock mortality due to drought and would improve productivity more than would be the case without better food availability for livestock.

As highlighted, the benefit-cost ratios for irrigation vary across the 16 districts of the province owing to variations in parameters, including yields of crops and prices of inputs and commodities. However, the general finding is that these are all greater than one and gravitate around 2.0 to as high as 3.6, implying that each locality has something to gain from an irrigation endeavour that changes the scales of production from the past levels (Table 8).

Table 8. Benefit Cost Ratios (BCRs) – Irrigation.

	Irrigation CBAs per hectare			Per Hectare Avoided Loss BCRs		
	DR10	DR15	DR20	DR10	DR15	DR20
Kalabo	3,0	2,7	2,5	2,5	2,2	2,0
Kaoma	3,6	3,2	3,0	2,4	2,2	2,0
Limulunga	3,6	3,3	3,0	3,0	2,7	2,5
Luampa	3,2	2,9	2,6	2,6	2,3	2,1
Lukulu	3,2	2,9	2,7	2,6	2,4	2,2
Mitete	3,1	2,8	2,5	2,4	2,2	2,0
Mongu	3,5	3,2	2,9	2,7	2,5	2,3
Mulobezi	2,9	2,7	2,4	2,6	2,4	2,2
Mwandi	3,1	2,8	2,6	2,8	2,6	2,3
Nalolo	3,2	2,9	2,7	3,0	2,7	2,5
Nkeyema	3,3	3,0	2,8	1,8	1,7	1,5
Senanga	3,1	2,8	2,6	2,6	2,3	2,1
Sesheke	3,0	2,7	2,5	2,6	2,3	2,1
Shangombo	2,8	2,6	2,3	2,5	2,3	2,1
Sikongo	3,5	3,2	2,9	3,3	3,0	2,7
Sioma	2,9	2,6	2,4	2,7	2,4	2,2

Note: IRI = irrigation, DT = Drought Tolerant, DR = Discount Rate, BCR = Benefit Cost Ratio.

The district-level heterogeneity shown in Table 8 underscores the importance of evaluating investment decisions based on local contexts to avoid prescribing projects that do not work. The CBA for avoided losses per hectare also shows that this is a worthwhile strategy as an AA. For every USD 1 invested in irrigation each district registered more than USD 1 worth of benefits per hectare in avoided losses and in some cases, the gains are more than 3.5 for each USD 1 invested. Sikongo, Limulunga, Sioma, Nalolo and Mwadi are among the districts that register the highest gains in avoided losses.

It is also useful to consider the amount of relief funding that would be saved by embarking on the irrigation undertaking. Table 9 shows the amount of relief funding saved per year over the 15-year period for each district to show the importance of an investment in irrigation as an anticipatory measure. Again, the BCRs for these avoided costs of relief are greater than 1, implying that they are worthwhile. But they are slightly lesser for Nkeyama District due to its high initial average productivity levels for all crops (1.44 MT/ha) as compared to the 0.8 MT/ha for the overall province. Therefore, Nkeyama does not benefit much from the intervention, while the rest overwhelmingly significantly.

Table 9. BCRs for avoided relief with IRI under different discount rates per year (Million USD).

	BCR (DR10)	BCR (DR15)	BCR (DR20)	Average Annual Relief funding saved
Kalabo	2,6	2,4	2,2	1,0

Kaoma	2,5	2,3	2,1	0,9
Limulunga	2,3	2,1	1,9	1,0
Luampa	3,0	2,7	2,5	0,9
Lukulu	2,8	2,5	2,3	0,5
Mitete	2,3	2,1	1,9	0,5
Mongu	2,2	2,0	1,8	0,7
Mulobezi	3,3	3,0	2,8	1,7
Mwandi	3,2	2,9	2,6	1,0
Nalolo	3,3	3,0	2,7	2,1
Nkeyema	1,5	1,3	1,2	0,4
Senanga	2,6	2,4	2,2	1,0
Sesheke	3,0	2,7	2,5	1,9
Shangombo	3,1	2,8	2,5	1,6
Sikongo	2,9	2,7	2,5	1,3
Sioma	3,2	2,9	2,6	1,6

Source. Authors based on crop forecast survey data.

Note: IRI = irrigation, DT = Drought Tolerant, DR = Discount Rate, BCR = Benefit Cost Ratio.

There is also considerable heterogeneity in terms of BCRs across the districts, with some districts including Sioma, Sikongo, Nalolo, Mulombezi and Shangombo generating more than USD 2.5 per each USD 1 invested, while others generate less but still worthwhile amounts per dollar invested in terms of relief saved. The absolute amounts of relief saved annually for each district range from around US 0.4 million in Nkeyema to as high as USD 2.1 million in Nalolo associated benefit-cost ratios of over 2.6 for a discount rate of 20% and 3.0 for a discount rate of 15%. Thus, investing in irrigation for a significant part of the land is in any case useful and worthwhile under the current assumptions. The amount of relief that may be needed in one drought year can easily surpass USD 6 million per district, as noted from the government's own estimates of food relief in 2024. The Government of Zambia sought ZMW12.6 billion (USD 504 million) for immediate food assistance for 84 districts averaging around USD 6 million per district (Government of Zambia 2024), which implies that in some cases irrigation AA could significantly reduce such relief needs. When compared with relief needed, irrigation AA appears to save between 90% to more than 100% of the relief which follows from increased production that eliminates the need for relief and in some cases provides excess supply that ends up reducing relief needs within the province and beyond a district.

5.3 Drought-Resistant Crop Varieties as an Anticipatory Action

Drought-tolerant crop varieties developed through biotechnology enable farmers to protect their harvest and minimize lossesduring severe drought by using water more efficiently. Where rainfall is completely absent, drought-tolerant varieties may also not have a significant impact on production protection. However, when rainfall failure is partial, drought tolerance in crops can be extremely useful, as yield reductions are lower than with conventional crop varieties. Where AA combines both drought-tolerant seeds and irrigation, the results may be even better in a drought year.

The adoption rates for drought-tolerant varieties in the province are low, which may explain the severe impacts that negative climatic changes have on agricultural production in the province. Unlike irrigation investments, where the setup costs are as high as USD 6,000 per hectare in the first year for farmer-led smallholder irrigation using motorized pumps, the costs are lower for adoption of drought-tolerant varieties. The differences in seed costs between the common high-yielding varieties and the drought-tolerant varieties are not as significant. The data for maize seed prices in Zambia appears to suggest that a markup of 1% to normal prices may be reasonable as an estimate. Since labour, fertilizer and other cost parameters are also not that different between drought-tolerant seeds and the other varieties, the per hectare costs of production are also similar.

Table 10 presents some discounted costs, benefits and avoided losses per hectare in 2015 USD and calculates the overall provincial benefit-cost ratios associated with adoption and the avoided losses. At all discount rates, adoption of the drought-tolerant varieties are worthwhile, and for every USD 1 invested, there is a corresponding return or value of USD 3.71 for a 10% discount rate. Similarly, the BCRs for avoided losses per hectare are higher than 1 which implies there is value in using this, underscoring that as an AA measure, encouraging mass adoption of drought-tolerant seeds can be worthwhile.

Table 10. BCR for DT crops and avoided loss due to investment in DT USD per ha.

	Costs DR 10	Costs DR 15	Costs DR20	Benefit s DR10	Benefit s DR 5	Benefit s DR20	Avoided Losses due to DT 10	Avoided Losses due to DT 15	Avoided Losses due to DT 20
0	12,824	12,824	12,824	26,932	26,932	26,932	11,652	11,652	11,652
1	6,196	5,926	5,679	24,903	23,821	22,828	9,076	8,681	8,32
2	5,675	5,192	4,768	23,021	21,063	19,344	9,558	8,745	8,031
3	5,197	4,548	4,003	21,275	18,619	16,387	8,16	7,141	6,285
4	4,76	3,984	3,361	19,657	16,455	13,879	8,033	6,724	5,672
5	5,155	4,127	3,336	18,156	14,538	11,751	7,999	6,405	5,177
6	4,031	3,087	2,391	16,766	12,841	9,947	6,749	5,169	4,004
7	3,691	2,704	2,007	15,479	11,34	8,418	5,914	4,333	3,217
8	3,379	2,368	1,684	14,287	10,012	7,123	5,731	4,016	2,857
9	3,093	2,073	1,414	13,032	8,735	5,956	5,106	3,423	2,334
10	3,324	2,131	1,392	12,023	7,708	5,036	3,908	2,506	1,637
11	2,593	1,59	996	11,089	6,8	4,258	4,408	2,703	1,693
12	2,374	1,393	836	10,226	5,998	3,599	4,008	2,351	1,411
13	2,173	1,219	701	9,428	5,29	3,042	3,807	2,136	1,229
14	1,989	1,067	588	8,691	4,664	2,57	3,406	1,828	1,007
15	1,82	934	494	8,009	4,112	2,172	3,16	1,622	857
BCRs				**3.71**	**3.61**	**3.51**	**1.47**	**1.44**	**1.41**

Source: Authors computations, BCR for avoided loss with DT

Note: IRI = irrigation, DT = Drought Tolerant, DR = Discount Rate, BCR = Benefit Cost Ratio.

Table 11. The Benefit Cost Ratios (BCRs) for adoption of DT, avoided losses and avoided deficits due to DT crops per district.

	DT Adoption DR 10	DT Adoption DR 15	DT Adoption DR 20	Avoided Losses due to DT DR 10	Avoided Losses due to DT DR 15	Avoided Losses due to DT DR 20
Kalabo	4,34	4,34	4,31	2,03	2,10	2,15
Kaoma	3,25	3,16	3,08	-1,40	-1,41	-1,42
Limulunga	3,08	3,02	2,95	0,60	0,62	0,63
Luampa	4,02	3,73	3,49	1,37	1,13	0,95
Lukulu	5,12	5,10	5,05	2,73	2,77	2,79
Mitete	3,02	2,96	2,89	0,72	0,73	0,74
Mongu	3,08	3,01	2,95	-0,06	-0,04	-0,02
Mulobezi	4,08	3,74	3,47	2,72	2,42	2,18
Mwandi	4,99	5,07	5,10	3,87	3,99	4,07
Nalolo	3,12	2,96	2,82	2,26	2,14	2,03
Nkeyema	3,27	3,22	3,18	-1,76	-1,75	-1,75
Senanga	3,71	3,60	3,49	1,41	1,37	1,33
Sesheke	3,73	3,62	3,52	2,19	2,13	2,08
Shangombo	3,56	3,43	3,32	2,34	2,27	2,20

Sikongo	3,58	3,47	3,37	2,54	2,49	2,45
Sioma	**3,60**	**3,49**	**3,38**	**2,81**	**2,73**	**2,65**

Note: IRI = irrigation, DT = Drought Tolerant, DR = Discount Rate, BCR = Benefit Cost Ratio.

The levels of avoided costs of relief funding associated with the drought-tolerant crop strategies average around USD 53 million per annum for the entire province, assuming all land is planted with drought-tolerant varieties (Table 12). The benefit-cost ratios are also significant and are 2.14 for the discount rate of 10% and around 2.01 for the discount rate of 20%. This also implies that as an anticipatory action, promotion of drought-tolerant varieties is worthwhile, since for every USD 1 invested, more than double that amount is realized in terms of costs of relief saved.

Table 12. Calculated BCR for avoided relief under DT crops (Million USD).

Year BCR	Cost to Produce USD DR 10%	Cost to Produce USD DR 15%	Cost to Produce USD DR 20%	Avoided Relief USD DR 10%	Avoided Relief USD DR 15%	Avoided Relief USD DR 20%
1	35.1	33.6	32.2	76	72.7	69.7
2	32.2	29.4	27	78.4	71.7	65.8
3	29.5	25.8	22.7	67.5	59.1	52
4	27.1	22.6	19.1	65.8	55	46.4
5	30.2	24.2	19.6	64.7	51.8	41.9
6	23	17.6	13.6	55.2	42.3	32.7
7	21.1	15.4	11.5	48.6	35.6	26.4
8	19.3	13.5	9.6	46.7	32.7	23.3
9	17.7	11.9	8.1	46.2	31	21.1
10	19.6	12.6	8.2	36.9	23.7	15.5
11	14.9	9.1	5.7	39.7	24.3	15.2
12	13.6	8	4.8	36.1	21.2	12.7
13	12.5	7	4	34	19.1	11
14	11.4	6.1	3.4	30.6	16.4	9.1
15	10.5	5.4	2.8	28.3	14.5	7.7
BCR				**2,14**	**2,07**	**2,01**

Note: IRI = irrigation, DT = Drought Tolerant, DR = Discount Rate, BCR = Benefit Cost Ratio.

There is also considerable heterogeneity across provinces. This AA would be associated with more benefits in many districts, including Mwandi, Lukulu, Sioma, Mulobezi, Sikongo, Nalolo, Shangombo, Sesheke and Kalabo with BCRs of 2 or higher. There are also significant benefits to be gained in the rest of the districts in terms of relief saved (Table 13). However, an action that promotes drought-tolerant crops alone is not as beneficial for Kaoma, Mongu and Nkeyema, which are already high-producing districts.

Table 13. Levels of relief and BCRs for avoided relief due to DT crops per district (Million USD) per year.

	BCR 10%	Relief With DT Crops	Relief Without DT Crops	Relief Saved
Kalabo	2,4	0.79	1.17	0.38
Kaoma	-1,7	1.51	1.25	0.26
Limulunga	0,8	0.07	0.22	0.15
Luampa	1,7	0.16	0.48	0.32
Lukulu	3,4	0.88	1.17	0.29

Mitete	1,0	0.21	0.29	0.09
Mongu	0,0	2.41	2.39	0.02
Mulobezi	3,3	0.76	0.26	1.02
Mwandi	5,0	0.29	0.38	0.67
Nalolo	2,8	0.14	0.77	0.92
Nkeyema	-2,9	0.96	0.64	0.32
Senanga	1,8	0.78	1.13	0.35
Sesheke	2,7	0.4	0.48	0.88
Shangombo	2,8	0.1	0.69	0.8
Sikongo	3,2	0.09	0.59	0.68
Sioma	3,4	0.17	0.72	0.89

Note: IRI = irrigation, DT = Drought Tolerant, DR = Discount Rate, BCR = Benefit Cost Ratio.

Under this scenario, the average discounted relief cost saved per district is around USD 600,000, which is far smaller than the USD 1.1 million in discounted savings per district obtainable under the irrigation strategy. Anticipatory action of drought-tolerant crops would thus save at least between 60% to almost all the costs of relief, owing to resilience built among the farming sector through promotion of drought-tolerant crops. A blanket drought-tolerant crops strategy would yield inferior results, however, compared to an irrigation strategy in areas where current practices offer better yields even in drought years. Therefore, contextual information must be taken into account before implementing such a strategy.

5.4 Combine Irrigation and Digital Twin as an Anticipatory Action

In the next strategy we combine the two strategies in which 47% of the cultivated land is irrigated and the remainder is planted with drought-tolerant seeds. This strategy takes advantage of the superior performance of drought-tolerant varieties under drought conditions to boost yields in the areas where irrigation may be infeasible due to other characteristics. It therefore adds strength to the positive impact of irrigation on high-yielding but non-drought-tolerant varieties.

Table 14. BCR for DT crops due to investment in DT plus IRI per ha.

BCR year	Costs IRI + DT DR 10	Cost IRI + DT DR 15	Cost IRI+DT DR 20	Benefit per ha DT + IRI DR 10	Benefit per ha DT + IRI DR 15	Benefit per ha DT + DR 20
0	3,701	3,701	3,701	3,456	3,456	3,456
1	624	597	572	3,196	3,057	2,929
2	570	522	479	2,954	2,703	2,482
3	521	456	401	2,730	2,389	2,103
4	476	398	336	2,522	2,111	1,781
5	828	663	536	2,330	1,865	1,508
6	414	317	246	2,151	1,648	1,276
7	378	277	206	1,986	1,455	1,080
8	345	242	172	1,833	1,284	914
9	315	211	144	1,686	1,130	771
10	532	341	223	1,556	997	652
11	263	161	101	1,435	880	551
12	240	141	85	1,323	776	466
13	219	123	71	1,220	684	394
14	200	107	59	1,124	604	333
15	183	94	50	1,036	532	281

Total	9,809	8,351	7,380	32,537	25,571	20,974
BCR				3,3	3,1	2,8

Note: calculated based on data from (Zamstats 2024). Abbreviations: IRI = irrigation, DT = Drought Tolerant, DR = Discount Rate, BCR = Benefit Cost Ratio.

An AA that combines irrigation and drought-tolerant varieties again yields positive net present values per hectare, leading to BCRs of at least 2.8 at a 20% discount rate and 3.3 at a 10% discount rate (Table 14). This implies that an AA combining drought-tolerant crops and irrigation is worthwhile, and for each USD invested, more than USD 2.8 in value is realized.

The avoided losses per hectare for the combined irrigation and drought-tolerant strategy are tabulated in Table 15, which illustrates that this AA is worthwhile, as it minimizes drought-related losses. Had this been implemented in the run-up to 2018, the losses from that drought would have been significantly reduced, and subsequent droughts/dry spells would have had limited negative impacts. The benefit-cost ratios associated with this are at least 2.1 at a 20% discount rate and 2.4 at a 10% discount rate.

Table 15. BCR for IRI and DT avoided losses due to investment in DT plus IRI per ha.

BCR year	Average of Avoided Loss per ha Drought Tolerant and Irrigation DR 10	Average of Avoided Loss per ha Drought Tolerant and Irrigation DR 15	Average of Avoided Loss per ha Drought Tolerant and Irrigation DR 20
0	2,547	2,547	2,547
1	2,249	2,151	2,061
2	2,152	1,969	1,808
3	1,946	1,703	1,499
4	1,829	1,531	1,291
5	1,726	1,382	1,117
6	1,554	1,190	922
7	1,414	1,036	769
8	1,322	927	659
9	1,213	813	554
10	1,069	685	448
11	1,036	635	398
12	952	558	335
13	885	496	285
14	809	434	239
15	747	383	203
Total	23,449	18,441	15,136
	2,4	2,2	2,1

Note: Calculated based on data from (Zamstats 2024). Abbreviations: IRI = irrigation, DT = Drought Tolerant, DR = Discount Rate, BCR = Benefit Cost Ratio.

The combined use of irrigation and drought-tolerant varieties shows better agricultural performance, as there is significant avoided losses through relief programs. The province would save around USD 105–178 million each year in terms of avoided relief by investing in this anticipatory strategy. When compared with the costs for generating these avoided losses, the BC ratios are significantly greater than 1 and specifically as much as 5.72 for the 10% discount rate and 4.93 for the 20% discount rate. This implies that for each USD invested in this strategy of irrigation and drought-tolerant crops, around USD 5.7 is generated (Table 16).

Table 16. BCR for avoided relief due to IRI and DT crops (Millions).

BCR year	Total Costs DT plus IRI DR 10	Total Costs DT plus IRI DR 15	Total Costs DT plus IRI DR 20	Avoided Relief DT plus IRI DR 10	Avoided Relief DT plus IRI DR 15	Avoided Relief DT plus IRI DR 20
1	2	1.9	1.9	17	16.2	15.6
2	1.8	1.7	1.6	16.2	14.8	13.6
3	1.7	1.5	1.3	14.7	12.8	11.3
4	1.5	1.3	1.1	13.8	11.5	9.7
5	2.6	2.1	1.7	13	10.4	8.4
6	1.3	1	0.8	11.7	8.9	6.9
7	1.2	0.9	0.7	10.6	7.8	5.8
8	1.1	0.8	0.6	9.9	7	5
9	1	0.7	0.5	9.3	6.2	4.2
10	1.7	1.1	0.7	8.2	5.2	3.4
11	0.9	0.5	0.3	7.9	4.8	3
12	0.8	0.5	0.3	7.3	4.3	2.6
13	0.7	0.4	0.2	6.7	3.8	2.2
14	0.6	0.3	0.2	6.2	3.3	1.8
15	0.6	0.3	0.2	5.7	2.9	1.5
Total	31	26.3	23.2	177.2	139.3	114.2
BCRs				5,72	5,29	4,93

Note: Calculated based on data from Zamstats (2024). Abbreviations: IRI = irrigation, DT = Drought Tolerant, DR = Discount Rate, BCR = Benefit Cost Ratio.

At the level of the district, the strategy that combines irrigation on part of the cultivated area and drought-tolerant crop varieties on the rest of the cultivated area shows mostly positive net gains, in that the BCR values for avoided relief are above 1, except in Nkeyama, where the current levels of productivity are already high. The BCR values for avoided losses per hectare in each district are also high, suggesting that a USD 1 investment in this anticipatory action yields more than USD 1 gains, and in many cases, these BCRs are greater than 2.5, reaching 3.2 in others, and reaching 7 for avoided relief (Table 17). There is evidence, therefore, that if Zambian authorities and stakeholders were to invest in these drought strategies, they would limit the impact of droughts in the local economies significantly. Irrigation and drought-tolerant crop strategies described in this report would save almost all (100%) relief costs, and furthermore, position the province to be an exporter of crops.

Table 17. BCR for avoided loss DT and IRI crops and avoided relief due to investment in DT plus IRI per ha.

	Avoided Loss DT plus IRI DR 10	Avoided Loss DT plus IRI DR 15	Avoided Loss BCRs DT plus IRI DR 20	Avoided Relief DT plus IRI DR10	Avoided Relief DT plus IRI DR 15	Avoided Relief DT plus IRI DR 20
Kalabo	2,5	2,4	2,2	5,8	5,5	5,1
Kaoma	1,5	1,4	1,3	3,6	3,3	3,1
Limulunga	2,2	2,0	1,9	4,9	4,5	4,2
Luampa	2,5	2,2	2,0	5,8	5,3	4,8
Lukulu	2,7	2,5	2,4	6,2	5,8	5,4
Mitete	2,0	1,8	1,7	4,4	4,1	3,9
Mongu	1,9	1,7	1,6	4,4	4,1	3,8
Mulobezi	3,0	2,7	2,5	6,8	6,2	5,7

Mwandi	3,2	3,0	2,8	7,3	6,9	6,5
Nalolo	2,9	2,6	2,4	6,6	6,1	5,6
Nkeyema	0,8	0,8	0,7	1,9	1,8	1,7
Senanga	2,3	2,1	2,0	5,3	4,9	4,5
Sesheke	2,7	2,5	2,3	6,1	5,7	5,3
Shangombo	2,7	2,5	2,3	6,1	5,7	5,3
Sikongo	2,8	2,6	2,4	6,4	6,0	5,6
Sioma	2,9	2,7	2,5	6,7	6,2	5,7

Source: Authors with data from Zambia forecast surveys

Note: calculated based on data from (Zamstats 2024). Abbreviations: IRI = irrigation, DT = Drought Tolerant, DR = Discount Rate, BCR = Benefit Cost Ratio.

All three strategies (irrigation, drought-tolerant crops and the combination of drought-tolerant crops and irrigation) have BCRs greater than 1, implying they are worthwhile investment options. Comparatively, irrigation combined with drought-tolerant maize appears to be better, followed by an irrigation-only scenario and lastly by drought-tolerant crops (Table 18). The BCR measure, the net present value (NPV) measure, as well as the avoided costs of relief quantum, show that combining irrigation with drought-resistant varieties is superior to the rest of the options. It saves the most relief money, has the highest net present values and the largest BCR ratios.

The irrigation and drought-tolerant crops option performs much better because when the two anticipatory action are combined, one takes advantage of both high yields associated with high-yielding varieties planted on irrigated land, and the resilience to drought conditions of the crops planted where it is not possible to irrigate owing to other physical and practical challenges. The BC ratios are as high as 4.93 for the irrigation and drought-tolerant scenario, meaning that for every USD 1 invested in the option, USD 4.93 is likely to be saved in avoided relief.

Table 18. BCR, NPV and avoided losses per year for each strategy.

	Drought Tolerance	Irrigation	Irrigation and Drought Tolerance
Average BCR for avoided losses/relief @20% discount rate	2.01	2.3	4.93
Average Avoided Relief (USD)	52 million	117 million	188 million
Average NPV of Avoided Loss (USD)	31 million	70 million	114 million
Ranking of AA	**3**	**2**	**1**

Note: Calculated based on data from Zamstats (2024). Abbreviations: IRI = irrigation, DT = Drought Tolerant, DR = Discount Rate, NPV = Net Present Value, AA = Anticipatory Action, BCR = Benefit Cost Ratio.

The net present values of all three options are positive, indicating that the options are economically viable. However, the drought-tolerant crop scenario has the lowest average NPV of USD 31 million over 15 years. The irrigation-only option yields an average NPV of over USD 70 million over the 15-year horizon, while the highest NPV (USD 114 million) is realised when irrigation is combined with drought-tolerant varieties on separate fields (Table 18). The irrigation and drought-tolerant crops option could save USD 188 million in relief costs, followed by the irrigation-only option, which could save over USD 117 million. In contrast, adopting drought-tolerant varieties would save approximately USD 52 million.

The internal rates of return (IRRs) for the cost and benefit structures for the investments considered herein are higher than the discount rates chosen and the lending interest rates. Most of the investments have a larger BCR for lower discount rates.

Money lending by the Central Bank of Zambia to commercial banks is at a maximum of 12% interest per annum, which means this AA is worthwhile because they show profitability even at discount rates of 20%. However, because farming usually faces uncertainty related to markets and other non-climate shocks, etc., lower interest rates are desirable. To be able to offer credit at lower interest rates, the government and partners need to develop innovative ways to deliver affordable credit.

Sensitivity Analysis

The results of the analyses hinge on assumptions related to levels and rates of change for prices of inputs and outputs for production activities. These are held to change uniformly over time across districts in the province. Prices may change differently in some cases, but because markets in rural areas work to some degree, the uniform price changes over time across districts may be realistic. To ensure that the results relate to this assumption, different prices for commodities and inputs were experimented with, without changing the ranking and viability of the options. Owing to the possibly larger standard errors associated with changes in some of the assumptions, the figures are rounded off to millions.

The results are also robust to changes in discount rates, although the range considered spanned 10–20%. The different AA prove viable even at other discount rates above 20%, which provides further confidence that this AA is worthwhile. It should be said, however, that to be viable, yields for irrigation have to be higher than 1.0 MT/ha, which characterizes non-irrigated agriculture in the province.

Conclusion

This study sought to understand whether various anticipatory action (AA) can be considered economically viable for purposes of limiting the impacts of drought in the Western province of Zambia, a location prone to frequent droughts and other crises that undermine agricultural productivity, driving food insecurity and food price inflation. Three scenarios, including mass adoption of drought-tolerant crop varieties, investing in irrigation and investing in both irrigation and drought-tolerant varieties on different pieces of land, were considered. The results elucidate that these measures can be effective as anticipatory measures. Combining drought-tolerant crop varieties and irrigation appears to yield the best results. The irrigation-only scenario comes second, and drought-tolerant varieties only are the least effective strategy, according to this study.

The benefit–cost ratios (BCRs) for all scenarios exceed one at the provincial, district and farm levels, indicating that each anticipatory action (AA) option evaluated in this study is economically viable at all three scales of analysis. In addition, the net present values (NPVs) are positive across scenarios, and the estimated savings in drought-related relief expenditures amount to several million US dollars at the provincial level, underscoring the strong economic justification for investing in anticipatory action.. The net present values and the relief costs saved for embarking on these participatory actions are in millions of USD. The savings in relief in some cases are as high as 10–30%, when the discounted values are compared to the relief costs reported by the government in 2024. If the savings are compounded and only present values of relief are considered, these AA save almost 100% of relief costs. It is important to state that given these results, the government of Zambia is better advised to embark on attracting investors to help finance these transformations in the agricultural sector because, besides being economically viable, there is an urgent need to build resilience. Irrigation infrastructure will be useful for many growing seasons, and the technical know-how imparted in the farming population in the use of those technologies or indeed the use of drought-tolerant crops/varieties can be of enormous importance beyond one growing season, which contributes to resilience building.

Given the findings, the Western Province of Zambia would benefit enormously from these interventions to mitigate the effects of perpetual droughts experienced there. The use of drought-tolerant crop varieties is also essential for drought-proofing agriculture. Yet the share of drought-tolerant crops in the crop mix in the Western Province is still low.

It is therefore extremely important to ensure efforts to mitigate the impacts of drought in the Western Province include the provision of drought-resistant crop varieties, water conservation and management measures, livestock restocking programs, and emergency food assistance. Equally important also are community-based initiatives, such as water harvesting, small-scale irrigation and agroforestry, to promote resilience and adaptive capacity among vulnerable communities.

Due to financial considerations, the widespread adoption and deployment of these technologies may take time. Nevertheless, it is crucial for the government and other stakeholders to continue the following:

1. Provide information on drought-tolerant seeds and, if feasible, supply those seeds to farmers.
2. Advise farmers and supply them with crop seeds that perform well under less rain, e.g., sweet potatoes and cassava, and develop a mixed cropping system that takes advantage of both high-yielding and drought-tolerant varieties.
3. Collaborate with research institutions, agricultural extension services and policymakers to introduce and promote drought-tolerant crop varieties tailored to the specific needs of vulnerable communities. Subsidies, seed banks and community-based seed distribution programs can also improve farmers' access to these critical resources (FAO 2023; Baudoin et al. 2017).
4. Subsidize irrigation equipment, especially those that can be accessed by small- and medium-scale farmers, including motorized fuel/solar systems, to make their production affordable in terms of being sustainable and scalable.

5. Invest in infrastructure (such as cisterns, reservoirs and storage tanks) to enhance groundwater usage and educate communities on rainwater harvesting techniques. While irrigation and enhanced water management are vital components in building resilience to droughts and ensuring sustainable agricultural production, implementing these solutions in some cases requires significant infrastructure investments (FAO 2023; Fakhruddin et al. 2021; Baudoin et al. 2017). Repairing and rehabilitating water infrastructure to ensure dams and water pumps, e.g., boreholes, are operational and extract water from the deep end of the wells is important.
6. Intensify irrigated farming to ensure they add to the pool of land that is under irrigation.
7. Address challenges in low adoption rates of irrigation systems among smallholder communities to increase the likelihood of communities adopting irrigation at larger scales. Challenges may stem from limited access to necessary equipment, complementary services, or technical knowledge (Grobicki et al. 2015).
8. Facilitate the development of community-based drought-risk contingency planning and preparedness initiatives, which consider AA that is shown to be economically worthwhile to ensure sustainability and stakeholder willingness to invest in such plans.

Limitations and Future Research

Future studies should broaden the range of anticipatory actions and implementation scenarios analyzed, as this study focuses on a limited subset of AA options.. Potential areas for expansion include early fodder and water delivery to livestock herds, mass maintenance and provision of water infrastructure and climate-linked crop insurance provided directly to districts or other local institutions within the farming system. Such future analyses should also account for indirect benefits and externalities, including improved household resilience, reduced reliance on emergency relief, enhanced ecosystem services and spillover effects on local markets and employment. Future research should also include a comprehensive account of non-market valuations for negative and positive externalities of all the AA in focus. To this extent, the economic analysis results need to be augmented with ecosystem services values, non-market valuation methods, including contingent valuation and complementary approaches such as choice experiments and benefit transfer..

It would also be useful for future research to focus on utilizing more localized and time-varying commodity and input prices to be used in estimating the costs and benefits of the actions under the study.

It is also important to note that irrigation is only a viable solution where a sustainable water supply exists. In regions where meteorological drought coincides with hydrological drought, irrigation may not be the most effective strategy. This underscores the need for location-specific solutions (FAO 2023; Fakhruddin et al. 2021), including combining complementary anticipatory action, as proposed in this study. Future research should therefore integrate hydrological and climate-related datasets into benefit–cost analyses to refine assumptions about water availability, hazard frequency and expected-yield responses. Such integration would enhance the spatial precision and policy relevance of anticipatory investment planning.

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Annexes

Annex 1

Table A1. Production shares per crop per province

	Central	Copperbelt	Eastern	Luapula	Lusaka	Muchinga	North Western	Northern	Southern	Western	Within Western Province
Bambara nuts	4,0	7,2	1,6	50,9	0,0	9,8	0,1	18,6	1,7	6,1	0,2
Barley	70,2	0,0	0,0	0,0	26,1	0,0	0,0	0,0	3,7	0,0	0,3
Cassava	0,0	0,0	0,0	0,0	0,0	0,0	0,0	100,0	0,0	0,0	0,0
Castor beans	100,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Coffee	100,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Cotton	18,1	0,9	66,1	0,0	0,2	10,3	0,0	0,0	4,4	0,0	2,4
Cow Peas	51,3	2,6	10,5	0,4	0,5	0,1	2,4	0,5	27,1	4,6	0,1
Finger Millet	0,0	0,0	0,0	43,9	27,0	29,1	0,0	0,0	0,0	0,0	0,0
Groundnuts	14,3	8,2	31,0	9,7	0,5	7,5	8,4	13,4	5,6	1,4	4,4
Irish potato	42,6	0,0	1,4	0,0	38,4	1,0	1,5	1,5	13,6	0,0	1,3
Maize	18,0	11,1	25,0	6,0	1,8	12,0	9,1	12,0	3,9	1,1	66,7
Millet	5,4	0,1	0,0	7,0	0,0	28,3	0,4	50,0	0,8	7,7	0,8
Mixed Beans	5,5	2,4	1,9	5,2	2,0	10,6	10,2	61,6	0,4	0,3	2,0
Paprika	80,7	0,1	7,7	0,0	0,0	0,0	0,0	7,8	0,0	3,7	0,0
Pineapple	0,0	0,0	0,0	0,3	0,0	0,0	99,3	0,4	0,0	0,0	0,5
Popcorn	56,8	24,7	3,3	4,1	4,1	1,6	3,3	1,8	0,3	0,0	0,2
Rice	0,0	0,0	9,4	8,7	0,0	30,0	7,1	38,0	0,0	6,9	1,0
Sorghum	21,1	2,7	2,1	1,6	0,2	37,5	19,5	4,7	4,2	6,3	0,2
Soybeans	41,3	19,4	25,2	0,3	8,4	0,7	0,5	1,6	2,4	0,2	9,4
Sugarcane	0,0	0,0	0,0	39,4	0,0	0,0	1,5	59,1	0,0	0,0	0,0
Sunflower	12,5	0,3	74,5	0,1	0,2	2,0	0,0	2,7	7,6	0,0	1,1
Sweet potato	33,5	13,8	3,8	8,8	0,4	12,9	8,1	12,0	6,0	0,8	3,6
Tobacco Burley	3,6	0,0	86,3	0,0	0,0	0,4	0,0	1,0	6,4	2,3	0,3
Tobacco Virginia	28,1	0,0	28,0	0,0	4,5	0,0	0,0	0,0	31,0	8,4	0,4
Wheat	59,7	23,1	0,0	0,0	8,6	0,0	0,0	0,0	8,5	0,0	5,1
Grand Total	22,6	11,4	23,5	5,1	3,1	10,0	7,6	11,3	4,3	1,1	100,0

Source: authors based on ZAM Stats data

Table A2. Assumptions and outcomes

	Total irrigated land (ha)	non-irrigated land (ha)	Consume demand maize Equivalent MT	Production_ Irrigation MT	Production non irrigated MT	Production _no action	Food Deficit with irrigation	Deficit no Irrigation MT	Avoided _ Deficit due to Irrigation (MT)	Total cost to_ produce avoided deficit-USD
Kalabo	3008,0	3829,4	30162,7	15104,7	2103,5	8055,6	-12954,5	-22107,1	-9152,6	3971357,2
Kaoma	3008,0	3395,8	39586,7	15104,7	7612,7	14841,0	-16869,3	-24745,7	-7876,4	4080955,0
Limulunga	3509,3	4785,8	16489,4	17622,2	1536,1	9128,7	2668,9	-7360,7	-10029,6	4727281,5
Luampa	2506,7	2741,7	16468,1	12587,3	2855,5	6358,6	-1025,3	-10109,5	-9084,2	3343349,7
Lukulu	1504,0	2040,8	25985,5	7552,4	1830,1	4182,2	-16603,0	-21803,2	-5200,2	2012958,3
Mitete	1504,0	1931,0	10697,8	7552,4	1696,6	4630,4	-1448,8	-6067,4	-4618,6	2061957,0
Mongu	2506,7	2995,6	53383,9	12587,3	1937,5	9070,3	-38859,2	-44313,6	-5454,4	3366972,1
Mulobezi	4010,7	5510,7	12232,0	20139,6	2953,7	5318,3	10861,4	-6913,6	-17775,0	5351115,9
Mwandi	2506,7	3320,6	10907,5	12587,3	1275,2	2449,0	2955,0	-8458,5	-11413,4	3399680,9
Nalolo	5013,3	6268,4	19874,3	25174,6	1320,5	2693,4	6620,7	-17180,9	-23801,7	6711122,2
Nkeyema	2005,3	2504,7	28625,8	10069,8	6414,9	13660,0	-12141,1	-14965,8	-2824,7	3011033,1
Senanga	3008,0	4077,7	30235,9	15104,7	3165,8	8526,9	-11965,3	-21709,0	-9743,7	4028477,1
Sesheke	5013,3	6589,4	19607,2	25174,6	3967,1	8758,2	9534,5	-10848,9	-20383,5	6729796,6
Shangombo	4010,7	5640,4	19922,1	20139,6	2898,7	6085,9	3116,3	-13836,2	-16952,5	5356381,4
Sikongo	3509,3	4221,2	16102,9	17622,2	231,6	169,4	1750,9	-15933,5	-17684,3	4746164,0
Sioma	4010,7	5100,0	17686,8	20139,6	1143,6	2256,2	3596,4	-15430,6	-19027,0	5370707,2
Total	50635	64953	367969	254263	42943	106184	-70763	-261784	-191022	68269309

Source: Authors based on Zambia Statistics data.

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