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The Future of Digital Agriculture in Rural Sector

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Abstract: *Rural areas are typically the backbone of agriculture, providing essential raw materials like grains, vegetables, fruits, and livestock, which are critical for food production, food processing industries, and related businesses. More over half of India's population depends on agriculture for their livelihood, making it as the backbone of the country's economy. Global agricultural development heavily relies on rural agriculture. However, rural agriculture in India faces numerous challenges, including low productivity, limited access to markets, and inadequate extension services. Digitalization has the potential to revolutionize rural agriculture in India through the increased productivity, lower costs, better decision-making, and higher agricultural incomes worldwide. The potential of digitalization in Indian rural agriculture is examined in this article, along with the applications of e-commerce platforms, digital extension services, and precision agriculture.*

Key Words: *e-commerce platforms, sustainable development, digitalization, and rural agriculture.*

1. INTRODUCTION

Despite decades of use, traditional farming practices are no longer adequate to fulfill the demands of a fast expanding population. There has never been a greater demand for efficient and sustainable farming methods. Digital technology have surfaced as a possible answer to the problems facing India's rural agriculture in recent years. By boosting productivity, cutting expenses, and enhancing decision-making, digital agriculture which includes the application of digital technologies like e-commerce platforms, digital extension services, and precision agriculture has the potential to revolutionize the agricultural industry.

`Digital agriculture can assist farmers in enhancing crop yields, minimizing water and fertilizer consumption and boosting soil health. It can also equip farmers with essential information and guidance, an optimal practice, as well as allow them to sell their products directly to their consumers and remove intermediaries. The government can take the essential role by offering funding and support for the development of digital infrastructure, alongside incentives to foster the digital literacy among the farmers. The private sector can add value by creating digital agriculture services and platforms that address the unique requirement of rural farmers.

In terms of agricultural production, **India** is the world's top producer of milk, jute, and pulses and the second-largest producer of wheat, rice, groundnuts, fruits, vegetables, cotton, and sugarcane. Additionally, it is one of the top producers of plantation crops, fish, livestock, poultry, and spices. Therefore, in some ways, output is not the main issue facing Indian agriculture, but farmers' incomes are unquestionably insufficient because of their small landholdings. The digital agriculture provides proper understanding to the farmers about the productivity, income and access to market services .

2. PURPOSE OF THE STUDY

The purpose of this study is to explore the potential of the digital agriculture in improving agricultural productivity and efficiency in India. The study also seeks to develop a framework for the adoption and implementation of digital agriculture in India. The ultimate goal is to improve the livelihoods and incomes of Indian farmers through digital agriculture.

3. OBJECT OF THE STUDY

- To investigate the current status of digital agriculture in India, including its benefits, challenges and adoption rates.
- To examine the role of digital agriculture in promoting sustainable agriculture practices.
- To analyze the impact the of digital agriculture on the livelihoods and incomes of Indian farmers.

4. RESEARCH METHDOLOGY

This study aims to explore the current status of digital technology and their applications, as well as the advances in technology, sustainability. The research follows a **descriptive and exploratory** design. The data collected from the secondary sources such as academic journals, reports, government publications and websites will be analyzed based on the **qualitative analysis** method .This methodology aims to identify key trends, practices, policies, and challenges related to the use of digital technologies in agriculture, by analyzing existing literature and reports.

5. LITERATURE REVIEW

Manish Mahant, Abhishek Shukla, Sunil Dixit, Dileshwer Patel, (2012)

The application of Information and Communication Technology (ICT) in agriculture is increasingly important. E-Agriculture involves the conceptualization, design, development, evaluation and application of innovative ways to use information and communication technologies (ICT) in rural domain, with a primary focus on agriculture.

Ugwuishiwu C.H., Udanor C.N., Ugwuishiwu B.O., (2012)

Agro-Information System that enables a farmer to have relevant information about a crop, such as the varieties and other requirements like soil type, temperature, type and quantity of fertilizer, time of planting, time of maturity, planting distance, diseases, pest, pest and Disease control measures, rainfall, sunshine, etc. of that crop. The level of application of this information determines the volume and efficiency of the crop yield. AIS software is designed and implemented which helps the farmer achieve the afore-mentioned objectives.

State of Indian agriculture (2015-16),

It talks about Indian agriculture, performance, challenges and way forward. It explains the growth of the agricultural sector, regional variations in agricultural growth, capital formation in agriculture, production performance, performance of the horticulture sector, correcting land use pattern, rejuvenating of irrigation tanks soil and health, drought proofing and water wise efficiency, agriculture to climate change, managing agricultural inputs better etc.

(Citation Blok and Gremmen, 2018)

In the agricultural sector, several concepts have emerged to express different forms of digitalization in agricultural production systems, value chains and more broadly food systems. These include Smart Farming.

6. RURAL SECTOR IN BUSINESS ENVIRONMENT

The rural sector plays a vital role in business because it provides significant agricultural production, raw materials, and employment. It supports industries such as food processing, textiles, and construction by providing essential resources such as crops, livestock, and natural materials. Local businesses, such as retail, manufacturing, and tourism, drive the rural economy by creating jobs and promoting sustainable practices like organic farming and renewable energy production. Additionally, rural areas encourage entrepreneurship, with many people starting businesses to meet local needs. The sector also plays an important role in supply chains and logistics, facilitating product distribution. As rural areas develop, they offer increasing potential for growth in agriculture, green industries, and tourism, making them indispensable to national economic prosperity and business sustainability.

7. ROLE OF AGRICULTURE IN RURAL SECTOR

Agriculture plays a fundamental and irreplaceable role in the rural sector, serving as the primary livelihood for millions of people and acting as the backbone of world's rural economy. In many developing countries, agriculture is not just a means of subsistence, but the primary source of income, employment, and social development. It plays a essential role in food security in rural areas. Smallholder farms produce much of the food consumed locally, ensuring that rural communities have access to a stable food supply. Agriculture maintains the rural communities economic stability. The implementation of digital technologies in rural sector has increase the sustainability.

8. DIGITAL AGRICULTURE

Digital Agriculture also known as Agriculture 4.0 or Smart agriculture utilizes modern technologies like IoT, Big Data Analysis, Cloud computing, AI, ML, Sensors, Robots etc. working together stream lined to get an optimized output. Smart agriculture provides farmers with a diverse set of tools to address several agricultural food production challenges associated with farm productivity, environmental impact, food security, crop losses, and sustainability. This digitization enables real-time monitoring, data collection, analysis and automated decision-making, leading to more efficient and sustainable agriculture.

Figure 1 DIGITAL AGRICULTURE

Smart agriculture enables the systems to think and make rational decisions without the involvement of the humans or with minimal involvement of the humans. Not only with the crop production but it also deals with the post harvesting activities like storage optimization, supply chain optimization. Digital agriculture promotes sustainable practices by optimizing resource use, reducing chemical inputs and minimizing environmental impact. This is key to addressing challenges such as soil degradation and climate change . As the involvement of humans is lesser than the traditional farming practices, the chances of errors reduce, thereby increasing the overall efficiency. With these advantages with digital agriculture, it is also important to meet consumers' needs at the production and distribution stages through building a system, which delivers food safety information. Shifting weather patterns such as increase in temperature, changes in precipitation levels, and ground water density, can affect farmers, especially those who are dependent on timely rains for their crops. Leveraging the cloud and AI to predict advisories for sowing, pest control and commodity pricing, is a major initiative towards creating increased income and providing stability for the agricultural community.

9. TECHNOLOGIES INVOLVED IN SMART AGRICULTURE

There are various subsystems involved, which work in loop with one another to make a successful smart agriculture system. These include various multi- disciplinary technologies which are in sync together. This section enlists some of those technologies:

Sensors:

They play a very major role in the digitalization of the agriculture. They are most important in collecting the real time data using which well rationalized decision can be made. They are spatially distributed and arranged for monitoring the physical conditions of the environment. These sensors may be wired or wireless. There are various sensors like

- Humidity sensor (used to measure the humidity of soil and the atmosphere or the closed environment)

- Temperature sensor (used to measure the temperature of the environment)
- pH sensor (to analyze the pH of the soil and the water)
- RFID sensors (for the true authentication of the user) etc.

The accuracy and precision highly matter as it is the primary information source to the system. There is also a need of error and break down detection in the sensors, so as to prevent any undesired action due to the wrong inputs by the sensors.

Internet of Things (IoT)

They enable the user to control and monitor the activities in the field remotely, when connected through the internet. Generally, the receiver node in IoT based monitoring systems uploads data to a web server so that any client device connected to the internet may access it . The transmission of this data takes place in the network layer, the design of which depends on the selection of suitable communication technologies relevant to the field size, farm location, and type of farming method.

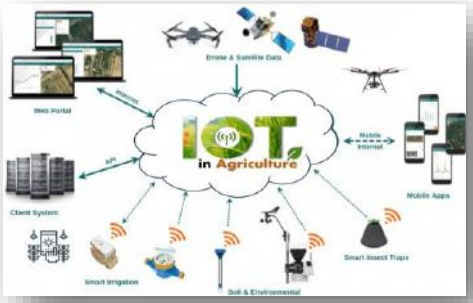

Figure 2 IOT IN AGRICULTURE

Cloud Computing

Cloud computing is one of the most widely used service in this modern era of digitalization. Cloud computing is a technology where integration of multiple devices and systems occurs which may or may not be present at one place. It performs various tasks such as data storage, management and retrieval and computing. The programs of AI, ML, DSS use the data and computation services provided by cloud computing. It enables remote collaboration and data sharing among stakeholders. This eliminates the need of physical hard drives and powerful CPU's at the location to facilitate computation with required speed.

Artificial Intelligence (AI)

The systems or machines which can think, analyze, posses' intelligence to make human like rational decisions are known as artificial intelligence. When systems like AI, IoT, and big data, Cloud computing in line with machine learning (ML), Neural networks, Natural language processing and deep learning (DL), is regarded as one of the key drivers behind the digitization of agriculture. Various data collected by the sensors are analyzed by the AI models and readily makes decision.

In agriculture, disease detection of the plants, weed detection, nutrients deficiency analysis by the symptoms shown by the plants visually, un-authorized person detection in the field, pests attacks on the crop, automatic harvesting and many other technologies readily make use of AI to analyze and make decision. Various other processes like irrigation, fertilizers addition to the soil, spraying pesticides can also be controlled by the AI. Many processes can also be optimized with the help of AI.

Machine Learning (ML)

Machine learning is known for analyzing the data, forming the relationships with the datasets. Machine learning tools are used in prediction, clustering, and classification problems, which uses the data stored in the cloud, which was preprocessed based on needs on the cloud.

Robots and UAVs

Robots have a wide range of applications within the agricultural industry from performing complex tasks such as monitoring crops and measuring PH levels in the soil, to simpler tasks of picking-and-packing fruits and vegetables and planting seeds. Add to that automation for ventilation systems and air control for livestock, milk production and arable irrigation, and it is clear that technology is the future for successful agriculture. On the other hand, UAVs(Unmanned Aerisl Vehicles) also known as drones are the aerial vehicles makes flight without a human onboard. It is found that pesticides when sprayed by UAVs are more effective than other means. UAVs are of various types which

can depend on the application. UAVs are also used for the image capturing from a height, which can serve as useful data by some AI or ML models.

10. INITIATIVES TAKEN BY THE GOVERNMENT TO PROMOTE DIGITALIZATION IN AGRICULTURE

The government of India has recognized the potential of digital agriculture to transform the country's agriculture sector and has launched several initiatives to promote its adoption.

DIGITAL AGRICULTURE MISSION IN INDIA:

On September 2, 2024, the Union Cabinet approved the Digital Agriculture Mission with a budget of Rs. 2,817 Crore, including a central government share of Rs. 1,940 Crore. This mission aims to transform India's agriculture sector by creating a robust Digital Public Infrastructure (DPI) and leveraging modern technologies. By 2026-27, the Mission targets the coverage of 11 crore farmers, thereby achieving productivity, transparency, and accessibility in agriculture. However, digital literacy and data security are some of the key challenges that lie ahead, to which solutions have to be found if the mission is to succeed.

Three Pillars of the Mission

The Digital Agriculture Mission is based on three pillars of foundation: AgriStack, Krishi DSS, and Soil Profile Maps. Each of these elements forms an integral part of bringing a flawless digital ecosystem to support the agriculture sector. AgriStack provides unique Farmer IDs and complete information on the crops, whereas Krishi DSS enhances the planning and distribution of resources using remote sensing and geospatial data. Soil Profile Maps shall improve the agglomeration of crop patterns and fertilizer applications.

OTHER INITIATIVES BY THE GOVERNMENT:

The Government has taken several initiatives to provide a fillip to digitization in agriculture. This digitization would aim at enhancing agricultural productivity, better market access, and farmers' welfare through:

- **Soil Health Card Scheme:** This scheme provided, in 2015, detailed information on the nutrient status of the farmers' soil and the recommendations on the appropriate crop and fertilizers.
- **Pradhan Mantri Fasal Bima Yojana:** In 2016, this crop insurance utilized digital technologies such as remote sensing, satellites, and drones for swift assessment and settlement of claims.
- **National Agriculture Market (e-NAM):** The pan-India single electronic trading portal for agricultural commodities initiated in 2016 provides a unified national market for agri-commodities with price transparency and reduced transaction cost.
- **Kisan Credit Card (KCC):** It ensures easy and timely availability of short-term credit to farmers. Digital KCCs facilitate easier application and disbursal of loans.
- **Pradhan Mantri Krishi Sinchai Yojana:** Initiated in 2015, this program promotes efficient farm-level use of irrigation water through the adoption of precision irrigation systems operated with digital monitoring and management and so on.

SOME OF ICRISAT'S INITIATIVES:

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is an international organisation which conducts agricultural research for rural development. Some of their initiatives are:

KRISHI VANI

Voice message based agro advisory- Farmers can get up to 35 voice messages in the local language for free each week using a specific SIM card in their mobile phones. The notes appear in 16 categories include weather, market, information

on crops, government initiatives, nutrition, health, and animals, among others. This is being implemented in Karnataka, Telangana and Andhra Pradesh states in India.

KRISHI GYAN SAGAR (KGS)

The Indian states of Andhra Pradesh, Telangana, and Karnataka are currently using an app to give smallholder farmers individualised advises. Krishi Gyan Sagar (KGS) enables data collection, uploading, and information sharing with farmers and operates on both a mobile device (tablet or smart phone) and the web.

11. E-COMMERCE IN AGRICULTURAL SECTOR

E-commerce of agricultural products refers to the online buying and selling of agricultural goods, such as crops, livestock, and other farm-produced products. This digital marketplace provides farmers with a platform to reach a broader customer base, bypassing traditional middlemen and physical market constraints. It offers an efficient, scalable, and cost-effective solution for farmers and agribusinesses to market their produce directly to consumers, retailers, and other businesses. With the integration of advanced technologies like mobile apps, AI for inventory and supply chain management, and real-time data analytics, e-commerce platforms are revolutionizing the agricultural sector.

Initially, e-commerce in Indian agriculture may have been limited to essential online marketplaces where agricultural products were listed for sale. However, over time, these platforms have evolved to offer a more comprehensive suite of services tailored to the needs of farmers, traders, and consumers. This evolution includes introducing real-time market information, supply chain tracking, digital payments, and value-added services like agronomic advice and farm management tools.

The growth of e-commerce in the agricultural products sector in India sheds light on the transformative potential of digital platforms to revolutionize agricultural trade and enhance socio-economic development. The rapid growth of e-commerce in Indian agriculture has been driven by increasing internet penetration, smart phone adoption, government initiatives, and technological advancements. These drivers have enabled farmers and rural entrepreneurs to overcome traditional barriers to market access, connect directly with consumers, and improve their livelihoods, welfare. On the other hand, disparities in access, digital divide, and market concentration pose challenges to equitable participation and distribution of benefits.

National Agriculture Market (e-NAM)

e-NAM, or the National Agriculture Market, is an online trading portal that connects agricultural markets across India. It was launched in 2016 by the Government of India. It is entirely supported by the Central Government and is managed by the Small Farmers Agribusiness Consortium (SFAC), which is overseen by the Ministry of Agriculture and Farmers' Welfare. It is a pan-India electronic trading portal that nets the prevailing Agricultural Produce Market Committees (APMC) Mandis for making a united national market for agricultural commodities. The e-NAM project would operate via the online portal that is linked to the states' Mandis (Wholesale markets). All the participating states will be providing the software (Website and Mobile Application) for e-NAM at no cost.

Figure 3 e-NAM

- E-NAM provides enhanced and expanded possibilities for selling products, resulting in fair market competition.
- It gives farmers access to the national market, with prices determined by the quality of their goods.
- Farmers benefit from better returns.

On the e-NAM platform, more than 1.75 crore farmers and 2.43 lakh traders have registered (as of March 31, 2023)**.** 2,575 FPOs have been added to the e-NAM platform. A trade value of 2.50 lakh crore has been recorded on the e-NAM platform. As of March 16, 2023, 1361 mandis from 23 states and four UTs were integrated with the e-NAM platform.

Digital India Award 2022: The Ministry of Agriculture's Electronic National Agriculture Market (e-NAM) programme received the Platinum Award (1st) in the Digital Empowerment of Citizens Category.

12. SUSTAINABLE AGRICULTURE DEVELOPMENT

Sustainable agriculture development integrates three main goals-- environmental health, economic prosperity and livelihood sustainability. To put it another way, sustainability is based on the idea that we must meet present needs without sacrificing the ability of future generation. Therefore, management of both natural and human resources is of prime importance. Management of human resources includes consideration of social responsibilities such as working and living conditions of farm families, the needs of rural communities, and consumer health and safety both in the present and the future. Management of land and natural resources involves maintaining and or enhancing this vital resource base for the long term.

The concept fosters stable and continuous production, with enough resources in the future. Its practices accord with the five principles of sustainable agriculture outlined by FAO:

- Boost food chain productivity.
- Protect and spare the environmental resources.
- Improve people's wellbeing and economic growth.
- Foster ecosystems and communities' resilience.
- Support with governmental initiatives and regulations.

National Mission on Sustainable Agriculture (NMSA)

It is one of the Missions launched under the National Action Plan on Climate Change (NAPCC) in 2008. The Mission aims to evolve and implement strategies to make Indian agriculture resilient to climate change. NMSA was approved for three major components

- Rainfed Area Development (RAD)
- On Farm Water Management (OFWM) and
- Soil Health Management (SHM).

Subsequently, four new programmes were introduced under the ambit of NMSA namely Soil Health Card (SHC),Paramparagat Krishi Vikas Yojana (PKVY), Mission Organic Value Chain Development in North Eastern Region.

The NMSA Strategy document was revised for the period 2018 to 2030 and has adopted an integrated holistic approach focusing more on vulnerable regions, deploying the best bet technologies and practices for adaptation and mitigation and

Empowering farmers through capacity building and financial support. Implementation strategies are designed with a time frame up to 2030.

The Goal of Sustainable Agriculture

The primary sustainable agriculture objectives are food and fiber security both these days and in the future. Other goals include:

- Ensuring soil fertility and encouraging biodiversity;
- Improving the ecological conditions and preventing pollution;
- Consuming less non-renewable resources (e.g., fossil fuels);
- Supporting rural economic development;
- Enhancing the quality of farmers' health, rights, and life in general;
- Raising people's environmental awareness and responsibility.

13. IMPACT OF DIGITAL AGRICULTURE

Digital agriculture, which incorporates advanced technologies has significantly transformed the agricultural sector. The innovations have not only improved farming productivity and sustainability but have also had a profound impact on the livelihoods of farmers and rural communities. Here's how digital agriculture is changing livelihoods:

- By using technology to optimize inputs like water, seeds, and fertilizers, farmers can reduce waste and costs. This increases their profit margins, as they only use the exact amounts needed to grow crops effectively.
- Digital agriculture facilitates access to financial services such as loans, insurance, and mobile banking. Farmers can now easily receive payments, apply for loans, and secure insurance through mobile platforms, improving financial inclusion in rural areas.
- Digital platforms also offer remote training and learning resources, helping farmers develop their skills without needing to travel long distances. This fosters continuous learning and supports the long-term growth of farmers' capabilities and livelihoods.
- The rise of digital agriculture has spurred the growth of agri-tech startups, creating new job opportunities in software development, data analytics, drone services, and other related fields. This fosters local economic growth and provides employment opportunities in rural areas, beyond traditional farming jobs.

14. CHALLENGES ASSOCIATED WITH DIGITALIZATION IN THE AGRICULTURE SECTOR

While the mission holds immense promise, it is also vulnerable to a set of challenges:

High Initial Capital Requirements:

- Adoption of technologies like drones, satellite imagery, and sensor-based systems requires significant investment, which is difficult for small farmers.
- Many farmers rely on government subsidies and financial schemes, which are often insufficient for large-scale adoption.

Small Land Holdings:

According to the Situation Assessment Survey (SAS) of Agricultural Households conducted by NSO, 89.4% of agricultural households own less than two hectares of land, which complicates the implementation of scalable digital solutions.

- Small farms cannot always justify the cost of digitisation, leading to low adoption rates in rural regions.

Digital Literacy Constraints:

Rural illiteracy and limited understanding of digital tools prevent many farmers from using advanced ICT solutions effectively.

- The disparity in tele-density, with Urban Tele-density at 133.72% and Rural Tele-density at 59.19% as of March 2024, presents a significant challenge for the digitization of agriculture in India, limiting rural farmers' access to essential digital tools.
- Lack of training programs hinders the adoption of even basic digital tools like soil sensors and yield monitoring apps.

Inadequate Rural Infrastructure:

- Inconsistent internet connectivity and power supply issues in rural areas slow the adoption of digital tools.
- Infrastructure like broadband access and mobile towers remains limited in remote regions, creating a digital divide.

Limited Access to Credit and Financing:

- Many small farmers lack access to formal credit due to poor creditworthiness or absence of collateral, making it difficult to invest in digitisation.
- The formal banking sector needs to develop farmer-friendly financial products to support technology adoption.

Data Trust and Security:

- Ensuring data trust, privacy, security, validation, and storage remains a significant hurdle in digital agriculture.
- Collaborative efforts between researchers and IT experts are essential to enhance agricultural data management, leveraging IoT technology for effective solutions.

Complexity in Data Capture:

- The diverse range of crops, climate zones, and soil conditions presents a challenge in integrating these variables under a unified digital framework.
- This complexity can hinder the widespread adoption of digital agriculture solutions.

15. FUTURE DIRECTIONS:

Strengthening Digital Infrastructure:

Broadband internet access, mobile towers, and digital literacy programs are essential to expand digital reach in rural areas. Investment in satellite imaging, soil health information systems, and land mapping will improve data accuracy, empowering data-driven decisions.

Encouraging Public-Private Partnerships:

Collaborations with tech startups, Farmers Producer Organisations (FPO), and private agri-tech firms can foster faster adoption of digital tools. FPOs can facilitate group purchases of digital resources for small farmers, reducing costs and increasing adoption rates.

Enhancing Farmer Capacity and Digital Literacy:

Government-led training programs and awareness campaigns can bridge the digital literacy gap, ensuring rural communities can leverage digital tools effectively. Extension workers should be trained to assist farmers in using ICT solutions, ensuring hands-on guidance.

Data Security and Privacy Measures:

With increased reliance on data through initiatives like AgriStack, robust data protection policies are essential to safeguard farmers' personal information. Clear guidelines on data usage, transparency, and farmer consent should be established to protect data integrity.

16. CONCLUSION

In conclusion, digital agriculture is a transformative force in the farming sector, providing innovative solutions to the challenges of sustainability, productivity, and food security. Farmers may improve agricultural methods, decrease resource waste, and increase yields while reducing environmental effect by utilizing technology such as IoT, AI, big data, drones, and blockchain. These advancements not only improve efficiency but also contribute to building resilience against climate change and global food insecurity. While challenges such as cost, infrastructure, and training remain, the potential benefits of digital agriculture are vast, positioning it as a key driver of future agricultural development and global food sustainability.

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