Examining Suitable Precision Irrigation Systems for Effective Farming in Manicaland Province in Zimbabwe

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ABSTRACT

This study examines the suitability of precision irrigation systems for effective farming in Manicaland Province, Zimbabwe. The Manicaland Province has been prone to a lot of climatic variability, especially droughts, water scarcity, and soil degradation. Therefore, it is important to implement efficient irrigation techniques in order to enhance agricultural productivity. From the literature, the researchers observed that policies, governance structures, and regulatory frameworks have a huge role in driving the adoption of precision irrigation system. However, there is a lack of comprehensive analysis on how these factors either promote or hinder precision irrigation practices in Zimbabwe. Therefore, it was necessary to study these institutional dynamics in helping policymakers create a conducive environment for farmers to adopt these technologies. There was a need for an impact assessment of existing precision irrigation initiatives in Zimbabwe. While various projects and pilot programs have been introduced, limited empirical studies have been conducted. Therefore, it is essential to undergo evaluation of their effectiveness, scalability, and long-term sustainability. Conducting such assessments will provide valuable insights into best practices and potential areas for improvement. The objectives included to assess the current status of irrigation systems, to evaluate the challenges and opportunities of the current irrigation methods used in Manicaland, to identify the most suitable precision irrigation systems for Manicaland and to develop a plan of implementation of the suitable precision irrigation systems in Manicaland. The researchers employed a mixed research methodology, incorporating both quantitative and qualitative approaches in the study. The researchers used a purposive sampling method for the identification and selection of participants for the study. The sample size for the study was 38 farmers and key informants. The data collection instruments used were questionnaires and interview

guides. The findings suggest that precision irrigation systems such as centre pivot, drip, and micro-jets hold significant potential for addressing water scarcity issues while improving agricultural efficiency in the province. Based on these insights, the study proposes recommendations for policy and practice, emphasizing the importance of capacity building, financial incentives, and further research to ensure the successful adoption of precision irrigation systems such as automated irrigation, air-based irrigation, drone irrigation and sub-surface drip irrigation systems in order to have food security in Manicaland.

Keywords: Effective Farming, Institutional Support, Manicaland Province, Precision Irrigation Systems, Water Scarcity**.**

INTRODUCTION

Precision irrigation is a water management approach in agriculture that involves applying water to crops in precise amounts and at specific times, based on real-time data about soil moisture, weather patterns, and crop needs. This technique uses advanced technologies such as sensors, Global Positioning System (GPS), automated valves, and remote monitoring systems to optimize water use efficiency, minimize waste, and enhance crop water productivity (Sadler *et al*., 2021; FAO, 2020). Unlike conventional irrigation, precision irrigation targets specific zones within a field or even individual plants, ensuring that water is applied only where and when it is needed, which contributes to sustainability and improved agricultural outcomes (Shani & Dudley, 2021).

Globally, precision irrigation has gained prominence. This is because there have been a number of concerns because of lack of water due to climatic change conditions. This is also leading to a negative effect on food security. According to FAO (2020), the agricultural sector is the largest consumer of freshwater. This is because it contributes to approximately 70% of global freshwater users. This has caused the emergence of advanced irrigation technologies for the improvement of crop water productivity. For instance, Israel is the first country to use precision irrigation techniques such as drip and sub-surface irrigation. It managed to achieve up to 90% water use efficiency. This was with a balance of maintaining high agricultural productivity (Shani & Dudley, 2021).

In Africa, one country which has managed to adopt these precision techniques is Morocco. It is using drip irrigation in its olive and citrus farming sectors. This has caused the reduction in water consumption by nearly 50%. This is achieved whilst the crop yields are seen to increase as well (Boularbah *et al*., 2022). South Africa has also made strides in precision irrigation. This is in particular to its vineyards and fruit-growing regions. The nation took advantage of technology in the mitigation of water stress (Bjornlund *et al*., 2020). However, Zimbabwe has been slow to adopt such innovations. This is evidenced by heavy reliance on inefficient and water-intensive irrigation systems such as surface, sprinkler, and bucket systems. Manicaland province is one of the country's key agricultural regions producing such crops as coffee, tea, bananas and avocados. This climatic variability and climate change has posed water challenges for irrigation in Manicaland. This has also been further catapulted by the use of inefficient irrigation techniques (Mhembwe *et al*., 2023). While the potential benefits of precision irrigation are evident, there is limited research on its implementation in Zimbabwe's specific agricultural and climatic contexts.

By identifying the most suitable precision irrigation models for Manicaland, the study will be a major contribution to how tailored solutions can be developed for addressing the specific needs and challenges of farmers. Therefore, this study is to bridge the knowledge gap and advocate for the adoption of innovative irrigation solutions in Zimbabwe's agricultural sector. This study aims to answer the following questions:

a)   What is the current status of irrigation in Manicaland Province Zimbabwe?

b)   What are the challenges and opportunities of the current irrigation methods used in Manicaland Province?

c)   What are the most suitable precision irrigation systems for Manicaland Province?

d)   What is the plan of implementation of the suitable precision irrigation systems in Manicaland Province Zimbabwe?

LITERATURE REVIEW

Precision irrigation has gained significant attention in modern agricultural practices. It has been popular because it exhibits a potential of improving crop water productivity.

Water Resource Challenges in Manicaland

Manicaland Province faces significant water resource challenges that affect agricultural productivity. The province experiences seasonal rainfall variability, characterized by erratic rainfall patterns and frequent droughts due to climate change (Makarau, 2021). These fluctuations in water availability limit the reliability of rain-fed agriculture, which remains the dominant farming system in the province. Furthermore, the growing demand for water across domestic, industrial, and agricultural sectors intensifies pressure on existing water sources such as the Odzi and Save Rivers (Mukuhlani & Nyamupingidza, 2024). Given this context, the adoption of efficient irrigation systems is not only necessary but urgent. Precision irrigation offers a viable solution by optimizing crop water productivity through technologies that monitor soil moisture and automation thereby conserving scarce water resources (Chikozho *et al*., 2020).

Economic Viability and Adoption of Precision Irrigation

Precision irrigation technologies such as drip systems, soil moisture sensors, and automated scheduling require substantial upfront capital, they have been shown to increase yields and reduce input costs in the long run (Madramootoo & Fyles, 2020). Smallholder farmers, often face financial and technical knowhow to adopting these technologies. However, research suggests that group-based financing, subsidies, and government support can improve adoption rates among resource-constrained farmers (Nyikadzino & Chikozho, 2022). Pilot projects such as the Goanna Ag GoField technology makes use of field sensors, satellite imagery, weather forecast and crop data to enable precise irrigation (Wayazata, 2024). Goanna's Ag proven technologies are helping cotton farmers in Missouri, Missisipi and Tennessee to improve crop water productivity.

Integration of Smart Irrigation Systems with Traditional Farming

The successful integration of smart irrigation systems with traditional farming practices in Manicaland depends on the compatibility of technology with indigenous knowledge systems. Traditional farming in the province relies heavily on seasonal calendars, soil fertility indicators, and communal water management. Smart irrigation technologies can complement these methods by providing real-time data that supports informed decision making, such as optimal irrigation timing and crop-specific water needs (Gadzirayi *et al*., 2021). For instance, low-cost, solar-powered drip irrigation systems have been successfully introduced in small-scale farms, enhancing crop water productivity without disrupting existing practices (Manzungu & van der Zaag, 2020). Integration is most effective when accompanied by farmer training, participatory research, and extension services that bridge the gap between modern science and local agricultural knowledge.

Policy and Institutional Support for Precision Irrigation in Zimbabwe

Policy and institutional frameworks play a critical role in promoting precision irrigation in Zimbabwe. The government, through the Ministry of Lands, Agriculture, Fisheries, Water and Rural Development, has emphasized irrigation development as part of its climate-smart agriculture strategy (GoZ, 2021). However, implementation has been inconsistent due to limited financial resources, weak coordination among stakeholders, and inadequate technical support. Despite this, there are encouraging signs, such as the National Irrigation Policy (2018), which outlines goals for expanding irrigated land and promoting water-saving technologies (Chikozho, 2020). Moreover, partnerships with international donors and NGOs have led to localized programs supporting precision agriculture. For sustained impact, more robust institutional mechanisms are needed to support farmer training, infrastructure investment, and access to affordable irrigation technologies (Sithole & Moyo, 2022).

Institutional Theory

From a technical point of view precision irrigation systems have the potential to increase crop water

productivity but its adoption is still lagging behind. Financial constraints and limited access to credit exacerbate the situation, as farmers often struggle to afford the high initial investment required for precision irrigation infrastructure (Peters, 2022). Institutional power dynamics, where influential stakeholders resist changes that might disrupt existing hierarchies, can also impede adoption. Thus, institutional legitimacy and stakeholder buy-in are crucial for the successful implementation of precision irrigation system in Zimbabwe.

Empirical Studies

Globally, numerous studies have demonstrated that precision irrigation is effective in improving water use efficiency and crop yields. A World Bank report titled *"Precision Irrigation: Making Every Drop Count"* highlights successful case studies from countries such as Israel and Spain. Similarly, India's National Mission on Micro Irrigation (NMMI) has promoted drip irrigation. This gave positive results which include improved water efficiency and agricultural output. This was specifically for states like Maharashtra and Karnataka (Sharma & Gupta, 2022). The Indian government adopted a proactive approach. They managed to provide financial subsidies, technical training, and policy support.

Continentally, several African nations have successfully implemented precision irrigation systems. In Kenya, the Non-Governmental Organization (NGO) One Acre Fund was put into place for the promotion of drip irrigation among farmers. They did this through the provision of training and access to credit. This lead to enhanced yields and reduction in water consumption. Ethiopia has also experienced increased adoption of microirrigation technologies. These technologies came along due to initiatives led by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). These programs have helped farmers enhance their productivity while conserving water resources (Keller, 2023).

In North Africa, countries like Egypt and Morocco have put in significant investments in precision irrigation technologies in order to address the issue of water scarcity. This is also to ensure food security. For instance, the Moroccan government's Green Morocco Plan (GMP) emphasizes the use of drip irrigation. They put it in place for the maximisation of agricultural output at the same time minimising water usage. The widespread adoption of smart irrigation techniques in Egypt has allowed farmers to achieve higher productivity despite the country's arid conditions.

Regionally, in Southern Africa there were also some initiatives such as the Growing Empowered Farmers (GEF) program which were put in place. This program played a huge role in promotion of precision irrigation. This program has introduced farmers to sustainable irrigation techniques. This introduction produced enhanced agricultural yields and economic benefits for farming communities. The success of such initiatives show that there is a huge potential in precision irrigation on increasing food security and economic sustainability in the region (Dennis & Nell, 2023).

Locally, agricultural productivity in Manicaland, is highly dependent on irrigation systems, particularly in the face of erratic rainfall patterns and climate change. Farmers utilize various irrigation methods based on factors such as crop type, water availability, cost, and land size.

Surface Irrigation Systems

Figure 2.1: Furrow irrigation System (Hye, 2014)

Surface irrigation methods, including border, furrow, and basin irrigation, remain prevalent among small-scale farmers. This is because they are usually cheaper to adopt. They also rely on natural gravity for the water flow. According to FAO (2021), surface irrigation is particularly effective in areas with heavy clay soils. This is because that type of soil gives room for the even spread of water. Maize, which is the staple food crop grown across the province, benefits significantly from this system due to its tolerance to standing water. Sugarcane, cultivated in parts of Middle Sabi and Chipinge, as well as rice, also thrive under these conditions. Surface irrigation systems can be improved by making use of hydro-flumes this provides improved conveyance efficiency and reduced water loss (Singh, 2020). Other approaches to improve crop water productivity in surface irrigation systems include the use of deficit irrigation and laser levelling of fields (Miao *et al*, 2021). Laser land levelling has demonstrated significant benefits in enhancing water use efficiency, crop yields, farm and profitability across various agricultural settings.

Sprinkler Irrigation Systems

Figure 2.2: Conventional Sprinkler (Rai et al., 2023)

Figure 2.3: Rain gun (Akinfolarin, 2022)

Figure 2.4: Reel irrigation (Banfi, 2024)

Sprinkler irrigation, encompassing centre pivot, rain gun, reel irrigation, and conventional sprinkler systems, is widely employed in commercial farming within Manicaland. This system ensures uniform water distribution. Therefore, this makes the region suitable for the large-scale cultivation of crops such as wheat, maize, and tobacco. Tobacco is one of the most important cash crops, particularly in areas like Mutasa and Rusape. Research by Chikowo *et al.* (2023) highlights the adaptability of sprinkler irrigation to various soil types, particularly sandy and loamy soils, which dominate parts of Manicaland province. However, these require high capital investments.

Drip Irrigation Systems

Figure 2.5: Drip irrigation systems (Pipelife, 2025)

Drip irrigation includes conventional and sub-surface drip systems. This system of irrigation has become popular in its use in horticultural farming. This is because of its water efficiency and ability to deliver water directly to plant roots. This system is particularly beneficial for high-value crops such as tomatoes and peppers. These crops are primarily grown for local markets. Macadamia nuts, a growing export crop mostly cultivated in Chipinge and surrounding areas, also benefit significantly from this system. These crops need precise water application to optimize yields. According to World Bank (2024), drip irrigation significantly reduces water

wastage and mitigates the risk of waterlogging, making it ideal for the province's sandy soils. However, the high cost of installation and maintenance presents a barrier for many smallholder farmers.

Micro-Irrigation Systems

Figure 2.6: Micro jets (Microjet, 2025)

Figure 2.7: Rain pipe (India Mart Catalogue, 2025)

Micro-irrigation, which includes micro jets and rain pipes, is commonly used in orchard farming. This method is applied to crops such as avocados. Avocados are grown commercially in Chipinge and Nyanga. Bananas are

also cultivated using this system. This is specifically for Honde Valley and Chimanimani. This is because these areas are major suppliers to Zimbabwean markets. Citrus fruits in the region similarly benefit from microirrigation practices. This system provides a controlled water supply. This reduces the loss of water due to evaporation. Singh et al. (2024) indicate that micro-irrigation enhances water conservation. This makes it applicable in semi-arid regions of Manicaland where water scarcity is a growing concern.

Other Systems (Solar-Powered, Manual, Bucket Irrigation)

In addition to conventional irrigation systems, farmers have increasingly adopted alternative methods like solar powered, manual, and bucket irrigation. These systems are especially used where there is insufficient electricity, finances, or poor infrastructure.

Solar-powered irrigation systems

Figure 2.8: solar powered irrigation system (Owino, 2024)

Solar-powered irrigation systems have gained considerable attention in recent years. This is because of its sustainability attribute. It is also a cost-effective alternative to fuel- or electricity-powered pumps. These systems use solar panels for the conversion of sunlight into energy. The solar energy will then be powering water pumps for irrigation. One of the major advantages is the drastic reduction of reliance on non-renewable energy sources. These energy sources include diesel or grid electricity. The energy sources exhibit disadvantages of being expensive and unreliable in rural settings (IRENA, 2021). Moreover, solar irrigation systems support climate smart agriculture through the reduction of carbon emissions. These systems provide a consistent water supply even in remote areas. This has made them a practical solution for smallholder farmers who face limited rainfall trends and exorbitant energy costs (FAO, 2023).

Manual irrigation methods

Figure 2.9: Manual Irrigation System (FAO,2023)

Manual irrigation methods are popular among small-scale farmers. These methods are used specifically for the farmers who cultivate less than one hectare of land. Bucket irrigation involves drawing water from nearby sources and manually watering crops using buckets or watering cans. These sources include rivers, wells, or boreholes. This method is labor-intensive. However, this is a low-cost option for farmers who do not have the capital or infrastructure for the investment in automated systems (Mutambara *et al*., 2022). It offers farmers some control over the timing and amount of water applied. However, the method cannot be applied for largescale farming. The method is also non-applicable during prolonged dry spells or droughts.

Manual irrigation systems

Figure 2.10: Treadle Pump (Mercy Cops, 2024)

Manual irrigation systems also include treadle pumps and gravity-fed systems. These methods are relatively affordable and do not require electricity. This increases their viability for farmers in off-grid areas. However, they can be physically demanding and limit the amount of land that can be irrigated. Therefore, they lack in terms of their productivity (USAID, 2022).

Research Gap

Despite the growing body of literature on precision irrigation, significant gaps remain, particularly in the Zimbabwean context (Senyolo, 2023). There have been global and regional studies which show that there are very huge benefits of precision irrigation (Senyolo, 2023). However, there has been limited research on the specific challenges and opportunities in Manicaland (Senyolo, 2023). Therefore, the authors understand that it is important to explore those gaps in the development of strategies in enhancing the adoption and effectiveness of precision irrigation in the province.

One critical area that requires further exploration is the role of institutional barriers and enablers (Mugandani *et al*., 2023). From the literature, the researchers observed that policies, governance structures, and regulatory frameworks have a huge role in driving the adoption of precision irrigation (Mugandani *et al*., 2023). However, there is a lack of comprehensive analysis on how these factors either promote or hinder precision irrigation practices in Zimbabwe. Therefore, these institutional dynamics warrant further study to inform policymakers in creating a conducive environment for farmers to adopt these technologies, while technological awareness and capacity building remain significant challenges. This is because most farmers are ignorant of these precision irrigation systems and how they are operated and maintained.

Therefore, research is required in the assessment of the existing knowledge gaps and development of targeted training programs. These programs will then improve the farmers' technical competencies and overall awareness of precision irrigation benefits. Furthermore, there is a need for an impact assessment of existing precision irrigation initiatives in Zimbabwe. While various projects and pilot programs have been introduced, limited empirical studies have been conducted. Therefore, their effectiveness, scalability, and long-term sustainability require evaluation. Conducting such assessments will provide valuable insights into best practices and potential areas for improvement.

METHODOLOGY

The research design that was used in this study is a mixed methods design. Mixed methods research combined both quantitative and qualitative methods to examine a research question. In this case, the researchers used questionnaires for the collection of data on the performance of the precision irrigation system. The researchers also used qualitative questions for the gathering of data on the perceptions and experiences of farmers and other stakeholders. This type of research design allowed the researchers to gain a comprehensive understanding of the impact of the precision irrigation system (Creswell, 2020). The data gathered from this study was analyzed using a variety of statistical methods. The researchers employed the use of descriptive and inferential statistics; Social Package of Social Sciences (SPSS) software for the quantitative data collected. The qualitative data was analyzed using thematic analysis. This involved identification and organisation of themes within the data (Nvivo Software).

The study population for this research were farmers in Manicaland who are using or considering using precision irrigation systems. The researchers used a purposive sampling method for the identification and selection of participants for the study. This included farmers who have experienced with precision irrigation systems, as well as those who are considering using them (Creswell, 2020). The sample size for the study was 38 farmers and key informants. A good rule of thumb is to aim for at least 30 participants in order to ensure that the results are representative and reliable (Creswell, 2020).

Informed consent is an important part of this research study. This is because the participants are human. Informed consent means that the participants have been given all the information they need to make an informed decision about whether or not to participate in the study. Therefore, the researchers obtained the informed consent in writing. The forms included details about the study, the risks and benefits of participating, and the rights of the participants (Creswell, 2020). Confidentiality and privacy was also maintained by using a number of strategies. Firstly, all data was stored securely, and only authorized researchers have access to it. Secondly, all participants were assigned a unique identification number, and their personal information was not included in any reports or publications (Creswell, 2020).

RESULTS AND DISCUSSION

Demographic analysis

Table 4.1: Demographic analysis results

Variable	Categories	Frequency (n=38)	Percentage (%)
Age (Years)	Below 30	2	5.26%
	31 – 40	7	18.4%
	41 – 50	11	28.9%
	Above 50	17	44.7%
	Nil	1	2.63%
Gender	Male	35	92.1%

Variable	Categories	Frequency (n=38)	Percentage (%)
	Female	3	7.89%
Marital status	Single	1	2.63%
	Married	33	86.8%
	Divorce	1	2.63%
	Nil	3	7.89%
Educational Qualifications	Primary	1	2.63%
	Secondary	11	28.9%
	Certificate	2	5.26%
	Diploma	7	18.4%
	Bachelors	11	28.9%
	Masters	6	15.8%
Agriculture Training/Knowledge	Yes	35	92.1%
	No	3	7.89%
Irrigation Training/Knowledge	Yes	33	86.8%
	No	5	13.1%
Designation	Agricultural Engineering Lecturer	1	2.63%
	Farm owner	6	15.7%
	Farmer	2	5.26%
	Farm manager	10	26.3%
	Irrigation engineer	2	5.26%
	Technician	3	7.89%
	Irrigation Management Committee chairman	6	15.7%
	Overseer	1	2.63%
	Senior lecturer	1	2.63%
	Lecturer and Geographic Information Systems (GIS) Expert	1	2.63%
	Lecturer and Horticulture technician	1	2.63%
	Supervisor	1	2.63%
	Irrigation Manager	1	2.63%

	Student	1	2.63%
	Nil	1	2.63%
Variable	**Categories**	**Frequency (n=38)**	**Percentage (%)**
Common Crops Grown	Maize	32	84.2%
	Sugar beans	18	47.4%
	Wheat	16	41.1%
	Soya beans	7	18.4%
	Fruits	12	31.6%
	Potatoes	5	13.1%
	Vegetables	29	76.3%
	Other	24	63.1%

The age distribution of participants shows that the majority (92.05%) are between 30 and 50 years old. This finding shows that most respondents are in their prime working years. This age range is where people are most active in farming and agronomic research (Moyo & Nyikahadzoi, 2023). The study showed that the people below 30 contributed to 7.89%. This shows that youth are not involved in agriculture (Chirau et al., 2022). The study revealed a gender imbalance, with 92.1% of participants being male and only 7.9% female. This finding was seen to be in alignment with other studies which found out that agriculture in Zimbabwe is male-dominated. This is mainly in technical areas such as irrigation and mechanization (Dube et al., 2023).

63.1% of respondents held tertiary education qualifications. This high level of education suggests that most of the study participants are educated for the ease of understanding and adoption of precision irrigation technologies (Mwangi et al., 2023). A majority of the participants (92.1%) had agricultural training. Additionally, the study found out that 86.8% were also trained on irrigation. This finding is in agreement with the finding that technical training is usually required in order to adopt precision farming technologies (Senyolo et al., 2023).

The majority of the participants were farmers contributing 42%. The relatively high percentage of small-scale farmers aligns with national statistics showing that Zimbabwe's agricultural sector is predominantly made up of smallholder farmers, who contribute significantly to food security (Mutambara et al., 2022). The most commonly grown crops in Manicaland were maize (84.2%) and Sugar beans (47.4%). These findings align with reports from Zimbabwe's Ministry of Agriculture, which lists maize, tobacco, and horticultural crops as the dominant agricultural crops grown in the region (GoZ, 2023).

Type of irrigation systems being used in Manicaland province

Figure 4.1 presents the responses regarding types of irrigation systems being used in Manicaland and associated challenges.
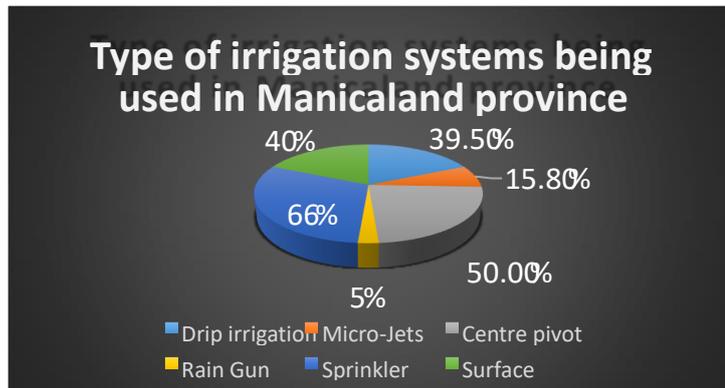

Figure 4.1: Types of Irrigation Systems Used and Associated Challenges

The most widely used irrigation system among respondents was sprinkler (66%). The study showed that afterwards, the respondents preferred use of center pivot (50%), drip (39.5%), micro-jets (15.8%). This finding were seen to align with findings by Zimudzi *et al* (2023), who identified that center pivot is usually the preferred way of irrigation because it is more efficient.

The researchers performed a Chi-square test to evaluate the relationship between the availability of irrigation resources and the choice of irrigation system.

Hypothesis:

•   **H₀:** There is no significant relationship between the availability of irrigation resources and the choice of irrigation system.

•   **H₁:** There is a significant relationship between the availability of irrigation resources and the choice of irrigation system.

Chi-Square Test Calculation:

Table 4.2: Chi-Square Test Results

Irrigation System	Observed Frequency (O)	Expected Frequency (E)	(O − E)² / E
Sprinkler	30	18.5	7.14
Drip Irrigation	10	18.5	3.91
Surface	9	18.5	4.87
Center Pivot	25	18.5	2.29
Total	**74**	**74**	**18.21**

Since the calculated Chi-square value (18.21) is greater than the critical value (7.815), we reject the null hypothesis. It is concluded that there is a significant relationship between the availability of irrigation

resources and the choice of irrigation system. In addition, the researchers performed a regression analysis for the assessment of the impact of knowledge and training on the probability of adopting precision irrigation systems.

The model revealed a significant correlation between technical training and the irrigation system adopted, with results as follows: (R^2 = 0.72, $p < 0.05$). This aligns with prior research which suggests that targeted training enhances technology uptake (Mazvimavi & Chikozho, 2022). Emerging themes from the study included sprinkler, center pivot, drip, and micro-jets irrigation systems. One of the respondents noted that, "*Center pivot irrigation is the most preferred system due to its efficiency in covering larger areas and its ability to distribute water evenly, which is critical for crops like maize and tobacco.*"

Challenges and Opportunities of Current Irrigation Methods

Participants cited key challenges such as high electricity costs and power outages (50%), expensive equipment and inputs (23%), substandard materials and infrastructure (47%), climate change (16%) and a lack of knowledge in selecting the right materials (8%)
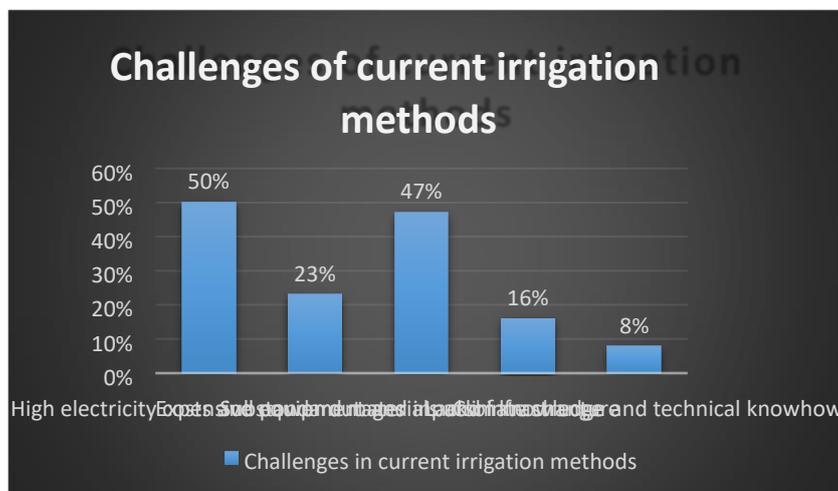

Figure 4.2: Challenges in Current Irrigation Methods

Electricity costs and power outages emerged as the dominant challenge in this study. This study's findings are in conjunction with Chisango *et al*. (2023). They found out that energy prices in Zimbabwe are causing major constraints on agricultural productivity. The study also revealed that expensive equipment and inputs (seeds, fertilizer, chemicals, etc) also affected agricultural productivity significantly. This is also in alignment with (Sithole & Moyo, 2022), who suggested that high capital investment limits smallholder farmers' ability to adopt modern irrigation methods. Substandard materials and poor infrastructure also present significant obstacles to the effective use of irrigation systems. Various irrigation projects in Zimbabwe usually fail due to insufficient maintenance and use of poor materials.

Therefore, this always leads to frequent system breakdowns and inefficiencies. The lack of proper infrastructure is exacerbated by inadequate support systems for farmers. This includes limited access to technical assistance, repair services, and spare parts for irrigation equipment. The researchers also found out from the study that climate change poses significant challenges to irrigation methods. This is because climate change alters rainfall patterns. It causes evaporation rates, and intensifies water scarcity. In Zimbabwe, smallholder irrigation schemes are increasingly affected by reduced water availability due to declining precipitation and rising temperatures. This results in heightened vulnerability among farmers Mwadzingeni et al. (2022). To adapt, many are turning to climate-smart techniques such as drip irrigation and solar-powered water systems. These systems are there, for the enhancement of water use efficiency and sustain agricultural productivity (Moyo *et al*., 2023). The researchers also noted that the lack of knowledge and technical know-how on modern irrigation methods is a major hindrance especially to these farmers in rural areas. As highlighted by Mazvimavi & Chikozho (2022), targeted training plays a critical role in improving technology uptake and irrigation efficiency.

Table 4.3 F-statistic results

Source of Variation	Sum of Squares	Degrees of Freedom (df)	Mean Square	F-Statistic	p-value
Between Groups (Farm Size)	15.00	3	5.00	17	<0.01
Within Groups	10.00	34	0.294		
Total	**25.00**	**37**			

The F-statistic value of 17 and the p-value of less than 0.01 indicate that there is a statistically significant difference between farm sizes in terms of the affordability of irrigation equipment. The smallholder farmers with larger farms are more likely to afford advanced irrigation systems due to greater resources and capital. This finding is consistent with previous studies, including that of Moyo (2022), which indicated that the financial capacity to invest in advanced technologies is typically higher for larger farms.

The themes that were observed in the qualitative analysis were high electricity costs and power outages, expensive equipment and inputs, substandard materials and infrastructure, climate change, and lack of knowledge and technology know how. One participant highlighted that, "*Equipment may be expensive at first but operational costs due to electricity costs are too high.*" The dominance of this issue aligns with studies by Chisango *et al.* (2023), which highlighted that energy costs in Zimbabwe are a critical constraint in agricultural productivity.

Pacrticipant 20 said, "*For me, I cannot afford these irrigation systems even though I see that they are needed.*" This aligns with Chisango *et al* (2023), who suggested that, larger farms are better able to manage the costs of modern equipment, but smaller farms are left at a disadvantage due to limited access to capital.

Identification of the most Suitable Precision Irrigation Systems

The results indicate that centre pivot irrigation is the most preferred system because 32.4% of the participants supported it.
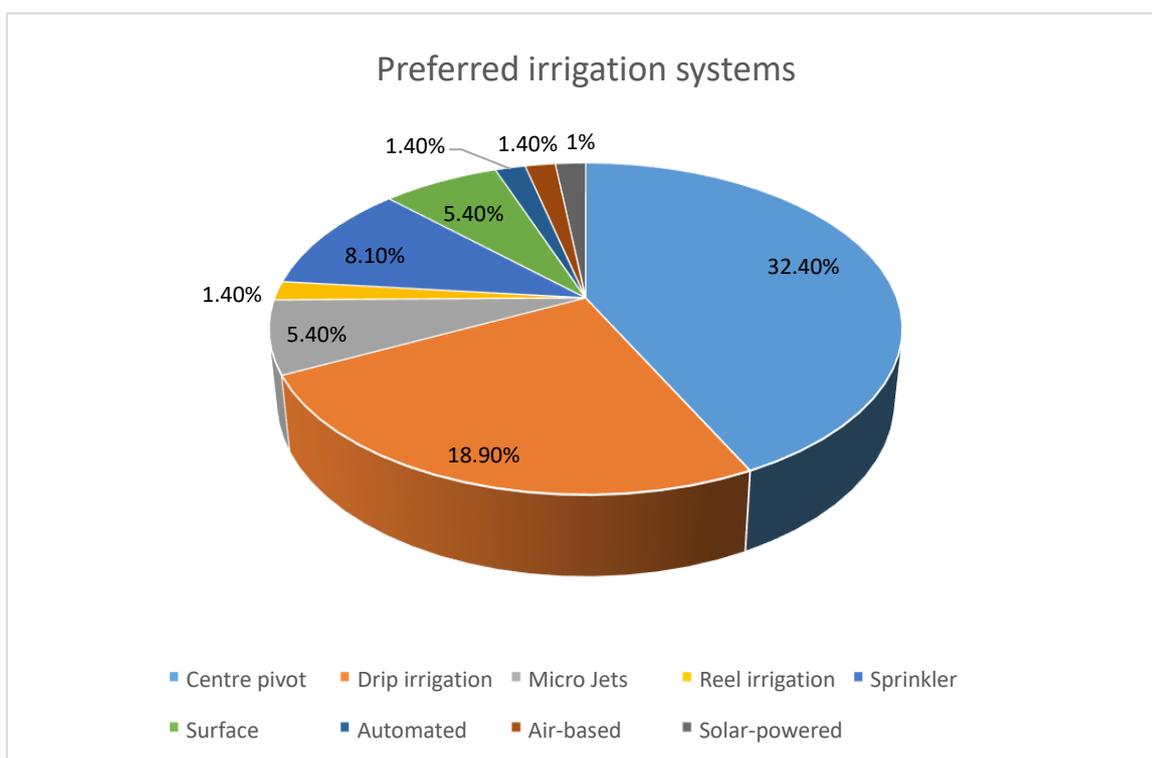

Figure 4.3: Most preferred irrigation systems

Table 4.4 Regression analysis results

Table 4.4 presents the regression analysis results that assess the impact of perceived benefits on the choice of irrigation system:

Predictor Variable	Coefficient (β)	Standard Error	t-Statistic	p-value
Perceived Benefits of Water Conservation	0.55	0.12	4.58	<0.01
Perceived Benefits of Energy Efficiency	0.45	0.10	4.50	<0.01
Constant	0.20	0.08	2.50	<0.05
R-Squared	0.61			

Table 4.5: Regression Results

Predictor Variable	Coefficient (β)	Standard Error	t-Statistic	p-value
Perceived Benefits of Water Conservation	0.55	0.12	4.58	<0.01
Perceived Benefits of Energy Efficiency	0.45	0.10	4.50	<0.01
Constant	0.20	0.08	2.50	<0.05
R-squared	**0.61**			

Summary of Computations

Variable	B	SE	t = β/SE	p-value
Water Conservation	0.55	0.12	4.58	<0.01
Energy Efficiency	0.45	0.10	4.50	<0.01
Constant (Intercept)	0.20	0.08	2.50	<0.05
R²				0.61

The results of this analysis show a strong relationship between the perceived benefits of water conservation and energy efficiency with the adoption of irrigation systems. The results also show that Centre Pivot is the most preferred when it comes to large-scale farming operations. There is a strong correlation between water conservation and energy efficiency. This relationship emphasizes the reason for preferring Centre Pivot irrigation system. Centre Pivot irrigation system is more commonly selected by large-scale farmers. This is because it has a higher capacity of covering extensive areas efficiently. There is also the reduction of labour costs and energy costs as compared to surface or sprinkler systems. Participant 18 highlighted this preference: *"The Centre Pivot system is ideal for large-scale farming because it can efficiently water a larger area."* This is in alignment with Food and Agriculture Organization (FAO, 2021), Center Pivot systems have a higher recognition because of higher efficiencies.

Plans of Implementation of the Suitable Precision Irrigation Systems

The major themes that were identified for successful implementation of a precision irrigation system include funding, suitable land and water availability, enough energy (electricity) and technical expertise. For instance, Participant 14 emphasized, "*Even if the technology is available, without adequate funding and technical knowhow, it's hard for smallholder farmers to make it work.*" Participant 21 noted that, "*Some areas don't have the right soil type or consistent water supply, which limits the viability of advanced irrigation systems.*" These insights align with the findings of Mutambara and Mupaso (2023), who concluded that infrastructure and knowledge gaps remain key barriers to the adoption of precision irrigation in southern Africa.

The need for funding aligns with previous studies (Zhou *et al*., 2022). This study found out that capital investment is a primary barrier on the implementation of precision irrigation. The researchers observed the mentioning of capacity building and training as crucial factors, reinforcing findings by Mutambara *et al*. (2023). They had suggested that knowledge gaps limit effective technology adoption.

Table 4.6 Multiple Regression analysis results

Predictor Variable	Coefficient (β)	Standard Error	t-Statistic	p-value
Funding	0.62	0.08	7.75	<0.01
Suitable Land & Water Availability	0.23	0.12	1.92	0.06
Technical Expertise	0.45	0.10	4.50	<0.05
Energy Availability	0.30	0.09	3.33	<0.01
Constant	0.15	0.07	2.14	<0.05
R-Squared	0.78			

Regression Results Table (Explained)

Predictor Variable	Coefficient (β)	Standard Error	t-Statistic	p-value
Funding	0.62	0.08	0.62 ÷ 0.08 = **7.75**	<0.01
Suitable Land & Water	0.23	0.12	0.23 ÷ 0.12 = **1.92**	0.06
Technical Expertise	0.45	0.10	0.45 ÷ 0.10 = **4.50**	<0.05
Energy Availability	0.30	0.09	0.30 ÷ 0.09 = **3.33**	<0.01
Constant (Intercept)	0.15	0.07	0.15 ÷ 0.07 = **2.14**	<0.05
R-squared	**0.78**			

The researchers found out that the coefficient for funding is 0.62. This indicates that for each unit increase in funding, there is a high probability of successfully having implementation of a precision irrigation system increases by 0.62. The p-value of <0.01 suggests that this predictoris highly statistically significant. This aligns with Zhou et al. (2022), who stressed out that capital investment is a major barrier in the adoption of precision irrigation systems. The coefficient for suitable land and water availability was found to be 0.23, and the p-value is 0.06. This is slightly above 0.05 which shows that even though land and water availability are important, they are not as strong a predictor of successful implementation compared to funding and technical expertise.

Energy availability is a highly significant predictor of successful implementation of an irrigation system. The coefficient of 0.30 suggests that adequate energy availability increases the likelihood of successful irrigation implementation. This finding is in agreement with Chisango et al (2023) who said that electricity is essential to operate irrigation systems efficiently. This is because high energy costs and frequent power outages are barriers. The coefficient for technical expertise was found to be 0.45. Since the p-value of <0.05 it shows that technical knowledge and skills are a statistically significant predictor of successful implementation of precision irrigation systems. This finding is in line with the research by Mutambara et al. (2023). This is because they highlighted lack of technical knowledge as a significant barrier to effective technology adoption.

The R-squared value of 0.74 indicates that 74% of the variance in successful implementation can be explained by the three predictor variables: funding, land & water availability, electricity availability, and technical expertise. This suggests a strong explanatory power of the model, although other factors might also influence successful adoption that were not included in this analysis. The qualitative analysis identified three major themes that influence the successful implementation of a precision irrigation system: financial constraints, resource availability, and knowledge gaps. These themes align with the quantitative findings, reinforcing the importance of funding, land and water availability, and technical expertise in adopting precision irrigation technology.

RECOMMENDATIONS

The researchers recommended the following strategies to ensure that precision irrigation methods are implemented by farmers in Manicaland efficiently and cost-effectively. From the study:

· **Promote the Adoption of Centre Pivot Irrigation Systems:**

Service providers should ensure that these systems are reasonably priced. They should also offer some payment options to ensure accessibility.

· **Train Farmers on System Maintenance**: Provide training on the proper installation, maintenance, and troubleshooting of irrigation systems to ensure their longevity and efficiency.

· **Water Harvesting Solutions**: Promote the development of rainwater harvesting systems for irrigation during dry spells, reducing dependence on expensive water sources.

· **Use of Smart Irrigation Technology**: Integrate precision agriculture technologies like soil moisture sensors and automated irrigation systems to optimize water usage.

· **Subsidies and Financial Support**: Recommend government subsidies and support for smallholder farmers to afford the initial investment in modern irrigation systems.

· **Promote Research and Development**: Encourage further research into the effectiveness of various irrigation systems tailored to different types of soil and crops in the province.

· **Enhance Farmer Education**: Develop programs to educate farmers on the benefits of precision irrigation and its role in improving crop yields and reducing water wastage.

· **Encourage Partnerships with Agribusinesses**: Foster collaborations between farmers, NGOs, and agribusinesses to scale up the adoption of advanced irrigation systems.

· **Promote Climate-Resilient Crops**: Suggest the adoption of drought-resistant crop varieties that complement the precision irrigation systems for enhanced food security.

· **Implement solar powered irrigation systems to reduce high energy costs**: to encourage farms to implement solar-powered irrigation systems.

CONCLUSION

Figure 6.1: Centre pivot (Zimudzi *et al*., 2023)

The study findings show that centre pivot irrigation is the most preferred system. The next preferred ones were drip and micro-jets irrigation systems. These three were preferred because they are efficient and suitable for the region's crops. The study also recommends that it is important to introduce advanced irrigation technologies. These include automated systems, remote sensing systems , and sub-surface drip irrigation to improve water management. Key factors for successful implementation include funding, suitable land and water availability, technical expertise, and reliable energy sources.

Further study area

The researchers recommend further study on the implementation of innovative precision irrigation systems.

These include automated irrigation, air-based irrigation, drone irrigation, and sub-surface drip irrigation systems. The study will be able to investigate their enhancement on agricultural productivity and ensuring food security in the province. By integrating these precision irrigation systems, farmers can optimize water conservation, reduce operational costs, and improve overall crop yields, contributing to long-term food security in Manicaland province, Zimbabwe.

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