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Viksit Bharat @ 2047 and the Future of Indian Agriculture: A Sustainable Growth Perspective

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A B S T R A C T

India's agricultural sector plays a ensuring food security, enhancing rural livelihoods, and promoting environmental sustainability. As the country envisions a developed India (Viksit Bharat) by 2047, sustainable agriculture emerges as a key component of this transformation. This review paper explores the current status, challenges, and potential pathways for sustainable agricultural development in India. It discusses technological advancements, policy frameworks, climate-resilient farming techniques, and socio-economic factors that can drive agricultural sustainability. The paper also highlights the role of digital innovations, precision farming, and community-based approaches in achieving long-term agricultural resilience and productivity. Strengthening financial inclusion, capacity building, and infrastructure is vital for smallholder farmers, alongside policy measures supporting agroforestry, organic farming, and sustainable resource management. Leveraging technology, improving rural infrastructure, and implementing inclusive policies will make Indian agriculture resilient and competitive by 2047. A multi-stakeholder approach, including government, private investment, cooperatives, and research institutions, is essential for a sustainable and self-reliant future.

Introduction

India's agricultural industry has been essential to maintaining food security, creating jobs, and promoting rural development. With an emphasis on economic expansion, social justice, technical innovation, environmental sustainability, and global leadership, this vision sets the lofty objective of making India a fully developed nation. India's expectations for a wealthy and sustainable future are fueled by the centennial of its independence, which serves as a symbolic goal (Jayasingh, *et. al.,* 2024). A vital component of India's economy that sustains the livelihoods of millions of people and guarantees food security, the agricultural sector is at the core of our strategy.

With a substantial national economic contribution and a sizable workforce, agriculture has been and is the foundation of the Indian economy. India must overhaul its agriculture industry if it is to become a developed country. In addition to providing for the expanding food needs of a growing population, the transition to sustainable agriculture is essential for maintaining both economic viability and environmental preservation.

It is impossible to overestimate the significance of sustainable agriculture in realizing the goal of Vikshit Bharat@2047. The need for food, feed, and raw resources is anticipated to increase dramatically as India's population is predicted to surpass 1.6 billion by 2047. The need for technology breakthroughs, resource restrictions, and climate change are just a few of the many issues facing the agriculture industry at the same time.

A approach to solve these issues while maintaining long-term food security and ecological balance is through sustainable agriculture, which combines social justice, economic profitability, and environmental health.

However, the sector's problems necessitate a paradigm shift toward inclusive, sustainable, and technology-driven growth as the country works to realize the Viksit Bharat @ 2047 goal. Even though they have their roots in India's agricultural past, traditional farming methods have increased soil erosion, reduced groundwater levels, increased dependency on chemical inputs, and increased susceptibility to climate change. Concurrently, the industry faces challenges such as poor productivity, dispersed landholdings, inefficient markets, and income inequality, which restricts its ability to contribute to the advancement of the national economy.

A robust, internationally competitive, and ecologically sustainable agricultural system that guarantees ecological balance, food security for all, and farmer wealth is what the Viksit Bharat 2047 project aims to achieve. A multifaceted strategy that incorporates data-driven decision-making, legislative changes, financial inclusion, infrastructure development, and technology developments is needed to accomplish this aim. Precision farming, climate-resilient crops, AI-based crop monitoring, and digital market connections are just a few of the innovations that have the potential to transform Indian agriculture and increase sustainability and production. Long-term sustainability also depends on legislative initiatives supporting regenerative agriculture, organic farming, and water-efficient irrigation methods.

In order to bring Indian agriculture into line with the Viksit Bharat 2047 vision, this study will assess the country's existing agricultural environment, highlight important obstacles, and provide strategic solutions. By 2047, India's agricultural industry may become self-sufficient, sustainable, and competitive on a global scale by encouraging cooperation between politicians, researchers, business partners, and farmer communities.

The objectives of the study are to examine the current state of Indian agriculture, identify its major challenges, and analyse the role of technological advancements, sustainable agricultural practices, and supportive policy frameworks in promoting its development. The study further aims to propose a comprehensive roadmap for building a sustainable, resilient, inclusive, and technology-driven agricultural sector capable of contributing significantly to India’s development goals by 2047.

Research Gap

Sustainable agricultural transformation in India is still dispersed and uneven, despite a plethora of governmental initiatives and technology improvements. However, there is a dearth of thorough study combining these components into a cohesive plan for Viksit Bharat 2047. Previous studies concentrate on specific factors like market access, climate resilience, or precision farming. Furthermore, the ways in which financial instruments, digital advances and multi-stakeholder engagement can all work together to promote agricultural sustainability are not sufficiently explored. In keeping with India's development objectives, this study attempts to close these gaps by offering a comprehensive framework for sustainable agricultural growth.

Materials and Methods

Using a qualitative and analytical methodology, this study makes use of:

- ✓ Analyzing secondary data involves examining government publications, policy papers, scholarly journals, and industry studies to evaluate the possibilities and difficulties facing agriculture today.
- ✓ Comparative Case Studies: To find best practices, effective sustainable agricultural models from different Indian states and global examples are examined.
- ✓ Policy Review: Examining current financial plans, technical advancements, and agricultural policies to

identify their shortcomings and efficacy.
- ✓ Stakeholder analysis is the process of assessing how government organizations, business ventures, farmer cooperatives, and academic institutions may influence Indian agriculture in the future.

Current Status of Agriculture in India:

Nearly 50% of India's workforce is employed in the agricultural sector, which accounts for 17–18% of the country's GDP (NSSO, 2021, Economic Survey of India, 2022-23). Agriculture was mostly practiced for household purposes in the past, but as time went on, new innovations and technology were developed to increase crop yields, and people began to make a living from it as well. However, in addition to the environmental risks, a number of socioeconomic challenges have surfaced (Bhatt *et al.,* 2019). The food chain's sustainability depends on agricultural technology. The Green Revolution (GR) is the finest example of how scale-independent technology has changed agricultural productivity.

The GR has resulted in several benefits, such as increased food availability, lower food prices, infrastructure development, poverty alleviation, and increased yields (McCullough *et al.,* 2012). It guaranteed agricultural output in countries like India and greatly allayed concerns that we had reached the threshold of food excess capacity, which occurs when population expansion exceeds agricultural productivity. Despite possessing only a small percentage of the world's agricultural area, India ranks second in terms of agricultural production worldwide. The main disadvantage of green revolution methods is that they are only applicable to a few particular crops. (Goswami *et al.,* 2017; Armanda *et al.,* 2019). The nation ranks second in the world for the production of wheat, rice, fruits, and vegetables, and first for the production of milk, pulses, and spices (FAO, 2022). The goal of sustainable development via the reduction of negative consequences is becoming more important as the world's population and environmental concerns continue to rise.

Major Challenges for Indian Agriculture in Current Scenario

Indian agriculture has a number of challenges, including productivity, climate change, resource depletion, market connections, and government policies and programs for agricultural growth, even though it provides the primary source of income for a significant portion of the population. Several factors that affect its growth and sustainability are to blame for these challenges.

Soil degradation

Over 100 million hectares of land in India are expected to experience soil deterioration. Water erosion accounts for 94 million hectares, acidity for 16 million hectares, floods for 14 million hectares, wind erosion for 9 million hectares, salt for 6 million hectares, and various environmental variables for 7 million hectares. India is home to 18% of the world's population, which is alarming given that it only makes up 2.4% of the planet's surface area. About half of all jobs are in the agricultural, forestry, and aquaculture sectors, which provide 17% of the nation's GDP. Significant losses of flora and extremely rich soils occur in the surrounding areas as a result of overburden removal from mining operations.

Both natural and man-made factors contribute to soil deterioration (Bhattacharyya *et al.,* 2015). According to Brausmann and Bretschger (2018), this list contains a variety of natural catastrophes, such as earthquakes, typhoons, storms, hurricanes, falling trees, rockfalls, volcanic activity, storms, thunderstorms, and bush fires. Land removal and deforestation, bad farming methods, improper disposal of chemical waste, grazing, mineral extraction, fast urbanization, and commercial expansion are all examples of man-made soil degradation. In India, soil erosion is caused by a variety of sociopolitical factors, such as growing urbanization, declining land area per person, agricultural leasing, illiteracy, and population growth. In conclusion, farming practices, fertilizers, and climate change are the primary causes of soil degradation in various agroclimatic areas (Bateman, 2019).

Productivity

Limited automation, inadequate irrigation infrastructure, and antiquated farming methods have resulted in low production relative to international norms (ICAR, 2020). Lack of access to contemporary technologies and an excessive dependence on conventional farming methods lower productivity and efficiency (FAO, 2021). Continuous monocropping and overuse of chemical fertilizers without sufficient organic matter replenishment are to blame for the declining fertility of the soil (Ministry of Agriculture, 2023). According to

Chauhan *et al.,* (2012), India's long-term practice of cereal-cereal rotations has led to nutritional imbalance, an increase in insect infestation, and soil deterioration. Therefore, the pulse-cereal rotation procedures need to be implemented in order to improve the crop. By preserving oil fertility, crop rotation aims to increase crop yield.

According to the Planning Commission (2020), around 86% of farmers are classified as small and marginal, operating on landholdings of less than 2 hectares, indicating that the agricultural industry is still highly fragmented. In addition to impeding economies of scale, fragmented and holding patterns restrict the deployment of large-scale automation (NABARD, 2021). Another factor affecting production potential is inadequate access to high-quality seeds, fertilizer, and insecticides (World Bank, 2022). Because extension services and information transmission are inadequate, there are yield gaps between research station trials and farm-level production (IFPRI, 2021). Farmers lose money due to post-harvest losses and inadequate storage facilities, which waste output (FAO, 2022).

Using integrated nutrient management, conservation agriculture, and precision farming methods can greatly increase production, according to research (ICAR, 2022). Older farming methods, inadequate irrigation systems, and little mechanization have resulted in low production relative to international norms (ICAR, 2020). Monsoon reliance affects yields in rain-fed areas.

Climate change

Crop yields, soil health, and water availability are all being impacted by climate change, which is drastically changing India's agricultural environment (IPCC, 2022). Frequent droughts and floods have been caused by rising temperatures and unpredictable rainfall patterns, which have an effect on farmer livelihoods and food security (World Bank, 2021). Climate change may cause a 6–10% decrease in wheat and rice yields by 2050, according to research, which would seriously affect India's food supply (NIAP, 2020). A major danger to agricultural output is the rise in disease outbreaks and insect infestations brought on by changing climatic conditions (FAO, 2022). Mitigating climate risks requires adaptive strategies such agroforestry practices, enhanced irrigation methods, and climate-resilient crops (NITI Aayog, 2021). Promoting climate-smart farming practices is the primary goal of the National Mission for Sustainable Agriculture (NMSA) (Ministry of Agriculture, 2023). Food security is under risk from rising temperatures and unpredictable rainfall patterns (IPCC, 2022). Cyclones, floods, and droughts occurring more frequently and having an impact on agriculture production (World Bank, 2021). Change in agricultural practices as a result of erratic monsoon seasons (NIAP, 2020).

Resource depletion

In the 1960s and 1970s, the Green Revolution greatly increased agricultural yield; nevertheless, excessive use of chemical fertilizers and intensive farming methods has resulted in degraded soil, depletion of groundwater, and decreased biodiversity (ICAR, 2021, Swaminathan, 2006).

In places like Punjab and Haryana, where over-extraction has caused water tables to drop, groundwater depletion is a result of excessive irrigation (Central Groundwater Board, 2021). According to the Ministry of Agriculture (2023), excessive use of chemical fertilizers and pesticides causes soil deterioration and falling fertility, which lowers long-term output. loss of traditional seed types and biodiversity, which increases reliance on high-yield hybrid seeds that also cost more to produce (FAO, 2022). Ecosystem balance and soil health are impacted by unsustainable land-use practices and declining forest cover (IPBES, 2020). Overgrazing and desertification worsen land degradation in arid and semi-arid nations (UNCCD, 2021). In coastal and canal-fed locations, ineffective irrigation techniques are causing salinity and waterlogging problems (ICAR, 2022).

In order to replenish soil and water resources, conservation-focused methods including organic farming, afforestation, and watershed management are required (NITI Aayog, 2022). Groundwater depletion in places like Punjab and Haryana as a result of over-irrigation (Central Groundwater Board, 2021). Overuse of chemical pesticides and fertilizers causes soil deterioration and a decrease in soil fertility (Ministry of Agriculture, 2023). Conventional seed varieties and biodiversity loss (FAO, 2022).

Market linkages

In rural regions, agricultural marketing remains a mess. Farmers are compelled to sell their agricultural output at a loss and rely on local merchants and intermediaries to get rid of it because they lack effective marketing channels. Most of the time, socioeconomic conditions force these farmers to perform distressed sales of their goods (Chakraborty, 2018). The impoverished farmer is required to sell his goods for whatever price is offered to him in order to satisfy his debt and other financial obligations. A large portion of small farmers continue to turn to local, avaricious moneylenders who demand outrageous interest rates because the existing financing programs for farmers are still in their infancy.

Despite the fact that farmers ought to benefit from their labor, some vultures trash it all. Despite assertions to the contrary, technology has only so far spread to urban areas. There are several loopholes in the existing legislation, and food costs would increase and people would have to fight to sustain themselves if there were no structured and regulated marketing system for agricultural products. Farmers must overcome several challenges and hurdles in order to receive a just and equitable compensation for their labor. Lack of storage infrastructure and disjointed supply chains make it difficult for farmers to reach markets (NITI Aayog, 2021).

Fluctuations in crop prices lead to farmer distress and uncertainty in income. Limited penetration of farmer-producer organizations (FPOs) and cooperatives in the value chain (IFPRI, 2021).

Technological Gaps and Adoption Barriers

Restricted availability of contemporary machinery and technology, especially for small and marginal farmers (FAO, 2022). Due to a lack of knowledge and financial constraints, precision farming methods and digital agricultural instruments are being adopted slowly (ICAR, 2021). The spread of agricultural technologies is hampered by poor rural infrastructure, such as insufficient roads, power, and digital connection (NABARD, 2022). Additionally, because to insufficient facilities for processing, transportation, and storage, around 10-15% of agricultural output is wasted after harvest, making post-harvest losses a serious problem (NSSO, 2021).

Financial Constraints and Credit Accessibility

Complex lending procedures and collateral restrictions make it difficult for small farmers to get institutional credit (RBI, 2021). Debt traps caused by a high reliance on unofficial credit sources (NABARD, 2021). Limited use of risk-reduction techniques and crop insurance programs (Agricultural Insurance Company of India, 2022). The National Mission for Sustainable Agriculture (NMSA) and Pradhan Mantri Kisan Samman Nidhi (PM-KISAN) are government programs designed to assist farmers; nonetheless, issues with rural infrastructure, policy implementation, and technology acceptance continue to exist. The growing use of digital agricultural solutions like as Kisan Call Centers and e-NAM (National agricultural Market), precision farming, and mechanization all point to a slow modernization trend (IFPRI, 2022).

Still, there are obstacles to widespread adoption, especially for small-scale farmers that lack funding and technical expertise. Additionally, post-harvest losses continue to be a significant problem, with insufficient facilities for processing, transportation, and storage resulting in the waste of around 10-15% of agricultural products (NSSO, 2021).

Sustainable Agriculture and Its Importance

Farming methods that satisfy present-day demands for food and fiber without endangering the capacity of future generations to satisfy their own requirements are referred to as sustainable agriculture. To guarantee long-term agricultural output, it combines social justice, economic profitability, and environmental health. The dynamic and changing field of sustainable agriculture necessitates the fusion of contemporary scientific advancements with ancient wisdom. At both the national and international levels, policies and institutional assistance are essential to ensure agricultural sustainability (NITI Aayog, 2022). The significance of sustainable agriculture and its contribution to food security, environmental preservation, and economic growth have been underlined by several studies.

The long-term goal of India under Vikshit Bharat @ 2047 requires a complete approach that integrates these achievements, even if these studies offer insightful information on sustainable agriculture.

Environmental Stewardship

A decreased need for artificial pesticides and fertilizers to stop soil and water contamination. A study by Kumar *et al.,* (2024) looked at the effects of agricultural biotechnology, emphasizing how gene-editing technologies like CRISPR, biofertilizers, and genetically modified (GM) crops might increase production and sustainability. The importance of organic farming in sustainable agriculture was also examined by Sharma *et al.,* (2024), who concentrated on traditional techniques that reduce dependency on pesticides and enhance soil health. Agroecological practices that are being employed include crop rotation, integrated pest management (IPM), and organic farming. Promoting agroforestry and conservation tillage to enhance soil health (Lal, 2020). In 2023, Dr. Kumar looks at the application of biopesticides in Indian agriculture as environmentally friendly alternatives to manmade insecticides.

Kumar stresses the need to switch to environmentally friendly pest control techniques like using products made from neem. The paper highlights the potential for biopesticides to be widely used while discussing their present restricted use. It is believed that biodiversity is necessary to develop novel biopesticides that can meet the growing demand for residue-free and organic crops. In order to speed up adoption, the research examines India's conventional knowledge systems, the difficulties in scaling production, and the necessity of supportive regulatory frameworks. In their study, Shahane and Shivay (2022) emphasize the value of healthy soil in organic farming and go over several ways to improve it. Conservation agriculture, which emphasizes crop rotation and little soil impact, is becoming more and more popular worldwide. According to the study, pollutants and desertification are two examples of soil deterioration that have a detrimental effect on agricultural output. The study notes that microbial inoculants, biodynamic formulation, crop rotation, agroforestry, and organic inputs like manures are all necessary for efficient soil health management. According to the study's findings, government programs like Soil Health Cards encourage balanced fertilization; nonetheless, organic farming may encounter difficulties such as reduced yields, higher premium pricing for organic products, and associated expenses for managing soil health. Focusing on integrated pest management (IPM) techniques, Meena *et al.,* (2024) showed how lowering the usage of chemical pesticides improves soil health and biodiversity. The possibility of biofertilizer-based organic nutrient management in North-East India for soil conservation and increased crop output was also examined by Bordoloi (2023). According to Tilman *et al.,* (2002), the preservation of biodiversity and integrated soil and water conservation are essential components of sustainable farming operations. It draws attention to the balance that exists between food security and environmental protection.

Economic Viability

Preserving the profitability of farming for present and future generations. Cutting costs and increasing productivity through the use of efficient resource management techniques (Altieri, 2018). To promote income and crop diversification while lowering financial risks. Improving price realization by fortifying value chains and agricultural markets (Pingali, 2019).

Social Responsibility

Boosting rural lives by giving agricultural workers decent pay and working conditions. Support for farmer cooperatives and the development of regional food systems. Encouraging fair access to wholesome food in order to address issues related to food security. Enabling women and underrepresented groups to participate in agricultural decision-making (FAO, 2022).

Use of Technology and Innovation

The use of GPS, sensors, and AI-driven analytics to optimize resource use, track soil health, and boost production is explained by Gebbers & Adamchuk (2010). The revolutionary importance of AI and IoT in contemporary agriculture was covered by Ashoor *et al.,* (2024). These technologies enable precision farming methods including automated irrigation systems, drone-based crop monitoring, and intelligent decision-support tools. More research was done by Rimpika *et al.,* (2023) on how data-driven technologies, GPS, and GIS maximize resource allocation and reduce environmental degradation in smallholder farms. Utilizing precision farming, biotechnology, and digital technologies to optimize resource consumption. Adoption of crops and seed varieties resistant to stress and climate change (FAO, 2022). Enhancing services for agricultural extension to facilitate information sharing among farmers. Intelligent farming solutions through the use of artificial intelligence (AI) and the Internet of Things (IoT).

Climate Adaptation and Mitigation

Promoting agroforestry and cover crops as ways to store carbon. Using renewable energy sources and appropriate livestock management to cut greenhouse gas emissions

(IPCC, 2022). Creating flexible coping mechanisms to deal with harsh weather and shifting climatic trends. Enhancing agricultural climate risk management and early warning systems (NITI Aayog, 2022). Encouraging crop types with high yields and resistance to drought in order to maintain food security in the face of climate change. Farmers in Odisha are now more resilient to unpredictable monsoons because to the adoption of drought-resistant rice cultivars (ICAR, 2022).

Key Drivers for Transforming Indian Agriculture by 2047 in Sustainable Agriculture

To ensure sustainable agriculture growth and the creation of an effective and resilient agricultural system, it is imperative to combine cutting-edge technology with sustainable practices in order to realize the vision of Vikshit Bharat by 2047. Using agricultural technologies that leverage robotics, AI, and loT to increase production and efficiency, such as digital agriculture, biotechnology, and precision farming, is one of the key elements. Crop diversity, IPM, and organic farming are examples of eco-friendly agricultural practices that contribute to maintaining environmental health. Effective management of water resources requires efficient irrigation and rainfall. By using particular methods and doing soil analysis, soil quality and production may be improved. In order to encourage the implementation of sustainable practices, financial institutions must provide agricultural funding in addition to regulatory and supporting policies and PPP.

Furthermore, by increasing efficacy and efficiency, developments in supply chain management, artificial intelligence, and machine learning are revolutionizing agriculture. Adopting these components would help India create a stable agricultural industry that will empower rural communities and help realize the country's ambition.

Technological Advancement

Precision farming

Precision farming is a significant advancement in modern farming methods as it increases agricultural output while lowering resource usage and environmental impact. According to Rimpika *et al.,* (2024), precision agriculture offers several benefits, including increased productivity, lower costs, environmental friendliness, and higher crop quality. Using state-of-the-art technology like GPS, GIS, remote sensing, IoT sensors, drones, and machine learning algorithms, this approach allows for accurate monitoring and management of crops and livestock. In order to accurately administer water, fertilizer, and pesticides based on specific field conditions, one of the key components is Variable Rate Technology (VRT), according to Lee, Strong, Briers, Murphrey, and Rajan (2024).

Precision farming uses tailored fertilizer and pesticide treatments to reduce input costs and boost crop yields by 20–30% (Rimpika *et al.,* 2023). By determining nitrogen levels and other soil properties through sampling and analysis, customized fertilization is made possible. Farmers may pinpoint areas for improvement by using real-time data on crop performance from harvesters equipped with yield monitoring sensors. These devices gather data, which is then evaluated to help with pest control, fertilizer, irrigation, and planting decisions.

Artificial Intelligence (AI) and IoT in agriculture

Rimpika *et al.,* (2024) said that Implementing AI, IoT, and satellite-based monitoring to maximize resource utilization and boost production should be done. To maximize resource utilization, precision farming makes use of data analytics, IoT, and AI methods that improve efficiency while lessening their influence on the environment include automatic irrigation, remote sensing, and soil monitoring. Maharashtra has improved yields and cut fertilizer consumption by 30% thanks to the use of AI-based soil health monitoring (IFPRI, 2023). By facilitating automation and predictive analysis, artificial intelligence (AI) and machine learning (ML) are revolutionizing the agriculture sector. According to Issa, Majed, Ameer, and Al-Jawahry (2024), Al-driven prediction models precisely estimate agricultural yields and weather patterns by analyzing large databases, including historical weather dates, soil conditions, and crop productivity.

These insights enables farmers to optimize planting schedules, resource allocation, and pest management strategies, reducing crop failure risk and improving productivity. The resilience of agriculture is increased by AI's capacity to forecast climatic anomalies and issue early warnings, which also enable farmers to adjust to climate change. Automation driven by AI is revolutionizing farming methods. Labor-intensive operations like planting, irrigation, harvesting, and agricultural monitoring are being carried out by smart technology, such as robots and driverless cars. The use of manual labor and chemical treatments is greatly reduced by these automated systems, which can determine crop maturity, diagnose illnesses, and even manage weeds when combined with computer vision and loT technology. For example, AI-enabled autonomous drones are used to precisely spray fertilizer and pesticides, reducing waste and guaranteeing environmentally pleasant farming methods.

Biotechnology and genetic improvements

Sustainable agriculture is greatly advanced by biotechnology, especially through genetically modified (GMO) crops. In the context of agriculture, biotechnology is the application of scientific methods and instruments to alter plants in order to increase their usefulness for farming. This covers tissue culture, genetic alteration, molecular markers, and other cutting-edge techniques. Numerous advantages of biotechnology include higher crop yields, decreased chemical use from genetically modified organisms and biopesticides, improved nutritional value, resource efficiency, biotechnology conservation, which reduces negative effects on the environment and human health, and economic benefits that help farmers save money and become more profitable.

Promising methods and instruments for tackling the problems of developing sustainable agriculture are provided by biotechnology. Enhancing crop resilience and decreasing reliance on chemical inputs are two benefits of biotechnology, which includes genetically modified (GM) crops and bio-fertilizers. Promised paths to increased harvests and climate adaption are provided by innovations like CRISPR gene editing. Bt cotton reduced pesticide use by over 50% while increasing output by 35%, according to Kumar *et al.,* (2024).

Role of Big Data and blockchain in agriculture

A research on the effects of blockchain technology on food supply networks and agriculture was carried out by Acharya *et al.,* in 2023. The research investigates the ways in which blockchain technology might improve security, traceability, and transparency. According to the report, blockchain may drastically change agricultural supply chains by boosting customer trust, decreasing fraud, and increasing transparency. The paper highlights the major technological and legal obstacles that need to be addressed while offering a thorough examination of blockchain's potential to revolutionize the gricultural supply chain. Its emphasis on the real-world applications of blockchain technology, together with the identification of existing challenges and recommendations for future research and policy initiatives.

Climate-Resilient Agriculture

Soil Health and Fertility

Because soil is a living ecosystem that promotes plant development and nutrient cycling, soil health is essential for sustainable agriculture. However, because of the overuse of chemical fertilizers, Indian agriculture confronts problems such soil erosion, nutrient depletion, and deterioration. Practices including increasing soil organic carbon, managing nutrients properly, and minimizing soil erosion are crucial to resolving these problems. Crop rotation, organic amendments, and limited tillage are important methods for enhancing soil health. Crop rotation improves soil structure, decreases pests, and diversifies the nutrients in the soil. While limited tillage helps maintain soil structure and stop erosion, organic additions like compost enhance soil with nutrients and organic matter. For the best crop development, fertilizer management and soil testing are essential. To reduce the impact on the environment and prevent misuse of pesticides, farmers can customize fertilizer delivery according to the pH and nutrient content of their soil. Soil testing has become more accurate and accessible because to technological advancements including mobile labs and easy-to-use kits. Through the integration of technology advancements and traditional wisdom, India can create robust agricultural systems that promote sustainability and long-term food security.

Climate-smart agricultural practices

A method for changing and reorienting food value chains and agricultural production systems to promote sustainable development and guarantee food security in the face of climate change is known as "climate-smart agriculture." The three primary goals of climate-smart agriculture are to: adapt and strengthen resistance to climate change; decrease and/or eliminate greenhouse gas emissions, if feasible; and sustainably raise agricultural production and incomes. This does not mean that every practice used in every setting should result in "triple wins" that benefit all three of these goals.

Agricultural producers in poor nations that are vulnerable to food insecurity due to climate change and who have few resources, no policy support, and few institutions to assist them adapt should pay special attention to the climate-smart agriculture strategy.

Water conservation and management strategies

Effective management of water resources becomes a vital pillar as the growth and development of the agricultural sector depend on the distribution and availability of water. Sustainable water resource management includes ensuring equitable distribution across regions, optimizing agricultural water usage, and enhancing rainwater collecting. The increasing strain on water due to population growth, industrial needs, and climate change necessitates a comprehensive and forward-looking strategy. Sustainable agriculture requires efficient watering techniques, such as sprinkler and drip systems. These systems assist cut down on water wastage by minimizing runoff and evaporation and delivering water equally across fields or straight to plant roots.

Different crop types and soil conditions can be accommodated by the flexibility of water application offered by sprinkler systems. Rainwater collection, particularly in regions susceptible to water shortage, is another essential strategy for ensuring water supply during dry times. Recharge wells, tanks, and ponds are examples of modern and traditional rainwater collection methods that may be used to expand water supplies. Throughout the monsoon season, ponds and tanks act as surface storage systems that collect runoff to offer an essential reserve for irrigation during dry periods. Groundwater levels rise as a result of recharge wells, which transfer surplus rainfall into underground aquifers. These methods provide a number of benefits, including higher agricultural yields, less demand on water supplies, and more effective use of water. They reduce dependency on external water sources and aid in water conservation. conserving water through the use of micro-irrigation methods like sprinkler and drip irrigation. Watershed development, rainwater collection, and micro-irrigation are sustainable water management techniques that guarantee effective resource use. In addition to saving water, smart irrigation technologies increase agricultural resistance to climate change. Smallholder farmers have benefited from a 60% improvement in water usage efficiency due to micro-irrigation techniques, according to Meena *et al.,* (2024). Rajasthani farmers have benefited from the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), which increased production and optimized water usage (World Bank, 2022).

Agroforestry and sustainable cropping systems

Agroforestry

Using agricultural practices based on trees to boost soil health and biodiversity. Maintaining ecological balance and producing both economic and environmental benefits need agroforestry, or the mix of trees and crops. Agroforestry systems improve biodiversity, climatic resilience, and soil health. In order to address environmental problems including soil degradation and biodiversity loss, agroforestry is now well recognized for its ability to combine forestry and agriculture. By diversifying crops and including trees, agroforestry reduces dependency on monoculture and agrochemicals, ensuring long-term ecological advantages. If properly regulated and successful models are expanded, agroforestry may significantly contribute to the growth of sustainable agriculture by promoting soil regeneration and climate adoption. Agroforestry models in Uttar Pradesh have shown improved farmer incomes while reducing soil erosion (ICAR, 2021)

Integrated Pest Management

A sustainable method of controlling pests, integrated pest management (IPM) greatly lessens reliance on chemical pesticides by integrating many strategies such mechanical control, crop rotation, and biological control. By using physical barriers, varied cropping systems, and natural predators to manage pest populations, this approach promotes healthier ecosystems and less environmental damage. These days, IPM is a vital instrument for reducing the overuse of chemical pesticides. Environmental deterioration and imbalances in soil health have resulted from the increased use of chemical pesticides and fertilizers (Kumar, 2023). A healthy balance of vital nutrients in the soil is promoted and ecological harm is minimized when IPM is used effectively to reduce chemical inputs. Recent government initiatives like the PM-PRANAM program, which encourages states to reduce their use of chemical fertilizers by encouraging organic fertilizers, Nano Urea, and Nano DAP, are in line with this. The shift to balanced fertilizer use and improved soil fertility has been further aided by the launch of "Urea Gold" and the soil health card program. Technological solutions, legislative assistance, and a greater emphasis on farmer training will all improve IPM in India.

Organic farming

India is positioned to lead the world in organic farming, which has seen tremendous growth in recent years. In addition to offering farmers the chance to access premium markets and boost their income, India's move to organic farming holds promise for bettering soil health. Organic farming has been actively promoted by the Indian government through specialized initiatives such as the Paramparagat Krishi Vikas Yojana (PKVY) and the Mission Organic Value Chain Development for North Eastern Region (MOVCDNER).

According to Sharma and Nagar (2024), organic farming offers a number of benefits, including the production of chemical-free crops and food grains, improved soil health, and less environmental pollution. Furthermore, organic farming encourages resource sustainability and biodiversity preservation. Organic products in India appear to have a promising future. Further expansion in this industry is anticipated due to sustained government backing and rising consumer demand for organic products.

Crop Diversification

A key tactic in sustainable agriculture is crop diversity, which boosts resistance to market swings, improves soil health, and fosters economic stability. According to Smith & Hijmans (2019), farmers may attain more balanced and lucrative farming systems by reorienting their attention from conventional monocultures like rice and wheat to alternative crops like pulses, oilseeds, and millets. In addition to lowering the risks brought on by market volatility, this strategy improves ecological sustainability. Diverse cropping patterns increase soil fertility, especially when legumes are used. As a result, the soil contains more nitrogen and less synthetic fertilizer is needed.

The government created the Crop Diversification Program (CDP) under the Rashtriya Krishi Vikas Yojana (RKVY). Furthermore, via enhanced production methods, access to high-yielding cultivars, and integrated pest control, the National Food Security Mission (NFSM) seeks to boost the productivity of commercial crops and food grains. Diversification is also promoted by financial incentives like the Minimum Support Price (MSP) policy.

Sustainable Livestock and Fisheries Management

Encouraging the use of aquaculture, livestock, and crops in integrated agricultural systems to increase sustainability and production. While maintaining environmental sustainability, West Bengal's integrated rice-fish farming has increased farmer earnings (ICAR, 2023).

Adoption of resilient seed varieties and stress-tolerant crops

Under the direction of the Indian Council of Agricultural Research (ICAR), the National Agricultural Research System (NARS), which is composed of ICAR Institutes and State/Central Agricultural Universities (CAU/SAU), created 2900 location-specific improved crop varieties and hybrids between 2014 and 2024. This category includes 88 sugarcane, 412 oilseeds, 437 pulses, 376 fiber crops, 178 fodder crops, 29 different vegetables, and 1380 grains. One or more biotic and/or abiotic stresses can be resisted by 2661 of the 2900 kinds (pasture crops 157, sugarcane 88, pulses 410, cereals 1258, oilseeds 368, fiber crops 358, and other crops 22) (ICAR-2024).

Policy and Governance

Agricultural reforms and government policies

Regulations for sustainable farming that support the environment and food security depend heavily on effective government policy. For Mohd Hamid, Dr. Inamur Rahaman, and Dr. Abhishek Kumar Singh, this effort includes the Pradhan Mantri Fasal Bima Yojan (PMFBY): Vikshit Bharat @ 2047: Through the Pradhan Mantri Kisan SAMPADA Yojana (PMKSY), Pathway offers insurance against agricultural loss from illnesses or natural disasters. It also supports supply chain management to cut waste and increase food shelf life. For the purchase of high-quality seeds, fertilizer, and sophisticated farming equipment, it also offers financial incentives and subsidies. Due to the fact that PPPs combine the capabilities of both sectors, they are essential in tackling agricultural difficulties. They make it easier to exchange ideas, transfer technology, and raise cash, which results in creative solutions and better use of available resources. PPPs also support supply chain strengthening, market access improvement, adoption of innovative farming practices, and research and development. In the end, public-private partnerships and efficient government policies provide a thorough foundation for India's agricultural growth to be sustainable.

Public and Private Sector Role

Government agencies, commercial agritech companies, and agricultural colleges can work together to strengthen research and development partnerships (Singh & Sharma, 2022). Innovative seed technology, climate-resilient crops, and smart farming methods may all be accelerated by funding agricultural research through public-private partnerships (PPPs) (Patel *et al.,* 2021). While the public sector makes sure that these technologies are accessible and affordable, the private sector may help by creating sophisticated machinery, AI-based solutions, and financial instruments for farmers (Gupta & Mehta, 2020). The transformation of Indian agriculture will also be greatly aided by programs like cross-sector information sharing, venture capital assistance for agribusiness entrepreneurs, and incubation centers (World Bank, 2021).

Global Best Practices

Taking inspiration from successful models in nations like the Netherlands and Israel. Utilizing Israel's cutting-edge irrigation technology, including as drip irrigation and desalination methods, will help India deal with its water shortage (Shani *et al.,* 2021). Furthermore, Israeli farmers may increase production and resource efficiency by implementing AI-driven agricultural solutions and precision agriculture (Weiss & Goldstein, 2020). The Netherlands provides insights into maximizing land usage and raising production per hectare because of its creative vertical agriculture and greenhouse farming practices (Janssen *et al.,* 2019). These best practices can greatly increase sustainability and resilience in Indian agriculture when they are adapted to the country's various agro-climatic zones (FAO, 2022).

Agriculture Finance

In order to provide financial services that are suited to farmers' requirements, agriculture finance is essential. Adopting contemporary technology and sustainable practices to boost agricultural output requires having access to reasonably priced financing. This industry is changing as a result of innovative financial models that provide smallholder farmers with more inclusive options, such as digital platforms and microfinance. Financial organizations that serve farmers by offering tailored lending programs and insurance options include commercial banks, RRBs, and cooperative banks. Small and marginal farmers are also being empowered by SHGs and microfinance. Access to agricultural financing has been significantly transformed via the Kisan financing Card (KCC) program. 7.35 crore KCCs with an 8.86 lakh crore credit limit have been granted by banks as of March 2023 (Hamid, Singh, & Rehaman, 2024).

Gross Capital Formation (GCF)

The total investment in material assets including farm equipment, buildings, and land improvements is measured by gross capital formation, or GCF. They demonstrate the dedication to upgrading agriculture. Investment from the GCF is essential for boosting sustainability and productivity, which includes post-harvest facilities that lower waste and maintain product quality, which would increase farmers' revenue. Growing public investment supports GCF's ongoing advancement in the agriculture sector. Increasing agricultural output requires the use of contemporary machinery, from simple tools to sophisticated equipment. This is accomplished through specialized hiring and training assistance, underscoring GCF's important role.

Rural Infrastructure and Market Reforms

Supply Chain Strengthening

For farmers to have better access to markets and minimize post-harvest losses, supply chain management must be done well. Longer periods of fresh vegetables are guaranteed by creative storing methods. Modern cold storage facilities help prevent waste and spoiling of perishable items. The entire efficacy of the supply chain is increased by better logistics. Produce that is transported efficiently and on schedule is guaranteed to reach the market in the best possible shape. Farmers are being revolutionized by e-commerce platforms like e-NAM (National Agriculture Market). Better price discovery is made possible, the gap between farmers and purchasers is closed, and the need for middlemen is reduced. When paired with digital market connections, developments in cold storage and logistics greatly enhance farmers' financial results.

Expanding logistical networks, adding more processing facilities, and upgrading cold storage facilities in order to create a more cohesive and effective supply chain. This entails boosting farm-to-market road connections, developing rural storage infrastructure, and utilizing blockchain technology for transparency and traceability. Reducing waste and raising farmer earnings can be achieved by expanding farmer access to agro-processing and post-harvest management practices. Supply chain enhancements may be financed and scaled with the use of public-private partnerships (PPPs) (Kumar & Rao, 2021). Furthermore, India's agricultural export potential may be increased by using international best practices in supply chain efficiency, as those in the European Union (FAO, 2022).

Digital Platforms

Indian agriculture is undergoing a change because of the use of digital platforms, which offer real-time market data, make direct connections between farmers and consumers easier, and improve supply chain effectiveness. Farmers may obtain transparent pricing with mobile applications like e-NAM and AgriBazaar, which lessen the impact of middlemen and guarantee higher profit margins. Furthermore, farmers receive tailored advice on crop health, weather predictions, and the best times to harvest via AI-powered digital advisory services (Rao & Mehta, 2021). Agricultural value chain traceability and transaction security are further guaranteed by the use of blockchain technology (Gupta *et al.,* 2022). Smallholder farmers may increase their productivity and income levels by utilizing these platforms to get access to financial services, government subsidies, and high-quality input markets (World Bank, 2023).

Role of Cooperatives and FPOs

Through improved market access, financial assistance, and collective negotiating power, cooperatives and Farmer Producer Organizations (FPOs) are essential to the empowerment of small and marginal farmers. Farmers may now get fair pricing for their goods thanks to these groups' assistance in reducing reliance on middlemen (Kumar & Singh, 2022). Cooperatives make it possible to buy supplies like machinery, seeds, and fertilizer in bulk at a reduced cost, increasing production and cost-effectiveness (Sharma *et al.,* 2021). Furthermore, by offering training on digital technologies, financial literacy, and contemporary agricultural methods, FPOs support capacity building (World Bank, 2023). The SFAC-backed FPO project and NABARD's financial aid programs are two examples of government initiatives that have played a key role in fortifying these organizations. Collective farming has the potential to achieve economic sustainability and rural development, as evidenced by successful models from nations such as Japan's agricultural cooperatives and India's AMUL model (FAO, 2022).

Socio-Economic Aspects

Rural Employment and Livelihood Diversification

Growing agro-based companies, encouraging agripreneurship, and aiding related industries like horticulture, dairy, and fisheries in order to provide job prospects in rural areas. Market connections and value addition can be facilitated by bolstering micro, small, and medium-sized businesses (MSMEs) in rural regions (Kumar *et al.,* 2021). Furthermore, financial assistance programs and skill-building activities for rural business owners can improve economic resilience and revenue diversification. According to the World Bank (2023), rural farmers and craftspeople may reach a wider audience by promoting digital literacy and e-commerce platform access.

Women and Youth Participation

Supporting initiatives for skill development and gender-inclusive policies to increase the involvement of women and young people in agriculture. According to Agarwal (2022), promoting women-led agribusinesses and self-help groups (SHGs) can enhance social empowerment and financial independence. Access to digital tools, entrepreneurial training, and creative agritech businesses can all boost youth engagement (Patel *et al.,* 2021). Agri-Entrepreneurship Schemes and the Mahila Kisan Sashaktikaran Pariyojana (MKSP) are two government programs that offer crucial assistance to young farmers and women. According to the FAO (2023), a competent workforce for sustainable agricultural development may be produced by combining modern farming methods with vocational training in schools and colleges.

Education and Skill Development

To provide farmers and agribusiness owners with up-to-date skills and information, agricultural universities and vocational training facilities must be strengthened. University curricula may improve sustainability and production by including climate-smart agriculture practices, precision farming methods, and digital education (Gupta & Sharma, 2022). Capacity building also heavily relies on programs like Krishi Vigyan Kendras (KVKs) and the National Skill Development Corporation's (NSDC) skill development programs.

The knowledge gap in rural regions can be further closed by growing mobile-based consulting services and online learning platforms (FAO, 2023). Partnerships between academic institutions, research centers, and agribusiness sectors can offer practical instruction and exposure to the most recent developments in agricultural technology (Patel *et al.,* 2021).

In conclusion, Achieving agricultural sustainability by 2047 requires policy reforms, stakeholder collaboration, and continuous research. Policies should focus on soil health, water conservation, sustainable cropping, and eco-friendly farming incentives. Governments must ensure infrastructure development, financial support, and fair markets. The private sector should invest in agri-tech, supply chains, and sustainable inputs. Farmers need access to knowledge, technology, and institutional backing. Research in climate-smart agriculture, precision farming, and alternative energy is crucial. A coordinated, science-driven approach will secure food security, economic stability, and environmental well-being for future generations.

Author Contributions

Pinal V. Vekariy: Investigation, formal analysis, writing—original draft. Sayan Patel: Validation, methodology, writing—reviewing. Helee Patel:—Formal analysis, writing—review and editing. Rucha U. Raval: Investigation, writing—reviewing. D. K. Varu: Resources, investigation writing—reviewing.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

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