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Research Article

Innovative and Cost Effective Water Harvesting and Value Addition in Agriculture for Sustainability: Case Study of Kitui and Wajir Counties, Kenya

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Abstract

The agricultural sector, especially in semi-arid regions like Kitui and Wajir Counties in Kenya, faces challenges of water scarcity and inconsistent agricultural yields due to erratic rainfall patterns. This study was underpinned by Sustainable Livelihoods Framework (SLF). The study assessed how water harvesting techniques contribute to improved water efficiency and agricultural productivity, while also examining the role of value addition in ensuring sustainability. Using a descriptive research design, the sample size for the study comprised of 25 farmers and 34 agricultural extension officers and county government officials. Data was collected using both structured questionnaire and Key Informant Interviews (KII). Quantitative data collected from farmers was analyzed with the aid of SPSS using both descriptive statistics and inferential analysis to assess effect of level of adoption of innovative water harvesting techniques on improvement in water efficiency and agricultural sustainability. The qualitative data collected was analyzed thematically through content analysis. The study's findings, were presented on tables and narrative form, giving analysis of the current state of water harvesting and value addition practices and their role in agricultural sustainability. The findings revealed that cost-efficient value addition practices had significant effect on agricultural sustainability in Kitui and Wajir Counties, Kenya, with an R-squared value of 0.584, indicating that these practices explain 58.4% of the variation in agricultural sustainability outcomes. Regression coefficients demonstrated a significant positive effect of value addition practices on sustainability, with a coefficient (B = 0.669, p-value = 0.000). The study concludes that cost-efficient value addition practices play a crucial role in improving agricultural sustainability by enhancing resource efficiency, market access, and profitability for farmers in these counties. In view of the findings, the study recommends that government and agricultural stakeholders should implement financial support programs, such as subsidies and grants, to alleviate the initial costs of adopting value addition practices.

Keywords

Water Harvesting, Value Addition, Agricultural Sustainability, Sustainable Livelihoods Framework (SLF), Kitui County, Wajir County

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1. Background to the Study

Water scarcity is a growing global concern, particularly in regions reliant on agriculture for economic development and food security [20]. Climate change, erratic rainfall patterns, and over-reliance on traditional rain-fed agricultural practices have worsened the situation. As the global population increases, the demand for water in agriculture is intensifying, making it imperative to explore sustainable water harvesting methods [21]. Therefore, innovative and cost-effective water harvesting systems have emerged as viable solutions for ensuring agricultural sustainability and addressing water deficits in agriculture-dependent regions. In many parts of the world, water harvesting systems have traditionally been simple and often inadequate in meeting the increasing demands of agriculture [15]. Farmers often have to deal with water shortages, leading to reduced crop yields and food insecurity.

With the growing need for more reliable and efficient methods, the development of innovative water harvesting techniques, such as rainwater harvesting, micro-catchment systems, and the integration of modern technologies, has gained traction [12]. These systems not only improve water availability but also enhance agricultural productivity by making irrigation more accessible and reliable. Researchers have developed hydrogel-based materials that can extract water from air, even in low-humidity conditions [24]. These materials show promise for small-scale, decentralized water production in water-stressed areas. Additionally, the integration of Internet of Things (IoT) and artificial intelligence in water harvesting systems has improved their performance and reduced operational costs [35]. Smart rainwater harvesting systems can now optimize water collection, storage, and distribution based on real-time weather data and water demand forecasts [29]. These technological innovations, combined with nature-based solutions and community-led initiatives, are paving the way for more resilient and sustainable water management practices globally.

Over 2 billion people live in countries experiencing high water stress, and this number is expected to grow significantly by 2050 [48]. In response to this crisis, many countries are adopting large-scale water harvesting initiatives. For instance, India's Jal Shakti Abhiyan campaign aims to make water conservation a mass movement, focusing on rainwater harvesting, watershed development, and the renovation of traditional water bodies [47]. The program has resulted in the creation of over 3.5 million water conservation structures across the country [33]. Similarly, Australia has implemented extensive managed aquifer recharge (MAR) projects, which involve artificially recharging groundwater aquifers with treated storm water and recycled water. The country now has over 200 MAR schemes, contributing significantly to water security in urban and rural areas [11].

Sub-Saharan Africa faces acute water challenges, with the World Bank estimating that 400 million people in the region lack access to basic drinking water [53]. In this context, innovative and cost-effective water harvesting solutions are crucial. One successful example is the sand dam technology widely adopted in Kenya, Ethiopia, and other countries in the region. These simple structures, built across seasonal riverbeds, are able to store up to 20 million liters of water in the sand, providing a reliable water source for local communities [16]. The African Development Bank has also been promoting rainwater harvesting through its Water for Africa Initiative, which aims to provide access to safe water and sanitation to 80 million people by 2025. In Tanzania alone, the initiative has supported the construction of over 10,000 rainwater harvesting systems, benefiting more than 50,000 people in rural areas [3]. These efforts, combined with community-based approaches and capacity building, are gradually improving water security across the continent, though significant challenges remain.

Innovative and cost-effective water harvesting techniques have been found to play important role in enhancing agricultural sustainability and value addition [12]. By ensuring a more reliable water supply, these methods enable farmers to increase crop production, diversify their yields, and extend growing seasons, thereby improving food security and economic outcomes. The implementation of rainwater harvesting systems in arid and semi-arid regions has allowed farmers to cultivate high-value crops that were previously unfeasible due to water scarcity. In India, the adoption of farm ponds and check dams has led to a significant increase in agricultural productivity, with some areas reporting yield increases of up to 30% for major crops [6]. Moreover, the availability of harvested water has facilitated the development of value-added activities such as aquaculture and agro-processing, providing additional income streams for rural communities. The integration of water harvesting techniques with precision agriculture and climate-smart farming practices further enhances agricultural sustainability. For example, combining rainwater harvesting with efficient irrigation systems like drip irrigation can reduce water consumption by up to 70% compared to traditional flood irrigation methods [53]. This not only conserves water but also minimizes soil erosion and nutrient leaching, contributing to long-term soil health.

In Sub-Saharan Africa, where smallholder farmers are mainly vulnerable to climate change, the adoption of water harvesting techniques has been shown to increase resilience and adaptive capacity. A study in Ethiopia found that farmers using water harvesting technologies were able to increase their income by 50% and reduce crop failures by 30% compared to those relying solely on rainfed agriculture [19]. Furthermore, water harvesting initiatives can catalyze broader sustainable development in agricultural communities. Furthermore, providing a more stable water supply for these projects often lead to increased investments in other agricultural inputs and technologies, such as improved seeds, fertilizers, and mechanization. This, in turn, has the potential to spark a virtuous cycle of productivity gains and income growth. In Tanzania, for instance, the implementation of community-based rainwater harvesting projects has been associated with a 42% increase in school enrollment rates and a 25% reduction in water-borne diseases [3]. These holistic benefits emphasizes the potential of innovative water harvesting to not only enhance agricultural productivity but also to contribute to broader sustainable development goals, including poverty reduction, gender equality, and improved health outcomes in rural areas.

Value addition in agriculture is also becoming a critical component in the drive for sustainability [2]. In addition to harvesting water, farmers can benefit from processes that enhance the quality, shelf-life, and marketability of their produce. Agricultural value addition involves processes such as grading, packaging, and processing, which transform raw agricultural products into finished goods with higher market value. Combining innovative water harvesting techniques with value addition can greatly enhance farmers' profitability and resilience to climate change impacts [42]. The integration of innovative water harvesting techniques and value addition offers multiple benefits, including reducing reliance on erratic rainfall, improving food security, and enhancing the economic stability of farming communities. In arid and semi-arid regions, where water scarcity is particularly acute, these methods provide a lifeline to farmers by ensuring a more consistent water supply and promoting sustainable agricultural practices [43]. Furthermore, value-added agricultural products can command higher prices in the market, allowing farmers to improve their incomes and livelihoods.

Technological developments have played a crucial role in promoting innovative and cost-effective water harvesting methods [50]. Technologies such as smart irrigation systems, water storage solutions, and soil moisture sensors have improved the efficiency of water usage in agriculture. These technologies enable farmers to optimize water resources and reduce wastage, thus contributing to the sustainability of water use in agriculture. The affordability and accessibility of these innovations are essential in ensuring that small-scale farmers, particularly in developing regions, can adopt these practices [11]. Many countries have successfully implemented innovative water harvesting systems, demonstrating their potential for broader application. For example, countries in the Middle East and North Africa have invested heavily in advanced irrigation technologies and water storage systems to combat water scarcity. These innovations, when adapted to local contexts, can serve as models for other regions struggling with similar challenges [19]. However, the cost of implementation remains a barrier for many smallholder farmers, necessitating the exploration of cost-effective solutions tailored to their needs. Incorporating community involvement and government support is crucial to the successful implementation of innovative water harvesting and value addition strategies. Policies promoting sustainable water management and incentivizing the adoption of value-adding technologies can encourage farmers to embrace these methods [4]. Moreover, local knowledge and practices should be integrated into modern water harvesting systems to ensure they are culturally appropriate and environmentally sustainable.

In Russia, recent efforts have focused on modernizing irrigation systems and implementing precision agriculture techniques to maximize water efficiency. For instance, the Stavropol region has seen success with drip irrigation and soil moisture sensors, reducing water usage by up to 30% while improving crop yields [36]. Meanwhile, Ukraine, despite ongoing conflicts, has been exploring innovative rainwater harvesting techniques, particularly in its western regions. The implementation of small-scale retention ponds and contour trenches has shown promising results in conserving water for agricultural use during dry periods [28]. Brazil, a global agricultural powerhouse, has been at the forefront of value addition in agriculture. The country's emphasis on vertical integration and agro-processing has significantly increased the value of its agricultural exports. The soybean industry in Brazil has invested heavily in processing facilities, producing high-value products like soybean oil and meal, which has increased export revenues by over 25% in the past five years [40].

In Rwanda, the government has implemented water harvesting strategy as part of its Vision 2050 plan. The country has invested in the construction of hillside terraces and small-scale irrigation systems, which have significantly increased agricultural productivity in drought-prone areas. For instance, the Gishwati-Mukura landscape restoration project has successfully integrated agroforestry with water harvesting techniques, resulting in a 40% increase in crop yields and improved soil conservation [24]. Additionally, Rwanda has been promoting value addition in its coffee sector, with a focus on specialty coffee processing and direct trade relationships, leading to a 35% increase in export earnings from coffee in the past three years [37]. In Tanzania the government has made strides in innovative water harvesting techniques, mostly in its semi-arid regions. The country has adopted a community-based approach to implementing sand dams and subsurface dams, which have proven effective in storing water for agricultural use during dry seasons. A good example is the Dodoma Region Water Harvesting Project, which has increased water availability for smallholder farmers by up to 60% [33]. In terms of value addition, Tanzania has focused on its cashew nut industry, investing in local processing facilities to produce cashew kernel oil and other high-value products.

Kenya has made significant strides in implementing innovative water harvesting techniques and promoting value addition in agriculture, driven by the need to enhance food security and adapt to climate change. However, the country still faces a number of challenges in fully realizing its agricultural potential. One of Kenya's most ambitious projects is the Galana-Kulalu Food Security Project, launched in 2014 to transform 1.75 million acres of semi-arid land into productive agricultural use. The project aimed to make use of water from the Galana and Tana rivers for irrigation, potentially producing up to 40 million bags of maize annually [34]. Despite initial setbacks, recent reports indicate that the project has brought 10,000 acres under irrigation, producing an average of 39 bags of maize per acre, significantly higher than the national average of 15 bags per acre [31]. However, the project has faced challenges including high implementation costs, environmental concerns, and issues with infrastructure development. Moreover, the government of Kenya initiated Water Harvesting and Storage Programme, which has led to the construction of over 4,000 small-scale water pans and earth dams across arid and semi-arid regions. This program has increased water storage capacity by approximately 25 million cubic meters, benefiting over 100,000 smallholder farmers [54]. In terms of value addition, Kenya has made progress in its tea and coffee sectors. The establishment of specialty tea processing facilities has increased the value of tea exports by 15% between 2020 and 2023 [31].

1.1. Statement of the Problem

The global agricultural sector faces unprecedented challenges in ensuring food security and sustainability amidst growing population pressures, climate change, and resource scarcity. Water scarcity, in particular, poses a significant threat to agricultural productivity and rural livelihoods. According to the United Nations, global water demand is projected to increase by 20-30% by 2050, with agriculture currently accounting for 70% of global freshwater withdrawals [47]. This increasing demand, coupled with the impacts of climate change, is expected to place over half of the world's population under water stress by 2030 [54]. In developing countries, where agriculture forms the backbone of the economy, the challenges are even more acute. Sub-Saharan Africa, for instance, uses only 5% of its renewable water resources for agriculture, compared to 41% in South Asia [17]. This underutilization is largely due to a lack of infrastructure and innovative water management techniques. As a result, over 220 million people in Sub-Saharan Africa face food insecurity, with this number projected to increase by 50% by 2030 if current trends continue [53].

The economic implications of water scarcity and inefficient agricultural practices are profound. Global economic losses due to water scarcity are estimated to reach $500 billion annually by 2025 [52]. In agriculture-dependent economies, these losses can be devastating. For example, in Kenya, droughts have been estimated to cost the economy up to 2.8% of GDP per year [25]. The need for innovative and cost-effective water harvesting techniques is therefore not just an environmental imperative but an economic necessity. Value addition in agriculture presents another critical challenge and opportunity. Despite producing significant amounts of raw agricultural commodities, many developing countries benefit from only a fraction of the potential value due to limited processing capabilities. For instance, Africa generates only 10% of global agricultural value addition despite possessing 60% of the world's arable land [3]. This lack of value addition translates to lost economic opportunities and reduced farmer incomes. In Uganda, for example, it's estimated that value addition could increase the worth of coffee exports by up to 50% [46].

The environmental sustainability of current agricultural practices is also a major concern. Unsustainable water use in agriculture contributes to soil degradation, affecting 33% of the Earth's land surface [48]. This degradation not only reduces agricultural productivity but also contributes to greenhouse gas emissions, exacerbating climate change. Moreover, inefficient irrigation practices lead to water losses of up to 60% in some regions, further straining already scarce water resources [22]. Addressing these interconnected challenges requires a holistic approach that combines innovative water harvesting techniques with sustainable value addition processes. However, the adoption of such techniques faces serious barriers, including high initial costs, lack of technical knowledge, and inadequate policy support. Similarly, despite the potential of value addition to increase agricultural incomes by 30-40%, less than 10% of smallholder farmers in Sub-Saharan Africa are engaged in significant value addition activities [3].

Located in the semi-arid eastern region, Kitui County experiences frequent droughts and erratic rainfall patterns, severely impacting agricultural productivity and food security. According to the Kitui County Integrated Development Plan (2023-2027), approximately three quarters of the county's population faces food insecurity, with this figure rising to 80% during drought years. The county's average annual rainfall ranges from 300 mm to 1050 mm, but with high variability and unpredictability [27]. This unreliability of rainfall, coupled with limited water harvesting infrastructure, has led to only 1.2% of the county's arable land being under irrigation, way below the national target of 10% [25]. Furthermore, value addition in agriculture remains underdeveloped in Kitui, with less than 5% of farmers engaged in any post-harvest processing activities, resulting in an estimated 30-40% post-harvest losses for key crops like mangoes and green grams [27].

In Wajir County, 49% of residents rely on unsafe water sources, with only 35.7% of urban and 55.4% of rural populations accessing improved water sources such as protected springs, boreholes, or rainwater collection systems [49]. The county’s water infrastructure includes over 320 boreholes and approximately 600 water pans designed for rainwater harvesting however, these are inadequate in meeting the county's water needs [49]. The lack of consistent access to water has further contributed to the region's agricultural challenges, with cyclical droughts affecting both livestock and crop productivity and leading to increased reliance on relief support for food security [49]. Additionally, low productivity levels in livestock and crop farming have hindered income generation for local farmers, necessitating policy support and investment in these sectors [49]. This study therefore sought to evaluate the effectiveness of innovative and cost-effective water harvesting techniques and value addition practices in enhancing agricultural sustainability in Kitui and Wajir Counties, Kenya.

1.2. Research Objectives

To assess the level of adoption of innovative water harvesting techniques in improving water efficiency and agricultural sustainability in Kitui and Wajir Counties, Kenya.

To evaluate the effectiveness of cost-efficient value addition practices in enhancing agricultural sustainability in Kitui and Wajir Counties, Kenya.

1.3. Research Questions

What is the level of adoption of innovative water harvesting techniques on improving water efficiency and agricultural productivity in Kitui and Wajir Counties, Kenya?

How effective are cost-efficient value addition practices in enhancing agricultural sustainability in Kitui and Wajir Counties, Kenya?

2. Literature Review

2.1. Theoretical Framework

This study was underpinned by The Sustainable Livelihoods Framework (SLF). This framework was developed by Chambers and Conway as a tool to understand and address poverty in developing countries. The framework explains the interconnected factors that affect people's ability to sustain their livelihoods over time, considering not only economic factors but also environmental and social influences [8, 38]. This approach aims to create interventions that support sustainable improvements in living standards while addressing risks and vulnerabilities. Sustainable Livelihoods Framework (SLF) recognizes five livelihood assets that individuals and communities rely on: human capital, social capital, natural capital, physical capital, and financial capital [10]. Each of these assets plays a critical role in informing a person's ability to sustain their livelihood. In the context of water harvesting and agriculture, natural capital, which includes land, water, and biodiversity, is particularly important. The availability of these resources determines how effectively communities can innovate and sustain agricultural practices [7, 6]. Human capital, which includes knowledge and skills, is also essential for implementing innovative and cost-effective water harvesting techniques.

The SLF is built around the vulnerability context, which refers to the external shocks, trends, and seasonality that affect people's livelihoods. Shocks such as droughts, economic downturns, and policy changes can significantly affect a community's ability to harvest water and sustain agricultural activities [8]. By addressing these vulnerabilities, the framework helps communities build resilience. In the case of Kitui and Wajir Counties, where water scarcity is a major challenge, the framework explains the importance of developing water harvesting techniques that can buffer against climate variability [10, 14]. Additionally, the SLF promotes adaptability, which is key in agriculture to cope with both environmental and economic changes. The framework also emphasizes livelihood strategies, which are the diverse actions people take to achieve their livelihood goals. These strategies can be farming, wage labour, or micro-enterprises. For communities in Kitui and Wajir Counties, a strategy could be the adoption of innovative water harvesting methods and value addition in agriculture [38]. Value addition, such as processing agricultural products to increase their market value, is a key way to enhance sustainability and profitability [14, 5]. The SLF's focus on diverse strategies is relevant to this study, as it shows the necessity of both water efficiency and agricultural productivity for sustainable livelihoods in semi-arid and arid areas.

The transforming structures and processes component of the SLF is also important in explaining how institutional, legal, and policy factors impact livelihoods. For example, government policies and agricultural extension services are able to influence the effectiveness of water harvesting and value addition practices [10]. In Kitui and Wajir Counties, the role of local governments and agricultural boards in supporting farmers to adopt sustainable practices is critical. The SLF shows how support structures can create an enabling environment for the success of these interventions [38, 6]. These factors can either support or constrain communities in achieving sustainability. The SLF is therefore relevant to the study as it explains ways to understand the assets, vulnerabilities, and strategies that communities use to sustain their livelihoods [8]. The SLF describes the need for sustainable resource use and resilient livelihood strategies. It also emphasizes the importance of transforming structures and processes, such as government policies, which can support or hinder sustainable agriculture in Kitui and Wajir Counties [10, 7].

2.2. Empirical Review

2.2.1. Innovative Water Harvesting Techniques and Agricultural Sustainability

A study assessed the impact of rainwater harvesting and fertilizer micro-dosing on the sustainability of rural households in two regions of Tanzania: semi-arid Dodoma and semi-humid Morogoro [23]. The study analyzed data from 892 households between 2013 and 2016, using 40 sustainability indicators and applying a Difference-in-Difference Propensity Score matching method to evaluate relative changes in sustainability. They found that in the dry Dodoma region, adopters of the innovations experienced less economic sustainability growth (6 percentage points) compared to non-adopters (11 percentage points). In contrast, in the humid Morogoro region, adopters saw a greater increase in food security (14 percentage points) compared to non-adopters (6 percentage points). The study indicated that while these innovations had positive effects on food security, their benefits varied by region and context, and scaling them without considering local conditions could lead to trade-offs. This analysis contributed to a more comprehensive understanding of the overall sustainability impacts of agricultural innovations at the farm level, emphasizing the need for context-specific approaches to sustainable intensification.

A comprehensive review of water harvesting research, focusing on its development and its potential to support agricultural production was conducted particularly in arid and semi-arid regions [39]. The review encompassed over 60 articles, explaining that water harvesting is a traditional conservation technique that plays a critical role in mitigating water scarcity and enhancing agricultural productivity. The study noted that the increasing competition for both water and land resources has exacerbated water shortages, posing significant threats to global food security. Technological advancements in rainwater harvesting were identified as crucial for ensuring food availability for the growing global population. However, the review also acknowledged that challenges often arise during the implementation of advanced water harvesting systems, mirroring issues faced in other technological applications. Despite these challenges, the paper emphasized that water harvesting, especially when integrated with other agricultural interventions, has great potential to improve food security, particularly in developing countries.

A study examined the influence of exogenous elements on the development of technological innovation systems, specifically focusing on rainwater harvesting for irrigation in Kenya [41]. The study explored how rainwater harvesting can enhance sustainable access to irrigation and improve farmers' resilience to climate change in semi-arid regions of sub-Saharan Africa. Despite decades of efforts by governments, NGOs, and development practitioners, the adoption of rainwater harvesting for irrigation in Kenya has remained limited. Unlike previous research that focused on hydro-geological, techno-managerial, or socio-economic factors, this study took a broader approach by analyzing macro-level cultural, political, economic, and environmental dynamics that have shaped the adoption of rainwater harvesting systems. Using the technological innovation systems concept, the authors examined historical processes at two sites to identify how these exogenous elements contributed to the enabling environment for rainwater harvesting adoption. They found that ecological, demographic, macroeconomic, political, cultural, and socio-economic elements played significant roles in explaining the capacity and quality of innovation systems. These external elements influenced the levels of adoption by creating systemic challenges or opportunities and impacting the pace of system development.

2.2.2. Value Addition Practices and Agricultural Sustainability

A study reviewed the concept of value addition in agricultural production and its alignment with the Sustainable Development Goals (SDGs) [13]. The study emphasized how value addition can enhance food security and agricultural sustainability, particularly in developing countries where small-scale farmers often face resource constraints and market access challenges. It discussed the significant opportunities for value addition through improving quality, reducing costs, and increasing the marketability of agricultural products, particularly in the context of globalized trade and climate change. By focusing on both technological innovations and institutional support, the study emphasized the need for targeted interventions to improve the economic, social, and environmental aspects of agricultural production, thereby aligning agricultural practices with the broader goals of sustainability and poverty eradication.

A study investigated the sustainable usage of non-timber forest products (NTFPs) within rural communities in Ghana, focusing on how local perceptions of climate change and value addition influence the use and sustainability of these resources [1]. The study aimed to assess the impact of social factors such as education, gender, and religion on local perceptions of climate change, NTFP value addition, and their potential to enhance livelihoods. Data were collected through key informant interviews and focus groups across five regions where NTFPs are prevalent in Ghana, involving 732 randomly selected locals. The researchers applied a logistic regression model to analyze the influence of social factors on perceptions. The results showed that while religion significantly influenced locals' perceptions of climate change, factors such as age, gender, education, and occupation did not. In terms of value addition to NTFPs, gender and education were found to be significant influencers, whereas religion and constraints related to time, finance, and skills were not. The study emphasized the need for tailored interventions that account for local perspectives, aiming to enhance the role of NTFPs in poverty alleviation and sustainable rural development.

A study was conducted to assess the impact of the Agricultural Credit Guarantee Scheme Fund (ACGSF) on agricultural value-added growth in Nigeria between 2003 and 2022 [9]. The study made use of annual time series data sourced from the Central Bank of Nigeria Statistical Bulletin and the World Bank Development Indicators. The researchers employed the Auto Regressive Distributed Lag (ARDL) model to analyze the relationship between the Agricultural Credit Guarantee Scheme Fund (the independent variable) and agricultural value-added growth rate (the dependent variable). The findings revealed a non-significant negative relationship between the ACGSF and agricultural value-added growth in Nigeria. The study recommended an increase in the funds allocated to the agricultural sector through the ACGSF to enhance agricultural value-added growth. The study also indicated that value-added agricultural products should focus on being customer-oriented, providing the desired products at the right place, assortment, and time to benefit both buyers and sellers.

A study explored the impact of farmers' involvement in the maize seed multiplication programme on their livelihoods in Baringo South Sub-County, Kenya [29]. The study investigated whether farmer participation in the programme influenced their ability to repay credit, make and sustain savings, and how these savings affected their ability to consistently meet family basic needs. The findings revealed that the sustainability of savings from the maize seed programme was statistically significant in improving farmers' livelihoods. Specifically, with a unit increase in the sustainability of savings, the odds of a farmer being unable to consistently provide for family needs decreased by 1.767. However, only 61.8% of farmers reported making income savings, while 22.1% were unable to save any income. The study recommended building farmers' capacity in financial management and creating a conducive environment to reduce losses, thereby safeguarding farmers' incomes and enhancing their productivity and livelihoods.

3. Research Methodology

This study employed a descriptive research design, which was deemed appropriate as it allowed observation and description of the current state of innovative and cost-effective water harvesting and value addition practices in agriculture for sustainability without modifying the environment. The approach facilitated the collection of data that is meant to provide information on the prevalence and characteristics of water harvesting methods, their impact on agricultural productivity, and the subsequent implications for sustainability in Kitui and Wajir Counties, Kenya. The target population for the study comprised farmers, agricultural extension officers and county government officials or representatives from the Ministry of Agriculture and Livestock Development and from the Ministry of Water, Sanitation, and Irrigation working in Kitui and Wajir Counties. The study purposively selected 25 farmers and 34 agricultural extension officers and government officials from the two counties to participate. Data was collected using both structured questionnaire for farmers and Key Informant Interview (KII). The small sample size was chosen to allow for an in-depth analysis of the specific experiences of stakeholders directly involved in water harvesting and value addition in agriculture, ensuring that the data collected was rich and relevant to the research objectives. The quantitative data collected from farmers was analyzed with the aid of SPSS using both descriptive statistics and inferential statistics, while qualitative data gathered through the KIIs was analyzed thematically using content analysis. The findings were presented in both narrative form and tables to effectively convey the information derived from the respondents.

4. Findings and Discussion

4.1. Response Rate and Demographic Information

The purpose of this study was to evaluate the effectiveness of innovative and cost-effective water harvesting techniques and value addition practices in enhancing agricultural sustainability in Kitui and Wajir Counties, Kenya. The specific objective were; to assess the level of adoption of innovative water harvesting techniques in improving water efficiency and agricultural sustainability in Kitui and Wajir Counties, Kenya and to evaluate the effectiveness of cost-efficient value addition practices in enhancing agricultural sustainability in Kitui and Wajir Counties, Kenya. The study administered questionnaires to a sample of 25 farmers while 34 agricultural extension officers and government officials from both counties were interviewed. Out of the 25 farmers, 22 responded, resulting in a response rate of 88%. Additionally, 34 agricultural extension officers and government officials (17 from each county) participated in interviews, achieving a full response rate of 100%.

Demographic information revealed a predominantly male representation among respondents, with 63.6% (14) males and 36.4% (8) females. This distribution suggests a male-dominated sample, reflecting higher involvement of men in the agricultural practices within Kitui and Wajir Counties. The age distribution indicates a good representation of older adults, with 36.4% (8) of respondents aged 46-55 years, followed by 31.8% (7) aged 56 and above. A smaller group 27.3% (6) fell within the 36-45-year age range, and only 4.5% (1) were aged between 18-35 years. This age distribution points to the fact that the respondents were primarily mature individuals, potentially with extensive experience in agriculture. Regarding educational attainment, the respondents displayed diverse educational qualifications. The largest proportion of the respondents held diplomas (31.8%, or 7), followed by an equal number with PhDs (31.8%, or 7) and bachelor's degrees (27.3%, or 6). A smaller group had obtained a master’s degree (9.1%, or 2), suggesting a high level of educational achievement overall. The majority of the respondents were from Kitui County (95.5%, or 21), with only a small representation from Wajir County (4.5%, or 1), indicating that the study findings primarily reflect the demographic and agricultural context of Kitui County farmers.

4.2. Descriptive Analysis

Descriptive analysis was used to describe the basic features of the data under study as they provide summaries about the sample and its measures because they provide simple summaries about the sample and the measures. Descriptive analysis simply forms the basis of every quantitative analysis of data and includes the mean and standard deviation [8]. Descriptive statistic of the study variables are presented and discussed below.

4.2.1. Descriptive Statistics on Level of Adoption of Innovative Water Harvesting Techniques

The study sought to assess the level of adoption of innovative water harvesting techniques in improving water efficiency and agricultural sustainability in Kitui and Wajir Counties, Kenya. Table 1 shows the descriptive statistics results.

Table 1. *Descriptive Statistics on Level of Adoption of Innovative Water Harvesting Techniques.*

Statement	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Mean	Std. dev.
Innovative water harvesting techniques have been widely adopted in Kitui and Wajir County.	45.50%	36.40%	9.10%	9.10%	0.00%	1.82	0.96
Water harvesting has led to increased water efficiency in agricultural practices.	27.30%	27.30%	9.10%	36.40%	0.00%	2.55	1.26
There is adequate support from the government to promote water harvesting techniques.	54.50%	22.70%	22.70%	0.00%	0.00%	1.68	0.84
Farmers are well informed about the benefits of innovative water harvesting techniques.	31.80%	40.90%	13.60%	13.60%	0.00%	2.09	1.02
There are challenges in adopting water harvesting techniques due to financial constraints.	18.20%	13.60%	18.20%	9.10%	40.90%	3.41	1.59
Training and education on water harvesting techniques are regularly conducted in Kitui and Wajir County.	36.40%	40.90%	9.10%	9.10%	4.50%	2.05	1.13
Innovative water harvesting has contributed to the sustainability of agricultural practices in Kitui and Wajir County.	31.80%	27.30%	22.70%	18.20%	0.00%	2.27	1.12

The results in Table 1 shows that a most of the farmers expressed low adoption of innovative water harvesting techniques in Kitui County, with 45.5% strongly disagreeing and 36.4% disagreeing, yielding a low mean score of 1.82 and a standard deviation of 0.96. This suggests limited uptake of these techniques, indicating potential barriers or resistance to their use in agricultural practices. When asked if water harvesting had improved water efficiency in agriculture, 36.4% agreed, while 27.3% strongly disagreed and an equal percentage disagreed, resulting in a moderate mean score of 2.55 with a standard deviation of 1.26. This mixed response suggests that, although some farmers acknowledge benefits in water efficiency, a significant portion remains unconvinced, possibly due to inconsistent or limited results.

Support from the government for promoting water harvesting techniques was perceived as inadequate, with 54.5% strongly disagreeing and 22.7% disagreeing, yielding a mean of 1.68 and a standard deviation of 0.84. This reflects a sentiment of insufficient governmental assistance, which may hinder widespread adoption. Furthermore, farmers' awareness of the benefits of innovative water harvesting techniques appears low, with 31.8% strongly disagreeing and 40.9% disagreeing, giving a mean score of 2.09 and a standard deviation of 1.02. This lack of awareness could indicate a gap in education and outreach efforts regarding these techniques.

Moreover, 40.9% of respondents strongly agreed that financial constraints posed challenges in adopting water harvesting techniques, with a mean score of 3.41 and a higher standard deviation of 1.59, emphasizing the significant financial barriers farmers face. Training and education efforts also appear limited, as 36.4% strongly disagreed and 40.9% disagreed that training was regularly conducted, resulting in a mean score of 2.05 with a standard deviation of 1.13. This suggests that more regular and widespread educational initiatives could enhance adoption rates.

Moreover, when considering the impact of innovative water harvesting on agricultural sustainability, responses were varied: 31.8% strongly disagreed, 27.3% disagreed, and 18.2% agreed, leading to a mean score of 2.27 and a standard deviation of 1.12. While some respondents see a positive impact on sustainability, the overall lack of consensus suggests that perceived benefits are not widespread. These descriptive statistics indicate a generally low adoption rate of water harvesting techniques, with financial limitations, insufficient government support, and lack of awareness and training as likely contributing factors. Enhanced efforts in policy support, financial aid, and educational outreach may be necessary to improve adoption and realize sustainable agricultural practices. Despite decades of efforts by governments, NGOs, and development practitioners, the adoption of rainwater harvesting for irrigation in Kenya has remained limited [41]. Unlike previous research that focused on hydro-geological, techno-managerial, or socio-economic factors, this study took a broader approach by analyzing macro-level cultural, political, economic, and environmental dynamics that have shaped the adoption of rainwater harvesting systems.

Thematic Analysis of Innovative Water Harvesting Techniques

The study further conducted interview in which majority of interviewees had placements across various ministries, with a strong representation from the Ministry of Water, Sanitation, and Irrigation, followed by the Ministry of Agriculture and Livestock Development, and the Ministry of Education. A smaller number noted affiliations with specific organizations such as the Wajir Water and Sewerage Company, NGO capacity-building in Science, Technology, and Innovation (STI), and Tyaa Wendo Gardens a recreational site focused on climate change in Mwingi. Additional placements included roles within the Ministry, agricultural extension roles, and individual farmers. The variety of placements reflects a diverse network working across sectors to address agriculture, water management, and climate adaptation needs in the region. During interviews, respondents were asked to indicate how widely innovative water harvesting techniques had been adopted by farmers in Kitui and Wajir Counties.

The interview revealed that the adoption of innovative water harvesting techniques remains limited, with many respondents describing uptake as low or inadequate. Kitui County, for instance, has seen minimal adoption of techniques like sand dams, earth dams, on-farm ponds, and roof water harvesting. A few farmers experimented with road water harvesting, but high siltation rates proved problematic. Some farmers practice cluster irrigation, where groups share a common water source. One interviewee from Kitui highlighted the situation, saying:

“Extremely little innovation on a scale of 0 to 10, I would put it at 2. Despite the recognition of these techniques’ benefits, practical adoption remains hindered by various factors, with estimates suggesting that fewer than 20% of farmers actively use these methods.”

The findings from the interview revealed that cost was a primary barrier to adopting water harvesting infrastructure, and many smallholder farmers in arid and semi-arid regions like Wajir and Kitui lack the necessary funds. High initial costs and limited access to credit make it difficult for farmers to install systems such as sand dams or gutter setups. One respondent noted:

“The biggest challenge for farmers is the high costs of materials and lack of financing.” Further, inadequate extension services mean that even farmers with resources may struggle due to a lack of technical knowledge to maintain and manage these systems effectively. There is need for skilled support, stating, farmers need guidance on choosing techniques and managing water effectively without it, adoption remains low.”

Moreover, the interview results indicated that environmental and social factors also influenced the adoption of these techniques. Erratic rainfall, high evaporation, and general water scarcity present challenges in areas like Wajir, where climate variability compounds the struggle for water access. Frequent droughts highlight the need for these water-saving techniques, yet traditional practices and cultural norms sometimes deter change. Reflecting on these challenges, a farmer shared;

“Most farmers have not embraced innovative water harvesting because of inadequate resources and knowledge. Only a few farmers are using harvested water for irrigation. This shows the need for broader education and sensitization efforts, as many remain unaware or hesitant to adopt unfamiliar methods”.

The findings from the interviews further revealed that Government and NGO support has positively impacted farmers where available, with programs like the Kenya Climate-Smart Agriculture Project (KCSAP) and the Water Sector Trust Fund (WSTF) providing technical assistance and financial aid. Demonstrations, pooled resources, and training have succeeded in raising awareness and changing mindsets in some areas. One participant commented:

“Programs like KCSAP have introduced farmers to these methods…without subsidies and training, I doubt adoption would grow. However, the majority still rely on traditional, often unsustainable, water management practices, emphasizing a need for broader, coordinated efforts to bridge these knowledge and resource gaps. Adoption of innovative water harvesting techniques remains minimal. Many farmers lack awareness or sufficient knowledge to implement these techniques effectively, while financial constraints and the high cost of materials also inhibit adoption”.

The respondents identified various water harvesting methods as effective for improving agricultural water efficiency in their regions. Methods like sand dams, shallow wells, and subsurface dams were frequently mentioned for their efficiency. One respondent noted that:

"The construction of sand/subsurface dams with a sump well upstream, equipped with a submersible pump and solar units, has been both cost-effective and highly efficient. Installation of dams to store rainwater for irrigation, which is widely used and valuable for extending water availability

into dry seasons".

Several respondents observed that methods like water pans and on-farm ponds are particularly beneficial. One individual shared that:

"On-farm water ponds are the most effective, especially in the northern and southern parts where they are cheaper and widely used. Additionally, in areas like Wajir, shallow wells are highly favoured for water retention and accessibility. Underground tanks, also known locally as "Barkad," were noted as a unique technique suited to certain regions, where they are used to store harvested water from rain".

It emerged from the interviews that the effectiveness of specific techniques often depends on regional topography and climate. Techniques like contour farming, micro-catchments, and surface water harvesting were recognized for their ability to maximize water retention in hilly areas. One respondent explained that:

"Contour farming and micro-catchments, including earth bunds and swales, allow runoff water to seep into the soil, replenishing groundwater. This approach has been particularly effective in Wajir North, where hilly terrain and sloping lands benefit from the slowed runoff and increased soil moisture".

Several respondents highlighted the practicality of sand dams, rooftop rainwater harvesting, and earth pans. Sand dams, in particular, were noted for their dual function of storing water and recharging groundwater, which is especially valuable during dry seasons. One participant remarked;

"Sand dams have been among the most effective methods, storing water within the sand, which reduces evaporation and protects it from contamination. Rooftop rainwater harvesting is an easy and cost-effective method for small-scale irrigation, with water stored in tanks from rainy seasons to sustain kitchen gardens or small farms".

The interviewees were further asked to indicate the challenges farmers face in adopting and implementing these water harvesting techniques.

In response, many respondents cited financial constraints as a major barrier. High initial costs for infrastructure like piping, pumps, and water storage facilities prevent widespread adoption. One respondent highlighted this challenge stating:

"The initial investment required for implementing these water harvesting techniques constructing sand dams, harvesting rainwater from rooftops, or setting up check dams can be astronomically high for the average farmer. Additionally, limited access to credit schemes tailored for water harvesting projects exacerbates this financial burden, making it difficult for small-scale farmers to implement these solutions without external support".

Moreover, technical knowledge and expertise were noted as significant hurdles. It was established that many farmers lacked the skills required to set up, maintain, and repair water harvesting systems. One participant mentioned:

"The skills required and financial implications make it hard for farmers to adopt these techniques effectively. While some government and NGO initiatives attempt to bridge this knowledge gap, their reach remains limited, especially in remote areas. Furthermore, the availability of quality extension services and skilled local technicians is lacking, which discourages the adoption of advanced water harvesting systems".

Environmental factors and infrastructure limitations further challenge farmers' efforts to implement water harvesting techniques. Irregular rainfall, high evaporation rates, and soil conditions that do not retain water well are common in arid and semi-arid regions. One of the interviewees explained that:

"In Wajir County, the high rate of evaporation and poor soil retention hinder effective water harvesting," one respondent explained. Seepage from ponds and evaporation losses reduce the amount of usable water, making systems like water pans less efficient. Additionally, many farmers struggle with inadequate storage facilities, which limits their ability to store harvested water effectively".

Institutional and social barriers also impact adoption. Some respondents pointed out that fragmented institutional support, such as inconsistent coordination between government agencies, NGOs, and community-based organizations, complicates access to necessary resources. One officer explained that:

"Lack of supportive policies and fragmented institutional support have made it difficult for farmers to get the assistance they need. Cultural resistance and adherence to traditional water management practices also slow the adoption of new techniques. For instance, farmers in some areas remain attached to conventional methods and are hesitant to try new, unfamiliar practices unless proven effective through sustained demonstrations and training".

These responses imply that financial limitations, insufficient knowledge, and lack of technical support significantly hinder the adoption of innovative water harvesting techniques among farmers in Kitui and Wajir Counties. Improved training and funding opportunities could potentially address these barriers and improve agricultural sustainability in the counties.

The respondents were further asked to give their opinions on how the adoption of innovative water harvesting techniques impacted agricultural productivity and sustainability in their Counties. Many respondents shared that the adoption of innovative water harvesting techniques has had a positive impact on agricultural productivity and food security in their regions. One farmer observed:

"It has really changed the way of farming, and farmers practicing it are reaping high rewards. In areas with water pans, dams, and other harvesting systems, there has been a noticeable increase in crop yields and year-round availability of fruits and vegetables".

However, some noted that the benefits depend heavily on appropriate placement and management, with one participant mentioning:

"The sump wells need to be well located in mature seasonal rivers, and sand harvesting controlled to prevent water loss."

Some respondents highlighted the economic and social benefits brought by these techniques, such as increased income and diversified livelihoods. For instance, several farmers have shifted towards horticultural farming, cultivating high-value crops like watermelon, pawpaw, mangoes and guava. This has helped reduce hunger and reliance on food aid in some areas. As one respondent shared:

"More people in the region have adopted farming as a source of livelihood because of the existence of water pans near their villages. This transformation has allowed farmers to produce food consistently and invest in sustainable practices that are resilient to the changing climate".

In regions like Wajir County, where the national government has invested in water harvesting infrastructure, farmers report significant improvements. Respondents mentioned that mega dams installed by the government in Wajir North have helped increase agricultural productivity, especially during seasons with adequate rainfall. One participant noted:

"If there is no drought and we get the two normal rainy seasons, then water harvesting is sustainable in Wajir County. Stored rainwater from Ethiopian highlands could provide a crucial resource if more extensive harvesting initiatives are pursued".

Overall, the adoption of these techniques has fostered resilience to climate variability and drought, which are common in arid and semi-arid counties. Many respondents highlighted that water harvesting systems, like sand dams and contour farming, help conserve soil, reduce erosion, and improve water infiltration. One farmer emphasized the value of these methods, stating:

"The use of water harvesting systems has improved the resilience of agricultural activities to climate variability and droughts."

4.2.2. Descriptive Statistics on Effectiveness of Cost-Efficient Value Addition Practices

The study sought to evaluate the effectiveness of cost-efficient value addition practices in enhancing agricultural sustainability in Kitui and Wajir Counties, Kenya. As noted earlier the majority of the respondents for the questionnaire were from Kitui County (95.5%, or 21), with only a small representation from Wajir County (4.5%, or 1), indicating that the study findings primarily reflect the demographic and agricultural context of Kitui County farmers in the quantitative questionnaire. Table 2 shows the descriptive statistics results.

Table 2. *Descriptive Statistics on Effectiveness of Cost-Efficient Value Addition Practices.*

Statement	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Mean	Std. Dev.
Value addition practices are widely adopted among farmers in Kitui and Wajir County.	54.50%	31.80%	4.50%	4.50%	4.50%	1.73	1.08
The cost of value addition practices is affordable for most farmers in the county.	54.50%	22.70%	9.10%	13.60%	0.00%	1.82	1.1
Value-added agricultural products have improved market access and profitability for farmers.	36.40%	40.90%	9.10%	9.10%	4.50%	2.05	1.13
There is adequate government support to promote cost-efficient value addition practices in Kitui and Wajir County.	54.50%	31.80%	4.50%	9.10%	0.00%	1.68	0.95
Farmers have sufficient knowledge and skills in value addition processes.	45.50%	40.90%	0.00%	13.60%	0.00%	1.82	1.01
Cost-efficient value addition has significantly contributed to agricultural sustainability in the county.	40.90%	31.80%	18.20%	4.50%	4.50%	2.01	1.11
There are significant challenges faced by farmers in adopting value addition practices, such as access to markets.	18.20%	9.10%	27.30%	27.30%	18.20%	3.18	1.37

The results in Table 2 show that the majority of respondents disagreed (86.3%) that value addition practices were widely adopted among farmers in Kitui County, with a mean score of 1.73 and a standard deviation of 1.08. This low adoption suggests that value addition is not yet a common practice, potentially due to barriers like cost or lack of awareness.

Similarly, most respondents (77.2%) disagreed that the cost of these practices was affordable for most farmers, reflected in a mean of 1.82 and a standard deviation of 1.1, implying that cost constraints are likely a major barrier to adoption. Regarding the impact on market access and profitability, a majority (77.3%) disagreed that value-added agricultural products had led to better market access and profitability for farmers, with a mean of 2.05 and a standard deviation of 1.13. This perception suggests that even with value addition, market access may remain challenging, potentially due to limited local demand or insufficient marketing channels. Additionally, most respondents (86.3%) disagreed that there was adequate government support for promoting cost-efficient value addition practices, with a mean of 1.68 and a standard deviation of 0.95, indicating a significant need for increased governmental assistance to encourage adoption.

In terms of knowledge and skills, 86.4% of respondents disagreed that farmers possessed sufficient knowledge of value addition processes, reflected in a mean score of 1.82 and a standard deviation of 1.01. This lack of expertise points to the necessity for more educational initiatives focused on value addition. The statement on the impact of cost-efficient value addition on agricultural sustainability also received high disagreement (72.7%), with a mean score of 2.01 and a standard deviation of 1.11. This suggests that respondents did not perceive value addition as significantly contributing to sustainability, potentially due to low adoption or limited observed benefits. However, regarding challenges, a majority (45.5%) agreed that farmers faced significant obstacles in adopting value addition practices, especially regarding market access, yielding a mean score of 3.18 and a standard deviation of 1.37. This highlights the need to address these challenges to enhance adoption rates. The implications of these findings suggest that more efforts in training, financial support, and market facilitation are required to make value addition a viable option for farmers and to enhance agricultural sustainability in Kitui and Wajir Counties. These findings are in agreement with observations made by previous study that while religion significantly influenced locals' perceptions of climate change, factors such as age, gender, education, and occupation did not [1]. In terms of value addition to non-timber forest products (NTFPs), gender and education were found to be significant influencers, whereas religion and constraints related to time, finance, and skills were not.

Thematic Analysis on Effectiveness of Cost-Efficient Value Addition Practices

During interviews, agricultural extension officers and government officials from the Ministry of Agriculture and Livestock Development and from the Ministry of Water, Sanitation, and Irrigation from the two counties were asked to describe the level of adoption of cost-efficient value addition practices among farmers in your County.

Many respondents described the adoption of cost-efficient value addition practices as very low. Several rated it at a 2 on a scale of 1 to 10, emphasizing that only a few farmers engage in value addition due to limited resources and skills. One respondent shared:

“The level is in the ratio, 1:10, reflecting the scarcity of such practices among farmers. Value addition practices are almost nonexistent and there is potential for growth, but substantial obstacles need to be addressed to achieve this”.

Economic challenges and lack of access to technology were recurring themes in respondents' feedback. Many farmers struggle to access processing equipment, training, and market linkages that would enable them to add value to their produce. One participant highlighted:

"The lack of access to readily available and affordable technologies, coupled with limited knowledge dissemination on value addition techniques, has kept the majority of farmers tethered to low-value, primary produce. This economic struggle has made farmers reliant on fluctuating market prices for their primary produce, often leaving them vulnerable to exploitation and economic hardship. In Wajir, for instance, some respondents pointed out that there is minimal watermelon value addition, leading to wasted resources in this crop’s value chain”.

Additionally, infrastructure and market access limitations hinder the widespread adoption of value addition practices. Respondents noted that poor road networks, unreliable electricity, and inadequate storage facilities make it challenging for farmers to engage in processing, packaging, and preservation. One participant commented on this challenge, saying:

“Wajir County faces significant infrastructure challenges, including poor road networks and limited access to reliable electricity, making it difficult for farmers to engage in value addition activities. Farmers in predominantly pastoralist regions also focus more on livestock, with some small-scale efforts in milk processing and hide preparation, but crop-related value addition is even less common due to low crop production”.

Government and NGO initiatives have attempted to promote value addition practices, but the impact is limited. Some respondents acknowledged that interventions by NGOs and development partners have helped introduce simple, cost-efficient techniques, such as milk cooling and honey processing. However, the reach of these programs is still minimal, and slow adoption rates persist. A participant remarked:

“While there have been introductions of small-scale processing technologies, like solar dryers, adoption remains low due to high initial costs and limited access to credit for farmers. Despite these challenges, some emerging opportunities were noted, with cooperatives and women’s groups beginning small-scale value addition efforts, such as milk processing and honey packaging, which are slowly expanding the economic potential of agriculture in these regions”.

Another question posed to respondents was: "What types of value addition practices have proven to be most beneficial for agricultural sustainability in your region?"

Respondents identified several key value addition practices that contribute to agricultural sustainability by increasing farmer income and reducing post-harvest losses. Growing fruits and vegetables, such as mangoes, pawpaws, and lemons, was frequently mentioned, along with irrigation-supported crop production. One respondent highlighted:

"Growing of vegetables and fruits like mangoes, oranges, and bananas has proven effective, as these high-value crops not only improve income but also diversify agricultural output. Additionally, using dam liners to avoid seepage, boreholes powered by solar pumps, and rainwater harvesting were noted as essential for supporting consistent irrigation, which enables year-round crop production".

It was also noted that in pastoralist regions like Wajir, value addition practices focused on livestock have emerged as crucial for sustainability. Practices like milk processing into dairy products (such as yogurt, ghee, and cheese) extend the product's shelf life and command higher market prices. One participant explained:

"Simple practices like milk cooling and pasteurization reduce spoilage, especially in hot climates, and increase the time milk can be stored before transportation. Additionally, meat drying into "nyirinyiri" (a traditional dried meat) has gained traction, as it helps preserve meat without refrigeration, allowing it to be sold at higher prices in areas with limited cold storage. Processing hides and skins for leather items like belts, sandals, and bags was also highlighted, creating additional revenue streams and employment opportunities".

Honey processing, particularly in beekeeping communities, has become an important value addition practice. Techniques like filtering and packaging honey extend its shelf life and make it more marketable, especially for external markets. One respondent mentioned:

"Beekeeping and proper honey processing, including filtering and packaging, have been beneficial. Beeswax processing is also a secondary income source, with potential for crafting small-scale products from wax, thus diversifying income for farmers involved in apiculture".

Other value addition practices that support sustainability include establishing community-based processing units and aggregation centers for products like honey and leather, which facilitate collective marketing and improve market access. For example, crop aggregation centers and professional bee harvesting hubs help streamline production and create more organized marketing channels. Farmers have also benefited from basic storage and preservation techniques, such as drying vegetables and conserving hay, which help maintain food supplies during dry seasons and increase resilience to climatic variations. These emerging practices show promise for improving economic stability and food security in these communities.

During interviews, the interviewees were further asked to indicate the major obstacles that hinder farmers from engaging in value addition practices, and how the challenges could be addressed. A prevalent issue mentioned by respondents was the lack of applied skills, relevant tools, and access to training for value addition. Many farmers lack the technical knowledge required to engage in processing, packaging, and preservation. One respondent suggested:

"This can be addressed through farmer training programs, emphasizing the need for skill-building initiatives. Non-Governmental Organizations (NGOs) and government programs could play a vital role in organizing capacity-building workshops to improve farmers' understanding of value addition techniques and their economic benefits".

Financial constraints were also a significant barrier. Limited access to capital prevents farmers from investing in value addition practices. One participant noted:

"Lack of capital is a big issue, and NGOs could assist by visiting the region with the aim of providing financial support. Expanding access to affordable credit, such as microloans or grants targeted specifically at value addition projects, would help farmers purchase necessary equipment and materials".

Infrastructure issues, including poor road networks, lack of electricity, and inadequate storage facilities, were also highlighted as barriers. For instance, one respondent shared:

"The lack of reliable power supply, cold storage, and efficient transportation limits farmers' ability to engage in post-harvest processing. Addressing these issues would require investment in rural infrastructure, such as roads, electricity, and centralized storage facilities. Establishing processing and storage centers, like milk cooling plants or solar-powered storage units, could help reduce post-harvest losses and make value addition more feasible for farmers".

Market access and limited demand for value-added products are additional obstacles. Farmers often struggle to find buyers who are willing to pay premium prices for processed goods. Strengthening market linkages through cooperatives or partnerships with private sector players could improve farmers' bargaining power and create reliable market channels for value-added products. One respondent mentioned:

"Building stronger market linkages through cooperatives and associations can improve access to larger markets. Such cooperatives could also organize collective marketing and provide training in digital marketing to help farmers expand their customer base".

Cultural resistance and traditional practices pose further challenges, with some farmers hesitant to adopt new practices. Demonstration projects and community outreach programs can help overcome this by showcasing the benefits of value addition and aligning it with traditional practices. Additionally, respondents highlighted the need for supportive government policies, such as tax incentives, subsidies, and clear quality standards. Implementing these policies would encourage more farmers to adopt value addition practices and help them tap into broader markets.

Finally, the respondents were asked to indicate how these value addition practices had contributed to enhancing the sustainability and profitability of agriculture in their Counties on the basis of their experiences. Many respondents noted that value addition practices had a meaningful impact on agricultural production and financial sustainability, particularly in semi-arid counties like Kitui, where rain-fed agriculture alone is unsustainable. One participant emphasized:

"These practices have greatly impacted agricultural production because Kitui relies on rain-fed agriculture, which is not sustainable. Through value addition, farmers can generate income throughout the year, reduce dependence on unpredictable rainfall, and consistently supply produce to the market, which enhances both stability and profitability".

Additionally, it was noted that the economic benefits of value addition were frequently highlighted. Farmers who have engaged in processing practices, such as converting milk into yogurt or cheese, report higher incomes due to increased market prices for processed goods. A respondent shared:

"Milk and meat value addition are very profitable, enhancing purchasing power in pastoralist communities. Through diversifying income sources, farmers are less reliant on a single crop or livestock product, which improves their resilience to market fluctuations. Additionally, processing goods like honey and dried fruits allows farmers to extend shelf life, reducing post-harvest losses and ensuring that they get maximum value for their efforts".

Furthermore, it was noted that value addition has also promoted sustainable resource use and resilience to climate variability. In areas like Wajir, where reliance on external resources can be challenging, farmers have started creating animal feed from locally sourced materials. This practice reduces the need for imported feed, lowers production costs, and encourages environmental sustainability. One participant noted:

"The production of animal feed from locally available resources fosters sustainability and reduces external dependence. Also, practices like drying vegetables, hay storage, and grain storage were also mentioned as effective for reducing waste and providing a steady food supply during drought periods, common in arid regions".

The broader economic and social impact of value addition practices was also recognized. Respondents explained that these practices encourage job creation and support local entrepreneurship, especially for women and youth involved in processing and marketing. Community-based processing units, cooperatives, and aggregation centers strengthen market linkages, improve bargaining power, and facilitate knowledge-sharing among farmers. As one respondent remarked:

"The establishment of cooperatives fosters community cohesion, increases bargaining power, and enhances knowledge sharing within the community. This collective approach not only contributes to economic growth but also strengthens community resilience and promotes sustainable agricultural practices across the region".

4.3. Regression Analysis

The study conducted regression analysis to establish the effect of cost-efficient value addition practices on agricultural sustainability in Kitui and Wajir Counties, Kenya. Tables 3 shows the model summary results.

Table 3. *Model Summary.*

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.764a	0.584	0.582	0.50574
a. Predictors: (Constant), Cost-Efficient Value Addition Practices				

The results in Table 3 show a coefficient of determination (R squared) of 0.584 and an adjusted R squared of 0.582. This implies that cost-efficient value addition practices account for 58.4 percent of the variation in agricultural sustainability in Kitui and Wajir Counties, Kenya. The remaining 41.6 percent of the variation in agricultural sustainability is attributable to other factors not included in the model. The standard error of the estimate is 0.50574, which indicates the average distance that the observed values fall from the regression line, providing a measure of the model's predictive accuracy in estimating the relationship between value addition practices and sustainability. Table 4 shows the analysis of variance results.

Table 4. *ANOVA.*

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	115.041	1	115.041	28.025	.000[b]
	Residual	82.104	20	4.105		
	Total	197.145	21			

a. Dependent Variable: Agricultural Sustainability

b. Predictors: (Constant), Cost-Efficient Value Addition Practices

The analysis of variance results in Table 4 show that the model was statistically significant in explaining the effect of cost-efficient value addition practices on agricultural sustainability in Kitui and Wajir Counties, as indicated by a p-value of 0.000, which is less than 0.05. The F value of 28.025 further supports the statistical significance of the model, suggesting that cost-efficient value addition practices significantly contribute to the variance in agricultural sustainability. The regression sum of squares (115.041), when compared to the residual sum of squares (82.104), reinforces the model's explanatory power, confirming its effectiveness in capturing the relationship between value addition practices and sustainability outcomes. Table 5 shows regression coefficient results.

Table 5. *Regression Coefficients.*

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.899	0.106		8.451	0.010
	Cost-Efficient Value Addition Practices	0.669	0.032	0.764	21.208	0.000

a. Dependent Variable: Agricultural Sustainability

The regression model therefore became;

$Y = 0.899+0.669X$

Where:

Y= Agricultural Sustainability

X= Cost-Efficient Value Addition Practices

The regression coefficients results in Table 5 indicate that cost-efficient value addition practices had a significant positive effect on agricultural sustainability in Kitui and Wajir Counties, with a p-value of 0.000, indicating significant effect(B = 0.669, P-value = 0.000). The constant term (B = 0.899, P-value = 0.010) was also significant, which confirms a strong positive relationship between cost-efficient value addition practices and the dependent variable, agricultural sustainability. This finding suggests that as cost-efficient value addition practices increase, agricultural sustainability also improves, indicating the importance of promoting these practices to enhance the long-term viability of agriculture in the region. The significant results demonstrate that value addition plays an important role in improving agricultural sustainability, likely by adding value to products, improving market access, and increasing profitability for farmers. These findings are consistent with a previous study which indicated that in the dry Dodoma region, adopters of the innovations experienced less economic sustainability growth compared to non-adopters [23]. These findings also concurs with conclusion made a previous study that, the increasing competition for both water and land resources has compounds water shortages, posing significant threats to global food security [39].

5. Conclusion

In light of the findings, the study concludes that cost-efficient value addition practices are significant in determining the agricultural sustainability in Kitui and Wajir Counties. There is widespread low adoption rates indicate a pressing need for strategies that make these practices accessible and affordable to local farmers, potentially through financial subsidies, training, and government-backed initiatives. The findings revealed strong positive relationship between value addition and sustainability indicating the potential benefits these practices bring, including improved market access, profitability, and resilience of agricultural systems to environmental challenges.

Furthermore, most farmers in the two counties have insufficient knowledge and technical skills pointing to the need for targeted educational programs that will help bridge the current awareness gap. Improved government support, alongside private sector engagement, are necessary in addressing both the financial and logistical barriers that prevent widespread adoption of innovative practices. In doing so, these interventions will be able to facilitate a more sustainable agricultural framework, allowing farmers in Kitui and Wajir Counties to better manage resources, increase productivity, and ensure long-term economic stability.

The study concludes that cost-efficient value addition practices are significantly linked to agricultural sustainability in Kitui and Wajir Counties, as evidenced by the positive impact of these practices on resource management, market access, and profitability. The regression results demonstrated that a considerable portion of the variance in agricultural sustainability can be explained by the adoption of value addition techniques, affirming that these practices are a key driver for sustaining agriculture in the region. Despite this, the overall low adoption rate suggests that while value addition is beneficial, there are substantial barriers that limit its reach among local farmers. These findings emphasize that cost-efficient value addition practices, if more widely adopted, have the potential to foster improved resource efficiency and economic resilience in these arid and semi-arid counties.

6. Recommendations

In view of the findings, several recommendations are proposed to improve the adoption of innovative water harvesting and cost-efficient value addition practices among farmers in Kitui and Wajir Counties, Kenya. For farmers, awareness and skills development should be prioritized to bridge the knowledge gap identified in the study. Farmers are encouraged to seek training opportunities, possibly through collaboration with agricultural extension officers and local institutions, to learn more about the benefits and technical aspects of these practices. Community-based training programs can be especially effective, enabling farmers to share experiences, resources, and techniques that improve water management and add value to their products, thereby enhancing sustainability and profitability.

The government authorities and relevant stakeholders should prioritize financial support programs, such as subsidies and grants, to offset the initial costs associated with implementing water harvesting and value addition practices. These financial aids would make it easier for small-scale farmers to adopt these techniques. Furthermore, creating a supportive regulatory framework that encourages private-sector involvement in rural areas could facilitate access to essential materials and infrastructure. Policies that incentivize private sector partnerships with local farmers would also encourage sustainable practices, as farmers will be more inclined to invest in their agricultural operations with greater resource access and market opportunities.

The findings also points to the need for a well-developed theoretical frameworks that integrate practical, context-specific factors influencing the adoption of agricultural technologies in arid and semi-arid regions. Future research could build on this study by developing models that account for financial, educational, and environmental challenges specific to such areas. Additionally, these models should include cultural and socioeconomic factors that may impact farmers' decision-making processes. Extending the theoretical framework to include sustainability and resilience metrics would allow for a more holistic understanding of how value addition and water management practices contribute to long-term agricultural stability.

The study further recommends designing targeted training and outreach programs focused on cost-efficient practices and accessible technologies. Institutions could collaborate with local governments to deliver region-specific training that addresses unique environmental challenges, such as water scarcity in Kitui and Wajir Counties. Through the implementation of tailored curricula that emphasize practical skills and demonstrate the benefits of sustainable practices, educational institutions can help cultivate a culture of innovation and sustainability among local farmers, thereby driving higher adoption rates.

Private and non-governmental organizations (NGOs) working in agricultural development, there is a clear opportunity to provide both material and advisory support. Programs that offer micro-loans, access to affordable agricultural tools, or technology transfers will be beneficial in encouraging farmers to adopt these practices. Non-Governmental Organizations (NGOs) should also support the development of market linkages that enhance the profitability of value-added products, thus motivating farmers to adopt value addition practices. Through supporting resource allocation, technical training, and marketing efforts, private and non-governmental organizations are able to play a critical role in promoting sustainable agriculture in Kitui and Wajir Counties.

Abbreviations

SLF	Sustainable Livelihoods Framework
KII	Key Informant Interviews
SPSS	Statistical Package for the Social Sciences
IoT	Internet of Things
MAR	Managed Aquifer Recharge
NGO	Non-Governmental Organization
STI	Science, Technology, and Innovation
KCSAP	Kenya Climate-Smart Agriculture Project
WSTF	Water Sector Trust Fund

ACGSF Agricultural Credit Guarantee Scheme Fund
ARDL Auto Regressive Distributed Lag

Conflicts of Interest

The authors declare no conflict of interest.

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