Research Article

Exploring the Economic Implications of IoT Adoption in Agriculture: A Cost-Benefit Study in Jazan, Saudi Arabia

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Abstract | This study examines the economic implications of IoT adoption in agriculture, highlighting significant positive correlations between IoT knowledge, smart irrigation techniques, and economic outcomes among farmers in Jazan. The results show that IoT technologies substantially improve farmers' resource efficiency, productivity, and sustainability for farmers, supporting the adoption of IoT solutions in the agricultural sector. Also, the study explores the potential economic impact of the adoption of Internet of Things technology in the agricultural sector, focusing on Jizan in Saudi Arabia and subsequently on Knowledge and Awareness of the Internet of Things, Smart Irrigation Techniques, and Benefits and Economic Outcomes, and consequently, how these factors influence the adoption of Internet of things technologies among local farmers. The results of the study show that farmers' knowledge and awareness of IoT technology and their willingness to adopt Internet of Things technologies have a significant positive correlation, which supports the first hypothesis. A second hypothesis that has been affirmed by this study is that the adoption of Smart Irrigation Techniques and the adoption of the Internet of Things are closely linked. IoT is becoming increasingly important to farmers who implement smart irrigation practices, which is reflected in their tendency to integrate IoT technologies into their agricultural operations as well. Accordingly, a third hypothesis is substantiated, which asserts that perceived benefits and economic outcomes of IoT adoption are the driving factors for the adoption of IoT. There is a strong tendency for farmers to embrace IoT technologies when they perceive substantial economic gains that can be obtained through their implementation. In Jizan's agricultural sector, these results highlight the economic rationale behind the adoption of IoT, emphasizing the importance of knowledge, sustainable practices, and incentives as primary drivers of IoT adoption. IoT adoption in the region has been described as a dynamic process, and this study contributes valuable insights into how IoT adoption is evolving within the region, offering implications for policymakers, agricultural stakeholders, and future research projects.

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Introduction

Traditional farming methods are changing as a result of the internet of things incorporation into agriculture, becoming more data-driven, effective, and profitable. IoT technologies hold great promise for tackling issues like water scarcity and climate variability in the Jazan region of Saudi Arabia, where distinct agricultural and environmental conditions necessitate creative solutions. With an emphasis on its economic ramifications and farmer acceptance, this study explores the potential of IoT to optimize agricultural practices while offering insights into the benefits and knowledge that motivate IoT use in the area. Due to the potential for these technologies to convert conventional farming methods into a data-driven, effective, and financially viable system, there has been a lot of interest in incorporating Internet of Things (IoT) technologies into agricultural practices in recent years (Gubbi *et al*., 2013; Mondal *et al*., 2021). Because of its distinct environmental conditions and agricultural significance, Jizan, a region in southwest Saudi Arabia that has emerged as one of the nation's most significant agricultural regions, offers special promise for the adoption of IoT solutions in agricultural practices. Jizan's agriculture industry faces many obstacles, from a shortage of fresh water to shifting weather patterns to improved resource management and higher output (Food and Agriculture Organization of the United Nations). Thus, IoT applications in Jizan present a great opportunity to overcome these challenges and to enhance the economic viability of farm practices as a result of the application of IoT technologies.

The term smart technology is not universally recognized and understood as a unique term. A very common understanding of automated adaptive behavior is that it refers to the ability to adapt and modify a given system's behavior so that it fits into the environment through the use of sensing and analyzing information so that performance can be improved (Nielsen *et al*., 2019). Several smart technologies exist today, bearing in mind that we already have a variety of ICT technologies, services, and devices at our fingertips (Popkova and Sergi, 2020), supporting a wide variety of applications in areas such as healthcare, education, business, agriculture (where AI and smart systems are being increasingly applied to optimize crop management and resource usage (Gulzar, 2024; Alkanan and Gulzar, 2024), and manufacturing (Cioffi *et al*., 2020; Chen, 2020; Issa *et al*., 2016). In general, if these technologies are applied effectively within complex systems, productivity and performance will be increased as a result. In addition, it is often regarded as having an increase in quality of life due to the fact that it contributes to the better meeting of human needs (Issa *et al*., 2017).

Smart technology in agriculture, often referred to as precision agriculture, leverages artificial intelligence (AI) and Internet of Things (IoT) devices to manage and optimize all facets of agricultural production (Gulzar *et al*., 2024a, b). These technologies enhance decision-making through real-time data collection and analysis, leading to improved yield and resource efficiency. AI-powered algorithms can predict optimal planting schedules, disease outbreaks, and irrigation needs (Gulzar, 2024; Amri *et al*., 2024; Gulzar *et al*., 2023), significantly improving the sustainability of farming practices. The Internet of Things will significantly affect various aspects of our lives, including advanced industries, smart cities, and the use of novel technologies in connected cars of the future (Kamienski *et al*., 2017; Jabbari *et al*., 2023). It is expected that the Internet of Things will have a far greater impact on agriculture than it has already done in the past.

The ease with which cutting-edge technologies, such as the internet of things, can be leveraged to address the complex challenges faced by modern agriculture has emerged as a transformative avenue for resolving some of the technical challenges inherent in modern agriculture to address the complex challenges inherent in modern agriculture. The Internet of Things, also known as the Internet of Things, is an emerging technology that consists of a network of interconnected devices that can collect and transmit data to revolutionize agricultural practices worldwide (Atzori *et al*., 2010; Dlodlo and Kalezhi, 2015). In the southwestern region of Saudi Arabia, there has been a great deal of discussion about the impact of the Internet of Things on the agricultural sector. Jizan is a region nestled in the southwestern reaches of the country. With its diverse agricultural landscape and climatic variability, Jizan is emblematic of many regions in the world that strive to maximize their use of resources and increase their agricultural productivity to maximize their income (Alotaibi *et al*., 2023). Jizan's agriculture fabric promises to be able to not only tackle the challenges posed by water scarcity and climate change, but also develop an agricultural ecosystem that is both sustainable and economically viable as a result of the integration of IoT technologies.

Considering the comprehensive economic implications of the adoption of IoT in agriculture, it is essential to conduct a detailed analysis of the cost-benefit dynamics that affect farmers' decisions as to whether they decide to adopt these technologies or not. The objective of this study is to conduct a comprehensive cost-benefit analysis on IoT adoption in agricultural operations in Jizan, Saudi Arabia, in order to identify factors that influence adoption decisions and evaluate the economic outcomes of these adoption decisions. The objective of this study is to provide insight into the economic feasibility and potential for improved agricultural sustainability through the integration of IoT in Jizan by examining the knowledge and awareness of IoT among farmers, benefits and economic outcomes, smart irrigation techniques.

Due to the fact that they have the potential to revolutionize traditional agriculture practices, Internet of Things (IoT) technologies have been increasingly popular in agriculture over the past few years because it appears they have the ability to change the way agricultural practices have been carried out. IoT is being used in agriculture in a variety of ways to monitor and manage various aspects of farming operations, utilizing sensors, data analytics, and communication networks (Asplund and Nadjm-Tehrani, 2016).

According to the Food and Agriculture Organization of the United Nations (FAO), the world's food production needs to increase by 70 % by 2050 in order to feed 9.6 billion people. Consequently, the Internet of Things can be used in order to develop smart agriculture as a result. A total of 36 billion dollars' worth of damages have been caused by both weather disasters and biological disasters, over the past ten years (Marcu *et al*., 2019). A wide range of options are available to assist in monitoring agriculture processes as well as providing outstanding features and facilities. However, it is necessary to consider the accuracy and relevance of the measurements when making decisions based on the results of the analysis carried out on the gathered data, which is a concern when it comes to making decisions. In collaboration with beecham research, liliberium is enhancing knowledge of smart agriculture as an application important to the Internet of Things market, offering a deeper understanding of how wireless sensor networks can have a positive impact on reducing crop losses and increasing production (Marcu *et al*., 2019).

IoT is an umbrella term that describes the movement of devices that are designed to perform individual tasks autonomously in order to carry out relevant tasks on their own (Dudhe *et al*., 2017). There are many examples of systems that regulate the temperature of a room or the alarm and surveillance systems as a result of dynamic control (Dudhe *et al*., 2017). As described in a Machine to Machine (M2M) model (Sohraby *et al*., 2018), the Internet of Things assumes that devices are embedded with embedded computing capabilities that enable them to communicate autonomously with other devices and systems. As part of the IoT paradigm, humans may also be expected to interact with the IoT (Mittal *et al*., 2015). With the advent of IoT technology, several different types of applications are becoming more and more common, including one based on industry, the other based on agriculture, and the third based on entertainment (Dudhe *et al*., 2017; Suppatvech *et al*., 2019). Recent advances in IoT ecosystems have resulted in many aspects of modern industry being sensitive to IoT developments, including the improvement of supply chains, tracking assets, and machine operation, which have all been impacted by the IoT developments (Gubbi *et al*., 2013).

A farmer can monitor and analyze crucial data in real time using internet of things technology including soil moisture content, temperature, humidity, and many other details in order to provide appropriate and correct support in real time. With the help of this data irrigation, fertilizer and other inputs can be optimized to improve crop yields and crop quality resulting in higher crop yields (Seelwal *et al*., 2024). Various studies have demonstrated that the IoT can allow farmers to better manage crops through the provision of affordable devices that can detect stress conditions in crop fields and alert a broader set of farmers about the crop condition in (Vitali *et al*., 2021). The application of this technology also provides access to a wide variety of data, enables the development of innovative farm services using machine learning techniques (MLT), and enables reliable storage. As a result of the internet of things, farmers have access to timely and accurate information that allows them to manage their crops efficiently and effectively. By doing so, they are able to make informed decisions, which will enhance their crop yields and reduce the costs associated with them. There are a number of internet of things-enabled sensors, which can help farmers get real-time soil moisture data, such as those available from Crop. By improving irrigation practices, they can optimize irrigation practices and reduce the amount of water that is consumed. Aside from that, there are additional benefits that can be derived from these technologies. These include, for example, the ability to make informed decisions regarding the application of fungicides, the ability to monitor nitrogen absorption by plants, and the ability to identify salt accumulation in soil (Chai *et al*., 2023). Moreover, John Deere's Field Connect system, which is used by a number of companies such as (Vitali *et al*., 2021), utilizes IoT sensors to monitor soil moisture, weather conditions in crops, and other environmental factors as a part of its monitoring process. As a result of collecting this data, farmers will be able to access it on a cloud-based platform where they will be able to optimize their irrigation and fertilization practices based on the data that will be collected.

As a result of climate change, the water cycle has been altered substantially, which has also led to an increase in drought severity (Hussain *et al*., 2022; Malik *et al*., 2023). Hence, in the current situation, the efficient use of water in agricultural systems is one of the biggest concerns. Because a large part of the world is inclined to droughts every year, there has been a lot of attention recently focused on water loss due to limited water supply. The traditional irrigation system, which is based on manual labor, cannot achieve water-saving goals and cannot supply enough water to meet the needs of farmers (Kanuru *et al*., 2021). This problem can be solved effectively by using intelligent irrigation techniques to not only provide the most efficient possible use of water but also to save it for the future (Bwambale *et al*., 2022). Moreover, smart irrigation can reduce the cost of the inputs for farmers, thus providing relief to them (Kanuru *et al*., 2021). By observing plants or crops in the field every day and scheduling irrigations, manual irrigation requires a lot of manpower. However, if you use a sensor-assisted irrigation system, it can identify soil moisture within the soil profile and initiate irrigation automatically, making irrigation control much more efficient than manual irrigation, which is much more efficient than manual irrigation (Ragab *et al*., 2022). An irrigation decision-support system will be used to monitor the water demand and control irrigation applications in crops by incorporating sensors that monitor soil moisture and climate conditions. In recent years, technological advancements have resulted in the development of decision-support-assisted irrigation systems, which have improved irrigation accuracy and efficiency (Ali *et al*., 2023). This system incorporates a soil moisture sensor, a climate sensor, and a cloud system that is assisted by the internet, so that real-time data analysis is possible online. As part of this study, we examined the impact of irrigation on crop growth and productivity estimation through the use of dynamic simulation models that were linked together. Moreover, based on the data analysis and predictions of the yields, an irrigation size has been determined, which is provided automatically concluded a system that controls the irrigation quantity. Using a remote control or mobile application (Muangprathub *et al*., 2019). The modern irrigation hub can also be easily controlled and operated via a remote control or mobile application. As can be seen in Figure 1.

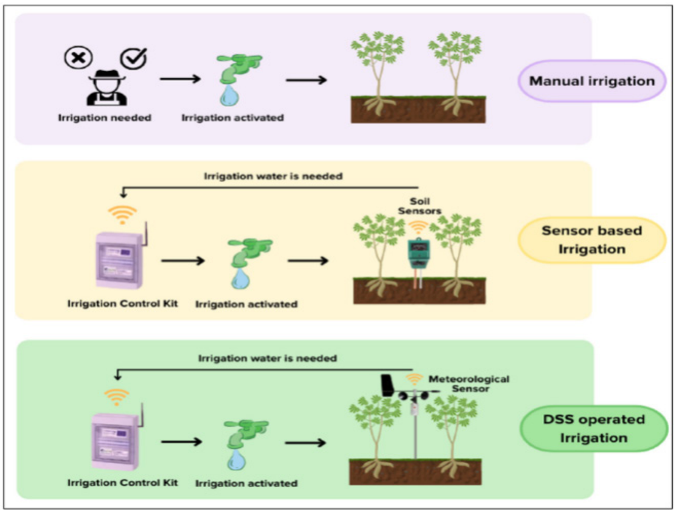

Figure 1: *Irrigation with manual techniques versus smart sensor based applications and systems that aid decision-making.*

In recent years, IoT (Internet of Things) technologies have gained considerable attention in the agricultural sector, with a significant increase in the adoption of these technologies. Throughout this section we will explore the adoption of IoT technologies among farmers and highlight the key factors that influence their decisions to adopt these technologies. It was found in a study conducted by (Smith *et al*., 2021). That the majority of farmers in the United States are aware of the Internet of Things technologies and have a positive attitude toward their adoption. Farmers seem to be increasingly interested in and accepting of Internet of Things technologies as a result of this survey. There are a number of factors that influence Internet of things technologies in different ways. There is no doubt that the benefits of these technologies play a crucial role in their adoption. A study by Liu *et al*. (2020) found that farmers perceive the IoT as a powerful tool that enables them to make proactive decisions, optimize resource allocation and monitor crop health in real time. In addition to the accuracy and timing of the information offered by Internet of Things technologies, Internet of Things technologies also enable real-time monitoring of crop conditions and environmental factors (Tao *et al*., 2021).

Although Internet of Things technologies are becoming increasingly popular in agriculture, there are still challenges associated with adopting them in the sector. Internet of Things devices can pose a barrier to adoption due to a lack of technical knowledge and skills that are required to operate them (Gao *et al*., 2021). The adoption of Internet of Things technologies in farming practices may require farmers to receive training and support in order to do so effectively. Moreover, there are concerns regarding the privacy and security of data that pose a challenge to adoption. There is a strong desire, on the part of farmers, to ensure that their personal data is protected and not misused (Khan *et al*., 2023).

A decisive role is played by the government in facilitating the adoption of Internet of Things technologies in agriculture, due to the support provided by the government. Farmers' decisions on how to adopt Internet of Things technology can be positively influenced by policies that promote the use of Internet of Things technologies, as well as provide financial incentives. A study carried out by Li and Wang (2021) demonstrated that farmers who perceived strong government support for the implementation of Internet of Things technologies were more likely to do so. Furthermore, in order for adoption to be successful, it is imperative to have access to information and training resources. There is a need for farmers to have access to reliable and pertinent information regarding IoT technologies, the benefits they provide, and how to effectively implement them. It has been reported that farmers can become more competent and knowledgeable in using Internet of Things technologies for crop monitoring by participating in training programs and workshops (Zheng *et al*., 2020).

As the use of Internet of Things technologies in agriculture has increased over the past few years, there has been an increasing awareness of its potential to improve efficiency and productivity in the agriculture sector. The use of Internet of Things technologies in the agricultural sector can be advantageous in many ways, including enhancing the monitoring of crops, enhancing productivity, and optimizing resource management, amongst others. This section aims to examine the extent to which farmers and stakeholders are becoming aware of the potential advantages and benefits that can be gained from the application of Internet of Things technologies in agriculture and what they can do in response to that.

Li *et al*. (2020) Internet of Things technologies that to improve crop health and growth during the growing season, farmers will be able to make more informed decisions regarding the allocation of resources based on the information obtained from Internet of Things technologies. As the study highlights, it is imperative for farmers to become aware of the capabilities and benefits of IoT technologies by increasing their levels of awareness. Similarly, Liu *et al*. (2020) discuss how IoT-based crop growth monitoring systems play an important role in ensuring that farmers have the ability to monitor key parameters such as soil moisture, temperature, and nutrient levels, which leads to better crop management practices and higher yields.

An IoT-based smart agriculture survey conducted by the company Hassan *et al*. (2020) showed that most farmers were aware of the concept of IoT-based smart agriculture to some degree. It was also found through the study that awareness levels differed according to the region and the size of the farm. In light of this, it is apparent how crucial it is to tailor awareness campaigns and educational activities to specific contexts and target groups in order to attain maximum impact.

There are many benefits and economic outcomes that can be achieved by applying Internet of Things (IoT) technology to agriculture, which is part of the reason why it has become a topic of major research interest.

Community farming

When IoT is implemented, there is a great chance of promoting community farming in rural areas by using IoT. Using the Internet of Things as a tool, we can improve services that create access to a common data storage system for the community by using the

Internet of Things. There is a strong potential that farmers and agricultural experts can share data and information in this way, resulting in more interactions between them 6 (Bo and Wang, 2011). Mobile apps and IoT facilities can also be used to share equipment within a community through the use of free and paid services based on the availability of these services through the use of mobile apps and IoT facilities within the community.

Safety control and fraud prevention

There are a number of challenges that face the agriculture sector, not just in terms of producing enough food but also being able to guarantee the safety and nutritional quality of the food produced. Food fraud has been reported on several occasions, which include adulteration, counterfeiting, and the addition of artificial substances to food (Marvin *et al*., 2016). This fraud poses a number of health risks as well as having a negative impact on the economy (Tähkäpää *et al*., 2015; Manning, 2016). As part of the discussion on food fraud in (Manning, 2016), it is identified that the IoT technology can assist in addressing some of the components of fraud, such as product integrity, process integrity, people integrity, and data integrity. Food can be traced qualitatively and logistically by utilizing the Internet of Things (IoT) (Folinas *et al*., 2006).

Competitive advantages

There is a strong expectation that agriculture will become more competitive as a result of food demand and innovative technology. It is also important to note that in the near future, there will be a wide range of new opportunities in the fields of trading, monitoring, and marketing as well. There are several reasons for this, including the use of IoT to enable data-driven agriculture. A reduction in costs, as well as a reduction in wastage, can be achieved by using farm inputs such as fertilizer and pesticides in an efficient manner. The result of this can be an increase in productivity. The adoption of the internet of things ecosystem has the potential to provide farmers with a competitive edge by increasing their ability to use real-time data to make informed decisions, and by doing so, improving their competitive advantage.

Wealth creation and distributions

The deployment of Internet of Things will lead to the development of new business models where single farmers will be able to avoid being exploited by "middlemen" and be able to establish direct contact with their consumers Dlodlo and Kalezhi (2015) resulting in higher profits for the farmers.

Cost reduction and wastage

The ability to remotely monitor devices and equipment is one of the perceived advantages of the IoT (Asplund and Nadjm-Tehrani, 2016). With the use of Internet of Things technology in agriculture, the time and money that would otherwise be spent by personnel physically inspecting large fields will be saved, as compared to personnel that would use vehicles or walk to inspect the fields. In order to reduce costs and wastage, IoT can be used as a tool to predict when and where pesticides and insecticides should be applied.

IoT technologies are increasingly being used in agriculture, but despite the growing body of research on the use of these technologies, there is still a notable gap among farmers in specific regions in terms of how they perceive and adopt these technologies, such as Jizan, Saudi Arabia, where they have a significant presence. The majority of Internet of Things applications in agriculture have been discussed in general terms or have examined how adoption patterns vary in different geographical contexts due to the lack of specific studies (Li *et al*., 2020; Wang and Tang, 2020). The specific factors that influence the adoption of Internet of Things technology in Jizan's agricultural sector remain largely unexplored, however even though their adoption in Jizan is predicted to grow. This study identifies a need for an extensive investigation in regards to the technical aspects of the adoption of the Internet of Things in agriculture with a special focus in Jizan, Saudi Arabia, to fill the research gap identified in this study. As part of this study, economic implications of the adoption of the IoT were explored, considering factors such as knowledge and awareness about Internet of Things, smart irrigation techniques (SIT) and also benefits and economic outcomes (BEO) resulting from adoption.

As a result of its location in Saudi Arabia's southwestern region, Jizan has its own unique agricultural landscape, with its own set of climatic conditions, crop varieties, and farming techniques, making it one of the most productive cities in the country. Farmers attitudes, awareness, and willingness to adopt Internet of Things technologies for agricultural use can be significantly influenced by context factors, which in turn can significantly affect farmers' adoption of Internet of Things devices.

This study aims to fill this gap in the literature by investigating how farmers in Jizan adopt Internet of Things technologies for crop monitoring through a focused investigation that explores the adoption of Internet of Things technologies for crop monitoring. As a result of these findings, we can hope that we will be able to develop a better understanding of the specific factors that influence the adoption intentions of farmers in Jizan. The factors that contribute to these outcomes are Knowledge and awareness about Internet of Things among farmers, the benefits and economic outcomes of using Internet of Things, as well as smart irrigation techniques. The knowledge gained from this study can be used to develop targeted policies and strategies to promote the successful implementation and utilization of Internet of Things technologies in Jizan's agriculture sector in order to help it prosper in the future.

Objective and hypothesis

Objective 1: To assess the knowledge and awareness of IoT in agriculture among farmers in Jizan, Saudi Arabia.

1st Hypothesis

Hypothesis (H1): The level of knowledge and awareness of IoT in agriculture significantly affects the adoption of IoT technologies in Jizan, Saudi Arabia.

Objective 2: To analyze the Smart Irrigation Techniques associated with adopting IoT technologies in agriculture in Jizan, Saudi Arabia.

2nd Hypothesis

Hypothesis (H2): Smart Irrigation Techniques significantly influence farmers' decisions to adopt IoT technologies in Jizan, Saudi Arabia.

Objective 3: To evaluate the benefits and economic outcomes experienced by farmers who have adopted IoT technologies in Jizan, Saudi Arabia.

3rd Hypothesis

Hypothesis (H3): There are significant differences in the perceived benefits and economic outcomes among farmers who have adopted IoT technologies in Jizan, Saudi Arabia.

Materials and Methods

Sampling was conducted with a total population of approximately 600 farmers in Jazan, Saudi Arabia. The study used stratified random sampling to ensure diverse representation based on farming experience, education, and farm size. A confidence interval of 95% with a margin of error of ±5% was used. A structured questionnaire was distributed to selected farmers as a means of collecting primary data. The purpose of the survey was to measure variables related to Knowledge and Awareness of IoT, Smart Irrigation Techniques, Benefits and Economic Outcomes, as well as other relevant factors related to the IoT. With the help of trained research assistants, questionnaires were administered to farmers in order to obtain their responses. Throughout the process, participants were assured that their responses would be kept confidential. As part of the study, 600 respondents were surveyed, consisting of farmers who have adopted IoT technologies as well as farmers who have not. A descriptive analysis was carried out to summarize the characteristics of the sample, including its demographics as well as its years of farming experience, by using descriptive statistics. For the purposes of examining the relationship between the independent variables (Knowledge and Awareness of IoT, Smart Irrigation Techniques, Benefits and Economic Outcomes) and the dependent variable, Adoption of Internet of Things technologies, multiple regression analysis was conducted. Durbin-Watson used for Autocorrelation and also applied Collinearity Statistics for multicollinearity. Cronbach's Alpha was used for reliability statistics. The data was analyzed using SPSS, and a significance level of 0.05 was used for hypothesis testing.

Reliability of the data collection tool

The most notable statistic is Cronbach's Alpha (α), which is .882 which is shown in Table 1. A Cronbach's Alpha of 0.70 or higher is typically considered good internal consistency. According to Alpha of 0.882 indicates that the 20 items in the questionnaire are highly consistent and measure the same underlying construct reliably. This suggests that the questionnaire is a reliable tool for assessing the variables or concepts of interest in research. Overall, the high Cronbach's Alpha value provides confidence in the internal reliability of the questionnaire, which is essential for conducting meaningful and reliable analyses in research on the economic analysis of IoT adoption in agriculture in Jizan, Saudi Arabia (Figure 2).

Figure 2: *Study area map, Jazan-Saudi Arabia.*

Table 1: *Reliability statistics.*

Mean	Variance	Std. deviation	Cronbach's Alpha α	N of items
57.68	208.39	14.436	0.882	20

Response rate regarding research tool

Table 2 shows a high response rate of 92.32% among farmers in Jizan, Saudi Arabia is a positive sign for research study. A strong level of engagement and interest were found in former among participating in questionnaire. This high response rate enhances the validity and reliability of research findings, as it indicates that a significant portion of farmer provided their input.

Results and Discussion

Demographic details of the respondents

The study was conducted to investigate the economic implications of Internet of Things adoption in agriculture in the region, and presented results from the study on Economic Analysis of IoT Adoption in Agriculture: A Cost-Benefit Study in Jizan, Saudi Arabia. To assess the impact of various factors on farmers adoption of Internet of Things technology, various factors such as Knowledge and Awareness of IoT, Smart Irrigation Technologies, Benefits and Economic Outcomes were examined. Each research objective and hypothesis are covered in a separate section. This study highlights how IoT adoption is economically based, underscoring that factor like awareness of IoT, smart irrigation techniques, perceived benefits, and economic outcomes drive IoT adoption among Jizan farmers.

Table 2: *Response rate.*

Respondent type	Total questionnaire	Return questionnaire	Percentage rate of questionnaire
Farmer	650	600	92.32

Table 3: *Frequency and percentage distribution of the demographic details of the respondents.*

Respondent type	Total questionnaire	Return questionnaire	Percentage rate of questionnaire
Farmer	650	600	92.32
Demography details of the respondents			
Variables	Frequency		Percentage (%)
Gender			
Male	394		65.7
Female	206		34.3
What is your educational level?			
Doctoral degree	131		21.8
Master's degree	188		31.3
Bachelor's degree	116		19.3
Undergraduate	165		27.5
Years of farming experience			
No experience	180		36.0
1 to 3-year experience	164		32.8
4 to 5-year experience	97		19.4
6 to 7-year experience	50		10.0
more than 7-year experience	9		1.8
What is your marital status?			
Single	128		21.3
Married	329		54.8
Divorced	111		18.5
Widowed	32		5.3
Farmers who have adopted IoT technologies or non-adopted			
Not adopted	277		46.2
Adopted	323		53.8

According to Table 3 and graphs show that gender distribution among respondents the majority (65.7%) are male, while 34.3% are female. This gender distribution provides insight into the composition of sample and may influence the analysis of IoT adoption and economic outcomes in agriculture in Jizan, Saudi Arabia. It's important to consider potential gender-specific factors when assessing the economic impact of IoT adoption, as there may be differences in technology adoption and outcomes between male and female farmers. The distribution of respondents based on their years of farming experience offers insightful context for comprehending the study's participant demographics. Notably, a significant portion of the respondents (36.0%) reported having no prior farming experience, while 32.8% had accumulated 1 to 3 years of experience. Additionally, 19.4% indicated 4 to 5 years of farming experience, 10.0% reported 6 to 7 years, and a smaller fraction, 1.8%, boasted more than 7 years of experience. The distribution of respondents across various educational levels underscores the diversity of educational backgrounds within the study's reveals that 21.8% of respondents hold Doctoral degrees, 31.3% possess Master's degrees, 19.3% have completed Bachelor's degrees, and 27.5% are at the Undergraduate level. The distribution of respondents across various marital statuses offers insight into the diverse marital backgrounds represented in the study's as 21.3% of respondents are single, while the majority, comprising 54.8%, are married. Additionally, 18.5% of respondents reported being divorced, while 5.3% indicated being widowed. The distribution of respondents into two distinct categories, "Not adopted" (46.2%) and "Adopted" (53.8%) IoT technologies, forms a pivotal variable within the study. This differentiation serves as the cornerstone for assessing the economic outcomes and perceptions of these two distinct groups of farmers. It enables a comprehensive cost-benefit analysis of IoT adoption within the agricultural landscape of Jizan, Saudi Arabia.

Results regarding hypothesis 1, Model summary, ANOVA and coefficients

The test results of hypothesis 1 are mentioned in Table 4. According to Table 4, the Durbin-Watson statistic is 1.845. Typically, values between 1.5 and 2.5 are considered acceptable, indicating that there is no significant autocorrelation in the residuals. According to model summary have strong evidence to conclude that there is a statistically significant and positive relationship between knowledge and awareness of IoT in agriculture (KAI) and the adoption of IoT technologies (AIT) in Jizan, Saudi Arabia, in line with the Hypothesis 1.

Moreover, ANOVA results have strong evidence to conclude that the level of knowledge and awareness of IoT in agriculture (KAI) significantly affects the adoption of IoT technologies (AIT) in Jizan, Saudi Arabia, consistent with Hypothesis 1 as shown in Table 4.

Similarly, Table 4 also expressed that the coefficient for knowledge and awareness of IoT (KAI) is 0.715. Means that, on average, for every one-unit increase in the level of knowledge and awareness of IoT in agriculture (KAI), the adoption of IoT technologies (AIT) increases by 0.715 units. The significance value associated with KAI is highly significant ($p < .001$), confirming that KAI is a statistically significant predictor of AIT. The high tolerance (1.000) and low

Table 4: *Hypothesis 1, model summary, ANOVA and coefficients.*

Model summary								
Model		**R**		**R square**	**Adjusted R square**	**Std. error of the estimate**	**Durbin-Watson**	
1		0.635[a]		0.404	0.403	3.82036	1.845	
ANOVA								
Model		**Sum of squares**		**Df**	**Mean square**	**F**	**Sig.**	
1	Regression	5907.054		1	5907.054	404.727	<.001[b]	
	Residual	8727.904		598	14.595			
	Total	14634.958		599				
Coefficients[a]								
Model		**Unstandardized coefficients**		**Standardized coefficients**	**T**	**Sig.**	**Collinearity statistics**	
		B	**Std. Error**	**Beta**			**Tolerance**	**VIF**
1	(Constant)	4.486	0.536		8.364	<0.001		
	KAI	0.715	0.036	0.635	20.118	<0.001	1.000	1.000
a. Predictors: (Constant), KAI								
b. Dependent Variable: AIT								

VIF (1.000) values for KAI suggest no issues with multicollinearity, indicating that KAI is a robust predictor in the model. Have strong evidence to conclude that the level of knowledge and awareness of IoT in agriculture (KAI) significantly and positively affects the adoption of IoT technologies (AIT) in Jizan, Saudi Arabia, consistent with Hypothesis 1.

Results regarding hypothesis 2, model summary, ANOVA and coefficients

The results regarding hypothesis 2 are given in Table 5 that the Durbin-Watson statistic is 1.797, indicating no significant autocorrelation in the residuals, which suggests that the model's assumptions are met. According to table have evidence to conclude that Smart Irrigation Techniques (SIT) have a statistically significant influence on farmers' decisions to adopt IoT technologies (AIT) in Jizan, Saudi Arabia, consistent with Hypothesis 2.

Furthermore, Table 5 highlighted that the significance value associated with the F-statistic is much less than 0.001 (<.001), which is highly significant. This further supports the conclusion that the regression model, with SIT as a predictor, is statistically significant and strong evidence to conclude that Smart Irrigation Techniques (SIT) have a statistically significant influence on farmers decisions to adopt IoT technologies (AIT) in Jizan, Saudi Arabia, consistent with Hypothesis 2.

Similarly, the coefficient for SIT is 0.648 as shown in Table 5. This means that, on average, for every one-unit increase in Smart Irrigation Techniques (SIT), the adoption of IoT technologies (AIT) increases by 0.648 units. The significance value associated with SIT is highly significant ($p < .001$), confirming that the coefficient for SIT is highly significant in explaining AIT. The high tolerance (1.000) and low VIF (1.000) values for SIT suggest no issues with multicollinearity, indicating that SIT is a robust predictor in the model. According to the Coefficients table, have strong evidence to conclude that Smart Irrigation Techniques (SIT) have a statistically significant and positive influence on farmers' decisions to adopt IoT technologies (AIT) among farmers in Jizan, Saudi Arabia, consistent with Hypothesis 2. The standardized coefficient (Beta) reinforces the practical significance of this relationship.

Results regarding hypothesis 3, model summary, ANOVA and coefficients

The Durbin-Watson statistic is 1.865, indicating no significant autocorrelation in the residuals shown in Table 6, which suggests that the model's assumptions are met. Based on the model summary, there is limited support for Hypothesis 3, which suggests that there are significant differences in the perceived benefits and economic outcomes among farmers who have adopted IoT technologies in Jizan, Saudi Arabia. The model suggests a relatively weak influence of perceived economic benefits and outcomes (BEO) on the adoption of IoT technologies (AIT).

Table 5: *Hypothesis 2, model summary, ANOVA and coefficients.*

Model summary								
Model		**R**		**R square**	**Adjusted R square**	**Std. error of the estimate**	**Durbin-Watson**	
1		0.596[a]		0.355	0.354	3.97308	1.797	
ANOVA								
Model		**Sum of squares**		**Df**	**Mean square**	**F**	**Sig.**	
1	Regression	5195.288		1	5195.288	329.120	<0.001[b]	
	Residual	9439.671		598	15.785			
	Total	14634.958		599				
Coefficients[a]								
Model		**Unstandardized coefficients**		**Standardized coefficients**	**T**	**Sig.**	**Collinearity statistics**	
		B	**Std. Error**	**Beta**			**Tolerance**	**VIF**
1	(Constant)	5.397	0.544		9.930	<.001		
	SIT	0.648	0.036	.596	18.142	<.001	1.000	1.000
a. Dependent Variable: AIT								
b. Predictors: (Constant), SIT								

Table 6: *Hypothesis 3, model summary, ANOVA and coefficients.*

Model summary								
Model		**R**		**R Square**	**Adjusted R square**	**Std. error of the estimate**	**Durbin-Watson**	
1		0.267[a]		.071	0.070	4.76800	1.865	
ANOVA								
Model		**Sum of squares**		**Df**	**Mean square**	**F**	**Sig.**	
1	Regression	1040.143		1	1040.143	45.753	<.001[b]	
	Residual	13594.815		598	22.734			
	Total	14634.958		599				
Coefficients[a]								
Model		**Unstandardized coefficients**		**Standardized coefficients**	**T**	**Sig.**	**Collinearity statistics**	
		B	**Std. error**	**Beta**			**Tolerance**	**VIF**
1	(Constant)	10.729	0.634		16.931	<0.001		
	BEO	0.293	0.043	0.267	6.764	<0.001	1.000	1.000
a. Dependent Variable: AIT								
b. Predictors: (Constant), BEO								

Moreover, F-Statistic (45.753) mentioned in Table 6, the high F-statistic value indicates that the regression model is statistically significant. This means that the relationship between BEO and AIT is not due to random chance. Instead, it suggests a meaningful and systematic relationship between the two variables. The significance value associated with the F-statistic is much less than 0.001 (<0.001), which is highly significant. This further supports the conclusion that the regression model, with BEO as a predictor, is statistically significant. Accordingly benefits and economic outcomes (BEO) have a statistically significant influence on farmers' decisions to adopt IoT technologies (AIT) among farmers in Jizan, Saudi Arabia, consistent with Hypothesis 3.

Furthermore, the coefficient for BEO is 0.293. This means that, on average, for every one-unit increase in benefits and economic outcomes (BEO), the adoption of IoT technologies (AIT) increases by 0.293 units shown in Table 6. The significance value associated with BEO is highly significant ($p < .001$), confirming that the coefficient for BEO is highly significant in explaining AIT. Benefits and economic outcomes (BEO) have a statistically significant and positive influence on farmers decisions to adopt IoT technologies (AIT) among farmers in Jizan, Saudi Arabia, consistent with Hypothesis 3. The standardized coefficient (Beta) reinforces the practical significance of this relationship.

Conclusions and Recommendations

This study sought to investigate the economic implications of IoT (Internet of Things) adoption in agriculture within the context of Jizan, Saudi Arabia. The research aimed to examine how factors such as Knowledge and Awareness of IoT (KAI), Smart Irrigation Techniques (SIT), and Benefits and Economic Outcomes (BEO) influence the adoption of IoT technologies among farmers in the region. A quantitative research approach was used in this study and primary data was collected by completing structured questionnaires. 1st hypothesis is knowledge and awareness of IoT in agriculture significantly affect the adoption of IoT technologies in Jizan, Saudi Arabia. The analysis revealed a significant positive relationship between Knowledge and Awareness of IoT and Adoption of IoT technologies among farmers in Jizan, Saudi Arabia. Those farmers who demonstrated higher levels of awareness and knowledge of IoT technologies were more likely to adopt them in their agricultural practices than those who demonstrated lower levels of knowledge and awareness. In view of this finding, it is evident that education and awareness initiatives must be promoted to enhance the adoption of IoT among farmers in the region to promote its adoption. According to 2ndhypothesisSmart Irrigation Techniques significantly influence farmers' decisions to adopt IoT technologies in Jizan, Saudi Arabia. The results indicated that Smart Irrigation Techniques have a statistically significant and positive influence on farmers decisions to adopt IoT technologies. It has been found that farmers who adopted Smart Irrigation Techniques were more inclined to adopt IoT technologies for the purpose of optimizing their irrigation practices. In the context of agriculture, this suggests that IoT adoption is driven largely by the implementation of efficient irrigation methods, which aligns with the broader goal of resource conservation, which allows for IoT adoption to take place. According to 3rd hypothesis the significant differences in the benefits and economic outcomes among farmers who have adopted IoT technologies in Jizan, Saudi Arabia. Benefits and Economic Outcomes were found to have a statistically significant and positive impact on the adoption of IoT technologies among farmers in Jizan, Saudi Arabia. The farmers who perceived greater economic benefits and positive outcomes from IoT adoption were more likely to adopt IoT technologies. This finding highlights the economic rationale behind IoT adoption in agriculture, suggesting that farmers are motivated by the potential for improved economic returns and outcomes.

Several critical decisions have emerged from the study titled "Economic Analysis of IoT Adoption in Agriculture: A Cost-Benefit Study in Jizan, Saudi Arabia," which provides a cost-benefit analysis of the advent of IoT in the region's agricultural sector. The study concluded that there was a significant positive relationship between knowledge and awareness of Internet of things (KAI) and the adoption of IoT technologies (AIT), indicating that investing in awareness and education initiatives is crucial. A further consideration is the promotion of Smart Irrigation Techniques (SIT), which has been found to influence farmers' IoT adoption decisions, leading to more resource-efficient practices by encouraging them to adopt SIT. Due to the positive impacts of benefits and economic outcomes (BEO) on adoption, financial incentives, such as subsidies and support programs, are a pivotal step in motivating farmers to adopt new technologies. Internet of Things implementation via providing technical as well as financial assistance is crucial in order to ensure success. In order to achieve this goal, continuous monitoring and evaluation of adoption trends should be established, and a collaborative approach should be promoted among stakeholders. Lastly, it is recommended that a well-defined policy framework be developed in order to align the efforts and policies with the study's recommendations, resulting in a successful integration of the Internet of Things in Jizan's agriculture, improved sustainability, and enhanced economic outcomes for farmers.

This study provides valuable insights into the economic dynamics of Internet of Things (IoT) adoption in agriculture in Jizan, Saudi Arabia. It demonstrates that fostering knowledge, promoting efficient practices, and highlighting economic benefits are crucial strategies for realizing the potential of Internet of Things (IoT) in agricultural sustainability and economic development.

This study suggests several recommendations for enhancing IoT adoption in agriculture including: Farmers are encouraged to adopt IoT technologies through training programs and financial incentives, which can significantly enhance their productivity and sustainability practices. Future research can explore region-specific economic outcomes, particularly regarding ROI and competitive advantages in the agricultural sector.The findings of this study shed light on the economic analysis of Internet of Things adoption in agriculture in Jizan, Saudi Arabia. They underscore the significance of factors such as knowledge, smart irrigation practices, and benefits and economic outcomes in driving Internet of Things adoption among farmers. Based on these findings, several recommendations can be made:

- Education and Awareness Initiatives: Policymakers and agricultural organizations should invest in educational programs to enhance farmers' knowledge and awareness of internet of things (IoT) technologies. These programs can empower farmers to make informed decisions about Internet of Things adoption.
- Promotion of Smart Irrigation: Encouraging the adoption of Smart Irrigation Techniques can serve as a gateway to wider Internet of Things adoption in agriculture. Training and incentives for implementing efficient irrigation methods can be beneficial.
- Economic Incentives: The study underscores the importance of emphasizing the economic advantages of Internet of Things (IoT) adoption. Financial incentives, subsidies, or support programs can be designed to facilitate Internet of Things(IoT) adoption among farmers.
- Further Research: Future research should delve deeper into specific economic outcomes, such as return on investment (ROI), cost savings, and market competitiveness, to provide a comprehensive economic assessment of Internet of Things (IoT) adoption in Jizan's agriculture sector.

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Novelty Statement

This study offers a novel contribution by providing a detailed cost-benefit analysis of IoT adoption in agriculture in Jizan, Saudi Arabia, demonstrating how knowledge, smart irrigation practices, and perceived economic benefits drive IoT adoption among local farmers. It sheds light on the economic incentives required to encourage sustainable and efficient agricultural practices in regions facing environmental challenges.

Author's Contribution

Yonis Gulzar and Faheem Ahmad Reegu: Research, analysis and original draft preparation
Arjumand Bano Soomro: Helped in conducting research and analysis
Mohammad Shuaib Mir, Abdul Zahir and Choo Wou Onn: Helped in relevant literature, editing and format setting

Conflict of interest
The authors have declared no conflict of interest.

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