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Leveraging Big Data in Climate Resilient Agriculture -A Review

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Abstract: The use of big data has revolutionized various industries, and agriculture is one of its most important industries. Leveraging big data in agriculture enables agriculturists to optimize resource use management, increase yield and improve sustainability in agriculture. This study explores the application of big data analytics in agriculture, focusing on main areas such as crop health monitoring, precision agriculture and supply chain management. Big data in agriculture involves collecting, analyzing and utilizing huge amounts of data from various sources, including satellite imagery, UAV sensory data, data from weather stations and AGV-collected data. For instance, satellite imagery system provides high-resolution data on crop health monitoring, allowing the farmer to timely intervention in the operations. In 2023, global satellite data usage in agriculture reached 120 petabytes which is almost 15% increase from last year's data. Various sensors deployed on UAVs collect real-time data on water stress detection, crop health monitoring, nutrition deficiency, surveillance, NDVI and land mapping. Sensor networks deployed on Automated Guide Vehicle collect real-time data on soil moisture, temperature, and nutrient levels which enables the precision farming practices. The studies indicated that the implementation of precision farming in agriculture can reduce water usage by up to 30% and enhance crop yields by 20%. Also, big data analytics provides the facility of predictive modelling and decision-making efficiency. Machine learning algorithms analyze historical and real-time data for forecasting crop yields, pest infestation and market trends of agricultural produce. Furthermore, the application of big data improves supply chain efficiency by availing insights into logistics management, market demands and fluctuations in price. In 2022, with the help of big data analytics, it was possible to reduce post-harvest losses by 12% in major agricultural regions. However, the integration of big data in agriculture faces challenges such as technical expertise, data privacy and high. Leveraging big data in agriculture holds responsibility for transforming the agricultural sector, ensuring food security and promoting sustainable practices.

Keywords: Big data, machine learning, UAV, AGV, NDVI.

I. **Introduction**Agriculture is one of the most climate sensitive industries, it faces dynamic threats from erratic rainfall, rising temperatures and extreme weather conditions. As per the survey global food production needs to be increase by 60% by 2050 to meet the demands of growing population [1-2]. However, climate change is the major factor affecting the reduction in crop productivity, with the estimated suggestion that each 1°C rise in global temperatures could result in a 7 % decrease in soybean crop yield and similar effects on other staples crops like wheat, maize and rice [3]. Data offers a transformative way approach to address these kinds of challenges. The data is defined by its volume, velocity and variety [13]. Big Data refers to the collection and analysis of large datasets from various sources to extract valuable insights. In agriculture, these data include climatic conditions, rainfall, soil properties, crop health, crop productivity and market trends. If the data is processed using advanced technological tools such as machine learning (ML), deep learning (DL), cloud computing and Geographic Information Systems (GIS), Big Data will empower entrepreneurs, farmers, researchers, and policymakers to develop a climate resilient agricultural system [4]. The application of new technologies in agriculture with the use of big data revolutionizes the sector. Only collection and analyzing big data can-not improve the crop productivity of an individual farms but also help in halting the global food crisis. Fig. 1 shows the agricultural input model [7].

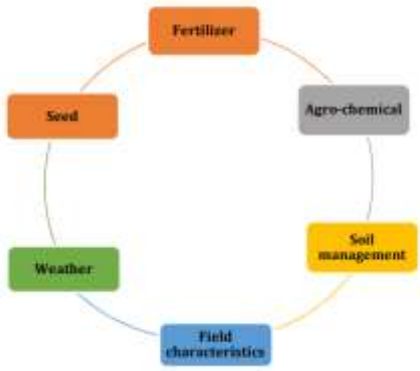

Fig. 1 Digital agricultural input model

1.1 What is Big Data

Big data refers to the large and complex dataset which are characterized by its volume, velocity and variety. It consists of huge amounts of structured, semi structured and unstructured data that cannot be easily handled and analyzed using traditional data processing tools and methods. The term "Big Data" is often associated with the three V's:

1. Volume: Big data consists of large volumes of data generated from different sources, such as sensors, data collecting devices, satellites etc. Therefore, this huge volume of data requires advanced tools and technologies for storage, processing, and analysis.

2. Velocity: Big data often generated at high speed and needs real-time or near-real-time processing. This dynamic flow of data requires systems capable of capturing, processing and analyzing data in a precise manner to get meaningful insights.

3. Variety: Big data observed in various forms, including structured, semi-structured, and unstructured data. It includes text, images, videos, audio, and other formats shown in figure 2. The tremendous diversity of data types and sources poses challenges in terms of storing, integration, analysis and interpretation [10].

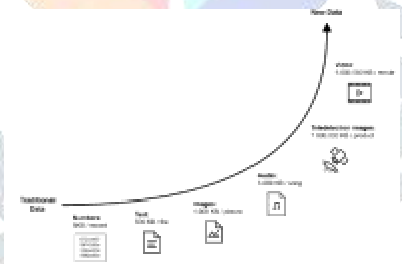

Fig. 2 Evolution of unstructured data

1.2 Role of big data in agriculture

Big data is a vast source of knowledge and information in agriculture which deals with huge amount of data of farmers and growers. Big Data in agriculture will grow up to a whopping 2 billion USD by 2025 [5-6]. It means that the entire industries have already know the potential of big data big data has significant potential to revolutionize the agricultural sector by enhancing crop productivity, sustainability in agriculture and decision-making processes. Applying big data solutions in agriculture requires overcoming challenges such as data collection, data integration, privacy and connectivity in rural areas. Also, these global issues have extended the scope of big data beyond farming and now it is covering the entire food supply chain and logistics. With the development in Internet of Things (IoTs), different components of agriculture and the supply chain and logistics are wirelessly connected, generating data that is accessible in real-time. The following figure 3 shows the role of big data in agriculture [8].

Fig. 3 Role of Big Data in agriculture

1.3 Types of big data in agriculture

i. Geospatial Data

In agriculture geospatial data refers to the use of location-based information to understand and manage the agricultural practices. It involves the collection, analysis and visualization of data related to the weather, crops, soil and other parameters that affects agricultural productivity. Geospatial technologies, such as Geographic Information Systems (GIS), Global Positioning Systems (GPS) and remote sensing (RS), plays an important role in obtaining and utilizing this data. There are some key applications and benefits of geospatial data in agriculture such as precision farming, crop health monitoring, Soil Analysis, Pest and Disease Management, Land Use Planning, Climate Resilience, Supply Chain Management [9].

ii. Meta Data

Metadata in big data plays a vital role in the field of agriculture. It provides additional information about the collected, stored and analyzed data, enabling better understanding and utilization of agricultural big data. Here are some ways metadata is used in the context of agriculture and big Data those are data source identification, Data Description and Context, Data Provenance and Traceability, Data Integration and Interoperability, Data Access and Discovery, Data Privacy and Security, Data Analysis and Interpretation, Overall, metadata in big data for agriculture acts as an important layer of information that enables effective data management, integration, analysis, and decision-making in the agricultural domain.

iii. Telematics

Telematics, when combined with big data, has the potential to revolutionize the agriculture industry. Telematics refers to the integration of telecommunications and informatics technologies for monitoring, analyzing, and managing remote assets, such as vehicles, machinery, and equipment. In the context of agriculture, telematics combined with big data analytics offers several benefits and applications such as Equipment and Fleet Management, Precision Agriculture, Yield Monitoring, Supply Chain Optimization, Safety and Security, Data and Driven Decision Making. In summary, telematics integrated with big data in agriculture offers numerous advantages, including improved equipment and fleet management, precision agriculture, yield monitoring, supply chain optimization, enhanced safety, and data-driven decision making [11]. These technologies have the potential to drive efficiency, productivity, and sustainability in the agricultural sector. Figure 4 shows the architecture of big data for atmospheric composition monitoring [12].

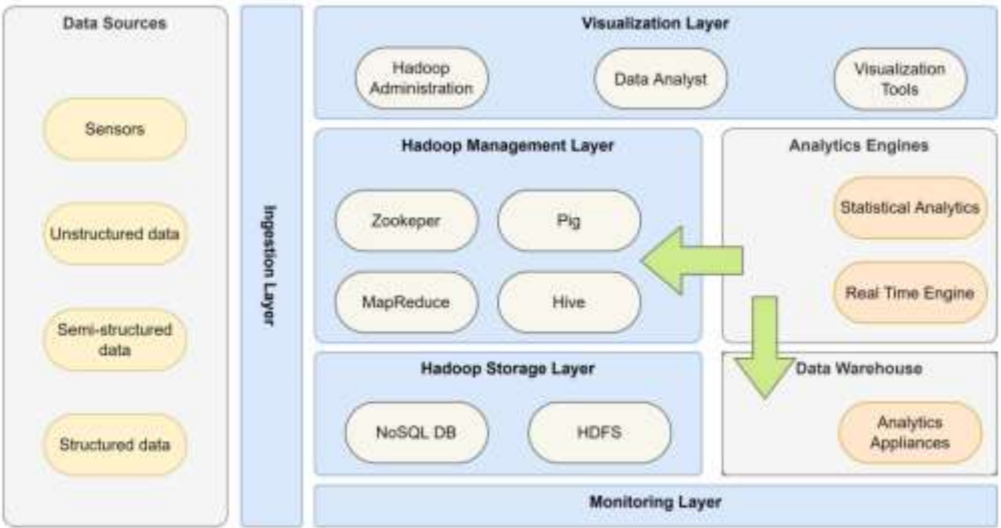

Fig. 4 Architecture of Big Data for atmospheric composition monitoring.

II. APPLICATIONS OF BIG DATA IN AGRICULTURE

Big data has a wide range of applications in agriculture which can revolutionize the way farming and agricultural practices are conducted. Here are some key applications of big data in agriculture:

2.1 Precision Agriculture

Big data analytics enables the precision agriculture, which involves the use of data-driven insights to optimize the resource use efficiency in farming practices. Farmers can collect and analyze the data on soil composition, moisture levels, weather conditions and crop health monitoring to make decisions about irrigation, fertilization and pesticide application. This particular approach can minimize resource waste, maximizes crop yields and reduces environmental impact. Below figure 5 shows the diagrammatic applications of big data in precision farming [20].

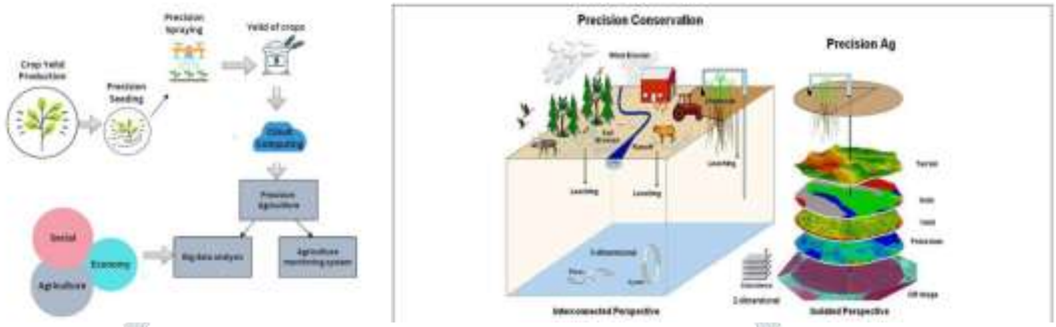

Fig. 5 Application of big data for precision farming

2.2 Crop and Livestock Management:

Big data allows farmers to manage and monitor crops and livestock more effectively. By analyzing data on growth rates, feed intake and health records, farmers can make decisions about irrigation, nutrition, disease prevention and overall management practices. This helps in enhancing crop productivity, animal welfare and profitability in the farming. Big data technology helps the farmer to select proper crop through using various algorithm analysis of input and output variables of a crop. There are some popular techniques which are used frequently for crop selection such as K-nearest neighbor, random forest, decision tree and artificial neural network. Big data technology usually analyzes natural calamities, climate, disasters, soil and other inputs for finding out suitable crop for a specific area.

2.3 Yield Prediction and Forecasting:

Yield prediction model can be used for predict and forecast crop yield by analyzing historical data, weather patterns, and other relevant variables, big data analytics. This information helps farmers and policymakers make informed decisions about marketing plan, price and resource allocation. It also helps in supply chain management and reduces food waste. Farmers can get the probable harvesting time and yield of the crops by using big data technologies through analyzing a various effective algorithm. By using this useful information, farmers can easily avoid yield harvest lost and manage the post harvest activities. Big data technologies help the farmer to get more yield by finding proper harvesting time which also helps to avoid any adverse and harsh climatic conditions.

2.4 Farm Resource Optimization:

Big data analytics enables farmers to optimize the use of resources such as water, energy, and fertilizers. By collecting and analyzing data on soil moisture, weather conditions, and crop growth patterns, farmers can implement precision irrigation and nutrient management strategies. This reduces resource wastage, improves efficiency, and promotes sustainable farming practices. Irrigation is an essential intercultural management factor for crop production. An accurate time and proper water supply can improve plant health otherwise it will be fallen into various problems like stunt growth, pest attack and wilting. Most of the developing countries face variability of climatic change, rainfall and drought. The smart irrigation system may be a solution for farmers to take a proper decision on irrigation. Big data technology can easily predict the irrigation requirement of the crop by using an artificial neural network [17]. Here figure 6 shows the truncated flowchart of the modelling and solution process for the irrigation practice.

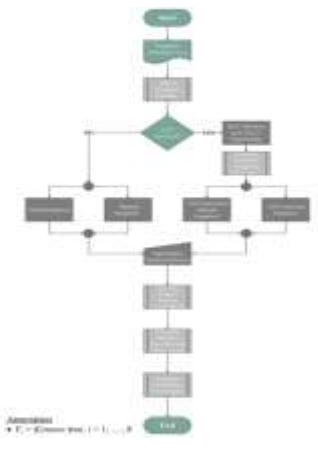

Fig. 6 Truncated flowchart of the modelling and solution process

2.5 Disease and Pest Management:

Big data analytics can help in early detection and management of diseases and pests in crops and livestock. By analyzing data on symptoms, weather conditions, and historical patterns, farmers can identify disease outbreaks or pest infestations, enabling timely intervention and control measures. This minimizes crop losses and the need for excessive pesticide use. Disease and pest infestation of the crop is a normal phenomenon in crop production but it reduces the quality and yield of the crop. If a farmer can control the disease and pest infestation, it will help to increase yield. Big data provides this opportunity to detect any disease infestation on the crop for which farmers can easily take measure to control the disease and the safe the crop.

2.6 Supply Chain Optimization:

Big data plays an important role in optimizing the agricultural supply chain. By collecting and analyzing data on inventory materials, transportation logistics and market demand, stakeholders can make preliminary decisions about storage, transportation and distribution of the produce. This reduces waste, improves efficiency and ensures timely delivery of agricultural products to markets.

2.7 Market and Consumer Insights:

Big data analytics helps in understanding the market trends, consumer choises and demand patterns of the agricultural produce. By analyzing data from sources such as social media, market surveys and sales records, agricultural businesses can make instant decisions about product development, marketing strategies and pricing of the products. This provides market competitiveness and customer satisfaction. Market information is required for getting profit from agricultural products. A farmer may face loss on their product due to ignorance about the market scenario. There are different kinds of market data such as input cost, price trends, demand and supply, cultivation cost, wages, marketing and transportation cost. Farmers can take decision easily from the result of big data analytics of these market information. The government can use the big data technology for market analysis and take proper monitoring on market.

2.8 Climate and Weather Monitoring

Big data analytics helps in monitoring climate change patterns and weather conditions. By analyzing historical weather data and real time information, farmers can make decisions about sowing schedules, harvesting and other farming practices. This helps in adapting to climate change, reducing risks and optimizing farm management practices. These applications demonstrate how big data is transforming agriculture by giving actionable inputs, optimizing resource usage, improving crop productivity and promoting sustainable farming practices. Environmental parameters have a great influence on crop cultivation, fish cultivation and livestock management practices. Since various stages of crop, plant require different temperature and humidity, therefore it is necessary for the farmer to learn about useful temperature and humidity that can be easily known by using big data analytics. Big data technology provides an opportunity for farmers to take decision for better crop management by analyzing different stages of crop cultivation such as planting time, intercultural operation, fertilization, pesticide management and harvesting. Farmers can easily avoid any adverse situation from weather forecasting [16]. Similarly, a farmer can take a decision about the soil management since the soil is also related to environmental factors. A farmer can get weather forecasting by using Support Vector Machine which is based on machine learning technique. This figure 7 shows the big data analytic methods for climate change and figure 8 shows the Framework of CSA applications and architecture of big data analytics [14-15]. Fig. 7 Big data analytics methods for climate change

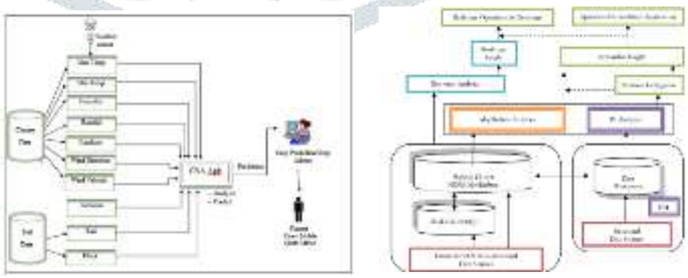

Fig. 8 Framework of CSA applications and architecture of big data analytics

III. CHALLENGES OF BIG DATA WITH AGRICULTURE

While big data offers a various opportunity in the agricultural sector, there are also several challenges that need to be addressed. There are some key challenges associated with the implementation and utilization of big data in agriculture:

a) Data Quality and Standardization: Agricultural data comes from different sources, including sensors, remote sensing, satellite and manual collection, leading to issues of data quality and standardization. Inaccuracies, inconsistencies and missing data can affect the reliability and accuracy of big data analytics. Ensuring data quality and establishing standardized protocols for collecting data, storage and sharing are essential challenges to overcome.

b) Data Integration and Interoperability: Agriculture consists of multiple data sources, such as soil data, weather data and crop monitoring data. Integrating and analyzing heterogeneous data from different sources can be challenging due to variations in data formats, structures and semantics.

c) Data Privacy and Security: Agricultural data often contains sensitive and proprietary information, such as geological farm locations, crop yields and market strategies. Protecting data privacy and ensuring data security is crucial to build trust among stakeholders. Implementing robust data protection measures including encryption, access controls and anonymization techniques, is a challenge that needs to be addressed.

d) Infrastructure and Connectivity: Access to reliable and high-speed internet connectivity is essential for the effective utilization of big data in agriculture. However, rural areas may face challenges in infrastructure development and connectivity, limiting the seamless flow of data and real-time analytics. Expanding infrastructure and ensuring connectivity in remote agricultural regions is a significant challenge.

e) Data Ownership and Governance: Big data in agriculture involves various stakeholders, including farmers, technology providers, researchers, and policymakers. Determining data ownership, usage rights, and governance frameworks can be complex. Establishing clear policies and frameworks for data ownership, access, and sharing while respecting the rights and interests of all stakeholders is a challenge.

f) Skills and Capacity Building: Effectively utilizing big data in agriculture requires specialized skills in data analytics, data management, and domain-specific knowledge. There is a shortage of skilled professionals in the agriculture sector who can leverage big data analytics effectively. Building capacity and providing training programs to enhance data literacy and analytical skills in the agricultural workforce is a challenge.

g) Cost and Infrastructure Constraints: Implementing big data solutions and infrastructure can be costly, particularly for small-scale farmers and agricultural enterprises. Investments in hardware, software, data storage, and analytical tools may pose financial constraints. Developing cost-effective solutions and promoting access to affordable technologies are significant challenges in making big data accessible to all stakeholders in agriculture. Addressing these challenges requires collaborative efforts from various stakeholders, including farmers, researchers, policymakers, technology providers, and regulatory bodies. Investments in infrastructure, capacity building, data governance frameworks, and data privacy measures are crucial to realizing the full potential of big data in agriculture.

IV. FUTURE OF AGRICULTURE WITH BIG DATA

The future of agriculture with big data is highly promising and holds immense potential for transforming the industry. Here are some key aspects that highlight the future of agriculture with Big Data:

a) Data-Driven Decision Making: With the increasing availability of big data in agriculture, decision-making processes will become more data-driven and precise. Farmers will be able to access real-time data on weather patterns, soil conditions, crop health, and market trends, enabling them to make informed decisions about planting, irrigation, fertilization, and harvesting. This data-driven approach will optimize resource usage, improve yields, and enhance overall farm management. b) Artificial Intelligence and Machine Learning: Big data combined with artificial intelligence (AI) and machine learning (ML) techniques will play a significant role in agriculture's future. AI and ML algorithms can analyze large volumes of agricultural data, identify patterns, and make predictions and recommendations. This will enable farmers to automate processes, detect anomalies, optimize pest and disease management, and implement precision agriculture techniques with greater accuracy and efficiency. c) Internet of Things (IoT) Integration: The integration of big data with IoT devices will revolutionize agriculture. IoT sensors and devices will collect real-time data from fields, livestock, and machinery, providing continuous monitoring and analysis. This data can be combined with other agricultural data sources, enabling farmers to make timely decisions, optimize operations, and prevent losses. For example, IoT devices can detect soil moisture levels, triggering automated irrigation systems for efficient water usage. d) Advanced Farm Management Systems: Big data will enable the development of advanced farm management systems that integrate multiple data sources and provide comprehensive insights. These systems will combine data on weather conditions, soil quality, machinery performance, and crop health to offer farmers holistic views of their operations. Farmers will be able to monitor and manage their farms remotely, optimize workflows, and improve overall productivity. e) Predictive Analytics and Risk Management: Big data analytics will facilitate predictive analytics and risk management in agriculture. By analyzing historical and real-time data, predictive models can forecast crop yields, market prices, and potential risks. Farmers will be able to proactively plan and manage their operations, mitigate risks, and optimize decision-making based on predictive insights. f) Sustainable and Smart Agriculture: Big data will contribute to the development of sustainable and smart agriculture practices. By analyzing data on resource usage, environmental factors, and ecological impacts, farmers can implement precision farming techniques that minimize waste, reduce environmental footprint, and enhance sustainability. Big data will also support traceability and certification systems, enabling consumers to make informed choices about sustainable agricultural products. g) Collaboration and Data Sharing: The future of agriculture with big data will involve increased collaboration and data sharing among stakeholders. Farmers, researchers, technology providers, and policymakers will work together to share data, best practices, and insights. Collaborative platforms and initiatives will facilitate data exchange, enabling stakeholders to leverage collective knowledge and drive innovation in the agriculture sector [18-19].

V. Conclusion

Big Data has emerged as a innovative advanced technology in the agricultural sector, addressing some of the most hectic problems in advanced farming. By enabling the efficient collection, analysis and utilization of huge datasets, it empowers agriculturists to optimize resource management, enhance productivity and promote sustainability in agriculture. The application of Big Data analytics has an important role in crop health monitoring, precision agriculture and supply chain management, with measurable benefits that demonstrate its potential to revolutionize the agricultural industry. The use of satellite imagery, UAV sensors, and AGV-collected data has significantly improved real-time or near real time monitoring and decision-making capabilities. In 2023, the global satellite data usage in agriculture sector reached 120 petabytes, marking a 15% increase from the previous year. UAVs and their integrated sensors provide valuable insights on water stress, crop health and nutrition deficiencies, whereas AGVs helps in soil analysis and temperature monitoring, leading to more precise and efficient farming practices. Studies highlight that precision agriculture enabled by Big Data has reduced water usage by up to 30% and increased crop yields by 20%, showcasing the tangible impacts of data-driven approaches. Along with resource optimization, Big Data enhances predictive modelling and decision-making through advanced machine learning algorithms. These tools analyze both historical and real-time data to forecast crop yields, detect pest infestations and anticipate market trends. Also, the supply chain efficiency has benefited immensely, with a 12% reduction in post-harvest losses in major agricultural regions recorded in 2022. However, challenges remain in the integration of Big Data within agriculture.

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