Transforming Agriculture With IoT in Nepal: Opportunities and Challenges

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Abstract

Internet of Things (IoT) has been developing rapidly for the last two decades and its application in diverse fields is increasing the performance and productivity by automation and sensor-based technology. It has been observed that the agriculture sector is using IoT-enabled technologies, *viz.* sensors, actuators, drones, and ultrasonic devices for automating most of the tasks that can reduce the amount of time; and to increase the overall efficiency and have a better crop yield, by making smarter decisions. Despite the largest portion of GDP in Nepal being contributed via agriculture, the traditional way of farming, lack of contemporary technologies and other infrastructure and crop-raiding animals; people are transforming the occupation and leaving the cultivating land bare. The landscape of the traditional agricultural system can be changed by introducing smart agriculture and precision farming. There are many opportunities for smart agriculture in Nepal, like improving the lifestyle of people and reducing overseas employment with sustainable agricultural development. In contrast, limited development in technology, digital divide and lack of governmental policy may challenge implementation.

***Keywords*:** smart agriculture, Internet of Things (IoT), precision agriculture, sensors, poly-houses, crop-raiding animals

Introduction

A few decades ago, agriculture was the main occupation of Nepal, and about 65% of the country's GDP was based on it (Timilsina et al., 2019). Later, the people have transformed their occupation from agriculture to service, industry, and remittance instead of improving agriculture and making it sustainable for survival. As a result, the major portion of land in the hilly region has been converted into bare land and forest. On the other hand, the limited portion (about 17%) of the total land is occupied by the *terai*

region, known for its fertile land, which has been utilized in the name of urbanization and development. This will create problems in the future regarding food and crops. The traditional and obsolete way of farming is also responsible for the reduction of agricultural production, which has been observed by many researchers (Duguma & Bai, 2025; Ahmed et al., 2018). One way to counter this problem can be a revolution in agriculture, which is possible by transforming agriculture to smart agriculture, as many developing countries have been adopting. The agriculture industry, government, and farmers need to embrace the IoT and related technologies like sensors, drones, and automation devices towards leveraging agricultural work to the next level, mitigating agriculture. As the IoT has been evolving rapidly, its widespread application in various disciplines such as healthcare, military, and surveillance does not leave the agriculture sector. Incentivizing youths in agriculture, reducing their number going overseas temporarily or permanently, and solving the problem of food starvation in the near future, it is mandatory to transform the traditional agriculture system into smart and precision agriculture. It is required to improve the agricultural products that incorporate the growing population and balanced food supply chain by introducing smart and precise agriculture.

Contributions of the Study

IoT applications in agriculture advances to diverse areas including automated irrigation system; soil and crop monitoring system and controlling system; livestock health tracking and monitoring system, and disease prevention, empowering farmers to optimize resources v*iz*. time and cost*;* boost productivity, protecting crops and harvesting from wild animals like monkey, wild boar (‘*Badel’*), hedgehog(‘*Doomsi’*) etc. This study mainly emphasized on the possibilities of deploying smart agriculture in Nepal:

- ✓ To enhance the lifestyle of farmers and make agriculture sustainable
- ✓ To reduce unemployment and motivate the youths towards precision farming
- ✓ To balance the food supply chain with growing population and reducing cultivated land
- ✓ To point out the challenges of smart agriculture implementation

Outlines of Study

It has been observed that agricultural products are improved by smart agriculture and precision farming in many developing countries (Abdennabi et al., 2024; Christopher et al. 2017; Duguma & Bai, 2025; Lamsal et al., 2023). Motivated by these facts, this

study presents the possibility of smart farming in Nepal with many opportunities and considerable challenges. The next section highlights the evolutionary development of smart agriculture with IoT applications. Extensive literature and practices for smart agriculture are mentioned in the literature review section. Some technologies that are more compatible to enhance the agriculture sector and sustain the farmers through agriculture in the context of Nepal are proposed in another section, method, and procedure. Finally, the paper is concluded with opportunities, challenges, and the future of smart agriculture in Nepal. The list of abbreviations used throughout this paper is listed in Table 1.

Table 1

List of Abbreviations

Terms	Abbreviations
AI	Artificial Intelligence
DQN-ENN	Deep Q-Network and Elman Neural Network
GDP	Gross Domestic Product
GIS	Geographical Information System
GPS	Global Positioning System
ICT	Information Communication Technology
IoT	Internet of Things
NFC	Near Filed Communication
RFID	Radio Frequency Identification
UAV	Unmanned Aerial Vehicle
WiLD	WiFi-based Long Distance
WSN	Wireless Sensor Network

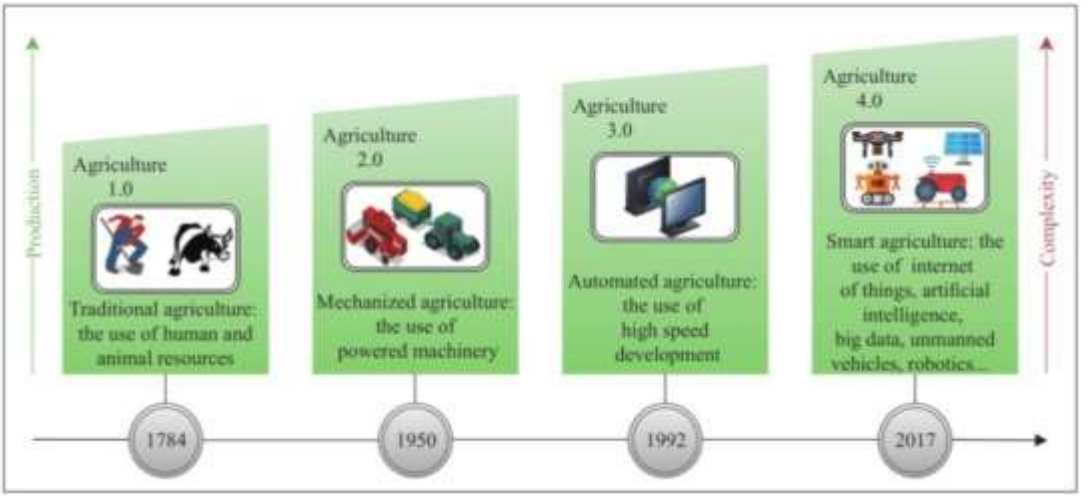
Evolution of Smart Agriculture

Over the years, traditional agriculture has undergone many changes, but still, farmers and researchers are progressively active in transforming the agricultural paradigm. The landscape of farming has been changed by contemporary technologies like artificial intelligence and IoT to perform fundamental activities of farming, irrigation, soil quality monitoring, and pest control through an automated system. According to history, farming was started about 1000BC, and till the 21st century, there have been many milestones of improvement in agriculture, which are categorized as Agriculture 1.0, Agriculture 2.0, Agriculture 3.0, and Agriculture 4.0 as depicted in Figure 1 (Friha et al., 2021; Gagliardi et al., 2022).

The traditional way of farming, where humans and animals were used for farming using simple mechanical tools, is referred to as Agriculture 1.0. During that era, the crop productivity was at a low level, and labor costs were high (Gagliardi et al., 2022). However, the investigation of myriad machinery tools and engines in the 19th century has proven to be a milestone in the agricultural revolution. Agriculture 2.0 was powered by these machineries with increased productivity and efficiency (Gagliardi et al., 2022). As the information and communication technology (ICT) revolutionized the various domains in the 20th century, the agricultural field remains exceptional. Consequently, various systems like GPS technology, remote sensing, and Geographic Information Systems (GIS) were integrated into farming operations to collect data on soil conditions, crop health, and weather patterns to optimize farming practices. This era was known as Agriculture 3.0. With an innovation of AI-powered technology, there is an ongoing digital revolution in farming characterized by a data-driven decision-making process in farming, integration of IoT technologies like drones, robotics, automated monitoring and controlling devices, etc. This characterizes another era of agriculture as Agriculture 4.0.

Figure 1

Evaluation of Smart Agriculture



Source: Friha et al., 2022

Literature Review

IoT applications transform traditional farming into ongoing digital farming characterized by sensors, automated devices, drones, monitoring and controlling devices, etc. From the early 21st century, there have been many practices and innovations in the field of smart agriculture and automated farming (Christopher et al., 2017; Ahmed et al., 2018; Dagar et al., 2018). Authors in (Chauhan et al., 2021) have discussed the various categories of sensors like pH sensor, GPS sensor, agriculture temperature sensor, resource monitoring sensors, etc., for monitoring and controlling climatic changes, harvesting, and so on. A Wi-Fi-based Long Distance (WiLD) network is integrated with the existing Wireless Sensor Network (WSN) in the rural areas for various agriculture and farming applications, thus reducing the network latency up to some extent and advancing the agricultural activity (Ahmed et al., 2017). Especially in the context of Nepal, authors (Lamsal et al. 2022; Lamsal et al., 2023) have introduced a cost-effective, customizable, scalable, and dependable IoT platform tailored expressly for smallholder farmers, empowering them to visualize, monitor, and control real-time data pertaining to their crops, livestock, and other agricultural assets. This real-world explorative study has concluded a 90-95% success rate in poly-houses during on-season grafting. In another study, the authors experimented with monitoring and regulating the climatic conditions of a poly-house in the mid-hill region (*Dhankuta*) of Nepal for successful off-season grafting of citrus fruits using an IoT platform. The climatic change inside the poly-house is maintained to the desired range using an exhaust fan, cooling pad, fogger, heating system, etc. via the Internet of Things (Lamsal et al., 2023). As the world population is growing rapidly and predicted to double by 2050, there is a need for more agricultural production, which necessitates examining the agricultural field. Consequently, Alazmia *et al.* (Alazmi et al., 2025) developed an IoT-integrated Deep Q-Network (DQN) and Elman Neural Network (ENN) for proactive crop healthcare in the agriculture sector. The details of contemporary IoT technologies used for the enhancement of agriculture are presented in Table 2.

With IoT and other contemporary technologies, the trend of research and innovation in agriculture is worth noting. The paper has presented the evolution of smart agriculture using IoT and smart agriculture in the rural arena by collecting data from the Google Scholar data repository. It has been observed that agriculture is highly prominent

with smart technology after 2020 (COVID-19 pandemic) and onwards, as depicted in Figure 2.

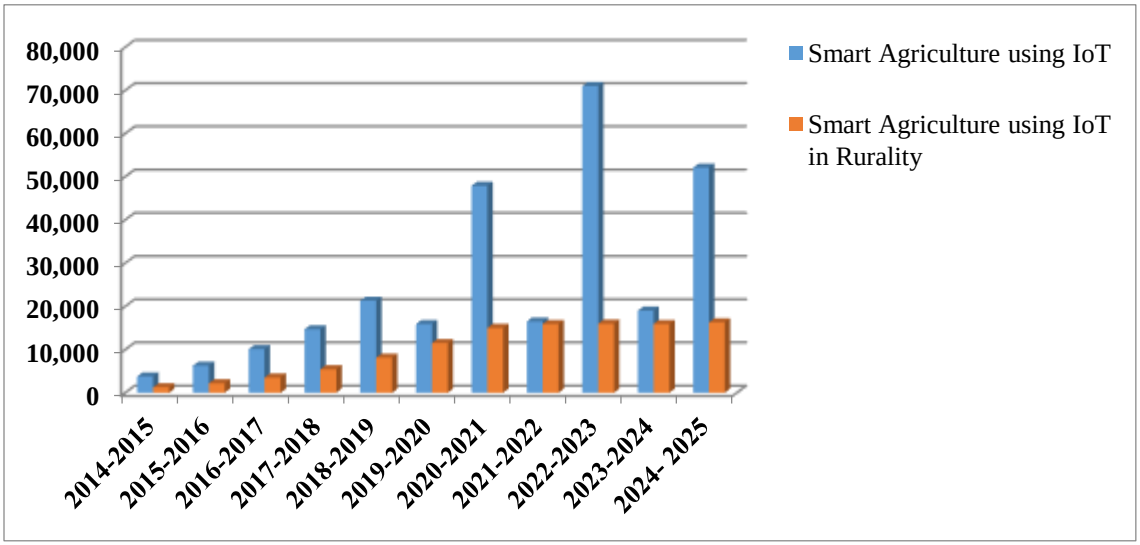
Table 2

Summary of Literature Review

Reference	Technology Used	Conclusions
Christopher et al., 2017	IoT-based large-scale pilots (LSPs) is used in four different domains in Europe	The LSP model can optimize operations in the food supply chain with reduced effort and costs for the producers, and higher food quality and safety, as well as extended food awareness for the consumer.
Abdennabi et al., 2024	Reviewed the sensor and IoT technology used in smart agriculture	Variety of sensors and IoT technology provide significant potential for enhancing food security and sustainable agricultural development.
Lamsal et al., 2023	IoT sensors and actuators are used to visualize, monitor and regulate the internal climate inside the poly-house.	Adoptable climate for grafting of citrus plant inside the poly-house is monitored and regulated via IoT sensors and healthy plants are grown with less mortality rate
Duguma et al., 2025	VOSviewer analysis tool is used for comprehensive literature search from the most reputable databases viz. as IEEE Xplore, ScienceDirect, Springer, and Google Scholar.	The global demand of food security can be achieved through interdisciplinary innovation including IoT-driven smart agriculture with big data analytics and real-time monitoring system
Muhammad et al., 2019	Analytical study of various wireless sensors, IoT in agriculture and unmanned aerial vehicles for smart agriculture	Wireless sensors, UAVs, cloud-computing, communication technologies are mandatory rather than optional for improving crop yields.
Dagar et al., 2018	IoT sensors like air temperature sensor, soil pH sensor, soil moisture sensor, humidity sensor, water volume sensors	Enhance the quality and quantity of agricultural production, save resources like water and electricity, economically efficient crop that cost less and make more profit
Alazmia et al., 2025	IoT framework integrated with Deep Q-Network (DQN) and Elman Neural Network (ENN)	Crop health is improved by using the Recursive Pattern Elimination technique for evaluating and extracting the data patterns.
Dhital et al. 2025	An automated LED ledger light deterrent system	Protecting the field crop and seeds from wild birds by integrating the sensor data from the detection system to the deterrent system.

Figure 2

Number of Publications Listed in Google Scholar With Specified Keywords



Methods and Technologies

This article draws findings from prior literature and research to examine innovative approaches for transforming agriculture with IoT in Nepal. The cutting-edge technologies that are being adopted in many countries for improving the agricultural sector are discussed below:

IoT Architecture for Smart Agriculture

The architecture for smart agriculture consists of four different layers, viz. perception, network, cloud, and application (Muhommad et al., 2019). Smart agriculture includes major activities like involving user engagement, data collection, secure data transmission, reliable storage, and an AI-powered intelligence system by integrating these layers. Using IoT architecture with wireless sensor networks and AI-assisted application agriculture practices has gained new heights to boost production and sustainable engagement in the agricultural sector.

a) Perception or Sensing layer is responsible for collecting data from the environment using tiny and low-powered (battery-operated) sensor devices and forwarding that data to the nearby gateway or edge server. Soil NPK sensor, soil moisture sensor, light sensor, water leakage sensor, soil pH scale sensor,

temperature and humidity sensor, smoke sensor, and plant disease sensor are typical types of sensors used in the agriculture sector for various purposes (Abdennabi et al., 2024). The actuators in the perception layer are responsible for numerous operations, such as irrigation and fertilizer, alarm, spraying pesticides and insecticides, protecting the crops from disease, etc.

b) Another layer in the IoT agriculture system is the network layer, which facilitates data transfer between the sensor and actuator layer and the cloud layer in real time. Near field communication (NFC) and radio frequency identification (RFID) are widely used communication techniques in IoT networks (Sharma & Bhatt, 2021).

c) Yet another level of computation is performed in the cloud layer of IoT. Data acquisition, filtering, manipulation, processing, and storage are seamlessly integrated in this layer. Cloud systems offer the framework for farmers to make rational decisions based on real-time data. Additionally, cloud platforms provide the dependability and scalability required for large-scale IoT systems (Sharma & Bhatt, 2025).

d) The application layer is the most crucial layer in smart IoT agriculture systems, where stakeholders can communicate with each other. It consists of several programs and apps that are user-friendly and interactive. The application layer helps the farmer to make precise decisions regarding crop management and scalability.

Global Positioning System (GPS)

GPS records the latitude, longitude, and elevation of the location and sends the real-time information to the farmer so that it can be used to locate defects in the crop or any other health issues regarding farming. Moreover, this technology can be integrated with video-sensors to detect the appearance of crop-raiding animals in the field and send real-time information to actuators to take some actions. A GPS tracker may be embedded with wild animals so that their presence in agricultural land can be reported earlier to take some action, either manually or seamlessly through actuators. This technique is used in areas where wild animals such as wild boar and elephants are destroying the crops.

Sensor Technologies

Sensor technologies incorporate many sensors, as mentioned in the perception layer of IoT architecture. Plant health relies on weather conditions, atmospheric

conditions, and soil conditions. In Nepal, small-scale and self-sustainable farmers use poly-houses for off-season, where sensor technology becomes a milestone. Sensors can report various information like pH scale of soil, moisture, humidity, temperature, nutrient level, water leakage, etc., which will help farmers make optimized resource utilization and rational decisions in real-time. These sensors can also diagnose diseases by sensing the various imaginaries of different parts of plants and any insects present therein. As the plant health is affected by many factors, such as soil moisture, nutrient availability, exposure to light, humidity, the amount of rainfall, the color of leaves, etc. (Abdennabi et al., 2024). They are monitored extensively by maintaining the optimum temperature and light intensity, and conserving water and energy through micro-irrigation. Modern wireless sensors are essential for gathering data on crop conditions and delivering valuable agricultural insights. These standalone sensors can be integrated with advanced farming equipment and heavy machinery, depending on specific application requirements. Prominent sensor characteristics include reliability, memory, portability, durability, coverage, and computational efficiency, making them suitable for agriculture (Miller et al., 2025).

Unmanned Aerial Vehicles (UAVs) and Drones

With the exponential deployment of IoT and smart technology in various fields, drones and UAVs have a significant impact on the agriculture sector. In recent study, it has been observed that the IoT has made remarkable progress in farming sectors like poultry, fishing, livestock farming, agro forestry, etc., but the infrastructure of communication, like base stations or Wi-Fi, is very limited in underdeveloped countries like Nepal, which prevents the growth of the IoT in this sector. In such an environment, UAVs and drones offer an alternative means of data collection as they visit and communicate with the wireless sensors spread over large areas for data acquisition, processing, and analysis.

Geographic Information System (GIS)

Most of the farmers in our country are becoming the victims of wrong decisions about the framing trends and their selection of crops in viable zones. This is the major issue caused by a lack of geo-information knowledge. GIS comprises both hardware and software components that support services such as data processing, storage, retrieval, attribute analysis, and location-based data. It generates maps and performs geographic and statistical analysis using spatial methods. Apart from these functions, GIS databases

provide information on field soil types, nutrient status, topography, irrigation, surface and subsurface drainage, quantity of chemical applications, and crop production, and also establish the relationship between elements that affect a crop on a particular farming field, supporting the farmers to make decisions precisely.

Crop Management and Monitoring Systems

It is to be noted that most of the cultivatable land in Nepal is barren because of wild animals like monkeys, wild boar, and hedgehogs. Though these animals are listed as crop-raiding animals, people are unable to protect crops and agricultural products from them, which is a major challenge in agriculture. This problem can be solved by adopting the IoT-enabled technology, which is proposed here.

a) Solar-Powered Alarms: These devices produce loud noises (ultrasonic sound) or flashing lights to scare animals away. They are especially useful for nocturnal animals like wild boars.

b) Motion-Sensing Sprinklers: These sprinklers release a sudden burst of water when they detect movement, scaring animals without causing harm. It seems difficult in mountain and hilly regions where there is a lack of water and irrigation, but quite suitable for plain regions.

c) Ultrasonic Animal Repellers: These devices emit high-frequency sounds that are inaudible to humans but irritating to animals, compelling them to leave that place.

Besides the aforementioned tools and technologies, many other contemporary technologies are being used in smart agriculture. Such technologies can have a great impact in the underdeveloped countries like Nepal to promote small-scale farmers and make the agriculture sector sustainable. Bluetooth-enabled devices can be used in small poly-houses so that various sensors and actuators communicate seamlessly. Fire detectors, climate monitoring, forecasting, and harvesting sensors are another level of sensors used in farming, which provide more efficient and effective agricultural methods, leading to better yields, decreased waste, and increased sustainability by giving farmers real-time data on crop yields and anticipated harvests.

Opportunities

With the advancement of technology, the agricultural sector is undergoing a transformation driven by data-informed decision-making. Smart technologies such as

UAVs, sensors, actuators, AI-assisted mobile applications, and blockchain have emerged as milestones in agricultural development. These innovations support farmers in various aspects, including decision-making, disease detection through image processing, soil analysis via sensors, market trend analysis, and crop selection—ultimately reducing manual effort while enhancing productivity (Thilakarathne et al., 2017). The agriculture landscape can be changed, making it smarter and sustainable, and advancing the overall development of Nepal. Smart agriculture will reduce the unemployment problem, making youth engagement in agriculture, and mitigating the emigration rate.

Challenges

Internet of Things (IoT) has evolved exponentially since 2010, and the number of connected devices in IoT networks is predicted to become 8 times the world population by 2030. These tiny and resource-constrained devices have been used in many fields like agriculture. Because of their architecture and lack of standardization, there are potential interoperability issues, and there is a potential security and privacy risk. Deploying smart technology in the agriculture sector of Nepal, motivating the people towards newer technology, and changing their attitudes towards adopting smart technology is really difficult because of the digital divide. Developing the infrastructure of communication and making the smart technology operable regardless of climatic conditions and geographical location is also a challenging factor. Implementing IoT in smart agriculture requires extensive data processing to enable efficient, data-driven decision-making, which demands many sensor nodes, various network gateways and protocols, and robust middleware to support the IoT devices—along with reliable and scalable network applications.

Results and Future Direction

Many countries have successfully transformed their geographical barriers and challenges into opportunities. Similarly, Nepal has significant potential to develop its economy sustainably through smart agriculture. Engaging youth in smart farming, integrating and advancing enabling technologies such as UAVs, drones, sensors, and actuators combined with AI and machine learning, as well as promoting farming startups

for young entrepreneurs, represent the future direction for developing smart agriculture. Since this study is based on a desk review methodology for transforming the landscape of the agriculture sector in the context of Nepal, a few outcomes can be suggestions for farmers to deploy these technologies and improve crop yields. Many countries having similar geographical diversities like Nepal have transformed their agricultural occupation using smart technology and agriculture 4.0.

Conclusions

Enhancing agricultural productivity is crucial not only in Nepal but across the globe to address the growing food demand driven by population growth. However, the decreasing participation of youth in agriculture threatens to leave vast areas of farmland barren and unproductive. Thus, it is recommended to focus on more innovative and newer technologies in agriculture for improving crop yield and handling the aforementioned issue. This paper addresses the major challenges in Nepal's agricultural sector and emphasizes the role of smart technologies, particularly the Internet of Things (IoT), in making agriculture more efficient and future-ready, while also encouraging greater youth involvement. For this purpose, wireless sensors, UAVs, cloud-computing, and communication technologies are discussed thoroughly. These technologies are much more compatible with the agriculture sector of an underdeveloped country like Nepal and make the agriculture sustainable and market-oriented rather than survival only. The paper also outlines techniques to address the issue of crop-raiding animals, particularly in the buffer zones and hilly regions of Nepal, where large areas of farmland remain uncultivated mainly due to these animals. Furthermore, the paper discusses recent research trends, such as machine learning and artificial intelligence, which are driving the transformation of agriculture from Agriculture 1.0 to Agriculture 4.0.

In short, it is never too late to initiate positive change; therefore, embracing smart technologies is essential to advancing agriculture into a more modern, efficient, and professional industry, moving beyond traditional practices.

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