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A review on the application of artificial intelligence and big data in agricultural farming systems for climate resilience

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Abstract

Climate variability and extreme weather events have emerged as major threats to agricultural sustainability across the world. In India, irregular rainfall, droughts, floods, heat stress and soil degradation are affecting crop productivity, farm income and food security. In recent years, the rapid growth of Artificial Intelligence (AI), Big Data analytics, Internet of Things (IoT), remote sensing and machine learning has created new opportunities for developing climate-resilient agricultural systems. These technologies enable farmers, researchers and policymakers to make data-driven decisions by analyzing large and complex datasets generated from weather stations, satellites, soil health monitoring systems, crop management records and farm machinery.

This review paper discusses the role of AI and Big Data in strengthening climate resilience in agriculture. It explains how statistical methods, machine learning models and data analytics are integrated to improve crop yield prediction, climate risk assessment, precision farming, irrigation management and pest surveillance. The review also highlights the importance of agricultural statistics in ensuring data quality, model validation and interpretation of results. In addition, the review paper examines the practical applications of AI in climate-resilient crop breeding and sustainable resource management.

The discussion is based on a review of published literature from scientific journals, conference proceedings and online academic repositories. The findings indicate that AI and Big Data can significantly improve agricultural productivity, reduce climate-related risks and support sustainable food systems. However, challenges such as high investment costs, lack of technical expertise, poor digital infrastructure and concerns related to data privacy continue to limit large-scale adoption. Despite these barriers, the future potential of AI-enabled climate-smart agriculture remains immense, particularly in developing countries where agriculture continues to support livelihoods and national economies.

Keywords: Climate variability, extreme weather, agriculture, climate-resilient farming

Introduction

Agriculture has always been closely linked with climatic conditions. Temperature, rainfall, humidity, sunlight and wind patterns directly influence crop growth, soil fertility, water availability and livestock productivity. However, the increasing intensity of climate change has made agricultural systems more vulnerable than ever before. Across many regions of India, farmers are experiencing irregular monsoon patterns, prolonged dry spells, sudden floods, cyclones and rising temperatures. These climatic disturbances reduce crop yields, increase pest outbreaks and threaten food security.

Traditional agricultural practices, although valuable, are often insufficient to address the complexity of present-day climate challenges. Modern farming systems generate enormous amounts of information through weather stations, soil testing laboratories, satellite imagery, drones, remote sensing devices, market records and farm management systems. Handling such large and diverse datasets manually becomes difficult and time-consuming. This has created the need for advanced technologies that can process, analyze and interpret agricultural data efficiently.

Artificial Intelligence and Big Data analytics have emerged as transformative tools in this context. AI refers to the ability of computer systems to mimic human intelligence for solving problems, recognizing patterns and making decisions. Big Data refers to large and complex datasets that cannot be processed effectively using conventional methods. Together, AI and Big Data provide a scientific framework for analyzing agricultural information and generating useful insights.

In climate-smart agriculture, these technologies help farmers and agricultural experts predict crop performance, monitor soil and weather conditions, detect diseases, optimize irrigation schedules and assess climate risks. AI-driven systems can identify hidden relationships among climatic variables and farming practices, enabling more accurate decision-making. Furthermore, the integration of statistical tools, machine learning techniques and data science improves the reliability of agricultural forecasting and policy planning.

The growing adoption of smartphones, IoT devices and cloud-based platforms has further accelerated the use of AI in agriculture. Precision agriculture, smart irrigation systems and automated pest detection models are increasingly being introduced in farming communities. Governments, research institutions and agricultural universities are also investing in digital agricultural technologies to promote sustainable farming practices.

This review paper explores how AI and Big Data contribute to climate resilience in agricultural farming systems. It also examines the role of agricultural statistics, machine learning and predictive analytics in improving agricultural productivity and sustainability under changing climatic conditions.

Objectives of the study

The major objectives of this review paper are:

1. To examine the role of Artificial Intelligence and Big Data analytics in agricultural farming systems.
2. To understand how AI and data-driven technologies contribute to climate-resilient agriculture.
3. To highlight the applications of AI, machine learning and agricultural statistics in crop management, irrigation, climate prediction and resource optimization.
4. To discuss the challenges and future potential of AI-enabled climate-smart agriculture.

Methodology

The review paper is based on a systematic review of scientific literature related to AI, Big Data and climate-smart agriculture. Relevant research papers, review articles and technical reports were collected from academic databases and platforms such as ResearchGate, MDPI, ScienceDirect and KrishiKosh. Keywords including “climate-resilient agriculture,” “AI in climate-smart farming,” “Big Data analytics in agriculture,” “precision farming,” and “machine learning for crop prediction” were used during the literature search process.

Approximately nineteen major research papers and reports were reviewed to identify recent developments and applications of AI in agriculture. The collected literature was analyzed carefully to understand different technological approaches, statistical tools and machine learning models used in climate-resilient farming systems.

The methodology followed in most AI-based agricultural studies generally includes several stages. First, data are collected from multiple sources such as IoT sensors, weather stations, satellite images, remote sensing systems and crop management records. These datasets are then cleaned, standardized and integrated

through data preprocessing techniques. After preprocessing, suitable machine learning algorithms are selected for model training and testing. Finally, model performance is evaluated using statistical indicators such as R^2 , Mean Squared Error (MSE), Root Mean Squared Error (RMSE) and Mean Absolute Error (MAE).

This systematic review approach provides a broad understanding of the practical role of AI and Big Data in improving agricultural resilience under changing climatic conditions.

Role of AI and Big Data in Climate-Resilient Agriculture

Climate-resilient agriculture aims to improve agricultural productivity while reducing vulnerability to climatic risks. AI and Big Data technologies support this objective by helping farmers make informed decisions based on scientific evidence and real-time information.

One of the major strengths of AI lies in its ability to analyze large volumes of agricultural data rapidly and accurately. Weather data, soil health records, crop growth information and market trends can be integrated into a unified system for better decision-making. Machine learning models can identify patterns and relationships that are often difficult for humans to recognize manually. (Khanna & Kaur, 2019) ^[11].

Big Data analytics enables researchers and agricultural planners to process structured and unstructured datasets generated from multiple sources. These include satellite imagery, climate models, farm sensors, mobile applications and agricultural surveys. By combining these datasets, it becomes possible to forecast weather events, estimate crop yields and evaluate climate risks more accurately.

Agricultural statistics also plays an important role in this process. Statistical tools help in sampling, data validation, trend analysis, regression modeling and interpretation of results. Statistical methods ensure that AI-based predictions are scientifically reliable and meaningful for practical use.

The integration of AI, machine learning and statistical analysis has led to the development of climate-smart agricultural systems that are more adaptive, efficient and sustainable. Farmers can now receive real-time recommendations regarding irrigation scheduling, fertilizer application, disease management and crop selection. Such systems reduce resource wastage while improving productivity and environmental sustainability.

Case Study: Microsoft AI Sowing Advisory Project in Andhra Pradesh, India

In 2017, Microsoft collaborated with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) to help small farmers in Andhra Pradesh cope with irregular rainfall and climate uncertainty. Farmers traditionally depended on guesswork and past experience to decide sowing dates, but changing weather patterns had made this unreliable.

Using AI, satellite data, soil moisture information, and historical weather records, the system sent personalized sowing advisories to farmers through mobile phones. The AI analyzed rainfall probability, temperature, and soil conditions to recommend the best sowing period.

One farmer from Devanakonda village shared that earlier he often lost seeds due to delayed rains. After following the AI advisory, he sowed groundnut at the recommended time and observed healthier crop growth and reduced seed loss.

Field results showed nearly a 30% increase in yield compared to neighboring farms that followed conventional practices. The project demonstrated how AI and big data can transform traditional farming into a climate-resilient system by helping

farmers make timely decisions, reduce risks, and improve productivity even under uncertain climatic conditions.

Precision Agriculture and Smart Farming

Precision agriculture is one of the most important applications of AI and Big Data in modern farming systems. It refers to the use of digital technologies for monitoring and managing agricultural operations with greater accuracy and efficiency.

In precision farming, data are collected continuously from fields using IoT sensors, drones, GPS devices and satellite imagery. These technologies provide information related to soil moisture, nutrient status, crop health, temperature and pest infestation. AI algorithms analyze these data and generate recommendations for farmers.

Soil health monitoring is an important component of precision agriculture. AI-enabled systems can evaluate soil nutrient status and identify deficiencies in nitrogen, phosphorus or potassium. Based on this information, farmers can apply fertilizers more efficiently, reducing both costs and environmental pollution.

Crop growth monitoring is another major application. Satellite images and remote sensing technologies help detect variations in crop growth across fields. AI models can identify stressed areas caused by drought, nutrient deficiency or disease outbreaks. This allows farmers to take corrective actions at an early stage.

Smart irrigation systems are increasingly being adopted in climate-smart agriculture. These systems use sensors and AI algorithms to determine the exact water requirement of crops. Irrigation schedules are adjusted automatically according to weather conditions and soil moisture levels. As a result, water use efficiency improves significantly while minimizing wastage. (Behera & Modak, 2024) ^[4].

Precision agriculture also contributes to sustainable farming by reducing excessive use of fertilizers, pesticides and water resources. It promotes environmentally friendly agricultural practices and helps maintain soil health over the long term.

Climate Prediction and Risk Assessment.

Climate prediction and risk assessment are critical for building resilient agricultural systems. Farmers often face uncertainty due to unpredictable rainfall patterns, extreme temperatures and natural disasters. AI and Big Data analytics help reduce this uncertainty by improving climate forecasting and early warning systems. (Wolfert *et al.*, 2017) ^[18].

Machine learning models are capable of analyzing historical climate data along with real-time weather information. These models can predict rainfall patterns, drought occurrences, flood risks and temperature fluctuations with improved accuracy. Predictive analytics allows farmers and policymakers to prepare in advance for adverse climatic events.

Climate modeling systems use large datasets from satellites, meteorological stations and environmental monitoring networks. AI helps process these datasets efficiently and identifies long-term climatic trends. Such information is valuable for agricultural planning, crop diversification and policy formulation. (Misra *et al.*, 2020) ^[13].

Early warning systems supported by AI can provide timely alerts regarding cyclones, droughts, pest outbreaks or disease epidemics. Farmers receiving early warnings are better prepared to protect crops, livestock and farm infrastructure. These systems are particularly useful in vulnerable regions where climate-related disasters occur frequently.

Risk assessment models also support agricultural insurance programs. By analyzing climate risks and yield variability, insurance companies can estimate potential losses more

accurately. This contributes to financial protection for farmers and reduces economic vulnerability in rural areas.

AI in Crop Breeding and Genetic Improvement

Crop breeding plays an important role in climate-resilient agriculture. Developing crop varieties that can tolerate drought, floods, salinity and temperature stress is essential for ensuring food security under changing climatic conditions.

AI technologies are increasingly being used in crop breeding programs. Large datasets related to plant genetics, environmental conditions and crop performance are analyzed using machine learning algorithms. These systems help researchers identify desirable genetic traits associated with stress tolerance, disease resistance and higher productivity.

Traditional breeding methods often require several years of field testing and experimentation. AI-assisted breeding accelerates this process by predicting plant performance under different climatic conditions. Researchers can analyze thousands of genetic combinations within a shorter period of time, improving the efficiency of breeding programs.

Genomic selection, phenotyping and predictive modeling are becoming important tools in smart crop breeding. Remote sensing and image analysis technologies also assist researchers in monitoring plant growth and identifying desirable characteristics. (Azadi *et al.*, 2025) ^[3].

Climate-resilient crop breeding supported by AI has the potential to develop improved varieties capable of adapting to future climatic uncertainties. This is particularly important for countries like India where millions of farmers depend on climate-sensitive crops for their livelihoods.

Case Study: AI-Based Wheat Breeding by CIMMYT

The International Maize and Wheat Improvement Center (CIMMYT) has been using artificial intelligence and machine learning to accelerate wheat breeding programs aimed at developing climate-resilient crop varieties.

Traditionally, breeding drought-tolerant or disease-resistant wheat varieties required many years of field trials. Scientists at CIMMYT introduced AI tools that analyze thousands of plant images, genetic markers, and environmental data to identify superior wheat lines much faster.

In field experiments across South Asia and Africa, AI-assisted breeding helped researchers quickly identify wheat varieties capable of tolerating heat stress caused by rising temperatures. Farmers participating in trial programs observed better grain filling and stable yields even during unusually hot seasons.

Researchers reported that AI reduced the time required for selecting promising crop varieties and improved breeding accuracy. This approach is particularly important in the context of climate change, where farmers urgently need crop varieties that can withstand drought, heat, floods, and emerging pests.

The case highlights how AI is not replacing breeders but assisting scientists in making faster and more precise decisions, ultimately helping ensure food security for future generations.

Sustainable Resource Management

Sustainable resource management is another major area where AI and Big Data contribute significantly. Agriculture depends heavily on natural resources such as water, soil and energy. Efficient management of these resources is essential for long-term sustainability.

Water management is one of the biggest challenges in agriculture. AI-based irrigation systems monitor soil moisture levels and weather conditions continuously. Farmers can apply

water precisely according to crop requirements, reducing over-irrigation and conserving groundwater resources. (FAO, 2022) [7].

Energy efficiency can also be improved through smart agricultural systems. Automated machinery, sensor-based monitoring and AI-driven scheduling reduce unnecessary energy consumption in farming operations. This contributes to lower production costs and reduced environmental impact.

Pest and disease management has become more effective with AI technologies. Image recognition systems and machine learning models can identify plant diseases at early stages using photographs captured through smartphones or drones. Farmers receive recommendations regarding suitable control measures before the infestation spreads widely. (Liakos *et al.*, 2018) [12].

Big Data analytics also supports nutrient management and crop rotation planning. By analyzing soil fertility trends and climatic conditions, AI systems recommend suitable cropping patterns and resource allocation strategies. This improves productivity while maintaining ecological balance.

Overall, sustainable resource management through AI contributes to climate adaptation, environmental conservation and economic stability in agricultural systems.

Case Study: Community Water Management in Hiware Bazar, Maharashtra

Hiware Bazar was once a drought-prone village suffering from water scarcity, crop failure, and migration. In the 1990s, villagers under the leadership of local community institutions began adopting sustainable resource management practices.

The village focused on watershed development, rainwater harvesting, contour trenching, and banning excessive groundwater extraction. Farmers shifted from water-intensive crops to sustainable cropping systems suitable for local rainfall conditions.

A farmer in the village recalled that earlier wells used to dry up before summer, forcing families to depend on tankers. After watershed management interventions, groundwater levels improved significantly and farming became profitable again.

Today, the village has become a model of sustainable agriculture and rural development. Crop productivity increased, milk production rose, and migration reduced drastically. The success of Hiware Bazar shows that sustainable management of soil and water resources not only protects the environment but also strengthens rural livelihoods and climate resilience.

Challenges in Adoption of AI and Big Data in Agriculture

Despite the enormous potential of AI and Big Data, several challenges continue to limit their adoption in agriculture, especially in developing countries. One major challenge is the high initial investment required for digital technologies. AI systems, sensors, drones, automated machinery and satellite services are often expensive for small and marginal farmers. Lack of affordable infrastructure reduces accessibility in rural areas.

Technical knowledge and digital literacy also remain limited among many farmers. Successful implementation of AI-based systems requires training and awareness regarding data collection, software usage and interpretation of results. Inadequate extension support can slow down technology adoption.

Data privacy and ownership issues have emerged as important concerns in digital agriculture. Farmers may hesitate to share agricultural data due to fear of misuse or commercial exploitation. Clear data governance policies are therefore

necessary. (Wiseman *et al.*, 2019) [19].

Another challenge is poor internet connectivity and electricity supply in remote rural regions. AI systems often depend on cloud computing and real-time data transmission, which require reliable digital infrastructure.

Model accuracy and data quality are equally important. Incomplete or biased datasets may produce unreliable predictions. Therefore, agricultural statistics and scientific validation remain essential for ensuring trustworthy AI applications.

In addition, socio-economic inequalities may widen if advanced technologies become accessible only to large commercial farms. Inclusive policies and affordable technological solutions are necessary to ensure equitable benefits for smallholder farmers.

Future Prospects of AI in Climate-Smart Agriculture

The future of AI and Big Data in agriculture appears highly promising. As digital technologies become more affordable and accessible, their application in climate-smart farming is expected to expand rapidly.

Advancements in machine learning, robotics and remote sensing will improve agricultural forecasting and decision-making further. Autonomous farm machinery, robotic weed control systems and AI-powered drones may become common features in modern agriculture.

Integration of AI with mobile applications can help farmers access real-time information regarding weather, market prices, disease outbreaks and crop management practices. Such systems can strengthen agricultural extension services and improve communication between researchers and farmers.

Big Data analytics may also support national and global food security planning. Governments can use AI-generated insights for policy formulation, disaster preparedness and resource allocation. Climate-resilient agricultural strategies based on scientific evidence will become increasingly important in the coming decades.

Educational institutions and agricultural universities are also expected to play a major role in promoting digital agriculture. Training programs, skill development initiatives and interdisciplinary research can prepare future agricultural professionals for technology-driven farming systems.

The successful integration of AI, Big Data and agricultural statistics has the potential to transform agriculture into a more sustainable, resilient and efficient sector capable of addressing future climate challenges.

Conclusion

The integration of Artificial Intelligence, Big Data analytics and agricultural statistics has introduced a new era in climate-resilient agriculture. These technologies provide scientific tools for analyzing complex agricultural datasets, predicting climatic risks and improving farm-level decision-making. Applications such as precision farming, smart irrigation, climate forecasting, disease surveillance and crop breeding demonstrate the transformative potential of AI in modern agriculture.

The review clearly indicates that AI-based agricultural systems can improve productivity, optimize resource utilization and strengthen resilience against climate variability. Agricultural statistics remains fundamental in ensuring data reliability, model validation and interpretation of analytical results.

However, several barriers including high investment costs, digital illiteracy, data privacy concerns and infrastructural limitations continue to affect widespread adoption. Addressing these challenges requires coordinated efforts from governments,

research institutions, private sectors and extension agencies.

Despite existing limitations, the future scope of AI and Big Data in agriculture is immense. As climate change continues to threaten food systems globally, technology-driven and data-oriented agricultural practices will become increasingly important. Climate-smart agriculture supported by AI has the potential to ensure sustainable food production, environmental conservation and improved livelihoods for farming communities.

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