PREDICTIVE ANALYTICS IN SMART FARMING - A CASE STUDY FOR TAMIL NADU

by

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Dedication

I dedicate this work to my **grandmother, the late Smti Sennammal**, whose wisdom, strength, and unwavering resilience continue to inspire me. Her values have left an everlasting impact on my life, shaping the person I have become.

I also dedicate this thesis to my **dearest uncle, the late Dr. A. Bharathi**, whose guidance and remarkable accomplishments have always been a source of motivation for me. His passion for knowledge and excellence continues to inspire my journey, reminding me of the power of perseverance and dedication.

Additionally, I extend this dedication to **all my late grandparents and great-grandparents**, whose sacrifices, values, and love have laid the foundation for my life. Their legacy lives on in every achievement I make, and I am forever grateful for the path they paved for me.

Acknowledgements

This journey has been one of the most challenging yet fulfilling experiences of my life, and I truly wouldn’t have made it here without the love and support of my family, friends, and well-wishers.

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To my **daughter, Teertha**, your infectious enthusiasm and endless motivation have been a guiding light for me. You reminded me why I started this journey, and your belief in me kept me going even in the toughest moments. You inspire me every single day.

I also want to extend my deepest appreciation to **my brother, Suresh , extended family, all my relatives, and my dear friends** who have been my unwavering support system. Their encouragement, kind words, and belief in me made all the difference. Whether it was a reassuring conversation, a motivating message, or simply their presence, their support has meant the world to me.

This achievement is not just mine—it belongs to each and every one of you who stood by me through this journey.

ABSTRACT

PREDICTIVE ANALYTICS IN SMART FARMING

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This thesis delves into the transformative potential of predictive analytics in smart farming, offering a thorough examination of cutting-edge technological solutions aimed at overcoming modern agricultural challenges. It begins by tracing the evolution of farming practices, from traditional methods rooted in experience to the present-day integration of technology-driven approaches. The study explores how innovations such as Artificial Intelligence (AI), the Internet of Things (IoT), Big Data, sensors, drones, and mobile internet are revolutionizing smart farming, enabling efficient data collection, storage, analysis, and decision-making to enhance agricultural productivity.

Focusing on Tamil Nadu, India, the research highlights the region's agricultural landscape, which faces significant challenges due to climate change, unpredictable rainfall, water mismanagement, and inefficient crop rotation. Traditional farming, heavily reliant on historical knowledge and experiential decision-making, struggles to mitigate these issues. By incorporating predictive analytics, automation, and data-driven farming techniques, this study investigates how technology can optimize water resource management and improve overall crop yield.

The findings reveal a steady rise in seasonal temperatures from 2020 to 2024, emphasizing the growing impact of climate change on agriculture. Additionally, an analysis of rainfall patterns from 2008 to 2022 shows significant variability, with some years experiencing excessive rainfall and others severe drought, leading to fluctuations in crop production. Key crops in Tamil Nadu—including paddy, cholam, cumbu, ragi, pulses, and oilseeds—are particularly affected by these climatic shifts and irrigation challenges.

By integrating predictive analytics and advanced farming technologies, this research provides valuable insights into mitigating climate-related risks, improving water management, and promoting sustainable agricultural practices. The study offers practical recommendations for policymakers, researchers, and farmers to adopt smart farming methods, fostering a more resilient and efficient agricultural ecosystem in the face of climate change.

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CHAPTER I:

INTRODUCTION

1.1 Introduction

Predictive analytics in publications on smart farming (FAO, 2021) will be investigated in light of past writings on the development of tools, machinery, farming methods, and science in relation to agriculture. Realistic answers to global problems can come from artificial intelligence (AI), the Internet of Things (IoT), Big Data, sensors, robotics, drones, predictive analytics (Wolfert et al., 2017), and mobile Internet. Data collecting, transmission, storage, analysis, and solution recommendations—all part of smart agricultural activities—Ge et al., 2019 Using cutting-edge technologies such (Garg et al., 2016; Inoue, 2020; SOUP Project, 2022; Iksch et al., 2021) smart farming

- Sensors
- Drones
- Robots
- Analytics tools and applications

These cutting-edge technologies help to automate the following important tasks:

- Harvesting
- Seedling
- Weed detection
- Irrigation
- Agricultural pest spraying, among others, et al.

1.1.1 History of Agriculture

People used most of their time hunting wild animals and harvesting wild vegetation in the earlier days. People began learning to plant cereal and root crops some 11,500 years ago. People also started living a farming-based existence during this period. The population grew over time, and reliance on agriculture grew as well. Individuals began farming, herding, and rearing wild animals. Domestication is the adaptation of wild plants and animals for human use.

Presumably, rice or corn, which Chinese farmers raised, was the first domesticated plant. Dogs were the first animals domesticated; they were hunting companions. Most likely, next was the domestication of goats and sheep. Individuals also kept pigs and cows. Most of these species had once been sought for meat and hides. Many of them nowadays also provide butter, cheese, and milk. Eventually, people used domesticated animals, such as oxen, to move, plow, and load.

1.1.2 Tools Evaluation

Agriculture evolved gradually over several millennia (FAO, 2021). The initial agricultural tool employed to inhibit the proliferation of berry-bearing plants was fire. Trees were cleared with axes, and breaking them up with digging sticks. Storage techniques also changed: food was piled in jars and clay-lined pots.

Channeling water from streams onto their crops (NWDA, 2023) helped to create the basic irrigation system.). People coordinated themselves and cooperatively developed and preserved improved irrigation systems in Egypt and China.

Egypt's and South Asia's farmers created a new wheat strain and baked bread.

Romans started implementing the greatest Asian and African agriculture methods. They developed farming methods for European soils and produced guidelines on their applications. The Chinese started also changing farming implements and techniques borrowed from surrounding kingdoms. In Vietnam, several rice cultivars were quickly gathered and taken up by Chinese farmers.

In the 15th and 16th centuries, explorers brought fresh agricultural goods and plants to Europe. Returning from Asia, they brought tea, coffee, and indigo—a plant used to create blue dye. They brought tobacco, peanuts, beans, corn (maize), potatoes, and tomatoes among American crops. A few of these enhanced diets became mainstays and changed others.

1.1.3 Machinery and Agriculture Science

Early on, farmers planted seeds by hand. The seed drill, developed by English Jethro Tull, produced rows of holes for the seeds. It was rather common in Europe until the 18th century's end The cotton gin was invented by Eli Whitney in 1794. (To separate cotton fiber from seed)

- Eli Whitney conceived the cotton gin in 1794. (To remove seed from cotton fiber)
- Cyrus McCormick developed a mechanical reaper in 1830. (To modernize the grain-cutting operation)
- The steel plow used in John Deere first appeared in 1837.

- Austria published Gregor Mendel's studies on heredity in 1866.
- New crop rotation techniques developed over this period as well. Many of these were embraced throughout Europe over the next century or more

Early in the 1900s, electricity first became a power source on farms in Germany and Japan (FAO, 2021). It ran several machinery, including water pumps, milking machines, and feeding equipment, as well as lit agricultural buildings.

To protect their crops from pests and illnesses, farmers used several methods (FAO, 2021). For more than a millennium, they relied on natural fertilizers such as ground bones, dung, wood ash, fish or parts, and bird and bat feces.

- Early in the 1800s, nitrogen, phosphorous, and potassium were found to be the elements most vital for plant development.
- The great dependence on chemicals has upset the ecosystem and sometimes destroyed both beneficial and detrimental species of animals. In addition, chemical use puts people's health at risk.

Still, some farmers use natural methods instead of insecticides. Agronomists are working to produce safer compounds for fertilizers and pesticides. No date; The Art and Science of Agriculture; National Geographic.org).

1.1.4 Farm Management

1.1.4.1 Soil

Soil is the loose surface layer covering most of the ground. Its makeup consists of both organic matter and inorganic particles. Apart from providing nutrients and water, soil gives agricultural plants structural support.

Soils have somewhat different physical and chemical traits from one another. Different soil types with particular strengths and shortcomings for agricultural output are produced by processes including leaching, weathering, and microbial activity (National Geographic, n.d.).

Mostly consisting of small particles and humus, the loose material or upper layer of mantle rock—regolith, a layer of loose, heterogeneous material overlying solid rock—can help plants flourish. Called "soil," this layer consists mostly of mineral and rock particles, broken-down organic substances, soil water, soil air, and living entities. Parent material, relief, climate, vegetation, living forms, and time all play major roles in determining soil formation (National Geographic, n.d.).

Usually, the soil consists of four elements:

- From the parent material, inorganic or mineral fractions.

- Organic stuff—decayed and broken down plants and animals.
- Air
- Hydrogen

Under particular natural conditions, soil is created; each component of the natural surroundings helps to create this intricate process known as "pedogenesis."

1.1.4.2 Types of Soil in India

Ancient times saw mostly Urvara (fertile) and Usara (sterile) classifications for soils.

The first to classify dirt scientifically was Vasily Dokuchaev. The Indian Council of Agricultural Research (ICAR, 2021) classified soils in India into eight groups. They include:

- Alluvial Sand
- Black Cotton Ground Soil
- Yellow and Red Soil
- Laterite Grounding Soil
- Forest or mountainous soil
- Desert or dry soil
- Alkaline and salt soil
- Peatty and marshy soil

ICAR lists eight varieties of soils. However, several Indian soils—such as Karewa soil, Sub-Montane Soil, Snowfield soil, and Grey/Brown Soil—are sub-types of the primary Indian Soil.

1.1.4.3 Water Management

One of the natural resources at sufficient levels is water. On Earth, this is a basic source of life. Drinking, washing, bathing, cleaning, cooking, irrigation, and other industrial and home uses all find applications for it (World Bank, 2023).

1.1.4.4 Sources of Water

There are several water sources. There is water covering roughly 97% of the surface of Earth. Three primary water sources exist:

- Rainwater.
- Groundwater – This covers springs and Wells, among other water bodies.

Among the several water bodies included in surface water are reservoirs, rivers, streams, ponds, lakes, and tanks.

Most nations nowadays are under hitherto unheard-of strain on their water supplies. With present methods, predictions indicate that the globe will suffer a 40% deficit between projected demand and available water supply by 2030, with a fast-rising global population (World Bank, 2023). Moreover, the main challenges to world stability and development are extreme weather occurrences (floods and droughts), hydrological uncertainty, and chronic water shortage. There is growing recognition of water scarcity and the part drought plays in worsening fragility and war.

Ten billion people will need a fifty percent rise in agricultural output by 2050, which presently consumes seventy percent of the resource, and a fifteen percent rise in water consumption (FAO, 2022). Apart from the growing demand, many regions of the globe lack resources. According to estimates, around one-quarter of the world's GDP is susceptible to this difficulty, and over 40% of people live in water-scarce places. One in four youngsters is expected to live in places suffering extreme water scarcity by 2040 (World Bank, 2023). For many nations today, water security presents a major and usually rising difficulty.

By changing hydrological cycles, making water more erratic, and raising the frequency and intensity of floods and drenches, climate change will aggravate the situation. Particularly vulnerable are the around 500 million people living in deltas and the roughly 1 billion people living in monsoonal basins. Property damage from floods is estimated at over $120 billion per year. Droughts provide, among other challenges, limits to the rural poor, who are greatly dependent on rainfall fluctuation for subsistence (World Bank, 2023).

1.1.4.5 Weeds Management

Growing in an area where a farmer does not want them to flourish, weeds are plants that either limit or totally interfere with crop development or output. For limited resources, including water, nutrients, and sunlight, they compete with crops.

Weeds compromise product quality, reduce crop productivity by 10–80%, and generate environmental and health risks. Invasive alien weeds are a significant threat to agriculture, forestry, and aquatic environments. Emerging as a major danger to agriculture, crop-specific problematic weeds—such as weedy rice in paddy fields—impact crop output, product quality, and farmers' land revenue.

In India, weed management has traditionally relied on hand weeding. However, rising labour shortages and increasing costs have led farmers to opt for more economical solutions, including herbicides, with the herbicide market growing at an annual rate of 15%. While Indian farmers are adopting Integrated Weed Management (IWM), the level of implementation varies across farms.

Effective weed management in various ecosystems relies on herbicides, used either alone or in combination. IWM advocates a blend of preventive, mechanical, cultural, chemical, and biological methods in crop production systems, as well as aquatic and forest ecosystems (OAR@ICRISat, 2023). Herbicide-resistant (HR) transgenic crops can improve weed management efficiency and promote conservation agriculture (CA) in India—provided the associated risks are comprehensively assessed before widespread adoption. Considering the risks of HR weed emergence, weed recurrence, and the persistent nature of weed populations, developing innovative and sustainable weed management strategies is essential to enhance profitability while protecting the environment (OAR@ICRISat, 2023)

1.1.4.5 Pest Management

An organism living and growing where it is not wanted can damage plants, people, buildings, and other organisms, including crops farmed for sustenance.

Insects, nematodes, mites, snails, slugs, and vertebrates including rats and birds abound among pests at Wild Willow Farm (2023). Based on their significance, pests could be agricultural, forest, home, medical, aesthetic, or veterinary.

Categories of Pests

Common pests: Those more often occurring on a crop closely associated with another. For example, Brinjal shoot and fruit borer.

Occasional pests: Usually occurring seldom and not closely related to a given crop (such as Snake gourd semi looper).

Seasonal pests are those that strike a given area of the year (e.g., groundnut red hairy caterpillar, RHC).

Constant pests: Present on practically all year-long crops (e.g., thrips on chillis).

Occurring in a few isolated places, sporadic pests include coconut slug caterpillars.

Epidemic pests: RHC in groundnut in Bhavan Taluk exhibits in a severe form in an area or locality at a certain season.

Endemic pests: Regularly occurring limited to a given area or locality (e.g., rice gall midge in Madurai District

1.1.4.6 Production Impact

Globally, the damage done by agricultural pests is catastrophic; roughly 10%–15% of the entire yield value is lost in arable crops alone.

1.2 Research Problem

Global warming, climate change, unseasonal rainfall, non-uniform solar activities, soil erosion, improper water management, suboptimal crop rotation, and pesticide mismanagement pose formidable obstacles to sustainable and efficient agricultural practices. In this context, the research aims to scrutinize present predictive analytics tools and methods utilized in smart farming, explicitly focusing on addressing these challenges.

Challenges in the Current Agricultural System:

Global Warming and Climate Change:

Climate Change: With temperature swings and extreme weather events influencing crop yields, the erratic character of climate change greatly influences agricultural ecosystems, so existing predictive analytics have to be evaluated for their capacity to fit changing climate patterns.

Irregular and unanticipated rainfall patterns endanger agricultural output; hence, the study will look at how predictive analytics models handle rainfall fluctuations and whether more precise predictions call for changes.

Variations in solar activity can influence crop development; hence, the research will look at how predictive analytics tools use solar activity data to project its influence on agriculture.

Soil Erosion:

Aiming to find holes in present approaches, the study will evaluate the performance of current predictive analytics models in forecasting and preventing soil erosion, therefore compromising the structural integrity of arable land.

Improper Water Management:

Effective water management techniques can result in water shortage or waterlogging, both negative for crop health. The study will look at how predictive analytics tools maximize water management strategies and point up areas needing work.

Crop Rotation:

The study will assess current predictive models for crop rotation and suggest improvements (Ge et al., 2019) to guarantee sustainable farming practices since suboptimal crop rotation techniques can deplete soil nutrients and raise sensitivity to pests.

Pesticide Management:

Pesticide mismanagement can damage the environment as well as agriculture. The study will look at predictive analytics techniques in pesticide management, assessing their environmental impact and accuracy to point up areas that might use improvement.

1.3 Purpose of Research

The study aims to compile past data and create predictive analytics. Different techniques will be applied in data-driven predictive analytics generation. The analytics will project a 360-degree perspective of smart farming. This approach's primary goal is to forecast problems ahead of time and provide fixes grounded on past performance.

- Capture Historical Data
    - Data Sources
    - Data Cleaning and Preprocessing
- Build Predictive Analytics
    - Algorithm Selection
    - Model Training
- Data-Driven Predictive Analytics
    - Integration of Analytics Models
- 360-degree View of Smart Farming
    - Data Coverage
    - Interconnected Insights
- Predict Issues in Advance
    - Early Warning Systems
- Patterns Analysis – based on historical data.

1.4 Research Purpose and Questions

Based on the research objective, how can unforeseen issues like rainfall, natural disasters, et al., be mitigated through predictive analytics?

Research Question

- How does climate and rainfall impact agriculture?
- How do we increase crop production?
- How do you do efficient water management?
- What are the key challenges in the current agriculture system?
- How can diseases be identified in the early stage?
- How do we reduce unnecessary expenses?
- How to forecast Market demand?

CHAPTER II:

REVIEW OF LITERATURE

2.1 Theoretical Framework

Smart farming is the practice of farming employing the most modern technology including artificial intelligence, the Internet of Things (IoT), and Big Data. Periodically, these technologies will transmit updates on plant development.

Data collecting will be facilitated by sensors, drone images, robots, et al.

Data-driven smart farming will enable tracking by means of data collecting from far-off sensors.

- Light
- Temperature
- Weather - Rainfall Pattern
- Soil Data
- Crop Data
- Water cycles
- Fertilizer requirements
- Disease Detection and Pest Management

Many farmers have started consulting data on key elements including soil, crops, animals, and weather in recent years. Few, if any, have access to sophisticated digital tools, nevertheless, to enable transformation of these data into useful, practical insights. Still lacking sophisticated connectivity and technology most areas are not ready

Advanced technology include sensors—soil and water, robotics, weather tracking, drones, et al. are applied in agriculture.

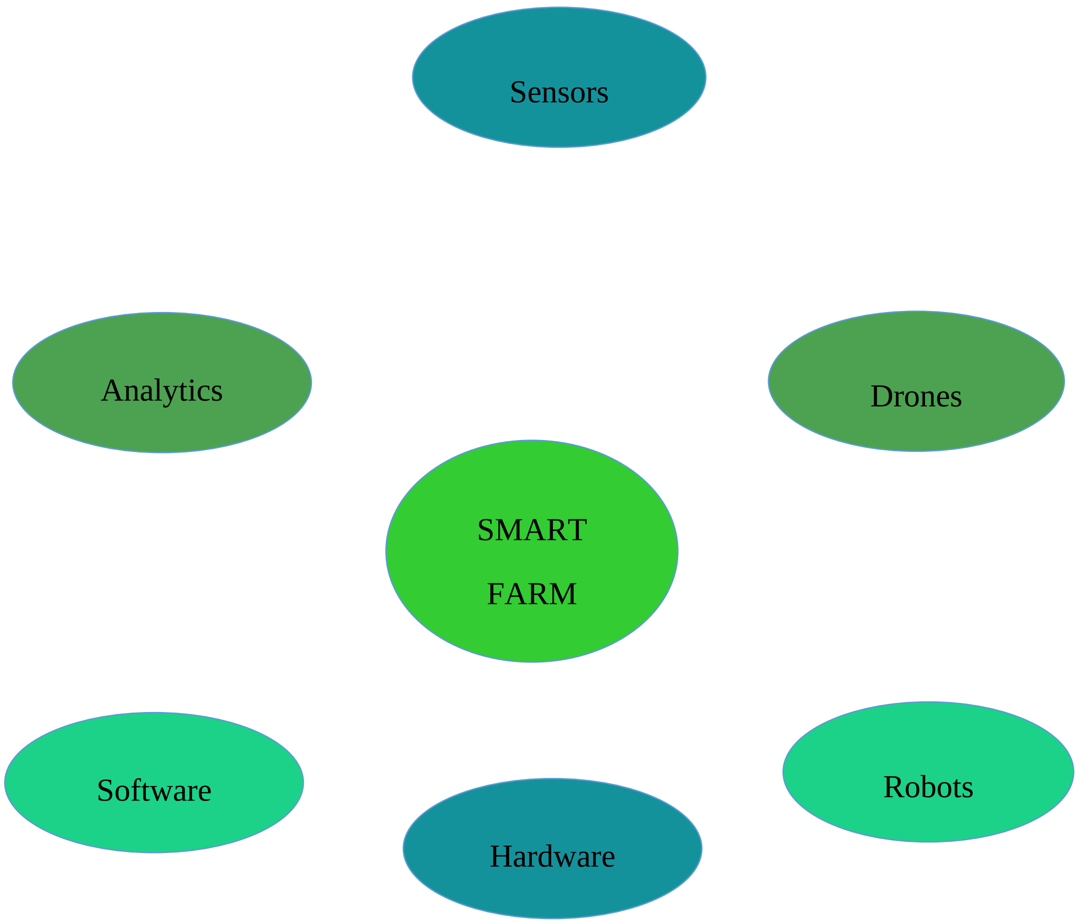

Figure 2.1 Smart farming and advanced technologies.

2.2 Advanced Technologies

2.2.1 Big Data in Smart Farming

Big data is the massive amount of everyday generated and gathered organized and unstructured data that companies produce and compile. It covers a lot of material from many sources—business transactions, social media, sensor data, and more. The three V's—volume, speed, and variety—define big data (Ge et al., 2019). Big data encompasses vast volumes—often terabytes, petabytes, or even exabytes—which cannot be handled by conventional methods of processing (Ge et al., 2019). Big data is produced and gathered at great speeds. For instance, every second, social media sites produce millions of postings, comments, and conversations. Organizations must have real-time or near-real-time processing capabilities to gain insightful analysis (Ge et al., 2019).

Big data spans structured data (relational databases), semi-structured data (XML, JSON), and unstructured data (text, photos, videos). Examining various data types calls for specific tools and approaches (Wolfert et al., 2017). For companies across sectors, big data offers significant promise. Through analysis and insight extraction, organizations can improve decision-making, uncover trends, enhance customer experiences, optimize operations, and innovate products and services (Ge et al., 2019).

Organizations using distributed storage systems (e.g., Hadoop Distributed File System), distributed processing frameworks (e.g., Apache Spark), and scalable databases (e.g., NoSQL) can effectively handle and process large data. Artificial intelligence, machine learning, and data mining are also critical in deriving actionable insights (Wolfert et al., 2017). However, big data brings challenges including data privacy, security, quality, and governance, all of which must be addressed to ensure ethical use (Ge et al., 2019). In the modern data-driven landscape, big data refers to large and sophisticated datasets used to derive insights and support informed decisions (Ge et al., 2019).

In agriculture, climate change and population growth pose increasing challenges. Smart farming leverages big data to guide decisions across the agricultural value chain (Wolfert et al., 2017). New technologies—such as IoT and cloud computing—enable robots and AI to support agricultural tasks. Big data, in this context, consists of diverse datasets used for decision-making (Wolfert et al., 2017). The review highlights that big data's impact spans the entire food supply chain, not just primary production. It supports real-time decisions and predictive insights in farming operations (Ge et al., 2019), and reshapes business models and power structures among stakeholders (Wolfert et al., 2017).

The evolving role of data may lead to either closed, highly integrated systems or open, flexible, cooperative models, depending on platform development and institutional support. Governance, data sharing models, and institutional frameworks will be essential to this transformation (Wolfert et al., 2017).

From that perspective, the research questions to be addressed in this review are:

1. What role does Big Data play in Smart Farming?
2. What stakeholders are involved, and how are they organized?
3. What do Big Data developments cause the expected changes?
4. What challenges need to be addressed about the previous questions?

2.2.2 Sensor Technology in Agriculture

By offering priceless data and insights to maximize farming methods, raise crop yields, and boost efficiency, sensor technology has transformed the area of agriculture. Sensor technology has several important uses in agriculture as follows:

Measuring the moisture content in the soil, soil moisture sensors let farmers decide on the best irrigation plan and avoid underwatering or overwatering. For seed germination and plant development, monitoring the soil temperature is essential, hence soil temperature sensors support this process. By measuring the amounts of vital elements such nitrogen, phosphorous, and potassium, soil nutrient sensors let farmers modify fertilizer applications depending on the particular requirements of the crops.

Usually, two techniques of detecting soil moisture are Meters and Sensors (Soil moisture blocks, TDRs, FDRs, et al.) (Evans et al., 1996) and Direct Inspection (Feel and appearance method, Hand-push probe, and Gravimetric method). In detecting soil moisture to evaluate crop development, the soil moisture sensors are rather efficient tools. Helping irrigation scheduling, precision agriculture, hydrology, residential gardens, landscapes, rainfall monitoring, environmental testing, et etc., soil moisture sensors track the water content at the root zone.

Various types of soil moisture sensors are available on the market.

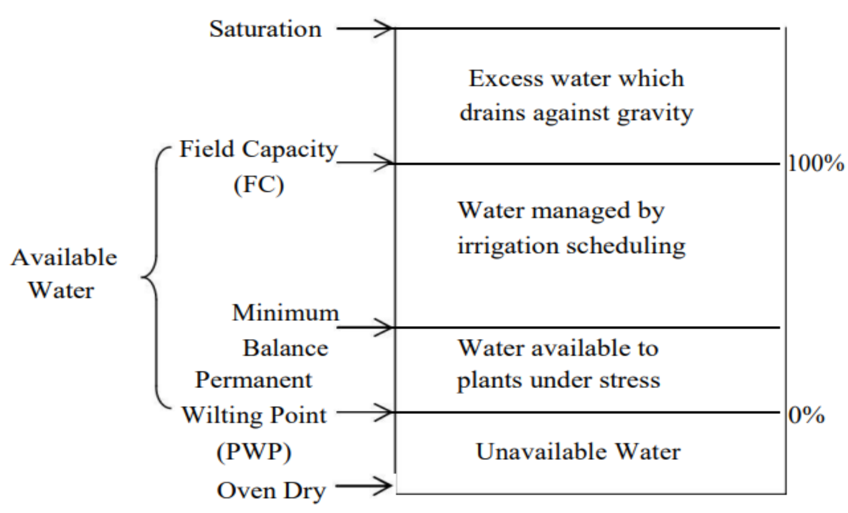

Figure 2.2.2: Sensor Technology in Agriculture. Adapted from Intellias (2023) and Evans et al. (1996)

Types of Sensors

- Tensiometers
- Granular Matrix Sensor (GMS)
- Time Domain Reflectometry (TDR)
- Frequency Domain Reflectometry (FDR)

Real-time temperature, humidity, rainfall, wind speed, and solar radiation—all of which are tracked by weather sensors—provide essential data that guide farmers in making decisions related to irrigation scheduling, pest and disease management, and optimal planting times (Intellias, 2023).

2.2.3 Impact of weather on crops

For farmers, changing weather is an inevitable event. Though it may not surprise them, variations in weather significantly impact agricultural output (Intellias, 2023).

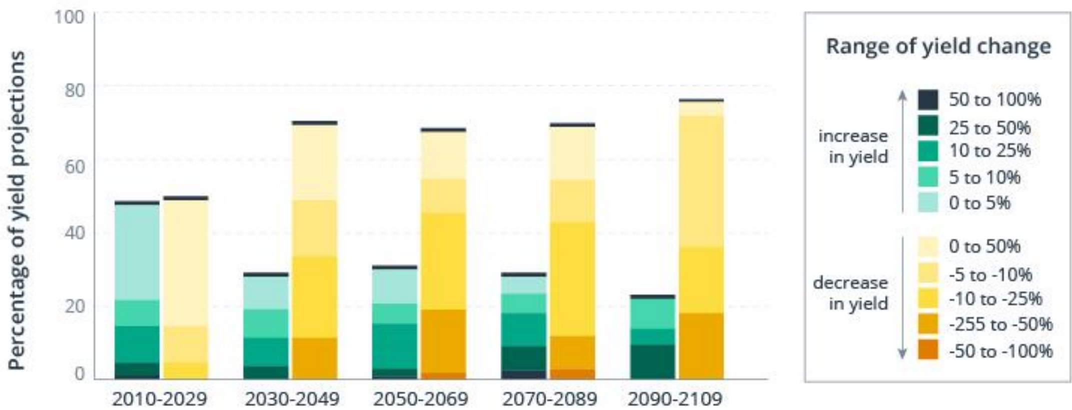

Figure 2.2.3 Projected impact of climate changes on agriculture. Adapted from Intellias (2023)

Technologies for monitoring agricultural weather have great advantages. Actually, accurate data and weather forecasting tools can enable you to forecast and minimize the effects of severe weather (Intellias, 2023).

2.2.4 The most critical weather data for Agriculture

Rainfall – Analyzing past rainfall at specified intervals offers strong observations and useful information for artificial intelligence algorithm-based future forecasts (Intellias, 2023).

Temperature— Tracking daily, monthly, and annual temperature variations helps one to understand crop conditions and inputs for more insights on conditions influencing weather change (Intellias, 2023).

Wind – Farmers can be alerted of approaching storms by wind direction and speed (Intellias, 2023).

Air pressure – Among the most important readings for forecasting variations in the temperature is air pressure (Intellias, 2023).

Humidity is a crucial indicator particularly in relation to rain preparation and wise water use (Intellias, 2023).

Later on, all of these databases can be compiled into one platform accessible from any device and used for weather monitoring. Dashboards can be tailored by farmers to track the most important information and show analytics for improved decision-making. On a smart weather dashboard, farmers also can visualize sensor data and environmental trends in real time to inform timely actions (Intellias, 2023). On a smart weather dashboard, farmers also can:

- set the number of measurements collected over a defined period (hours, days, weeks, months, years)

- track all historical data or choose a period to display
- observe community data from other farms as open-source information
- locate all sensors across fields to know where weather changes may already be impacting crops
- correlate metrics to build forecasts, accounting for all potential hazards, and get suggestions for protecting fields

Figure 2.2.4 A typical application for agriculture weather forecasting technology. Adapted from Intellias (2023)

2.2.5 IoT sensors for weather monitoring

IoT sensors build the basis for a larger linked system for agricultural weather monitoring. These systems depend on a field of field data collecting network of linked sensors. After the gathered data is processed by cloud computing systems, alarms and alerts on possible weather dangers compromising crops are produced (Intellias, 2023).

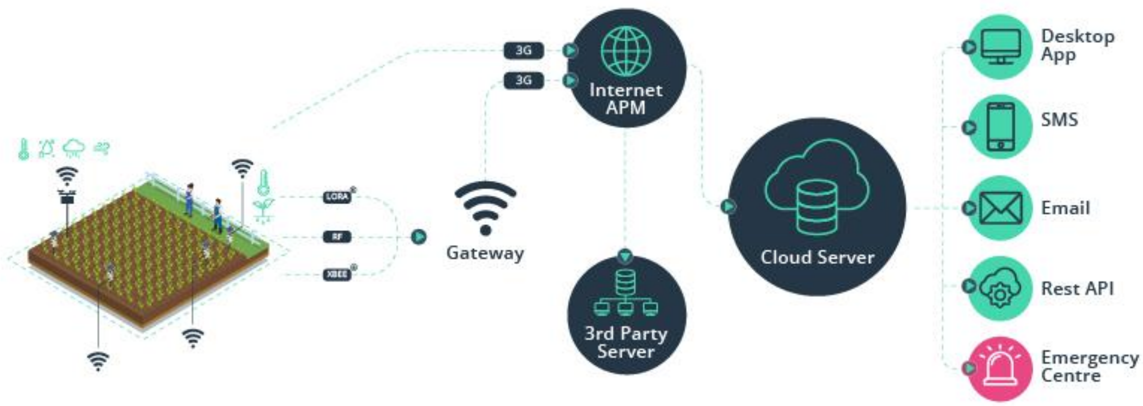

Figure 2.2.5 Connected system of IoT sensors for weather monitoring. Adapted from Intellias (2023)

IoT solutions provide real-time environmental and soil data access for farmers to help them to make ahead of change action plans. A system can alert on approaching frost or downpour when it detects upsetting data from weather sensors (Intellias, 2023).

2.2.6 Satellite data and hardware stations used for weather forecasting technology in agriculture

Farmers can use aerial photographs to monitor crop yields and conduct agricultural weather forecasting in addition to adopting satellite data for several uses. There two uses for satellites. First, it provides data for applications like farmers' weather forecasts; second, it is an Earthly transmitter of data gathered from agricultural meteorological stations. But this second use case is costly since satellite data transfer runs around $1,000 per kilobyte. Using satellites to access geospatial and meteorological data, weather forecasting technologies lets farmers prepare crops for unusual or extreme weather (Intellias, 2023). Agribusinesses also monitor world climate changes and forecast weather calamities including fires and floods using satellites for meteorology. Most of the time, government agencies oversee satellites, so they are not flexible enough for particular usage scenarios. Still, they give the whole picture of the local meteorological conditions. Gathering satellite pictures and data helps AgriTech applications to help forecast crop output depending on field monitoring and weather conditions. It also guides smart watering depending on variations in the temperature to distribute possibly harmful pesticides over the land (Intellias, 2023).

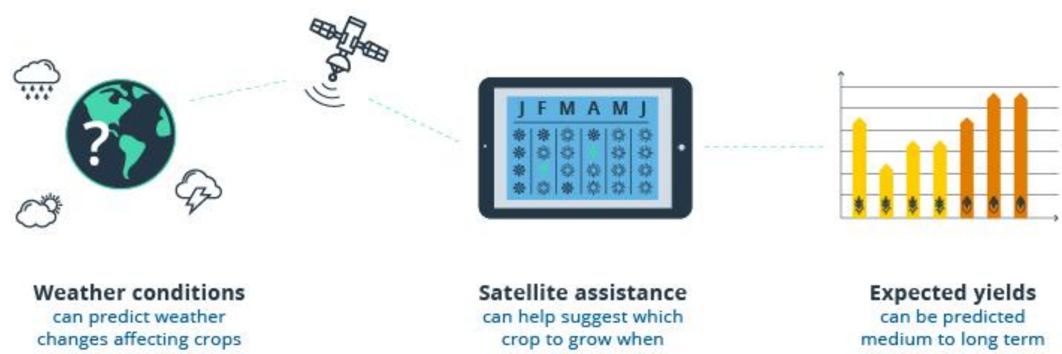

Figure 2.2.6 Satellite weather forecasting. Adapted from Intellias (2023)

2.2.7 AI and machine learning to predict weather events

The most recent and exciting technical development for agriculture is the use of artificial intelligence and machine learning to weather prediction. For instance, IBM Watson technology has produced a decision platform specifically for agriculture. Like every artificial intelligence tool, weather prediction depends on data to instruct machine learning algorithms. Accurate localized weather forecasts can be produced by crowdsourcing this data from local hardware weather stations, satellites, and linked sensors. To process vast data sets, these forecasts need a lot of computer capability; so, appropriate storage is required to retain this data for further usage (Intellias, 2023).

Figure 2.2.7 AI & Machine learning weather prediction. Adapted from Intellias (2023)

Accurate predictions depend on data quality and labeling since deep learning algorithms mostly depend on the nature of training data. Following the training of a deep learning model, proper understanding of weather conditions should be obtained by means of data sorting and recognition of weather patterns (Intellias, 2023).

Effective weather prediction depends much on the growth of accurate data sources. Thousands of weather stations are on Earth's surface while more than 1,000 weather monitoring satellites are presently circling the planet. The most recent addition are IoT-connected sensors placed on individual farms. These give sufficient inputs to educate algorithms how to differentiate between cloud patterns, identify the effects of small temperature and humidity variations, and spot possible threats depending on changes in wind direction that might bring weather fronts from other areas (Intellias, 2023).

Sensors for crop health indicators like chlorophyll levels, canopy temperature, and vegetation indices include hyperspectral cameras or multispectral sensors. By means of this information, one can spot indicators of stress, nutritional deficits, or pest infestations, therefore facilitating quick actions to save crop loss (Intellias, 2023).

2.2.8 Crop Health Monitoring with IoT-enabled Precision Agriculture Solution

Given the rising demand for food and the rise in the human population, one wonders how farmers have lately been handling crop health. Managing things manually used to be not seen as particularly difficult. But given the rising production, population, and demand, it is currently quite challenging for the farmers to adequately check the crop quality.

IoT in farming represents a major development in gateway connectivity and sensors. It is also linked to a user-friendly interface, which lets an automated management system handle simpler monitoring. Usually, traditional crop health management calls for fungicides, insecticides, hand labor, and others. Still, it is always altering in response to financial limitations, scientific advances, and social pressures. Involving research and improvements for pest management and crop management programs, IoT technology is poised to bring a significant change in the farming sector. To maximize plant health and beneficial economic returns, crop management combines with pest monitoring, therefore reducing the negative impact on the environment. IoT technology has helped to greatly enhance illness management. To guarantee optimal output and quality products, farmers can now monitor several data factors including nutrient impacts, calcium, et al., real-time (Wolfert et al., 2017).

Drone-based sensors: Fields can be aerial photographed by drones fitted with cameras, multispectral or thermal sensors. This information offers important new angles on crop health, plant density, irrigation problems, and early pest or disease identification.

Particularly on farms with many small-sized farmlands, like in Japan and most Asian countries, drone-based remote sensing is useful for the timely collecting of high-quality diagnostic information (Inoue, 2020) for agricultural management. But with the current explosion in drone use in agriculture, the combined knowledge or success of remote sensing studies has not always been utilized to good advantage. Spectral remote sensing is already acknowledged as among the most difficult industrial uses for drones. Consequently, a research by the authors on the evolution and uses of drone sensing systems would offer insightful information for pragmatic uses in smart farming. Applications to farmer's fields confirmed the system's performance and functionality.

2.2.9 Platform and sensing system

The following diagram shows the general layout of the sensing system together with the fundamental data processing and diagnostic information generating workflow. The platform was a bespoke model of the high-performance multicopper drone ACSL-PF1 created by ACSL (Chiba, Japan). The diameter all around was 110 cm. The flight period was up to 50 minutes and the payload overall weighed up to 6 kg. PC allows pre-design of the flight paths for observation; all flights from take-off to landing can be automatically controlled depending on GPS and altimeter. Remotely from a tablet PC, one can totally control the operation of the machine. To guarantee outstanding data security and customizing flexibility as well as to support the domestic drone business, we created this novel sensing system employing only domestic drones (Inoue, 2020).

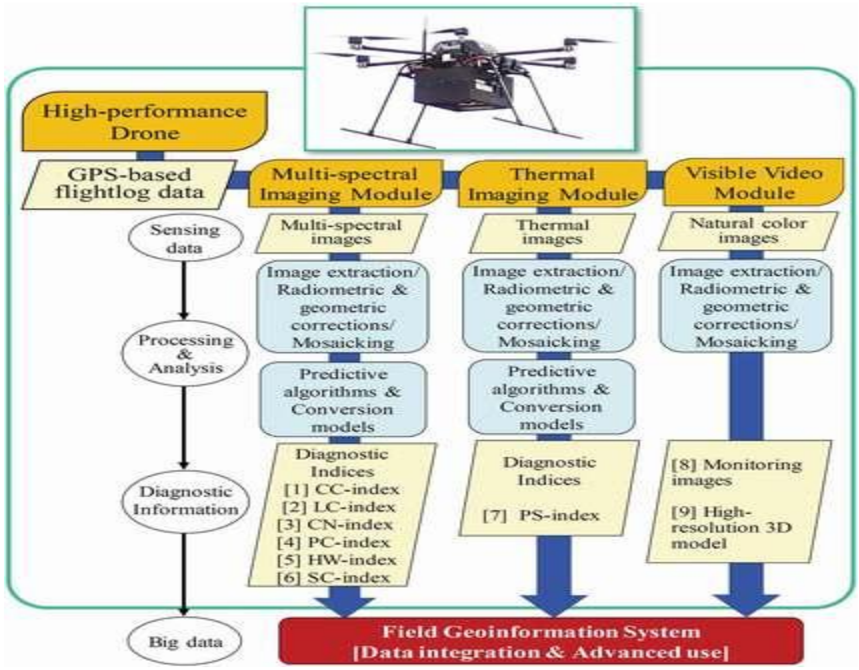

Figure 2.2.9 Advanced drone remote sensing system and function.

On the drone platform three imaging modules—that is, multispectral, thermal, and video imaging modules—were installed. Originally designed by the authors, the multispectral imaging module included five bands spanning 400–900 nm wavelength range. Analyzing several hyperspectral datasets helped to choose the core wavelength and width of every waveband. The multispectral image had a FOV of 43° x 43° and 2016 × 2016 pixels (8 bit). To capture the incidence irradiance in the same spectral bands, air temperature, and humidity (rotoronic, HC2-S3 H), as well as GPS data at 10 Hz, a portable ground-based data logging device was developed (Inoue, 2020).

The thermal imaging module comprised a micrometeorological sensor (rotoronic, HC2-S3 H), an Optris, PI-LW thermal infrared imager, and a mini-PC for computation, recording, and control. High-resolution movies (1920 x 1080) including GPS data were captured by the color video module (SONY, FDR-X3000) (Inoue, 2020).

The normal flying conditions were 4 m s-1 and a height of 100 m. Using the drone-based remote sensing system, a lot of visual data was gathered under different farming environments on nearby Japanese farms. Using GPS and calibration-source data, our integrated data-processing system did semi-automatically radiometric and geometric calibrations as well as orthomosaic processing of such picture data including the main part of PhotoScan (Agisoft) (Inoue, 2020).

2.2.10 Algorithms and functions

Raw photos were processed automatically to provide physically consistent image data—that is, spectral reflectance images—which were then translated to diagnostic maps. Comprehensive study of hyperspectral datasets produced optimum algorithms (spectral indices) and predictive models for the most significant diagnostic variables in SF. The multispectral module allows one to evaluate, for instance, canopy and leaf chlorophyll content (CC-index, LC-index), canopy nitrogen content (CN-index), photosynthetic capacity (PC-index), headwater content (HW-index), and soil carbon content (SC-index).

Furthermore produced from biophysical analysis of infrared heat data and micrometeorological data was plant stress indicator (PS-index). Between the most severe stress state (PS-index = 1) and non-stress condition (PS-index = 0), the PS-index—0–1—represents the relative degree of stress. This method presents a condensed form of the crop water stress and deficit indices (Inoue, 2020).

Semi-automatically produced using the overlapping frame images taken from the video footage and GPS data derived using the SfM method, the 3D models of agricultural surfaces were developed (Inoue, 2020).

2.2.11 Applications and verifications

These algorithms' applicability was also explicitly confirmed using datasets acquired from farmers' fields via the drone technology. Although the statistical significance was significantly less than that of hyperspectral datasets (r2 = 0.65 ~ 0.98), it was nevertheless helpful for smart farming diagnosis. For the canopy nitrogen concentration, for instance, the normalized RMSE was about 10%; at current, the practical levels of fertilizer application are as erratic as three or four classes. The findings would relate to varied fertilizers with great precision. With stomatal conductance measurements in wheat, the plant stress indicator (PS-index) showed a really good correlation (r2 = 0.76). Still, wider application would depend on a more complex normalizing of environmental effects (Inoue, 2020).

The integrated processing system produced semi-automatically high-resolution maps of those diagnostic indicators, which were applied in operational case studies in farmers' wheat and rice fields. For wheat's fertilizer management diagnosis, the CC-index proved useful, for instance. This knowledge maximizes the nitrogen fertilizer application dosage required for greater grain yield and quality. Calculated in real-time during a flight, the PS-index might be communicated wirelessly to the ground to remotely control the actuators. Plant height or surface irregularity of land could be evaluated using the 3D surface models. The simplest simple use is automated bird's eye observation from low altitudes; yet, it also offers valuable knowledge on weeds, irrigation facilities, plant lodging, illnesses, and so on (Inoue, 2020).

Overall, our case study revealed that, mostly at farms with a 100-ha size, advanced drone-based remote sensing would be helpful for the timely and effective monitoring of crops, soils, weeds, diseases, et al (Inoue, 2020).

2.2.12 Recommendations – Good practices for drone-based remote sensing of crops and soils

Thanks to their low cost and simplicity of use, local agencies or farm managers can make advantage of drone-based remote sensing systems. Since it is rather straightforward to acquire color photos or multispectral images, simple maps of spectral indices such NDVI are usually created. It is not commonly known, yet, that producing consistent diagnostic maps calls for meticulous measuring and processing techniques. For spectral images, for instance, several sensor and ambient factors including sensitivity and solar light influence their quality. In useful applications, effective data collecting over large agricultural fields depends on fast operation of drone systems. Digital number (DN) images acquired have to be translated to physically consistent reflectance images. To produce agronomically relevant images from such reflectance or thermal shots, suitable algorithms must be used in processing them (Inoue, 2020).

Good practices are thus needed for the complete process, from flight planning, acquisition, and image data processing to diagnosis map creation. Here some fundamental phases of the process are covered (Inoue, 2020).

2.2.13 Flight planning for efficient acquisition of high-quality imagery

Strongly influencing the quality of data (e.g., spatial resolution, overlapping rate) and data gathering efficiency (e.g., area per hour) are the altitude, route, and flying speed. Most drone systems allow GPS data to enable automatic flight along pre-planned paths. Therefore, considering the size/topography of farmland, spatial resolution overlapping rate of photos, and ground conditions, flight paths and specifications should be created meticulously beforehand. Furthermore crucial is the time of day the photograph was taken since the sun's direction and elevation influence the data quality (Inoue, 2020).

2.2.14 Acquisition of high-quality spectral imagery

Drone flight performance, sensor characteristics, and environmental factors all influence spectral image quality. Apart from the drone's attitude and vibration, electromagnetic waves can affect the recorders, controllers, and sensor function. A dumper and a global shutter would help to lessen vibration's effect. Avoiding windy situations is advisable since radiometric inaccuracy would result from varying direction of the optical axis. One should give much thought to the exposure time, dynamic range, sensitivity, vignetting of the picture sensor. Among the environmental factors, the most important one is the variation of sun illumination brought about by clouds and sun elevation. Obtaining physically consistent reflectance images requires radiometric correction. Still, operations under stable skies would simplify the later image processing (Inoue, 2020).

2.2.15 Image processing for sufficient radiometric accuracy

Digital number (DN) images captured by multispectral sensors must be transformed into physically consistent spectral reflectance images if one is to produce accurate diagnosis maps. DN pictures can be calibrated with a sequence of gray scales with known reflectance values. Assuming that the illumination conditions were comparable for all obtained images throughout a flight, this method requires the grayscales to be included inside at least some of the multispectral images and then DN images are transformed to reflectance images. Still, consider that variations in solar illumination throughout a flight could cause notable ambiguity. Measuring the intensity of reference light at the acquisition period of DN pictures is another calibration technique. Ground-based or onboard spectral sensors allow one to continuously record such reference data. Calibrated coefficients and reference data let one determine the reflectance pictures. Vignetting and a detector sensitivity differential produce spatial nonuniformity inside an image. Overall calibration of the optical system is advised to measure the effect of these complicated faults on the DN-reflectance relationship at individual pixels since the fundamental knowledge of the physical specifics of such optical devices is not revealed (Inoue, 2020).

2.2.16 Image processing for sufficient geometrical accuracy

Usually, the area of interest cannot be covered by the size of single photographs. To produce wider orthomosaic images, then, many overlapping photos are taken. The SfM technique allows one to build semi-automatically the orthomosaic and/or 3D surface pictures. Usually ranging from 60% to 90%, the overlapping ratios must be tuned if a substantial point cloud is to be created. reliable and fast SfM orthomosaic processing depends on reliable GPS data for each images. Since GPS-based agricultural equipment uses diagnostic maps and since the georeferenced photos will be combined as big data, accurate georectification is absolutely crucial (Inoue, 2020).

2.2.17 Generation and systematic use of diagnostic information

Diagnostic maps can be produced using a wide spectrum of algorithms. Strong and adaptable algorithms could find great sources in hyperspectral data of soils and crops. Nonetheless, the conditions and preferences of end users should guide customizing of data-processing procedures, conversion algorithms, and diagnostic map format. More user-friendly web-GIS applications are desired since diagnostic maps may be rapidly delivered to the end users using network infrastructure. Robotic equipment standardizing digitized maps would improve the connection between agricultural technology and remote sensing toward smart farming (Inoue, 2020).

Yield monitors fitted to harvesters or combine harvesters gather information on crop yield, moisture content, and other criteria. This data enables farmers to maximize harvesting techniques, project yields, and evaluate field variability (Inoue, 2020).

2.2.18 Field sensors

One might do spectral reflectance tests both in the lab and in the outdoors. Though each of these devices senses light, their names in the field of spectral measurements are identical; yet, they are somewhat different and have different purposes. Commonly used are radiometers, spectrometers, and spectroradiometers. To estimate crop production, high-resolution hyperspectral digital multispectral sensors, spectrometers, and a range of additional ground optical sensors have been presented to gather reflectance data at different spectrum points. A form of ground-based remote sensing, field spectroscopy records many spectral bands spanning the electromagnetic spectrum (350–2500 nm). Spectroscopic data at the ground and leaf level in the visible and infrared ranges of the electromagnetic spectrum is based on the concept that light interacts with the plant and the reflectance characteristics of a green leaf. This helps one to measure the chemical properties of the leaves and calculate folious nitrogen concentration (Inoue, 2020).

Sensors for livestock monitoring can track ambient variables, behavior, and general state of health. While wearable technologies track animal activity and feeding patterns and even identify estrus in breeding animals, temperature sensors can detect heat stress in dairy cows (Ge et al., 2019).

In irrigation systems, irrigation sensors—which track water levels in reservoirs, tanks, or canals—ensure effective water management and help to stop water waste. By helping to estimate irrigation water use, flow sensors enable exact water application and help to lower water consumption.

Irrigation is the artificial application of water to crops meant to meet their needs. Irrigation could also supply nutrients for the crops. Wells, ponds, lakes, canals, tube wells, and even dams provide the several irrigation sources of water. Irrigation supplies the moisture needed for germination, development and growth, as well as other connected purposes (FAO, 2022).

varied crops have varied irrigation frequencies, rates, amounts, and times; likewise, soil types and seasons affect these factors. Summer crops, for instance, call for more water than winter ones.

Let us examine several irrigation systems and their application techniques.

2.2.19 Types of Irrigation

Different types of irrigation are practiced to improve crop yield. These types of irrigation systems are implemented based on variations in soil, climate, crops, and resource availability (FAO, 2022). The main types of irrigation followed by farmers include:

Surface Irrigation

In this system, no irrigation pump is involved. Water is distributed across the land by gravity. This is one of the oldest and most widely used forms of irrigation and is particularly suitable for flat terrains and large-scale field crops (Geerts and Raes, 2009).

Localized Irrigation

In this system, water is applied directly to the root zone of each plant through a network of pipes under low pressure. This includes drip and micro-sprinkler irrigation, which are known for their high efficiency in water usage, especially in arid and semi-arid regions (Pereira et al., 2002).

Sprinkler Irrigation

Water is distributed from a central location by overhead high-pressure sprinklers or from sprinklers mounted on a moving platform. This system mimics natural rainfall and is suitable for a variety of crops and topographies. It provides uniform water distribution but requires energy for pumping and may cause water loss through evaporation or wind drift (Brouwer et al., 1985).

Drip Irrigation

In this type, small drops of water are delivered directly to the plant root zone through a network of valves, pipes, tubing, and emitters. Although highly efficient in water usage, drip irrigation systems require regular maintenance to prevent clogging. It is ideal for high-value crops and regions with limited water availability (Keller and Bliesner, 1990.

Centre Pivot Irrigation

Here, water is distributed through a rotating sprinkler system mounted on wheeled towers that move in a circular pattern across the field. This system is commonly used in large-scale commercial farms, especially in countries like the United States. While it offers efficient water application, initial setup and operational costs can be high (Yazar, 2004).

Sub Irrigation

Also known as subirrigation, this method raises the water table to allow water to reach plant roots by capillary action. Water is distributed through pumping stations, gates, ditches, and canals. It is mainly used in areas with high water tables and specific soil conditions and can reduce evaporation and deep percolation losses (Ayars et al., 2002).

Manual Irrigation

This is a labor-intensive and time-consuming irrigation system. Manual labor distributes water through watering cans. It is usually adopted in small-scale farming or gardens where automation is not feasible. Although cost-effective, this method is not suitable for large-scale agricultural production due to inefficiency and high labor demands (FAO, 2022).

Methods of Irrigation

Irrigation can be carried out by two different methods:

- Traditional Methods

- Modern Methods

Traditional Methods of Irrigation

In this method, irrigation is done manually. A farmer pulls water from wells or canals by himself or using cattle and carries it to the farming fields. This method can vary in different regions.

The main advantage of this method is that it is cheap. However, its efficiency is poor because of the uneven distribution of water. Also, the chances of water loss are very high (Kijne et al., 2003).

Some examples of traditional systems are pulley systems, lever systems, and chain pumps. The pump system is the most common and used widely (Narayanamoorthy, 1997).

Modern Methods of Irrigation

The modern method compensates for the disadvantages of traditional methods and thus helps ensure proper water usage.

The modern method involves two systems:

- Sprinkler system
- Drip system

Sprinkler System

As its name suggests, a sprinkler system sprinkles water over the crop, helping to ensure an even distribution of water. This method is highly advisable in areas facing water scarcity (Perry and Steduto, 2017).

Here, a pump is connected to pipes, which generates pressure, and water is sprinkled through the pipes' nozzles. This system is ideal for irrigating uneven lands and is commonly used for crops like cereals and vegetables (FAO, 2022).

Drip System

In the drip system, water is supplied drop by drop at the roots using a hose or pipe. This method can also be used in regions with limited water availability. Drip irrigation reduces evaporation losses and allows for targeted water delivery, thereby enhancing water-use efficiency (Postel et al., 2001; Keller and Bliesner, 1990).

Importance of Irrigation

The importance of irrigation can be explained in the following points:

• Insufficient and uncertain rainfall adversely affects agriculture. Low rainfall causes droughts and famines. Irrigation helps to increase productivity even in low rainfall (World Bank, 2023).

• The productivity of irrigated land is higher than that of unirrigated land (FAO, 2022).

• Multiple cropping is not possible in India because most regions' rainy season is specific. However, the climate supports cultivation throughout the year. Irrigation facilities make it possible to grow more than one crop in most of the areas of the country (ICAR, 2021).

• Irrigation has helped to bring most of the fallow land under cultivation (Perry and Steduto, 2017).

• Irrigation has stabilized the output and yield levels (Keller and Bliesner, 1990).

• Irrigation increases the availability of water supply, increasing the farmers' income (Postel et al., 2001).

Irrigation should be optimum because even over-irrigation can spoil crop production. Excess water leads to waterlogging, hinders germination, increases salt concentration, and uproots roots because they cannot withstand standing water. Thus, the proper method must be used for the best cultivation (FAO, 2022; World Bank, 2023).

Weed and pest detection sensors: Optical sensors or cameras can detect and differentiate between crops and weeds, allowing for targeted weed control measures (Shanahan et al., 2001). Insect traps equipped with sensors can detect pest activity and help implement integrated pest management strategies (Lee et al., 2014).

These sensor technologies enable farmers to make data-driven decisions, optimize resource allocation, minimize environmental impact, and ultimately improve agricultural productivity and sustainability (Wolfert et al., 2017).

2.2.20 Drone Technology in Agriculture

Drones are extensively used for

- Spraying fertilizers
- Aerial surveillance
- Crop monitoring
- Land inspection
- Inspecting for damaged or rotting crops

2.2.21 Robot Technology in Agriculture

Agricultural robots automate slow, repetitive, and dull tasks for farmers, allowing them to focus more on improving overall production yields. Some of the most common robots in agriculture are used for:

- Harvesting and picking
- Weed control
- Autonomous mowing, pruning, seeding, spraying and thinning
- Phenotyping
- Sorting and packing
- Utility platforms

Harvesting and picking is one of the most popular robotic applications in agriculture due to the accuracy and speed that robots can achieve to improve the size of yields and reduce waste from crops being left in the field (Robotics in Agriculture: Types and Applications. (n.d.). Automate. Retrieved November 21, 2022).

2.2.22 Analytics

Analytics refers to the application of computer techniques to identify and document significant trends in data. Its primary aim is to provide insights that significantly influence decisions. By definition, analytics relies on historical data, as data reflects past events. The term "analytics" became widely known in 2005, mainly due to the launch of Google Analytics. However, the core concepts underlying analytics have existed for years, often expressed under other names such as cybernetics, data analysis, neural networks, pattern recognition, statistics, knowledge discovery, data mining, and more recently, data science. The growing importance of analytics in recent years can be attributed to organizations gathering more data and summarizing it effectively for enhancing estimates, projections, decisions, and efficiency (Davenport, 2013; Shmueli & Koppius, 2011).

2.2.23 Predictive Analytics

Predictive analytics is the method of discovering interesting and significant trends in data. It draws from several allied fields that have been used for over a century to find trends in data, such as pattern recognition, statistics, machine learning, artificial intelligence, and data mining. What distinguishes predictive analytics from other forms of analytics?

Firstly, predictive analytics is data-driven, meaning algorithms derive important traits of models from the data rather than from analyst assumptions. In other words, data-driven algorithms generate models from the data itself. The induction process may involve determining which variables to include in the model, setting parameters defining the model, identifying weights or coefficients, or determining model complexity (Shmueli & Koppius, 2011).

Secondly, predictive analytics systems automatically detect patterns in data. Strong induction methods find coefficients or weights for the models, as well as their structure. For example, decision tree algorithms identify the values of the variables to apply in making predictions and learn which inputs best predict a target variable. Other algorithms can be altered to search for the optimal set of inputs and model parameters using exhaustive or greedy searches. The variable is added to the model if it reduces model error; otherwise, it is eliminated (Abbott, 2021).

Many software packages and algorithms also automate another task: transforming input variables into useful forms for predictive models. For instance, if there are one hundred candidate variables for models that need to be altered to eliminate skew, rather than scripting each transformation one at a time, predictive analytics tools can perform this in a single step (Shmueli & Koppius, 2011).

It is important to note that great algorithms have no common sense. Predictive analytics does nothing that an analyst could not accomplish with pencil and paper or a spreadsheet given enough time. For example, imagine a binary target variable with values 0 and 1 and a supervised learning dataset of fifty inputs. Plotting each variable one at a time in a histogram can help determine which inputs most closely relate to the goal variable. With fifty inputs, you would need to view fifty histograms. For those working on predictive models, this is not uncommon.

If patterns require the simultaneous examination of two variables, a scatter plot can be used. In the case of fifty variables, there are 1,225 scatter plots to review. To investigate all possible three-way combinations, you would need to examine 19,600 3D scatter plots. Even the most committed modelers would struggle to commit the time required to look at that many plots (Abbott, 2021).

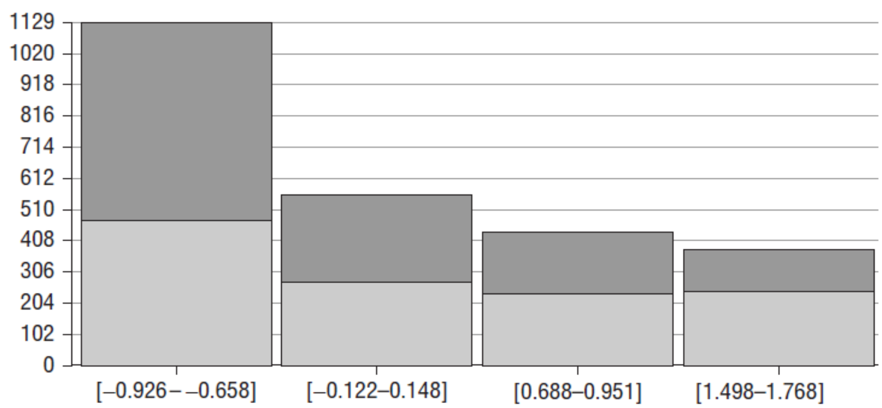

Figure 2.2.23 Histogram. Adapted from Abbott (2014)

To sort among all the possible combinations of data inputs—the patterns—and find the most fascinating ones, you need algorithms. The analyst can then concentrate on these trends, which are surely a far smaller set of inputs to investigate. Out of the 19,600 three-way combinations of inputs, a predictive model might find six of the variables as the most important factors supporting correct models. Out of these six variables, the top three also are quite good predictors and far better than any two. You now have a reasonable subset of 63 instead of around 20,000 to examine. One of the most powerful features of predictive analytics is its ability to pinpoint which data inputs most influence trends (Abbott, 2021).

Supervised vs. Unsupervised Learning

Two categories of algorithms for predictive modeling are usually unsupervised and supervised learning approaches. In models of supervised learning, the supervisor is the target variable—a column that denotes values to forecast from other columns in the data. When the model is applied to assist in decisions, the target variable is the value unknown or the response to a query the company would wish to address. Supervised learning is also known occasionally as predictive modeling. Either regression for continuous target variables or classification for categorical target variables define the main predictive modeling techniques. Target variables could include if a consumer bought a good, the purchase value, whether a transaction was fraudulent, whether a customer said they loved a movie, how many days will pass before the next gift a donor would make should a loan default occur, or should a product fail? Predictive models cannot be developed using records without value for the target variable (Abott, 2023).

There is no target variable in unsupervised learning—sometimes known as descriptive modeling. Input values' proximity to one another determines how they are grouped or clustered. Every group or cluster has labels to show which one a record fits. Unsupervised learning is also referred to as segmentation in several applications, like customer analytics, because of the models' purposes—that of grouping consumers into categories (Abott, 2023).

Although the inputs to the model are known in supervised learning, there are situations whereby the goal variable is unseen or unknown. The most often occurring cause for this is a goal variable, an event, decision, or other action occurring at a point in the future to the observed inputs to the model. Response models, cross-sell, and up-sell models operate this way: Can you forecast, given what is known about a client, whether they would buy a given product in the future? Some definitions of predictive analytics highlight how algorithms should be used for forecasting or predicting of future events or behavior. Although this is somewhat common, it is definitely not always the case. The target variable can be an unseen variable—that of a missing value. Predictive models can estimate missing value from other examples of tax returns where the values are known if a taxpayer neglected to file a return in a previous year (Abott, 2023).

Parametric vs. Non-Parametric Models

Predictive analytics methods in both parametric and non-parametric form abound. Parametric algorithms—that is, models—assume known data distribution. Though not all, many parametric techniques and statistical tests assume normal distributions and search for linear correlations in the data. Usually not assuming distributions, machine learning algorithms are regarded as non-parametric or distribution-free models (Abott, 2023).

Parametric models have the advantage in that, in case the distributions are known, extensive data attributes are known. Consequently, it is possible to demonstrate certain characteristics of algorithms concerning errors, convergence, and certainty of learnt coefficients. Nevertheless, the analyst usually spends a lot of effort converting the data to realize these benefits based on the presumptions (Abott, 2023).

Since non-parametric models save the analyst much time in data preparation by not assuming underlying assumptions about the data distribution, they are significantly more versatile. On the other hand, significantly less is known about the data a priori, so non-parametric techniques usually iterative without any assurance that the best or optimal solution has been discovered (Abott, 2023).

2.3 Summary

The primary research method for this study is literature review and conceptual modeling.

This literature review studied various advanced tools and technologies used for Smart farming. Based on a study of existing articles, most predictive analytics frameworks are designed to increase crop productivity and reduce manpower.

Identified a few gaps in the current predictive analytics for SMART FARMING

- Recommendation for crop rotation based on history of data
- Solution recommendations based on the current manual agricultural method/Knowledge
  - Pesticide
  - Seasonal crop details, et al.

Based on Historical data – predict weather and avoid crop waste.

CHAPTER III:

METHODOLOGY

3.1 Overview of the Research Problem

Global warming, climate change, irregular rainfall, inadequate water management, and poor crop rotation methods—all of which limit crop development and output—the agricultural industry challenges (FAO, 2021; IPCC, 2022; Aggarwal et al., 2021). If we are to reach sustainable and efficient agriculture, these challenges represent significant roadblocks that have to be crossed. With a specific attention on solving problems and increasing agricultural output, this paper seeks to investigate the tools and methodologies of predictive analytics applied in smart agriculture (Jain et al., 2021).

Challenges in the Current Agricultural System:

Global Warming and Climate Change:

Unseasoned Rainfall: Unseasonal precipitation is the term used to describe unconventional and variable rainfall patterns endangering agricultural productivity (Rao et al., 2020; MoEFCC, 2021). The project will assess whether modifications are required to obtain better accuracy in forecasts and investigate how predictive analytics systems could help to alleviate variances in rainfall (Jain et al., 2021).

Improper Water Management:

Effective water management techniques can produce either waterlogging or scarcity, both of which are bad for agricultural output (Shah & Kumar, 2019; CWC, 2020). The study will point up areas that require work and show how predictive analytics technology maximize water management plans (World Bank, 2020).

Climate Change: The erratic character of climate change greatly affects agricultural ecosystems; severe events and temperature swings impair crop productivity (IPCC, 2022; Aggarwal et al., 2021). Predictive analytics that are now in use have to be evaluated for their adaptability with the times (Jain et al., 2021).

3.2 Operationalization of Theoretical Constructs

Tamil Nadu is in the southern part of India. It is an important part of the country's agriculture and grows many foods, such as paddy, cholam, cumbu, ragi, cereals, pulses, groundnuts, and gingelly (Government of Tamil Nadu, 2020). The current system for farming in the area is mostly built on old-fashioned methods and what we know from the past. Lack of technology and reliance on data for making decisions make things less efficient, less productive, and less able to adapt to climate change (Ramachandran & Selvaraj, 2018).

3.2.1 Traditional Knowledge and Practices

- Definition: The way farmers make decisions about farming based on what they know from the past and their own experiences.
- **Operationalization:**
    - Operationalization indicators include the use of verbal or unwritten instructions in farming choices.
    - Dependence on local weather patterns, culture stories, or group traditions.
    - Set up plans for making decisions about planting, harvesting, and watering based on what you've learned from past experiences.

3.2.2 Automation and Technological Adoption

- What it means: Using predictive analytics, automated systems, and Internet of Things (IoT) tools in farming.
- **Operationalization:**
    - As a sign of operationalization, the ease of access to and use of modern farming tools like weather forecasting software and soil sensors is included.
    - How many farmers use technology to help them make decisions.
    - The amount of digital literacy among Tamil Nadu farmers.
        - Getting the data: Use regional studies to look at how agricultural tools are being used.

3.2.3 Crop Productivity

- Definition: The amount of food that can be grown on a plot of important crops in Tamil Nadu, taking into account both traditional and modern farming methods (Tamil Nadu Agricultural University, 2019).
- **Operationalization**:
    - Yield per hectare for paddy, cholam, cumbu, ragi, grains, pulses, groundnuts, and gingelly are some of the indicators for operationalization.
    - Yield changes depending on how the crops are watered, the weather, and how many resources are used (Government of Tamil Nadu, 2020).
    - **Data Collection**:
        - Collecting data means getting numbers about crop production at the district level from government reports or farming records (Government of Tamil Nadu, 2020).
        - Compare the yields of fields that are managed the old-fashioned way and those that use predictive methods (Jain et al., 2021).

3.2.4 Climate and Environmental Factors

Changes in the surroundings and the weather affect how crops grow and how farming is done.

Making things work:

- How often and how bad unseasonal rain, droughts, and changes in temperature happen.
- Measuring the quality of the soil (nutrient levels, pH, and moisture content).
- Get weather information to see how the temperature has changed over the last ten years.

3.3 Research Purpose and Questions

The purpose of this research is to help identify the pattern of unforeseen issues through predictive analytics like rainfall, natural disasters, et al which will help mitigate in advance

- How does climate and rainfall impact agriculture?
- How to increase crop production?
- How to do efficient water management?

3.4 Research Design

Logical Flow of Climate, Rainfall, Agriculture, and Irrigation

Tamil Nadu's agricultural landscape is shaped by its climate, rainfall, and irrigation infrastructure, which are vital in determining crop yield and sustainability. Below is a structured breakdown of how these elements interact.

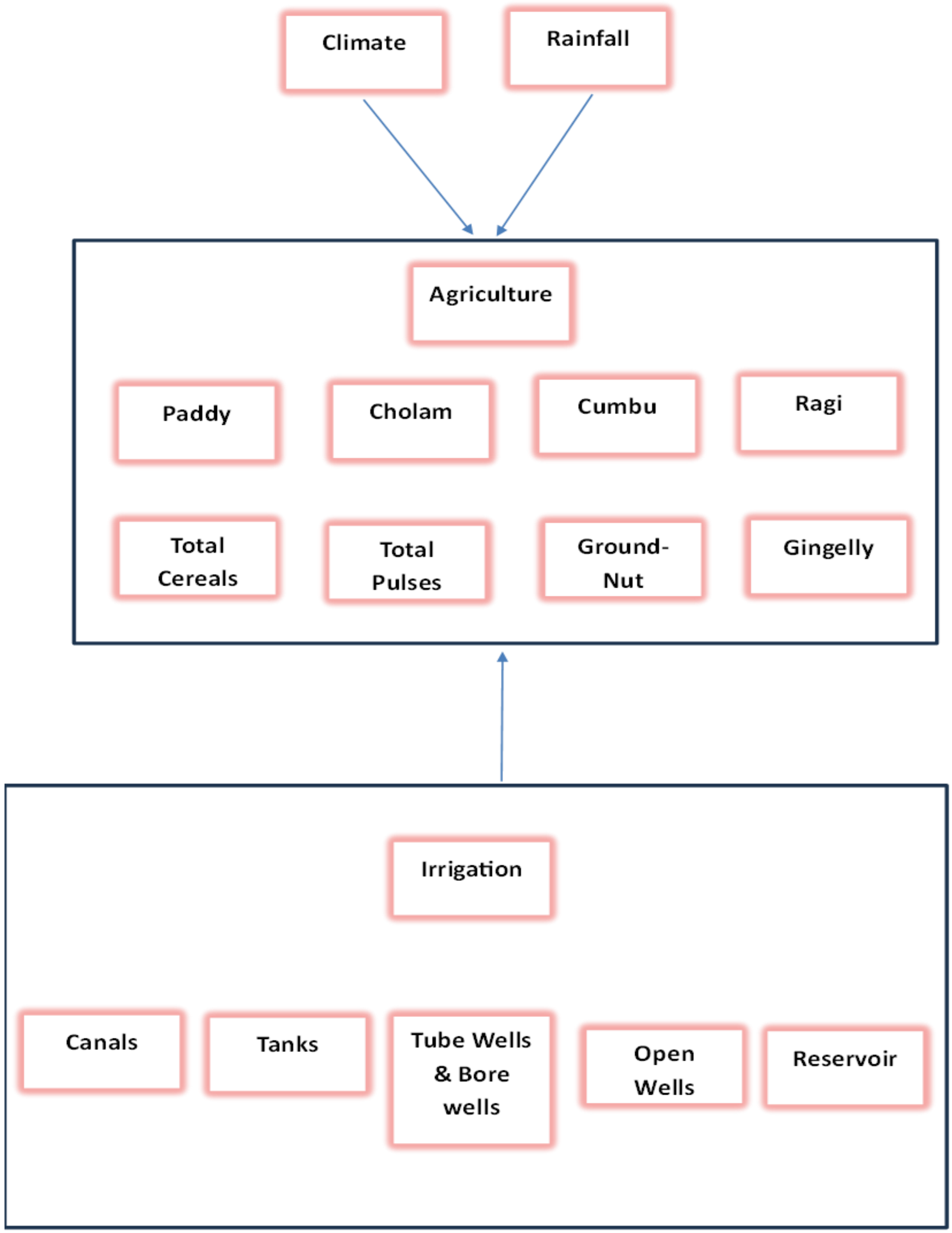

Figure 3.4.1 illustrates Logical view of Climate, Rainfall, Agriculture, and Irrigation.

3.4.1 Climate and Rainfall: The Foundation of Agriculture

- Climate and rainfall are very important to agriculture because they affect how much water is available, the state of the soil, and the crops that can be grown.
- Tamil Nadu has three main wet seasons, and each one affects crop yields in different ways.

Agriculture: A Climate-Dependent Sector

  - Agriculture is one field that is greatly affected by climate. Most farming methods in Tamil Nadu are based on irrigation systems and the rainy seasons.
  - Cereals like rice, cholam (sorghum), cumbu (pearl millet), ragi (finger millet), and others are mostly grown in the state.
  - Pulses are made up of different kinds of beans, like Black Gram, Green Gram, and Red Gram.
  - Groundnut and sesame are the main oilseeds (Gingelly).

Irrigation: The Lifeline for Agriculture

- Rainfall alone isn't enough for farming all year, so irrigation devices are needed to keep water levels stable.
- Different irrigation sources include:
  - Canals are man-made waterways that are used to move water from lakes.
  - Tanks are common ways to store water that are made to hold summer rain.
  - Tube wells and bore wells are used to get water from the ground, but too much use can lead to depletion.
  - Traditional ways to get water for irrigation are through open wells, but their supply changes based on how much rain falls.

- Reservoirs are large systems for storing water that are meant to help more than one area.

3.4.2 Rainfall Patterns in Tamil Nadu

Tamil Nadu's rainfall patterns shape its agricultural productivity. The state receives rain from three primary sources:

Southwest Monsoon (June - September)

- Among the western districts, Nilgiris, Kanyakumari, Coimbatore, Dharmapiri, and Salem stand highest in advantage.
- Gets concentrated in the Western Ghats about 150 cm of rainfall.
- While Nilgiris gets 70% of its annual rainfall from this monsoon, the rain shadow effect causes less rainfall for central and eastern Tamil Nadu.

Northeast Monsoon (October - December)

- With most of the yearly rainfall, Tamil Nadu's farmers rely on this monsoon most substantially.
- Rainfall intensity falls east to west; coastal regions include Chennai, Cuddalore, Thiruvallur, and Nagapattinam get 150–250 cm of rain; inland areas get less.

Cyclonic Rainfall (November - December)

- Additional rain brought by bay of Bengal cyclones occasionally causes floods.
- Kanyakumari district gains most since it gets rain from all three monsoons.
- Tiruppur and Coimbatore have the least yearly rainfall.

3.4.3 Understanding Seasonal Climate Patterns in Tamil Nadu

Summer (March - June)

- Peak in May and June; temperature ranges from 30°C to 40°C; hottest areas are Madurai, Vellore, Tiruchirappalli, occasionally even above 42°C.
- Coastal Influence: Chennai and surrounds have significant humidity.

Monsoon (June - September)

- Temperature: 25°C - 35°C.
- Rainfall: Mostly from the Southwest Monsoon, rainfall is moderate to heavy.
- Humidity: High humidity makes one feel warmer than the real temperature.

Northeast Monsoon (October - December)

- Temperature: 20°C - 30°C.
- Rainfall: Usually the main season of rainfall, occasionally flooding coastal towns results from it.
- Cooler Evenings: Temps in inland areas range from 18°C to 22°C.

Winter (January - February)

- Temperature: 15 to 25 degrees Celsius; hill stations drop below 10 degrees Celsius.
- Most pleasant season: low humidity and moderate temperatures make things agreeable.

Season	Average High Temperature	Average Low Temperature	Notable Cities (Average Highs)
Winter (Jan - Feb)	29°C - 31°C	19°C - 22°C	Chennai (29°C), Coimbatore (31°C)
Summer (Mar - May)	34°C - 38°C	24°C - 27°C	Chennai (38°C), Madurai (38°C)
Monsoon (Jun - Sep)	32°C - 35°C	24°C - 26°C	Chennai (35°C), Coimbatore (34°C)
Post-Monsoon (Oct - Dec)	29°C - 32°C	22°C - 24°C	Chennai (32°C), Madurai (31°C)

Table 3.4.3.1 illustrates the Sessional temperatures

3.4.4 Agriculture in Tamil Nadu: Crop Overview

Tamil Nadu's diverse climate supports multiple crops across its districts.

Paddy (Rice)

- Staple crop, cultivated primarily in the Cauvery Delta region.
- Seasons: Samba (Aug-Jan), Kuruvai (Jun-Sep), and Navarai (Dec-Mar).
- Major Producing Districts: Thanjavur, Tiruvarur, Nagapattinam, Trichy.

Area (‘000 hec)	Production (‘000 tonnes)	Productivity (kg/hec)
2,217	7,906	3,566

Table 3.4.4.1 illustrates paddy area, production, and productivity details

Ragi (Finger Millet)

- Drought-resistant millet, rich in calcium, iron, and fiber.
- Major Producing Districts: Dharmapuri, Krishnagiri, Salem, Vellore.

Area (‘000 hec)	Production (‘000 tonnes)	Productivity (kg/hec)
74	227	3,056

Table 3.4.4.2 illustrates Ragi area, production, and productivity details.

Groundnut & Gingelly (Sesame)

- Groundnut: A key oilseed crop, grown in Kharif and Rabi seasons.
- Gingelly: Primarily used for sesame oil production.

Crop	Area (‘000 hec)	Production (‘000 tonnes)	Productivity (kg/hec)
Groundnut	372	1,047	2,812
Gingelly	47	28	589

Table 3.4.4.3 illustrates the Groundnut & Gingelly area and the production and productivity details.

3.5 Population and Sample

Climate-related sample data was collected from the Tamil Nadu State Government Statistical Handbook. Sample data given below.

3.5.1 Climate

Climate
Year
Session
South West Monsoon - Actual
Approximate Average Temperature (°C)

Table 3.5.1 Climate Table Structure

Year	Winter (°C)	Summer (°C)	Monsoon (°C)	Post-Monsoon (°C)
2020	25	32	28	27
2021	25.2	32.2	28.2	27.2
2022	25.4	32.4	28.4	27.4
2023	25.6	32.6	28.6	27.6
2024	25.8	32.8	28.8	27.8

Table 3.5.2 **Climate Sample Data**

Rainfall sample data was obtained from the Tamil Nadu State Government Statistical Handbook. Below is the sample data.

3.5.2 Rainfall

Rainfall
Year
South West Monsoon - Normal
South West Monsoon - Actual
North East Monsoon - Normal
North East Monsoon - Actual
Winter Season - Normal
Winter Season - Actual
Hot Weather Season - Normal
Hot Weather Season - Actual
Total - Normal
Total - Actual

Table 3.5.2.1 Rainfall Table Structure

Year	*South West Monsoon - Normal*	*South West Monsoon - Actual*	*North East Monsoon - Normal*	*North East Monsoon - Actual*	*Winter Season - Normal*	*Winter Season - Actual*	*Hot Weather Season - Normal*	*Hot Weather Season - Actual*	*Total - Normal*	*Total - Actual*	*% Deviation from Normal*
2008-09	287.6	333.5	431.1	552.7	35.3	7.7	129.1	129.2	911.6	1023.1	12.2
2009-10	316.0	317.0	431	482.6	35.3	12	129	127	911.6	938	3
2010-11	319.2	383.6	430.3	605.2	31.3	36.3	127.8	140.0	908.6	1165.1	28.2
2011-12	321.2	300.5	441.2	540.8	31.3	9.5	128	86.3	921.6	937	1.7
2012-13	321.3	245.9	440.4	370.5	31.3	34.5	128.0	92.2	921.0	743.1	-19.3
2013-14	321.2	325.4	441	294.3	31.3	13.8	128.0	157.1	921.5	790.6	-14.2
2014-15	321.2	305.5	441	430.3	31.3	10.9	128.0	241.2	921.5	987.9	7.2
2015-16	330.9	295.7	470.7	695.8	32.6	2.9	128.2	123.6	962.4	1118.0	16.1
2016-17	330.8	265.8	468.0	174.0	32.9	41.7	127.1	116.6	958.9	598.1	-37.6
2017-18	331.0	421.09	468	429.28	33	17.99	128	148.9	959.9	1017	6.0
2018-19	293.2	330.8	351.8	468.0	4.6	32.9	49.3	128.2	698.8	960.0	37.4
2019-20	345.4	417.7	477.6	478.4	29.8	11.6	125.1	78.1	977.9	985.8	0.8
2020-21	345.4	441.2	476.3	512.2	29.5	154.6	122.0	124.9	973.2	1232.8	26.7
2021-22	328.4	477.7	441.7	444.8	28.0	42.4	125.5	166.5	923.6	1131	23

Table 3.5.2.2 Rainfall Sample Data

3.5.3 Water Irrigation

Water irrigation sample data was gathered from the Tamil Nadu State Statistical Handbook.

Below is the sample data.

Irrigation
Year
Canals
Tanks
Tube Wells & Bore Wells
Open Wells

Table 3.5.3.1 Water Irrigation Table Structure

Year	*Canals*	*Tanks*	*Tube Wells & Bore Wells*	*Open Wells*	*Other Sources*	*Total (excl. supp. Wells)*	*GROSS Area Irrigated*	*GROSS Area Sown*	*Percentage of the Area Sown to Area Irrigated*	*Net Area Irrigated*	*Net Area Sown*	*Percentage of Area Sown to Area Irrigated*
2021-22	6,83,806	4,10,214	5,45,846	12,84,933	4,703	29,29,502	31,18,814	49,94,588	62.44	29,29,502	49,08,941	59.68
2020-21	6,67,818	3,72,316	5,28,262	11,91,244	4,254	27,63,894	36,06,294	61,55,731	58.58	27,63,894	48,33,296	57.18
2019-20	6,47,983	3,51,484	5,18,392	11,50,929	-	26,72,403	34,10,316	59,42,134	57.39	2,67,403	47,38,297	56.40
2018-19	6,36,063	3,21,947	5,16,336	10,86,587	4,519	25,65,452	31,83,232	56,72,086	56.12	25,65,452	45,82,422	55.98
2017-18	5,89,264	3,58,113	5,20,604	11,56,527	2,157	26,26,665	32,77,744	57,29,576	57	26,26,665	46,38,561	57

Table 3.5.3.2 Water Irrigation Sample Data

3.5.4 Water Irrigation - Reservoir

Irrigation - Reservoir
year
Name of the Reservoir
Full Reservoir Depth in Metres
Feet

Capacity @ F.R.L in M.Cum
Capacity @ F.R.L in M.cft
Highest Level Reached Metres
Date
Lowest Level Reached Metres
Date
Total Water Release d in TMC

Table 3.5.4.1 Irrigation – Reservoir Table Structure

year	*Name of the Reservoir*	*Full Reservoir Depth in Metres*	*Feet*	Capacity @ F.R.L in M.Cum	Capacity @ F.R.L in M.cft	*Highest Level Reached Metres*	*Lowest Level Reached Metres*	Total Water Release d in TMC
2021-22	Mettur	36.58	120	2647	93470	36.61	19.994	237.338
2021-22	Bhavanisagar	32.00	105	929	32800	31.98	26.49	73.660
2021-22	Amaravathy	27.43	90	115	4047	27.30	16.68	19.282
2021-22	Periyar	43.29	142	217	7666	43.29	38.08	36.670
2021-22	Vaigai	21.64	71	172	6091	21.40	16.12	32.220
2021-22	Papanasam	43.60	143	156	5500	42.87	19.65	34.046
2021-22	Manimuthar	35.97	118	156	5511	35.98	19.17	6.624
2021-22	Pechiparai	14.63	48	123	4350	14.32	11.11	9.420
2021-22	Perunchani	23.47	77	82	2890	23.12	4.60	11.260
2021-22	Krishnagiri	15.85	52	47	1666	15.83	11.72	13.850
2021-22	Sathanur	36.27	119	207	7321	30.18	24.34	30.040
2021-22	Poondi	10.67	35	92	3231	10.67	5.77	37.330
2021-22	Sholayar	48.77	160	143	5046	49.93	0.51	22.740
2021-22	Parambikulam	21.95	72	380	13408	21.92	8.06	17.820
2021-22	Aliyar	36.58	120	109	3864	36.52	21.43	15.380
2021-22	Thirumoorthy	18.29	60	49	1744	17.64	8.04	22.080
2020-21	Mettur	36.58	120	2647	93470	32.54	19.498	195.662

2020-21	Bhavanisagar	32.00	105	929	32800	31.09	24.11	54.929
2020-21	Amaravathy	27.43	90	115	4047	27.40	7.22	17.329
2020-21	Periyar	43.29	142	217	7666	41.77	34.21	23.860
2020-21	Vaigai	21.64	71	172	6091	21.46	9.09	16.650
2020-21	Papanasam	43.60	143	156	5500	43.53	10.83	90.808
2020-21	Manimuthar	35.97	118	156	5511	36.00	18.95	8.169
2020-21	Pechiparai	14.63	48	123	4350	14.12	8.79	13.926
2020-21	Perunchani	23.47	77	82	2890	22.63	9.30	7.792
2020-21	Krishnagiri	15.85	52	47	1666	15.62	0.00	6.090
2020-21	Sathanur	36.27	119	207	7321	34.04	23.58	4.500
2020-21	Poondi	10.67	35	92	3231	10.67	5.13	10.340
2020-21	Sholayar	48.77	160	143	5046	49.89	0.55	20.050
2020-21	Parambikulam	21.95	72	380	13408	21.89	13.59	29.000
2020-21	Aliyar	36.58	120	109	3864	36.54	15.83	12.030
2020-21	Thirumoorthy	18.29	60	49	1744	17.76	6.00	19.660
2019-20	Mettur	36.58	120	2647	93470	36.86	11.930	205.105
2019-20	Bhavanisagar	32.00	105	929	32800	32.00	16.40	68.910
2019-20	Amaravathy	27.43	90	115	4047	26.25	7.39	9.794
2019-20	Periyar	43.29	142	217	7666	39.98	34.15	21.970
2019-20	Vaigai	21.64	71	172	6091	21.01	8.45	16.850
2019-20	Papanasam	43.60	143	156	5500	43.48	2.74	20.747
2019-20	Manimuthar	35.97	118	156	5511	35.25	12.50	6.487
2019-20	Pechiparai	14.63	48	123	4350	13.87	0.24	18.790
2019-20	Perunchani	23.47	77	82	2890	22.23	5.24	11.650
2019-20	Krishnagiri	15.85	52	47	1666	12.95	6.85	7.042
2019-20	Sathanur	36.27	119	207	7321	29.80	20.61	2.180
2019-20	Poondi	10.67	35	92	3231	9.14	3.89	7.450
2019-20	Sholayar	48.77	160	143	5046	49.65	0.61	36.587
2019-20	Parambikulam	21.95	72	380	13408	21.70	4.01	22.860
2019-20	Aliyar	36.58	120	109	3864	36.36	18.07	11.540
2019-20	Thirumoorthy	18.29	60	49	1744	16.58	3.84	16.340
2018-19	Mettur	36.58	120	2647	93470	36.69	9.997	359.615
2018-19	Bhavanisagar	32.00	105	929	32800	31.08	4.69	89.150
2018-19	Amaravathy	27.43	90	115	4047	26.85	7.28	18.590
2018-19	Periyar	43.29	142	217	7666	43.35	34.21	37.890
2018-19	Vaigai	21.64	71	172	6091	21.12	10.06	23.650
2018-19	Papanasam	43.60	143	156	5500	43.28	5.58	25.489
2018-19	Manimuthar	35.97	118	156	5511	32.66	21.50	5.429
2018-19	Pechiparai	14.63	48	123	4350	11.70	0.27	13.315
2018-19	Perunchani	23.47	77	82	2890	23.26	7.82	10.680
2018-19	Krishnagiri	15.85	52	47	1666	12.82	7.77	1.660

2018-19	Sathanur	36.27	119	207	7321	29.30	21.69	2.450
2018-19	Poondi	10.67	35	92	3231	8.97	3.74	9.800
2018-19	Sholayar	48.77	160	143	5046	49.96	1.30	34.210
2018-19	Parambikulam	21.95	72	380	13408	21.93	1.62	40.850
2018-19	Aliyar	36.58	120	109	3864	36.24	15.83	17.580
2018-19	Thirumoorthy	18.29	60	49	1744	17.64	3.27	22.230
2017-18	Mettur	36.58	120	2647	93470	29.87	5987.000	103.155
2017-18	Bhavanisagar	32.00	105	929	32800	25.07	11.77	29.100
2017-18	Amaravathy	27.43	90	115	4047	25.53	5.79	8.235
2017-18	Periyar	43.29	142	217	7666	39.72	33.10	14.737
2017-18	Vaigai	21.64	71	172	6091	18.29	6.21	7.990
2017-18	Papanasam	43.60	143	156	5500	42.23	4.77	21.316
2017-18	Manimuthar	35.97	118	156	5511	34.70	9.83	5.510
2017-18	Pechiparai	14.63	48	123	4350	13.76	0.54	10.186
2017-18	Perunchani	23.47	77	82	2890	23.20	3.31	5.256
2017-18	Krishnagiri	15.85	52	47	1666	15.64	9.74	18.835
2017-18	Sathanur	36.27	119	207	7321	36.28	22.07	13.330
2017-18	Poondi	10.67	35	92	3231	9.54	3.99	0.020
2017-18	Sholayar	48.77	160	143	5046	45.46	0.96	17.899
2017-18	Parambikulam	21.95	72	380	13408	12.40	1.67	11.180
2017-18	Aliyar	36.58	120	109	3864	27.95	15.24	8.710
2017-18	Thirumoorthy	18.29	60	49	1744	17.27	3.18	1.935

Table 3.5.4.2 -Reservoir Sample Data

Year	*Canals*	*Tanks*	*Tube Wells & Bore Wells*	*Open Wells*	*Other Sources*	*Total (excl. supp. Wells)*	*GROSS Area Irrigated*	*GROSS Area Sown*	*Percentage of the Area Sown to Area Irrigated*	*Net Area Irrigated*	*Net Area Sown*	*Percentage of Area Sown to Area Irrigated*
2021-22	6,83,806	4,10,214	5,45,846	12,84,933	4,703	29,29,502	31,18,814	49,94,588	62.44	29,29,502	49,08,941	59.68
2020-21	6,67,818	3,72,316	5,28,262	11,91,244	4,254	27,63,894	36,06,294	61,55,731	58.58	27,63,894	48,33,296	57.18
2019-20	6,47,983	3,51,484	5,18,392	11,50,929	-	26,72,403	34,10,316	59,42,134	57.39	2,67,403	47,38,297	56.40
2018-19	6,36,063	3,21,947	5,16,336	10,86,587	4,519	25,65,452	31,83,232	56,72,086	56.12	25,65,452	45,82,422	55.98
2017-18	5,89,264	3,58,113	5,20,604	11,56,527	2,157	26,26,665	32,77,744	57,29,576	57	26,26,665	46,38,561	57

Table 3.5.4.3 Other water sources

3.5.5 Agriculture

Paddy, Ragi, Cumbu, Cholam, Total Cereals, Total Pulses, Groundnut, and Gingelly are the primary agricultural products in Tamil Nadu. Sample data on total area, productivity, and production was collected from the Tamil Nadu Government Statistical Handbook.

Paddy
Year
Paddy - Area
Paddy - Productivity Kg. /Hec.
Paddy – Production ‘000Tonnes

Table 3.5.5.1 Paddy – Table Structure

Year	Paddy - Area	Paddy - Productivity Kg. /Hec.	Paddy - Production ‘000Tonnes
2016-17	1443	2463	3554
2017-18	1829	3630	6638
2018-19	1721	3562	6132
2019-20	1907	3809	7265
2020-21	2036	3380	6882
2021-22	2218	3566	7906

Table 3.5.5.1.1 Paddy – Sample Data

Cholam

Year
Cholam - Area
Cholam - Productivity Kg./Hec.
Cholam – Production ‘000Tonnes

Table 3.5.5.2 Cholam – Table Structure

Year	Cholam - Area	Cholam - Productivity Kg./Hec.	Cholam - Production ‘000Tonnes
2016-17	268	573	154
2017-18	386	1117	431
2018-19	386	1204	464
2019-20	450	1155	520
2020-21	405	1054	427
2021-22	397	912	362

Table 3.5.5.2.1 Cholam – Sample Data

Cumbu
Year
Cumbu - Area
Cumbu - Productivity Kg. /Hec.
Cumbu – Production ‘000’Tonnes

Table 3.5.5.3 Cumbu – Table Structure

Year	Cumbu - Area	Cumbu - Productivity Kg. /Hec.	Cumbu - Production ‘000’Tonnes
2016-17	50	2058	102

2017-18	63	2277	144
2018-19	47	2517	118
2019-20	67	2743	185
2020-21	67	2357	159
2021-22	60	2437	146

Table 3.5.5.3.1 Cumbu Sample Data

Ragi
Year
Ragi - Area
Ragi - Productivity Kg. /Hec.
Ragi – Production ‘000’Tonnes

Table 3.5.5.4 Ragi – Table Structure

Year	Ragi - Area	Ragi - Productivity Kg. /Hec.	Ragi - Production ‘000’Tonnes
2016-17	61	1865	114
2017-18	87	3714	321
2018-19	79	3257	256
2019-20	85	3247	274
2020-21	83	3480	289
2021-22	74	3056	227

Table 3.5.5.4.1 Ragi – Sample Data

Total Cereals
Year

Total Cereals - Area
Total Cereals - Productivity Kg./Hec.
Total Cereals – Production '000 Tonnes

Table 3.5.5.5 Total Cereals – Table Structure

Year	Total Cereals - Area	Total Cereals - Productivity Kg./Hec.	Total Cereals - Production '000 Tonnes
2016-17	2161	2267	4899
2017-18	2714	3743	10157
2018-19	2645	3719	9839
2019-20	2869	3798	10897
2020-21	3017	3432	10352
2021-22	3172	3432	11499

Table 3.5.5.5.1 Total Cereals – Sample Data

Total Pulses
Year
Total Pulses - Area
Total Pulses - Productivity Kg./Hec.
Total Pulses – Production '000 Tonnes

Table 3.5.5.6 Total Pulses – Table Structure

Year	Total Pulses - Area	Total Pulses - Productivity Kg./Hec.	Total Pulses - Production '000 Tonnes
2016-17	785	430	338
2017-18	825	675	556

2018-19	851	648	551
2019-20	824	735	605
2020-21	803	589	473
2021-22	802	589	499

Table 3.5.5.6.1 Total Pulses – Sample Data

Ground-Nut
Year
Groundnut - Area
Groundnut - Productivity Kg. /Hec.
Groundnut – Production '000' Tonnes

Table 3.5.5.7 Groundnut – Table Structure

Year	Groundnut - Area	Groundnut - Productivity Kg. /Hec.	Groundnut - Production '000' Tonnes
2016-17	282	2085	589
2017-18	327	3078	1007
2018-19	335	2716	911
2019-20	347	2980	1033
2020-21	409	2502	1023
2021-22	372	2812	1047

Table 3.5.5.7.1 Groundnut – Sample Data

GINGELLY
Year
Gin- gelly - Area

GINGELLY - Productivity Kg. /Hec.
GINGELLY - Production‘000’Tonnes

Table 3.5.5.8 GINGELLY – Table Structure

Year	Gin- gelly - Area	GINGELLY - Productivity Kg. /Hec.	GINGELLY - Production ‘000’ Tonnes
2016-17	28	384	11
2017-18	42	555	23
2018-19	44	548	24
2019-20	53	688	36
2020-21	53	654	34
2021-22	47	589	28

Table 3.5.5.8.1 GINGELLY – Sample Data

3.6 Data Collection Procedures

Tamil Nadu is one of the states in India that publishes annual statistics for all areas, including Agriculture.

- Statistical Handbook of Tamil Nadu used as the Data source
- Agriculture production details by Crop
- Rainfall statistics
- Water Management

3.7 Data Analysis

Data was captured from the Tamil Nadu government website and the Statistical Handbook of Tamil Nadu. The key tables are below.

- Climate
- Rainfall
- Agriculture
- Irrigation
    - Canals, Tube wells & Bore wells, Tanks, other sources
    - Reservoir
    - Crop-wise Irrigation

3.7.1 Climate Analysis

Climate significantly impacts agriculture, affecting crop yields, livestock health, soil quality, and farm productivity. Below are the average temperature details.

Year	Winter (°C)	Summer (°C)	Monsoon (°C)	Post-Monsoon (°C)
2020	25	32	28	27
2021	25.2	32.2	28.2	27.2
2022	25.4	32.4	28.4	27.4
2023	25.6	32.6	28.6	27.6
2024	25.8	32.8	28.8	27.8

Table 3.7.1 Climate

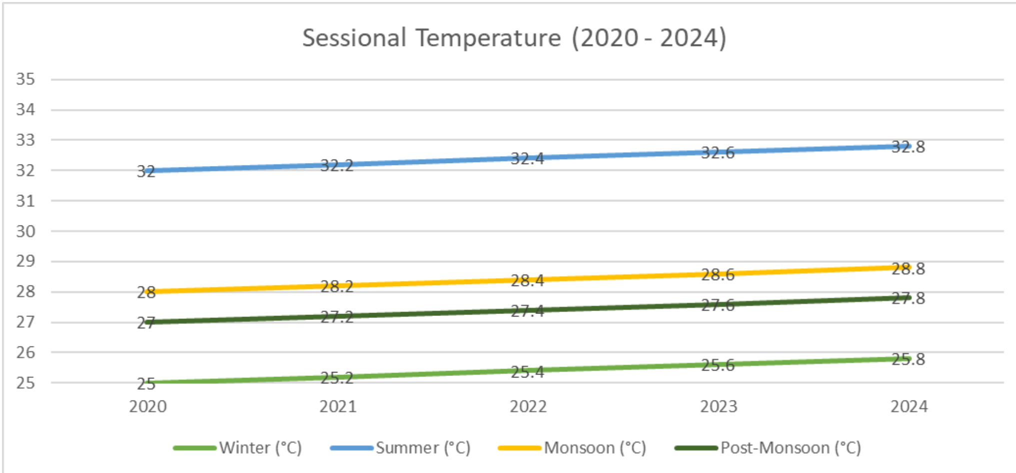

Figure 3.7.2 Sessional Temperature

Consistent Increase in Temperatures Across All Seasons

- The milder winters are shown by the Winter season rising from 25.0°C (2020) to 25.8°C (2024).
- Suggesting a slow warming trend, summer temperatures have also progressively climbed from 32.0°C to 32.8°C; monsoon and post-monsoon seasons also saw an increase in average temperatures, therefore reflecting a general warming environment.

Implications of Rising Summer Temperatures

- Given July temperatures approaching 33°C, heat waves could start to occur more regularly.
- Rising summer temperatures can influence agriculture, therefore affecting evaporation rates and possibly water shortages; they can also increase energy use (cooling demand).

Monsoon and Post-Monsoon Trends

- Rainfall patterns may change if monsoon temperatures (28.0°C to 28.8°C) keep rising steadily.

- Rising post-monsoon temperatures between 27.0°C and 27.8°C might cause extended warm conditions, hence raising humidity and discomfort levels.
- For four seasons—Winter, Summer, Monsoon, and Post-Monsoon—historical temperature records (2020–2024).

For Summer, Monsoon, and Post-Monsoon we calculated forecasts with a linear regression model.

Year	Winter (°C)	Summer (°C)	Monsoon (°C)	Post-Monsoon (°C)
2025	26	33	29	28
2026	26.2	33.2	29.2	28.2
2027	26.4	33.4	29.4	28.4
2028	26.6	33.6	29.6	28.6
2029	26.8	33.8	29.8	28.8

Table 3.7.1.3 Climate

3.7.2 Rainfall

Year	*South West Monsoon - Normal*	*South West Monsoon - Actual*	*North East Monsoon - Normal*	*North East Monsoon - Actual*	*Winter Season - Normal*	*Winter Season - Actual*	*Hot Weather Season - Normal*	*Hot Weather Season - Actual*	*Total - Normal*	*Total - Actual*	*% Deviation from Normal*
2008-09	287.6	333.5	431.1	552.7	35.3	7.7	129.1	129.2	911.6	1023.1	12.2
2009-10	316.0	317.0	431	482.6	35.3	12	129	127	911.6	938	3
2010-11	319.2	383.6	430.3	605.2	31.3	36.3	127.8	140.0	908.6	1165.1	28.2
2011-12	321.2	300.5	441.2	540.8	31.3	9.5	128	86.3	921.6	937	1.7
2012-13	321.3	245.9	440.4	370.5	31.3	34.5	128.0	92.2	921.0	743.1	-19.3
2013-14	321.2	325.4	441	294.3	31.3	13.8	128.0	157.1	921.5	790.6	-14.2
2014-15	321.2	305.5	441	430.3	31.3	10.9	128.0	241.2	921.5	987.9	7.2
2015-16	330.9	295.7	470.7	695.8	32.6	2.9	128.2	123.6	962.4	1118.0	16.1
2016-17	330.8	265.8	468.0	174.0	32.9	41.7	127.1	116.6	958.9	598.1	-37.6
2017-18	331.0	421.09	468	429.28	33	17.99	128	148.9	959.9	1017	6.0
2018-19	293.2	330.8	351.8	468.0	4.6	32.9	49.3	128.2	698.8	960.0	37.4
2019-20	345.4	417.7	477.6	478.4	29.8	11.6	125.1	78.1	977.9	985.8	0.8
2020-21	345.4	441.2	476.3	512.2	29.5	154.6	122.0	124.9	973.2	1232.8	26.7
2021-22	328.4	477.7	441.7	444.8	28.0	42.4	125.5	166.5	923.6	1131	23

Table 3.7.2.1 Overall Tamil Nadu Rainfall Normal vs Actual pattern (2008 – 2022)

Key Observations:

- The actual rainfall fluctuates significantly compared to the normal rain, indicating deviations from expected patterns.
- Years with Excess Rainfall: 2010-11, 2015-16, 2018-19, and 2020-21 show significant spikes above normal rainfall.
- Years with Deficient Rainfall: 2012-13 and 2016-17 show considerable dips below normal rainfall.
- Extreme Variability: Some years, such as 2016-17, show drastic reductions, whereas 2020-21 witnessed a sharp peak.

Here is a graphical representation of **Total Normal vs. Actual Rainfall (2008-2022)**:

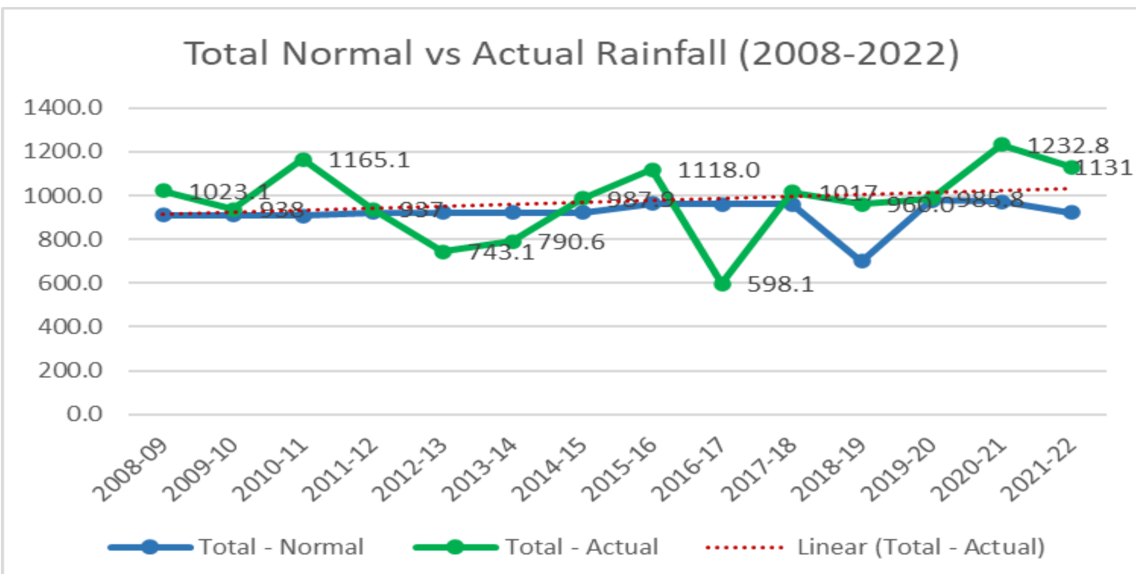

Figure 3.7.2.2 Total Normal vs Actual Rainfall

Rainfall Trends and Variability (2008-2022)

Rainfall over the years has shown significant ups and downs, influenced mainly by monsoon variations and changing weather patterns. Some years received much more rainfall than expected, while others saw severe shortages.

Changes in Total Rainfall

- Biggest increase in rainfall:
  - 2018-19 (+37.4%) and 2020-21 (+26.7%) saw much higher rainfall than usual.
  - 2010-11 (+28.2%) also significantly increased total rainfall.
- Biggest decrease in rainfall:
  - 2016-17 (-37.6%) had the lowest rainfall, falling far below normal.
  - 2012-13 (-19.3%) also had a major shortage of rainfall.

These changes in rainfall levels can impact agriculture, water supply, and weather conditions.

South West Monsoon Trends (June–September)

The South West Monsoon is the most crucial season for rainfall in many regions.

- Good Monsoon Years (More Rainfall than Normal)
  - 2010-11 (383.6 mm) and 2021-22 (477.7 mm) received much rain than usual.
  - 2019-20 (417.7 mm) and 2020-21 (441.2 mm) were also above normal.
- Poor Monsoon Years (Less Rainfall than Normal)
  - 2012-13 (245.9 mm) and 2016-17 (265.8 mm) saw very low rainfall, which could have caused droughts.
  - 2015-16 (295.7 mm) also had lower-than-normal rainfall.

A weak South West Monsoon can lead to water shortages, dry conditions, and lower crop production.

North East Monsoon Trends (October–December)

The North East Monsoon also saw big changes in rainfall from year to year.

- Heavy Rainfall Years:

- 2015-16 (695.8 mm) received much rain, far more than the normal 470.7 mm.
- 2010-11 (605.2 mm) and 2020-21 (512.2 mm) were also very wet years.

- Dry Years with Low Rainfall:
    - 2016-17 (174.0 mm) had the lowest North East Monsoon rainfall, less than half the normal amount.
    - 2013-14 (294.3 mm) and 2012-13 (370.5 mm) also had below-normal rainfall.

Low rainfall in this season can lead to water shortages and impact agriculture.

Winter and Hot Weather Season Rainfall

Though these seasons contribute less rainfall, some unusual patterns were observed.

- Winter Rainfall (January–March)
    - Usually, winter rainfall is low, but 2020-21 saw a major increase (154.6 mm) compared to 29.5 mm.
    - 2016-17 (41.7 mm) and 2021-22 (42.4 mm) also had more than usual.
    - 2015-16 (2.9 mm) had almost no winter rain.

Hot Weather Rainfall (April–May)

- This season usually has stable rainfall, but some years saw big jumps:
    - 2014-15 (241.2 mm) and 2021-22 (166.5 mm) had much higher rain than normal.
- 2019-20 (78.1 mm) and 2016-17 (116.6 mm) had less rainfall.

Changes in these seasons can affect summer temperatures, farming, and water storage.

Extreme Rainfall Years

Some years saw major differences from normal rainfall:

- Worst year with the least rainfall:
  - 2016-17 (-37.6%) had the biggest shortage of rainfall in the entire dataset.
- Years with the most extra rainfall:
  - 2018-19 (+37.4%) and 2020-21 (+26.7%) had very high rainfall, much more than normal.

Extreme weather years like these can cause droughts or floods, impacting daily life.

Overall Rainfall Analysis Summary:

- Big changes in yearly rainfall show that monsoons are unpredictable.
- The South West Monsoon plays the biggest role in total rainfall.
- The North East Monsoon also varies a lot, affecting post-monsoon agriculture.
- Winter and hot weather rains are mostly stable but sometimes see unexpected spikes.
- 2016-17 had the worst drought, while 2018-19 had the most excess rain.

Detailed Analysis of Rainfall Patterns for 5 years (2017-2022)

Total Normal vs. Total Actual Rainfall for the five years (2017-18 to 2021-22). The blue line represents normal expected rainfall, while the green line represents actual recorded rainfall. A red dotted trendline is also included to show the general trend in actual rainfall over the years.

Observations and Key Trends

1. 2017-18: Near Normal Rainfall (Slightly Above Expected)
   - Normal Rainfall: 959.9 mm
   - Actual Rainfall: 1017 mm

- Deviation: +6.0% (Slightly above normal)
- The actual rainfall was slightly higher than normal, indicating a stable monsoon year with no extreme weather conditions.

2. 2018-19: Major Rainfall Deficiency (-37.4%)
    - Normal Rainfall: 698.8 mm
    - Actual Rainfall: 960 mm
    - Deviation: +37.4% (Significant excess)
    - The year saw a sharp increase in actual rainfall, exceeding normal levels. This indicates a strong monsoon with higher-than-usual precipitation.
3. 2019-20: Near Normal Rainfall (Slightly Above Expected)
    - Normal Rainfall: 977.9 mm
    - Actual Rainfall: 985.8 mm
    - Deviation: +0.8% (Almost normal)
    - This year's rainfall was very close to normal, showing balanced weather conditions with no significant floods or droughts.
4. 2020-21: Extremely High Rainfall (+26.7%)
    - Normal Rainfall: 973.2 mm
    - Actual Rainfall: 1232.8 mm
    - Deviation: +26.7% (Significant excess)
    - One of the wettest years in this period, with actual rainfall far exceeding normal levels.
    - Likely caused by strong monsoon activity, possibly influenced by La Niña conditions, leading to increased precipitation.
5. 2021-22: Significant Excess Rainfall (+23%)
    - Normal Rainfall: 923.6 mm

- Actual Rainfall: 1131 mm
- Deviation: +23.0%
- Similar to 2020-21, this year also experienced excess rainfall, though slightly less extreme.
- The trend indicates a gradual increase in actual rainfall over time, suggesting changing climate conditions.

Key Findings and Inferences

- Extreme Variability: The last five years show large variations in rainfall, with some years being close to normal (2017-18 and 2019-20), while others saw significant excess rain (2018-19, 2020-21, and 2021-22).
- Rising Trend in Rainfall: The red trendline in the graph shows that actual rainfall has gradually increased over the years.
- 2020-21 & 2021-22 Had Excess Rainfall: These years had more than 20% higher rainfall than normal, indicating strong monsoons, possible climate shifts, or external weather influences (e.g., El Niño/La Niña effects).
- 2018-19 Stood Out: The year saw the highest positive deviation (+37.4%), making it the wettest year in the last five years.

The below graph represents the seasonal rainfall patterns for the five years (2017-18 to 2021-22). The four major seasons analyzed are:

- South West Monsoon (June-September)
- North East Monsoon (October-December)
- Winter Season (January-March)
- Hot Weather Season (April-May)

South West Monsoon (June-September)

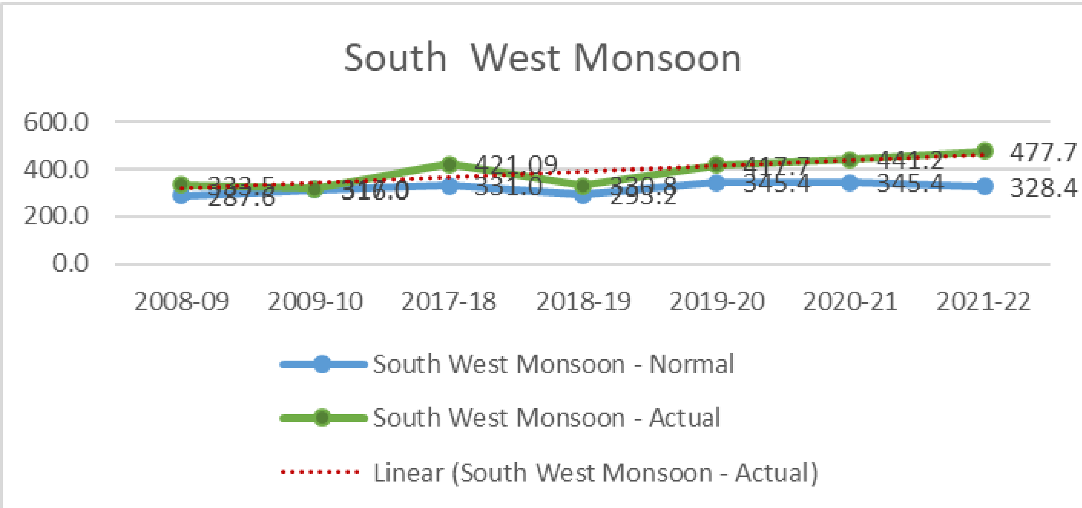

Figure 3.7.2.1 South west Monsoon

South West Monsoon Trends

- The South West Monsoon is the largest contributor to annual rainfall.
- 2018-19 saw a significant drop (330.8 mm), but the monsoon strengthened again in the following years.
- 2021-22 recorded the highest rainfall (477.7 mm), steadily increasing over the years.
- This indicates a strengthening monsoon in recent years, possibly due to changing climate patterns.

North East Monsoon (October-December)

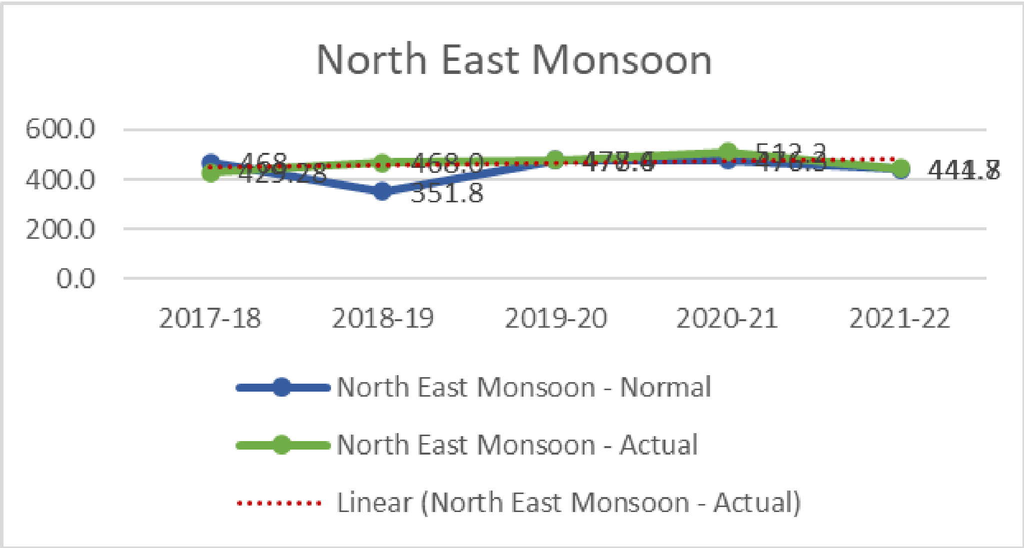

Figure 3.7.2.2 North East Monsoon

North East Monsoon Trends

- The North East Monsoon is the second biggest contributor to annual rainfall.
- 2017-18 had relatively lower rainfall (429.28 mm) but peaked in 2020-21 (512.2 mm).
- 2021-22 saw a decline (444.8 mm) but remained above earlier years.
- This suggests variability in post-monsoon rainfall, with some years having extreme rainfall and others being closer to normal.

Winter Season (January-March)

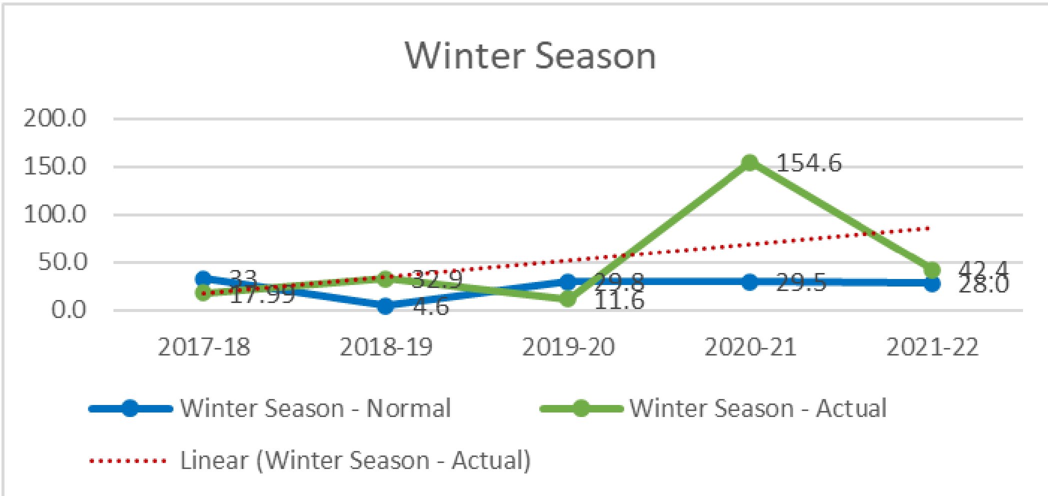

Figure 3.7.2.3 Winter session

Winter Rainfall Trends

- Winter rainfall is usually very low, but 2020-21 saw an extreme spike (154.6 mm).
- The 2019-20 winter season was the driest (11.6 mm), while 2021-22 also saw higher-than-usual winter rainfall (42.4 mm).
- This sharp increase in winter rainfall in 2020-21 suggests unusual weather conditions, possibly influenced by global climatic changes (La Niña or unseasonal cyclonic activity).

Hot Weather Season (April-May)

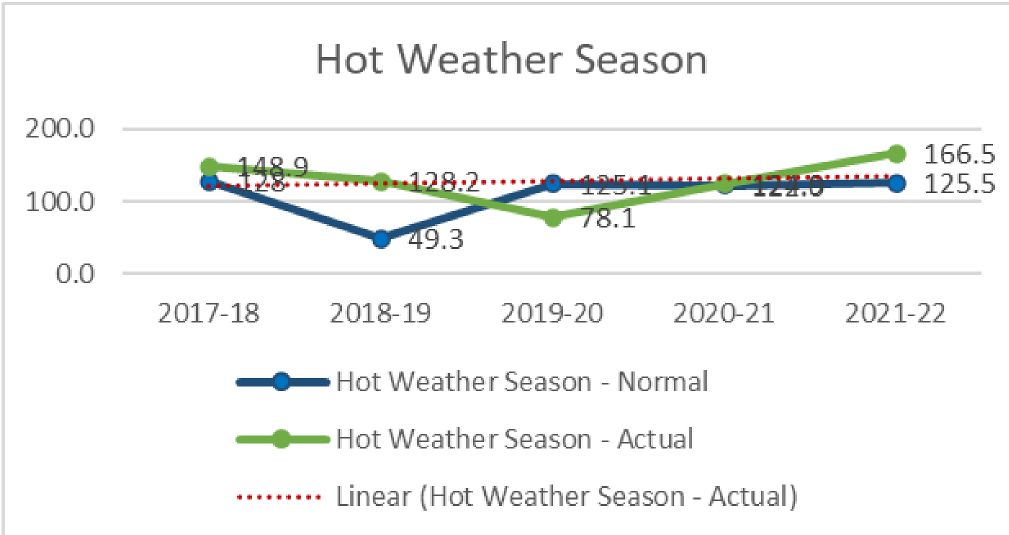

Figure 3.7.2.4 Hot weather session

Hot Weather Season Trends

- Hot weather rainfall has been relatively stable but fluctuating.
- 2019-20 recorded the lowest hot weather season rainfall (78.1 mm).
- 2021-22 saw an increase to 166.5 mm, the highest in the last five years.
- The gradual rise in hot weather rainfall may indicate increasing pre-monsoon storms or changing atmospheric moisture levels.

Sessional Analysis Summary

- South West Monsoon Rainfall is Increasing: The monsoon became stronger, particularly in 2020-21 and 2021-22.
- North East Monsoon is Unpredictable: Some years, like 2020-21, saw very high rainfall, while others remained close to normal.
- Winter Rainfall is Becoming More Extreme: 2020-21 had unusually high winter rainfall, possibly due to unexpected weather systems.

- Hot Weather Season Rainfall is Rising Gradually: The rainfall before the monsoon season has slightly increased, potentially due to climate-related changes.

3.7.3 Agriculture

Paddy Production in Tamil Nadu

One of the main crops grown in Tamil Nadu is paddy, or rice, which makes a big difference in the state's agricultural income. The state has a variety of agroclimatic conditions that make it possible to grow rice all year long.

Paddy Cultivation Seasons in Tamil Nadu

Paddy is cultivated in Tamil Nadu across three major seasons:

- Samba (September to January or February): This is Tamil Nadu's most important paddy-growing season. It includes about 50–60% of all the rice that is grown.
- From June to September, there is a short crop season called Kuruvai. It mostly happens in delta areas, especially the Cauvery delta.
- From January to April, it is grown in some parts of the state that have access to irrigation.

Major Paddy Growing Districts in Tamil Nadu

- It is known as the "Rice Bowl of Tamil Nadu," and it is an important place for growing rice.
- Tiruvarur: This area has rich land that helps grow a lot of rice.
- Nagapattinam: This is another important area in the Cauvery Delta for growing rice.
- Tiruchirapalli: Makes a big difference in growing rice.
- Cuddalore: Lands that are well-watered and good for growing rice.

- Vilupuram: Lots of rice is grown there every year.
- Madurai, Dindigul, and Ramanathapuram are some other places where rice is grown.

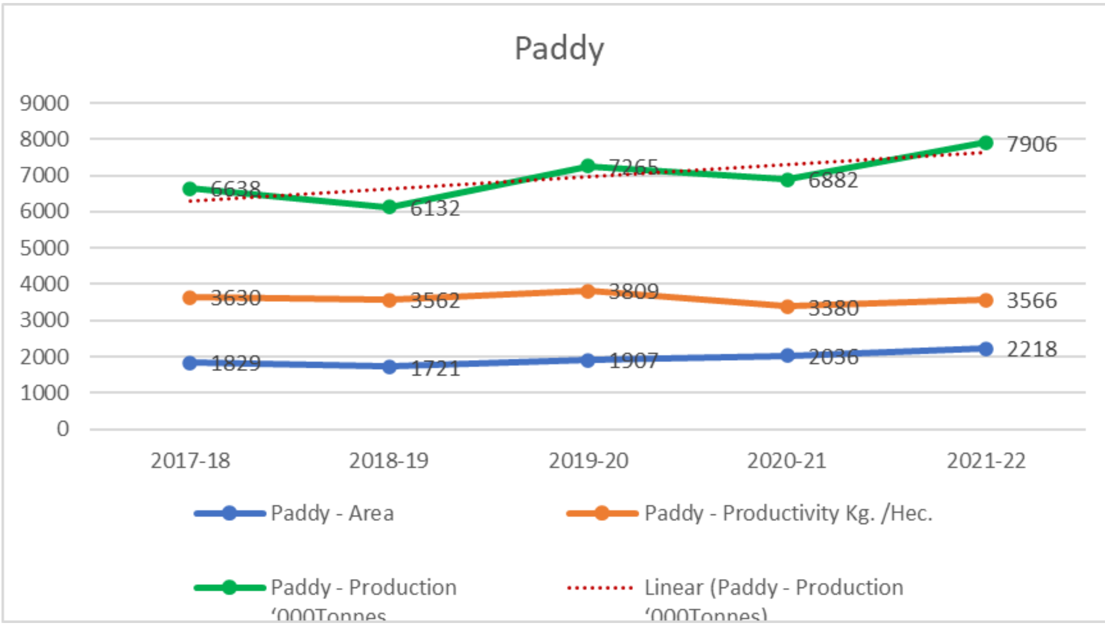

Figure 3.7.3.1 Paddy

Increasing Cultivated Area:

- From 1443 thousand hectares (2016-17) to 2218 thousand hectares (2021-22), the area under paddy farming has grown.
- This points to improved irrigation systems, friendly laws, and more farmer involvement.

Fluctuating Productivity:

- Over years, paddy output has varied.

- While 2020-21 showed a decline to 3350 kg/Hec, 2019–20 had the highest productivity—3809 kg/Hec.
- Variations in rainfall, pest assaults, climate, and fertilizer availability could all affect elements.

Production Growth:

- From 3554 (“000 Tonnes) in 2016-17 to 7906 (“000 Tonnes) in 2021-22 production has gradually climbed.
- Why The expansion in cultivated area helped to sustain a greater overall output even if productivity fell in 2020-21.

Impact of Area vs. Productivity:

- Productivity clearly increased in 2017–18 and 2019–20, which caused a notable rise in output (6638 and 7265 "000 Tonnes, respectively").
- Although output (3380 kg/Hec) dropped in 2020–21, growing planted area helped to maintain production high.
- Driven by increased farmed areas and modest productivity, 2021–22 achieved the highest production (7906 "000 Tonnes").

Cholam (Sorghum) Production in Tamil Nadu

Tamil Nadu grows the essential millet crop cholam (sorghum). Used for food, fuel, and industry, this drought-resistant crop grows best in semi-arid environments. Dryland farming areas with little irrigation are usually where it is farmed.

Major Cholam Cultivation Districts in Tamil Nadu

- Salem is among the top cholam producing districts.
- Tiruchirapalli grows cholam largely under rain-fed circumstances.

- Dindigul: Not insignificant area of production.
- Madurai develops cholam as a dryland crop.
- Ramathapuram: Given its arid climate, fit for cholam.
- Virudhunagar: Also quite important for sorghum farming.
- Coimbatore and Erode: Grow cholam in mixed crops systems.

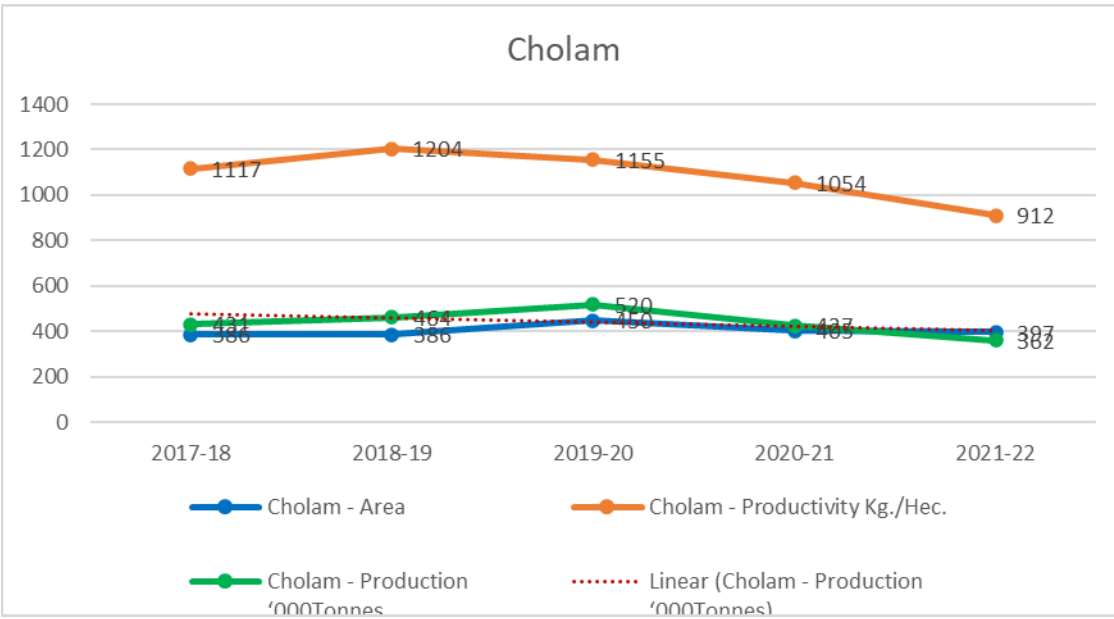

Figure 3.7.3.2 Cholam

Increase in Cultivated Area (2016-20):

- Due to its resistance in drought-prone areas, the cultivated area for cholam rose from 268 (‘000 Hec.) in 2016-17 to 450 (‘000 Hec%) in 2019-20.
- There is a drop following 2019–2020; the area drops to 397 (000 Hec.). in 2021–22.

Productivity Fluctuations:

- With the lowest productivity (573 kg/Hec), 2016–17 produced low output (154 000 tonnes).

- Productivity increased significantly in 2017-18 (1117 kg/Hec) and 2018-19 (1204 kg/Hec), hence driving more output.
- Productivity fell following 2019–20, falling to 912 kg/Hec in 2021–22.

Production Peak in 2019-20:

- Because of more area and productivity, 2019–20 (520,000 tonnes) showed the highest production.
- Following 2019–20, output fell gradually; mostly due to declining productivity, it dropped to 362 ("000 Tonnes) in 2021–22.

Cumbu (Pearl Millet) Production in Tamil Nadu

Grown extensively in Tamil Nadu, Cumbu—also known as Pearl Millet—is a very nutrient-dense crop resistant to drought. Its capacity to survive low rainfall and high temperatures makes it mostly grown in dry and semi-arid areas. Essential to the millet output of the state, cumbu finds use in food, feed, and industry.

Major Cumbu Cultivation Districts in Tamil Nadu

- Villupuram is one of the top cumbu growing districts.
- Tiruvannamalai: Not least of which influences cumbu output.
- Vallore: grows cumbu under dryland agricultural settings.
- Salem: Renowned for raising pearl millet in rain-fed regions.
- Ramanathapuram: Drought tolerance makes this ideal for cumbu.
- Madurai uses millet-based farming to grow cumbu.

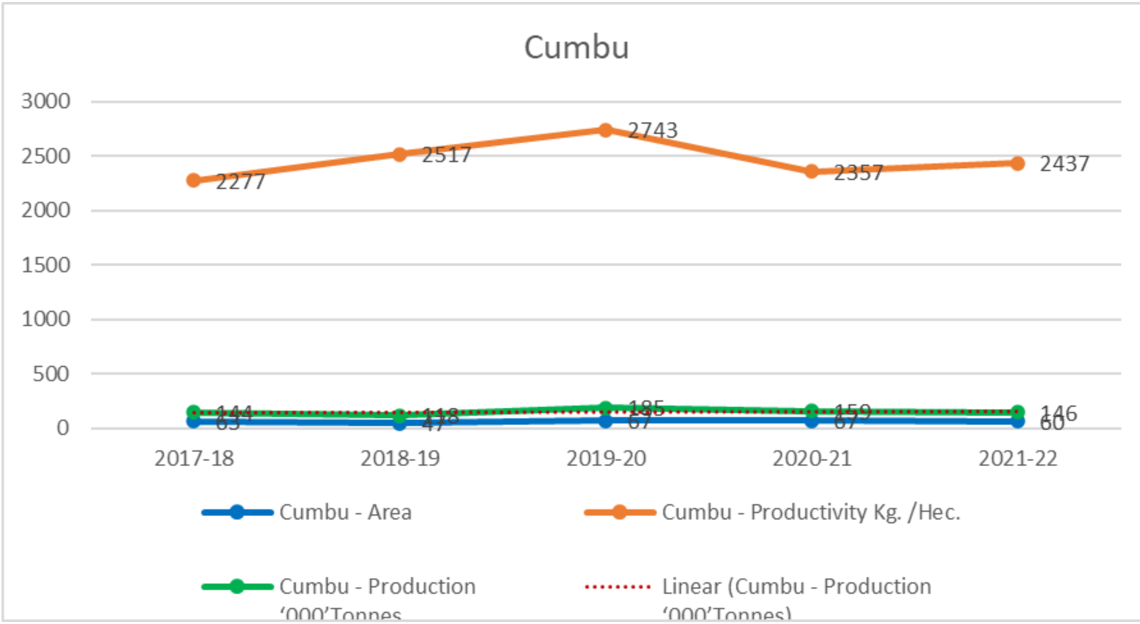

Figure 3.7.3.3 Cumbu

Fluctuating Cultivated Area:

- Increased production came from the area set aside for cumbu farming rising from 50,000 hectares in 2016-17 to 67,000 hectares in 2019-20.
- The area dropped to 60,000 hectares in 2021–22, indicating a declining farming activity.

Productivity Peaks in 2019-20:

- Productivity steadily increased from 2058 kg/Hec in 2016-17 to 2743 kg/Hec in 2019-20, therefore attaining the highest production of 185,000 tons that year.
- Productivity dropped to 2357 kg/Hec in 2020-21 following the 2019–20 period, then slightly rose to 2437 kg/Hec in 2021–22.

Impact on Production:

- Attributed to an enlarged area and optimal productivity, the highest production of 185,000 tons came in 2019–20.

- Reduced production (146,000 tons in 2021-22) resulted from declines in area and productivity during 2020–21 and 2021–22.

Ragi (Finger Millet) Production in Tamil Nadu

Among the most nutritious and drought-resistant millet species grown in Tamil Nadu are ragi, or finger millet. Especially in rural areas, it is a vital part of the diet since it is plentiful in calcium, iron, and dietary fiber. Mostly as a rain-fed crop, it is grown in semi-arid areas. Principal Ragi Production Districts in Tamil Nadu.

Major Ragi Cultivation Districts in Tamil Nadu

- Dharmapiri: Among the state's ragi producers, one of greatest numbers.
- Krishnagiri: Renowned for their major contribution to ragi output.
- Salem: A major area expanding ragi under dryland cultivation.
- Erode: Designed for millet growing.
- Vallore: generates ragi in reasonable amounts.
- Tiruvannamalai: An other significant area of ragi production.

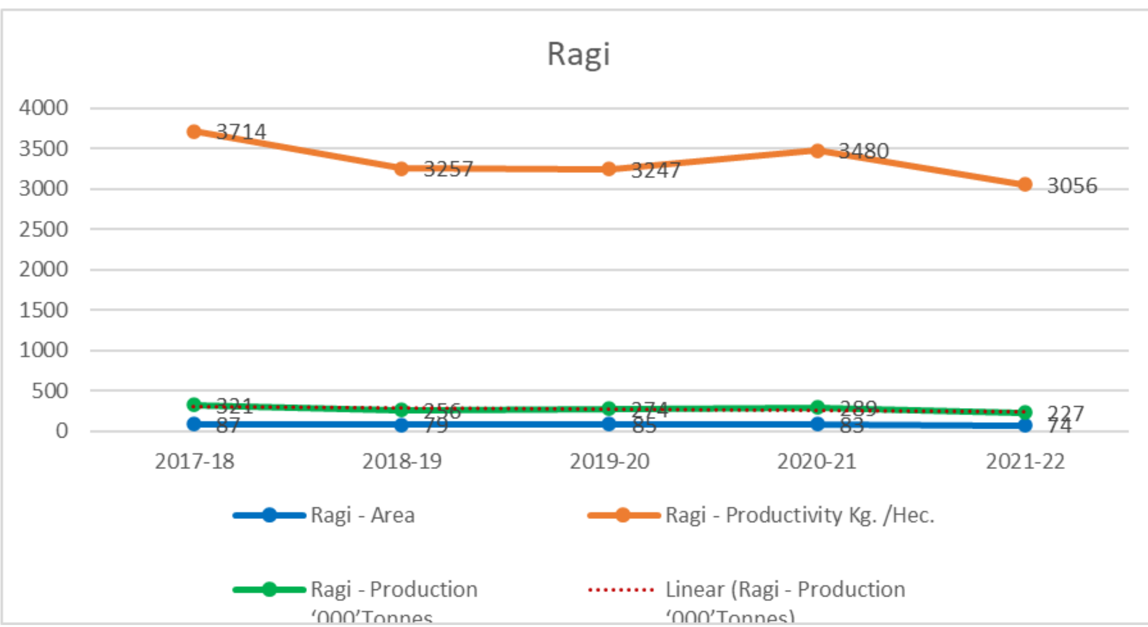

Figure 3.7.3.4 Ragi

Significant Increase in Productivity in 2017-18:

- From 1865 kg/Hec (2016-17) to 3714 kg/Hec (2017-18), the productivity doubled.
- Production surged dramatically from 114 (‘000 Tonnes) to 321 (‘000 Tonnes) as a result.

Peak Production in 2017-18:

- 2017–18 had the largest ragi production (321 "000 Tonnes) due to both expanded area (87 "000 Hec.) and maximum productivity (3714 kg/Hec).
- Productivity and output followed a varying trajectory following this high.

Productivity and Area Fluctuations:

- Productivity ranged between 3056 and 3450 kg/Hec from 2018–19 to 2021–22.
- Production dropped as the planted area dropped from 87 (‘000 Hec.) in 2017-18 to 74 (‘000 Hec+) in 2021-22.

Decline in Production Post 2017-18:

- Though output stayed somewhat high, a smaller planted area helped to lower overall production.
- Mostly owing to less area, production dropped to 227 (000 tonnes) in 2021–22.

Total Cereals Production in Tamil Nadu

Tamil Nadu's agricultural output depends critically on cereals such paddy, cholam (sorghum), cumbia (pearl millet), and ragi (finger millet). In food security, animal feed, and industrial uses these crops are indispensible.

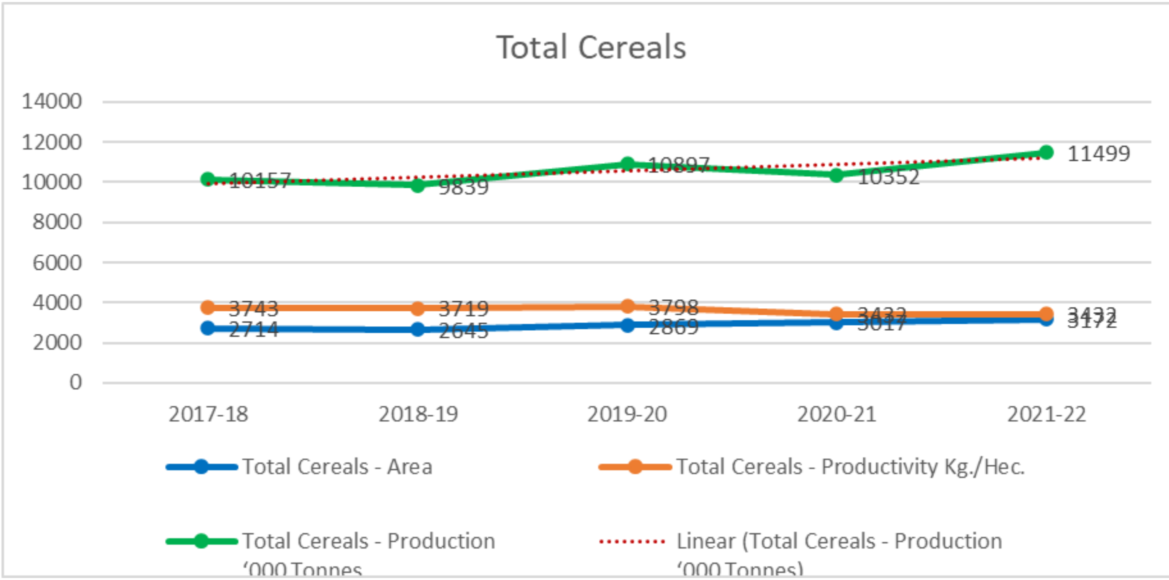

Figure 3.7.3.5 Total Cereals

Significant Increase in Cultivated Area:

- From 2161 ("000 Hec.) in 2016-17 to 3172 ("000 Hec)," the total cultivated area grew.
- This shows growing attention on cereal farming, maybe motivated by demand and favorable legislation.

Highest Productivity in 2017-18:

- Productivity peaked in 2017-18 at 3743 kg/Hec, which caused a sharp rise in output.
- Productivity fell after 2019–20 and stayed at 3432 kg/Hec for 2020–21 and 2021–22.

Production Growth with Fluctuations:

- Driven by the biggest farmed area despite lower yield, 2021–22 (11499 000 tonnes) had the highest production year.
- A surge in production caused by 2017–18 saw an amazing increase of 10157 000 tonnes.

- Following years had steady production; small reductions in 2018-19 and 2020-21 preceded a recovery in 2021-22.

Total Pulses Production in Tamil Nadu

Tamil Nadu's agriculture depends much on pulses, which also provide a major dietary source of protein. Typical grown pulses are cowpea, black gram, green gram, and red gram. Usually grown under dryland circumstances, pulses help to greatly increase soil fertility by nitrogen fixation.

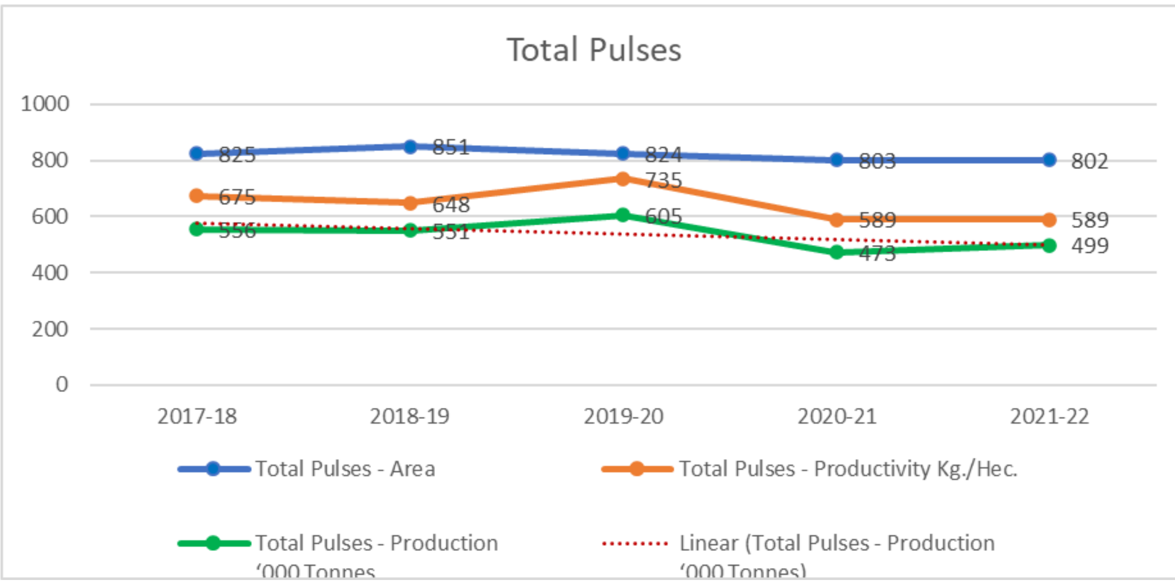

Figure 3.7.3.6 Total Pulses

Increase in Area from 2016-18, then Stabilization:

- The area under pulse cultivation increased from 785 (‘000 Hec.) in 2016-17 to 851 (‘000 Hec.) in 2018-19.
- However, after 2019-20, the area remained stable around 802-803 (‘000 Hec.).

Highest Productivity in 2019-20:

- The peak productivity was recorded in 2019-20 (735 Kg/Hec), leading to the highest production of 605 (‘000 Tonnes).
- Post-2019-20, productivity dropped to 589 Kg/Hec, affecting total production.

Production Growth and Decline:

- Production peaked in 2019-20 at 605 (‘000 Tonnes) due to high productivity.
- 2020-21 and 2021-22 saw a decline in production (473 and 499 ‘000 Tonnes, respectively) due to lower productivity despite stable cultivated area.

Groundnut Production in Tamil Nadu

Groundnut (Peanut) is one of the major oilseed crops cultivated in Tamil Nadu. It is widely grown in rain-fed and irrigated conditions and is an essential source of edible oil and protein.

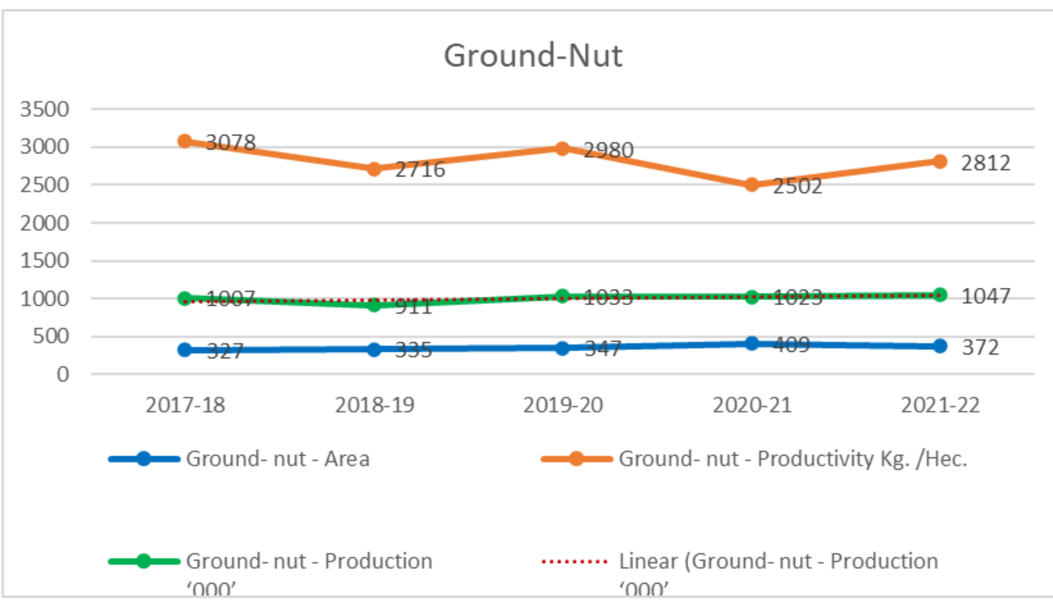

Figure 3.7.3.7 Groundnut

Steady Increase in Cultivated Area (2016-21):

- The area under groundnut cultivation increased from 282 (‘000 Hec.) in 2016-17 to a peak of 409 (‘000 Hec.) in 2020-21.
- However, in 2021-22, the area decreased to 372 (‘000 Hec.).

Highest Productivity in 2017-18:

- The highest productivity was recorded in 2017-18 (3078 Kg/Hec), leading to one of the highest production levels (1007 ‘000 Tonnes).
- Productivity fluctuated in subsequent years, declining to 2502 Kg/Hec in 2020-21, but recovered to 2812 Kg/Hec in 2021-22.

Production Growth with Fluctuations:

- The highest production was recorded in 2021-22 (1047 ‘000 Tonnes) despite lower cultivated area, indicating improved productivity.
- 2020-21 saw a decline in productivity, affecting production despite a larger cultivation area.
- 2017-18 and 2019-20 also had high production due to increased productivity.

Gingelly (Sesame) Production in Tamil Nadu (2016-22)

Gingelly (Sesame) is a valuable oilseed crop grown in Tamil Nadu, mainly under dryland conditions. It is widely used for edible oil extraction and in traditional food preparations. The crop is known for its resilience to drought and high oil content.

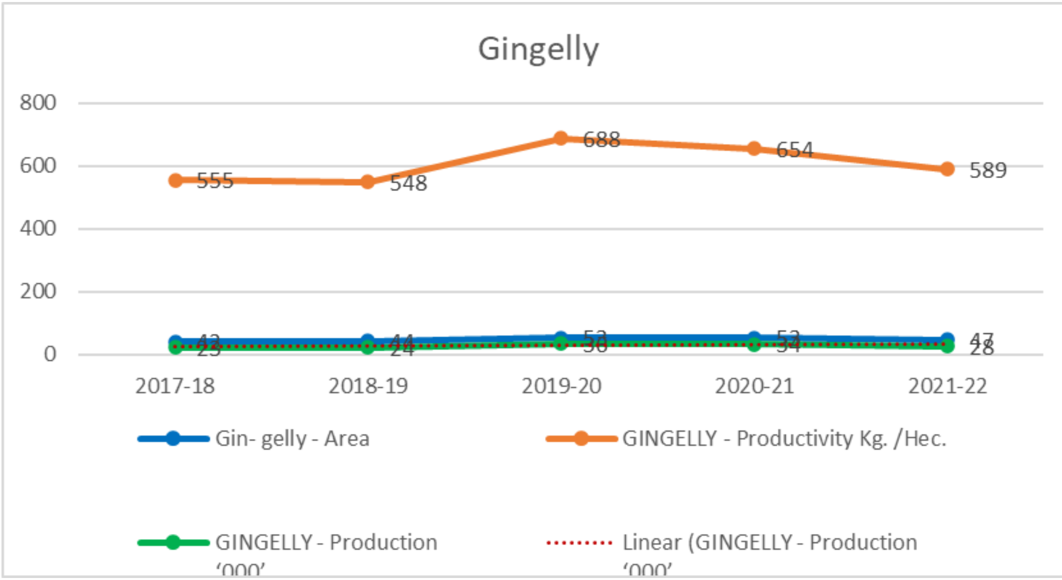

Figure 3.7.3.8 Gingelly

Increase in Cultivated Area Until 2019-20:

- The cultivated area increased from 28 (‘000 Hec.) in 2016-17 to 53 (‘000 Hec.) in 2019-20.
- However, in 2021-22, the area decreased to 47 (‘000 Hec.), impacting total production.

Highest Productivity in 2019-20:

- The highest productivity was recorded in 2019-20 (688 Kg/Hec), leading to the highest production (36 ‘000 Tonnes).
- Productivity declined slightly in the following years, reaching 589 Kg/Hec in 2021-22.

Production Trends:

- Production peaked in 2019-20 at 36 (‘000 Tonnes) due to increased area and productivity.

- In 2021-22, production dropped to 28 (‘000 Tonnes) due to lower cultivated area and declining productivity.

Water Irrigation

Comprehensive Study of Tamil Nadu's Water Irrigation for Different Crops 2017–22

Maintaining agriculture in Tamil Nadu depends critically on water irrigation, particularly for water-intensive crops like sugarcane and paddy. Crops with different irrigation requirements include groundnut, cotton, millets (Cholam, Cumbu, Ragi), and groundnut. The irrigation trends for several crops from 2017 to 2022 are fully broken out below.

High Paddy and Sugarcane Irrigation Coverage

- Reflecting its great reliance on water, Paddy continuously boasts over 93% irrigation coverage from 2017 to 2022.

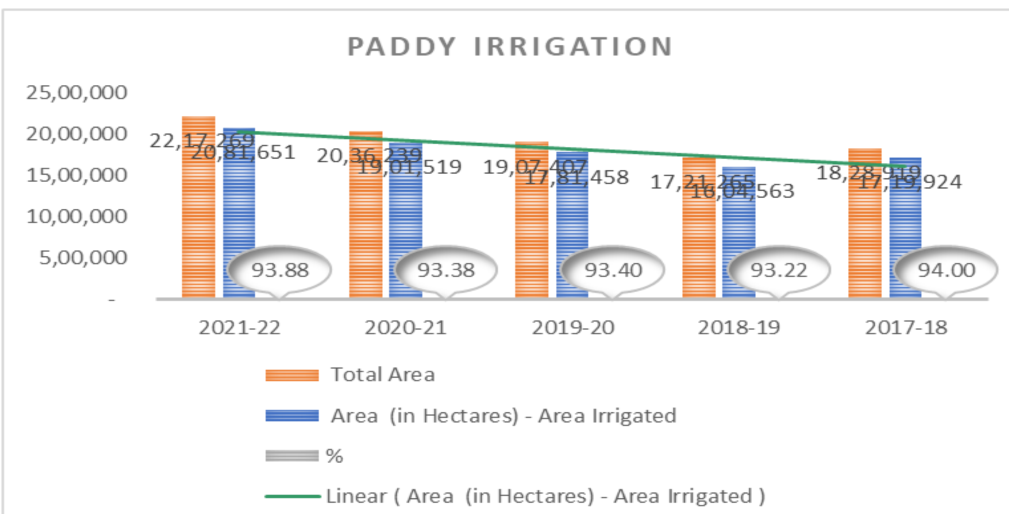

Figure 3.7.3.9.1 Paddy Irrigation

- The irrigated area for paddy increased from 1.7 million hectares in 2017-18 to 2.08 million hectares in 2021-22.

- Sugarcane had nearly 100% irrigation coverage yearly, confirming that it is a fully irrigated crop in Tamil Nadu.

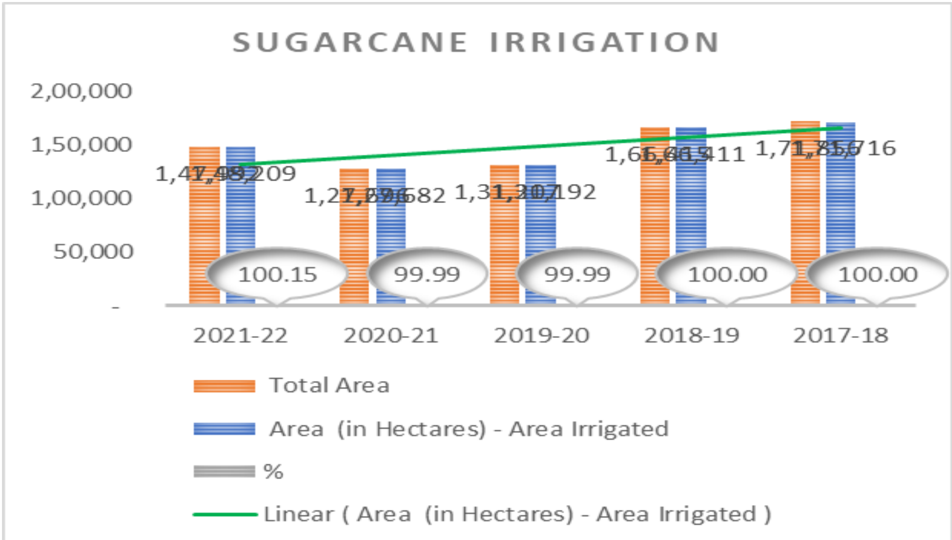

Figure 3.7.3.9.1.2 Sugarcane Irrigation

- Despite its high water requirement, sugarcane's irrigated area remained relatively stable, indicating well-managed irrigation resources for this crop.

Fluctuating Irrigation for Millets (Cholam, Cumbu, Ragi)

- Cholam (Sorghum) had low irrigation coverage, fluctuating between 9-11%. This suggests it is mainly cultivated in rainfed areas with minimal irrigation support.
- Cumbu (Pearl Millet) saw slightly better irrigation than Cholam, ranging from 12% to 15%, but still primarily dependent on rainwater.

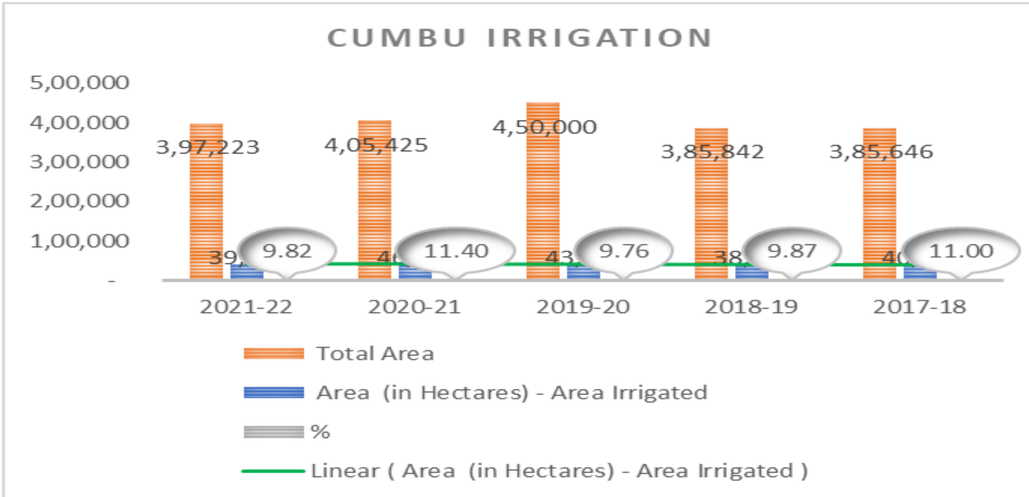

Figure 3.7.3.9.3 Cumbu Irrigation

- Ragi (Finger Millet) had higher irrigation coverage than other millets, varying from 20% in 2021-22 to 28% in 2017-18, showing partial irrigation dependency.

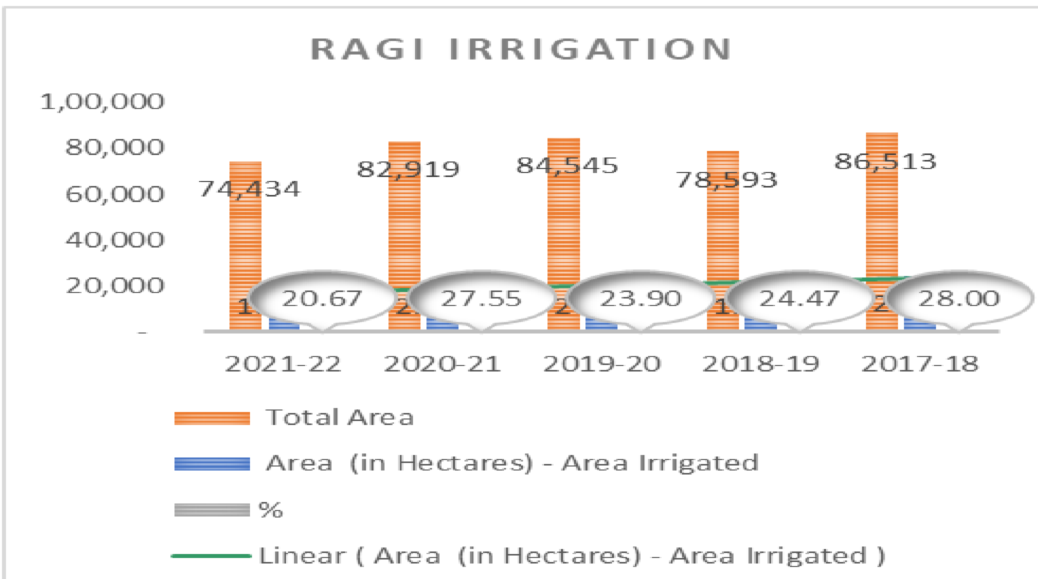

Figure 3.7.3.9.4.1 Ragi Irrigation

Implications:

- Millets are drought-resistant crops, but improving irrigation support can enhance productivity, especially during rainfall deficit.

- Government policies should promote micro-irrigation techniques like sprinklers and drip irrigation for millet farming.

Overall Stable Irrigation Trends Across the Years

- Despite individual crop fluctuations, the total irrigated area across Tamil Nadu remained stable.
- Paddy and sugarcane received priority in irrigation, ensuring stable food and sugar production.
- Millets, groundnut, and cotton received limited irrigation, but their cultivation continued, showing resilience in Tamil Nadu's farming systems.

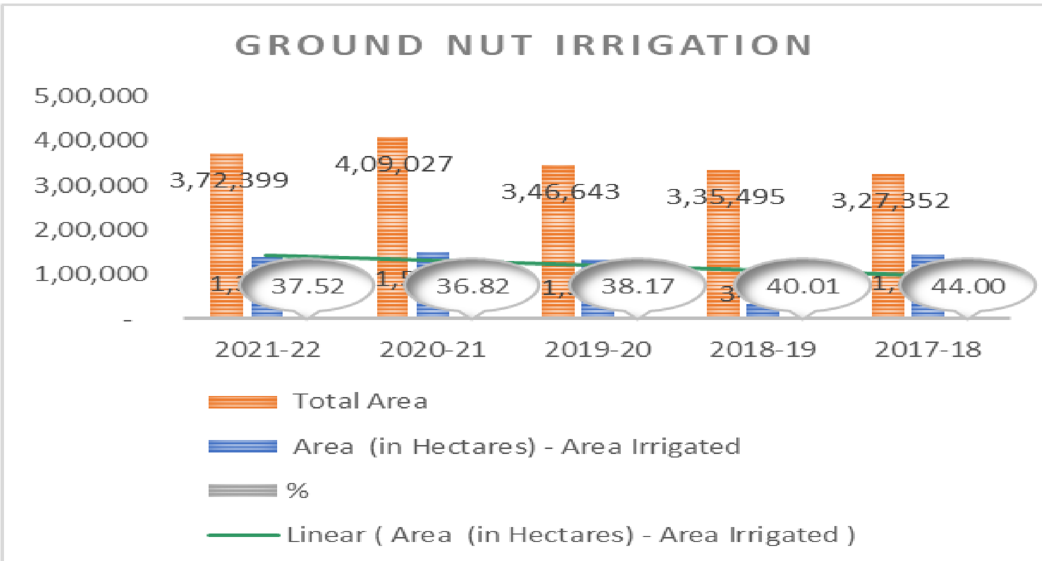

Figure 3.7.3.9.4.2 Ground Nut Irrigation

Implications:

- Expanding irrigation for drought-resistant crops can enhance productivity and farmer incomes.
- Promoting sustainable water management practices such as drip irrigation, efficient canal systems, and groundwater recharge is essential for long-term water security.

Recommendations for Improving Irrigation Efficiency in Tamil Nadu

- Use micro-irrigation systems to encourage drip and sprinkler irrigation for peanuts, cotton, and millets so improving water economy.
- By using check dams and rainwater collecting systems, one can aid to store water for irrigation during dry spells.

- Modernize Canal and Reservoir Systems: Improving irrigation infrastructure can help to reduce water losses and hence increase efficiency.
- Encouragement of climate-resilient rice, sugarcane, and millet varieties helps to lessen reliance on too much irrigation by means of drought-resistant crop variances.
- Help farmers with irrigation subsidies: By helping them to develop effective irrigation systems, you help to conserve water.

Sown and Irrigated Areas in Tamil Nadu (2016-22)

- Increase in Cultivated Land – Gross Area Sown grew from 5129 ('000 Hectares) in 2016-17 to 6348 ('000 Hectares) in 2021-22, showing agricultural expansion.

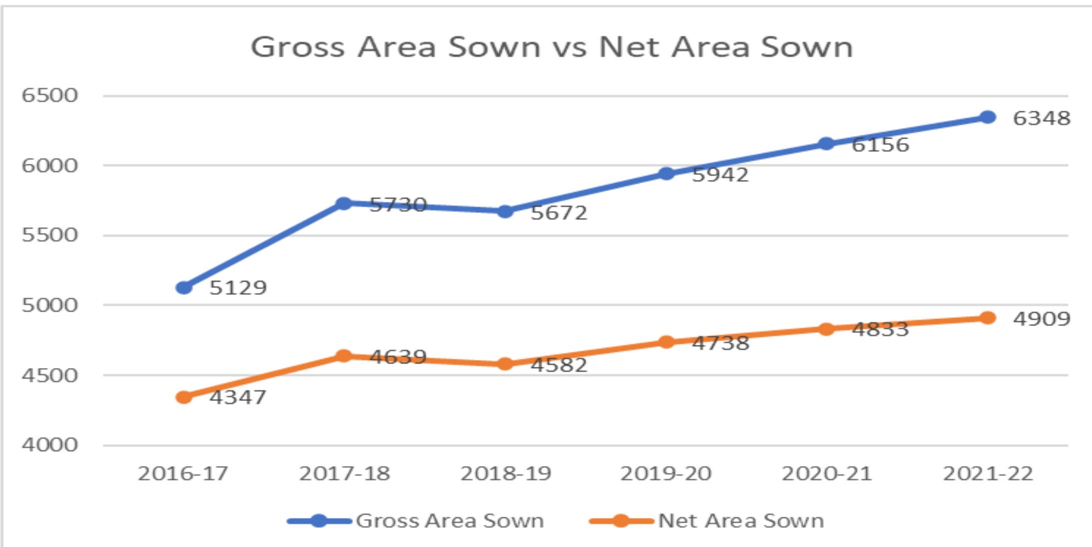

Figure 3.7.3.9.4.3 Gross Area Sown vs Net Area Sown

- Improved Irrigation Coverage – Net Area Irrigated increased from 2385 ('000 Hectares) to 2930 ('000 Hectares), indicating better water availability for crops.

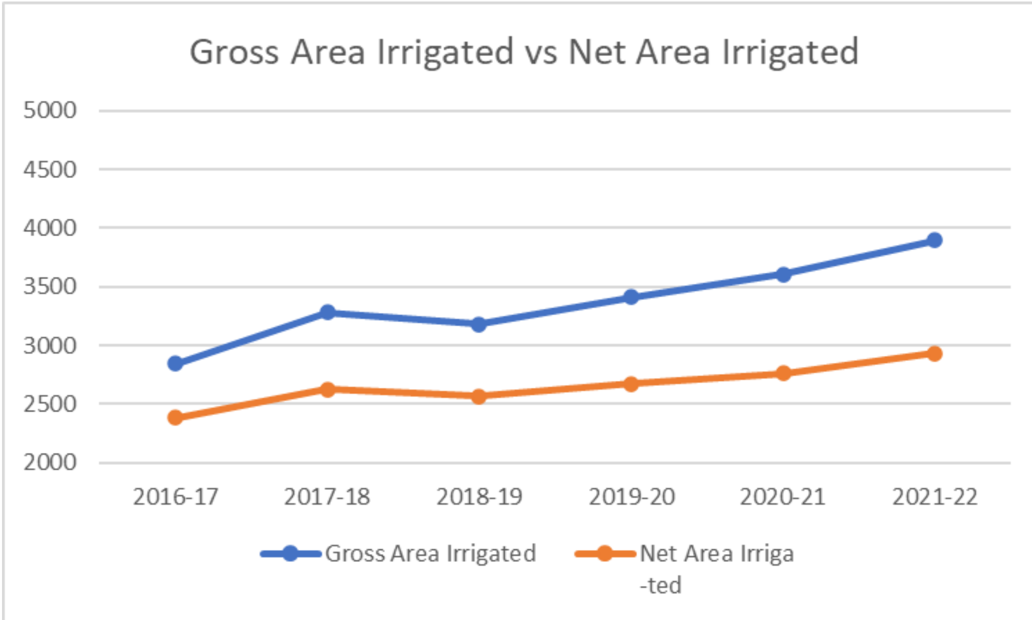

Figure 3.7.3.9.4.4 Gross Area Irrigated vs Net Area Irrigated

- Multi-Cropping Adoption – The gap between Gross and Net Area Sown widened, suggesting higher crop intensification and better land utilization.
- Higher Dependence on Irrigation – Irrigated land as a percentage of total cultivated land rose from 54.8% to 59.7%, reducing reliance on monsoon rains.
- Need for Sustainable Water Management – Despite improvements, nearly 40% of farmland is still rain-fed, requiring better irrigation expansion, groundwater recharge, and efficient water use.

Detailed Insights on Water Sources and Irrigation Trends in Tamil Nadu (2017-22)

- Canals and Open Wells are the Primary Irrigation Sources – Open wells remain the dominant irrigation source, supporting over 12.8 lakh hectares in 2021-22, while canals provide the second-largest irrigation coverage (6.83 lakh hectares in 2021-22).

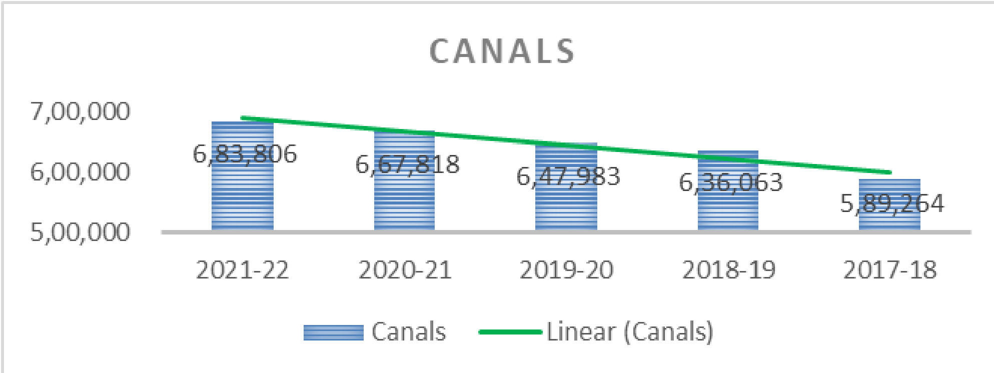

Figure 3.7.3.9.4.5 CANALS

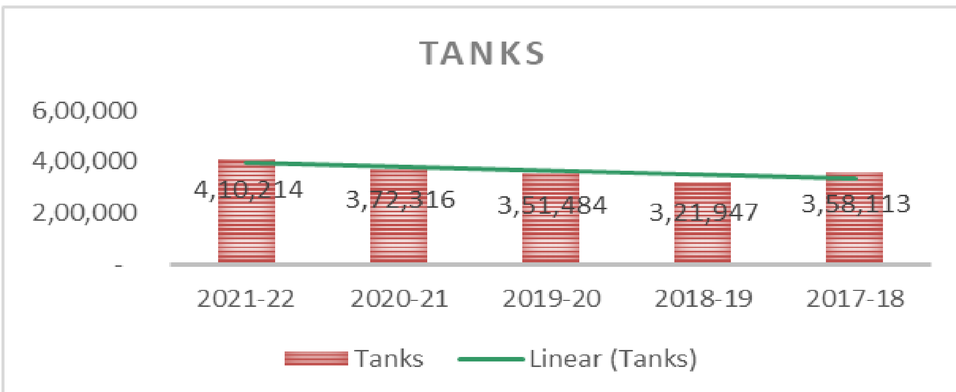

Figure 3.7.3.9.4.6 TANKS

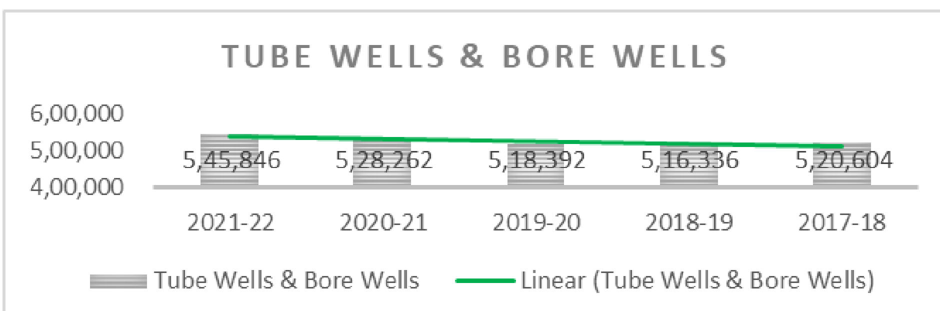

Figure 3.7.3.9.4.7 Tube Wells & Bore wells

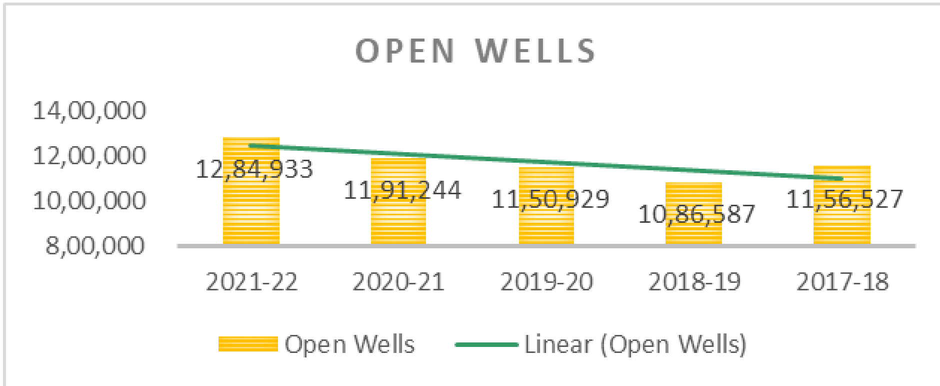

Figure 3.7.3.9.4.8 Open wells

- Gross and Net Area Irrigated Increased Steadily – Gross Area Irrigated rose from 32.77 lakh hectares in 2017-18 to 36.06 lakh hectares in 2020-21, ensuring better irrigation access for crops and improving agricultural productivity.

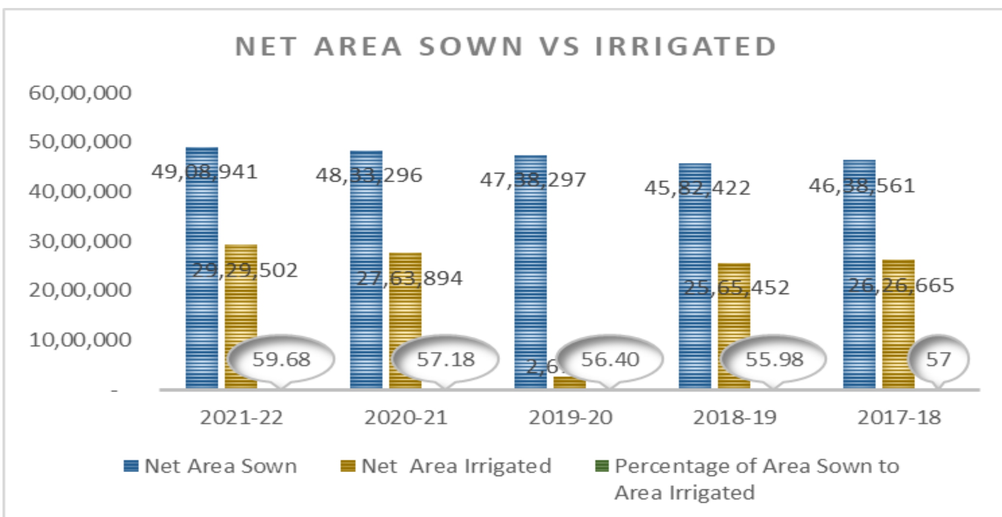

Figure 3.7.3.9.4.9 Net Area Sown vs Irrigated

- Percentage of Sown Area to Irrigated Area Improved – The percentage of irrigated area to gross sown area increased from 56.12% in 2018-19 to 62.44% in 2021-22, indicating better irrigation efficiency and improved water management practices.

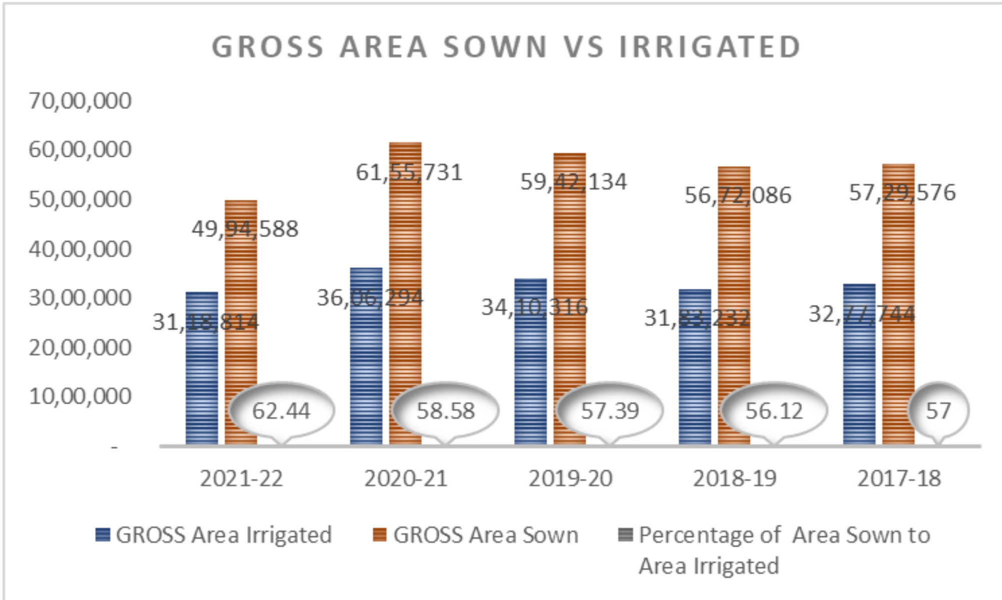

Figure 3.7.3.9.4.10 Gross Area Sown vs Irrigated

- Decrease in Tank Irrigation Amidst Increase in Canal Utilization: Canal irrigation expanded from 5.89 lakh hectares to 6.83 lakh hectares by 2021-22, indicating a greater dependence on canal-fed irrigation, while tank irrigation diminished from 3.58 lakh hectares in 2017-18 to 3.21 lakh hectares.
- Escalating Reliance on Tube Wells and Bore Wells — Tube wells and bore wells accounted for 5.45 lakh hectares in 2021-22, an increase from 5.16 lakh hectares in 2018-19, indicating heightened dependence on groundwater.
- Fluctuations in Net Irrigated Area – Net Area Irrigated peaked at 29.29 lakh hectares in 2021-22, rising from 25.65 lakh hectares in 2018-19, ensuring better irrigation coverage for more farmland.
- Declining Dependence on Other Water Sources – Other sources of irrigation (such as check dams and percolation ponds) declined significantly, from 4,519 hectares in 2018-19 to just 4,703 hectares in 2021-22, indicating a need for alternative water conservation measures.
- Growing Irrigation Infrastructure – The steady increase in irrigated areas indicates improvements in government-backed irrigation schemes, canal maintenance, and groundwater recharge programs.
- Variations in Net Irrigated Area — The Net Area Irrigated peaked at 29.29 lakh hectares in 2021-22, up from 25.65 lakh hectares in 2018-19, hence expanding irrigation coverage across a larger area of farmland.

- Emphasis on Water Efficiency in the Future—Enhancing drip irrigation, rainwater gathering, and optimizing canal networks would be essential for achieving long-term irrigation sustainability in Tamil Nadu.

Recommendations for Improving Water Conservation and Irrigation Efficiency in Tamil Nadu

Suppose Tamil Nadu wishes to guarantee long-term water security and sustainable irrigation. In that case, it has to concentrate on several distinct areas, including effective water usage, groundwater recharge, and sophisticated irrigation techniques. These are some key concepts for more effective water saving and control:

Extend Drip and Sprinkler Irrigation Systems

- Food outputs can rise while water use declines by up to 50% with drip irrigation.
- To get water to foods such vegetables, oilseeds, and pulses, sprinkler irrigation is a suitable method.
- Government financing and incentives ought to enable more people apply micro-irrigation.

Advocate surface water conservation and Rainwater Harvesting

- Tell farmers they should create farm ponds, percolation tanks, and check dams to preserve extra water for irrigation.
- Create temple tanks and ooranis (village ponds) stronger to enable rural regions retain more water. These are age-old water storage methods.
- Install rainwater collecting devices on rooftops in cities and outlying communities to increase groundwater levels.

Improve Reservoir and Canal Management

- Maintaining current canal systems will ensure that crops receive water effectively and that less water is wasted.
- By means of desiluting and sealing channels, more water may be moved across them and water leaks can be stopped.

- Set up automated water distribution systems in ponds to monitor and maximize the irrigation water output.

Strengthen Groundwater Recharge Projects

- Projects involving watershed management, borewell recharge systems, and percolation pits constitute advance artificial groundwater recharge techniques.
- Back community-based water management projects to help to lower overly high groundwater usage.
- More rigid guidelines for borewell drilling and encourage other water-saving techniques.

Diversification of Crops and Water-Conserving Cultivars

- Replace high-water-consuming crops like rice and sugarcane with drought-resistant, less water-intensive crops such millets (Cholam, Cumbu, ragi).
- Promote methods of multi-cropping and intercropping to maximize water use over crop cycles.
- Provide short-lived, high-yield crop varieties with low water requirements that will ensure significant output.

Implementation of Intelligent Irrigation Technologies

- Deploy IoT-driven smart irrigation systems that autonomously regulate water distribution according to soil moisture content.
- Utilize GIS and satellite-based water management systems to assess irrigation effectiveness and identify areas experiencing water stress.
- Educate farmers on precision agriculture methodologies that enhance water efficiency while increasing crop yield.

Increase Public Awareness and Farmer Training Programs

- Conduct awareness campaigns and training sessions on water conservation techniques, efficient irrigation, and best agricultural practices.
- Promote water budgeting and community-led irrigation management to encourage responsible water use.
- Encourage participatory groundwater monitoring where farmers actively measure and track water table levels in their region.

Strengthen Government Policies and Incentives for Water Conservation

- Expand subsidy programs provided by state and central governments for drip irrigation, farm ponds, and groundwater recharge structures.
- Implement water pricing mechanisms to encourage responsible usage and mitigate wastage.
- Encourage collaborations between public and private sectors to finance extensive irrigation and water conservation initiatives.

Optimize wastewater treatment and support irrigation reusing of it

- Promote the use of wastewater for agricultural irrigation and re-purposing to help to lessen reliance on freshwater supplies.
- Encourage irrigation of non-consumable crops using greywater—domestic wastewater.
- Create bio-filtration systems for irrigation applications to treat and reuse municipal and industrial wastewater.

Strategies for Climate-Resilient Water Management

- Enhance early warning systems to assist farmers in preparing for droughts and water scarcity.
- Integrate climate change adaptation strategies into water resource planning, including the promotion of rainfed agriculture in semi-arid areas.
- Create real-time water monitoring dashboards to monitor the state's reservoir levels, groundwater depletion, and irrigation efficiency.

Analysis of Reservoir Water Management in Tamil Nadu (2017-2022)

The examination of significant reservoirs in Tamil Nadu from 2017 to 2022 offers critical insights regarding water storage, usage, and distribution efficiency. The following points delineate essential observations and recommendations intended to enhance the management of reservoir water resources.

Principal Insights

- Varying Water Levels Over Time
    - Mettur Dam, the largest reservoir in Tamil Nadu, exhibited fluctuating water releases, with 237.33 TMC in 2021-22 and just 195.66 TMC in 2020-21.

    - Other reservoirs, such as Vaigai, Papanasam, and Bhavanisagar, had analogous oscillations, signifying diverse monsoon patterns influencing storage levels.

- Reservoirs Running Under Their Designed Capacity
    - Many reservoirs fell short of their Full Reservoir Level (FRL), either from regulated outflow brought on by changing weather conditions or from insufficient rainfall accumulation.
    - Reaching in the 2020–21 season just 41.77 meters, much below its Full Reservoir Level (FRL) of 43.29 meters.
- Sudden Decreases in Minimum Water Levels
    - Numerous reservoirs experienced substantial reductions in minimum water levels, adversely affecting downstream irrigation and potable water availability.
    - For instance, the Poondi reservoir diminished to only 5.77 meters in 2021-22, limiting its utilization during the arid season.
    - Significant Reliance on a Limited Number of Principal Reservoirs.
    - Mettur Dam constitutes a substantial portion of Tamil Nadu's agricultural water, rendering water security susceptible to variations.

3.8 Research Design Limitations

The research design relies solely on data from government websites and statistical records provided by the Tamil Nadu government.

Inconsistent and Incomplete Data

- Rainfall data varies across sources (IMD, NASA, local weather stations), leading to inconsistencies.
- Lack of granular, district-level data makes it challenging to capture local climate variations.

Challenges in Predicting Rainfall Variability

- Existing climate models struggle to accurately forecast monsoon fluctuations, El Niño, and sudden weather changes.
- Short-term studies may not reveal long-term climate change impacts, while long-term data may become outdated.

Limited Applicability Across Regions

- Findings from one region may not apply to another due to differences in soil types, irrigation facilities, and cropping patterns.
- Flood management strategies for Assam may not suit Rajasthan's drought conditions.

Slow Policy Implementation & Farmer Awareness

- Research findings take too long to translate into government policies and field-level action.
- Many farmers lack access to real-time weather alerts or understanding of climate-smart techniques.

Technological and Infrastructure Gaps

- AI-based rainfall prediction models are improving but unreliable for short-term monsoon forecasts.
- Low adoption of smart irrigation, IoT-based monitoring, and precision farming due to high costs and limited rural infrastructure.

3.9 Conclusion

The temperature trends from 2020 to 2024 suggest gradual climate warming in Tamil Nadu, affecting all seasons. This highlights the need for adaptive strategies, including improved water management, urban greening, and heatwave preparedness.

The rainfall pattern from 2017 to 2022 shows that monsoons have been strengthening, winter rainfall is becoming more unpredictable, and pre-monsoon rains are slightly increasing. These trends suggest possible climate shifts impacting agriculture, water availability, and overall weather conditions.

Tamil Nadu has made significant progress in crop production, increasing cultivated and irrigated areas and ensuring stable food security. However, irrigation coverage and water availability fluctuations highlight the need for sustainable water management. Reservoirs play a critical role, but inefficient storage, irregular water releases, and over-reliance on a few sources create vulnerabilities. Expanding rainwater harvesting, modernizing irrigation infrastructure, and improving groundwater recharge can enhance water security. Adopting smart water management, crop diversification, and efficient irrigation techniques will ensure long-term agricultural sustainability in Tamil Nadu.

CHAPTER IV:

RESULTS

4.1 How does climate and Rainfall impact agriculture?

The temperature from 2020 to 2024 clearly indicates gradual climate warming in Tamil Nadu, affecting all seasons. This temperature increase tells us the need for adaptive strategies, including improved water management, urban greening, and heatwave preparedness.

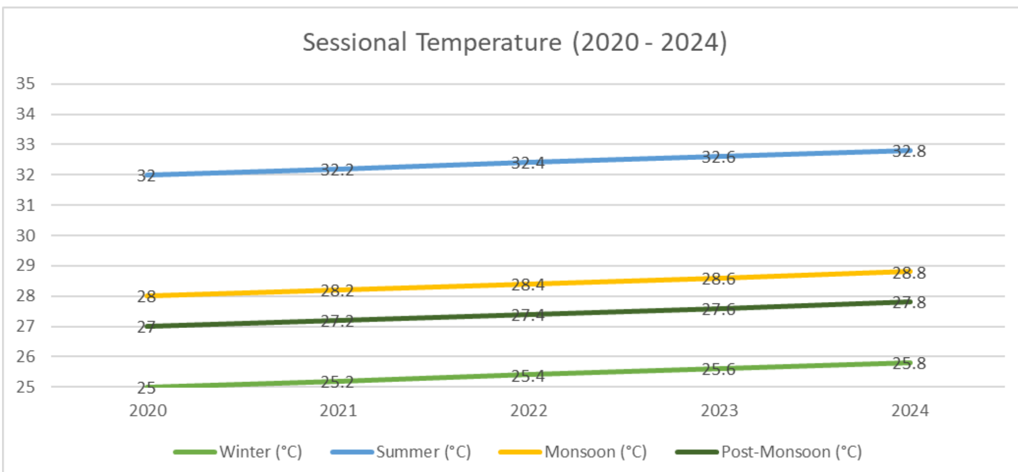

Figure 4.1 Sessional Temperature

Projected Temperature Trends in Tamil Nadu (2025-2029) – Forecast Overview

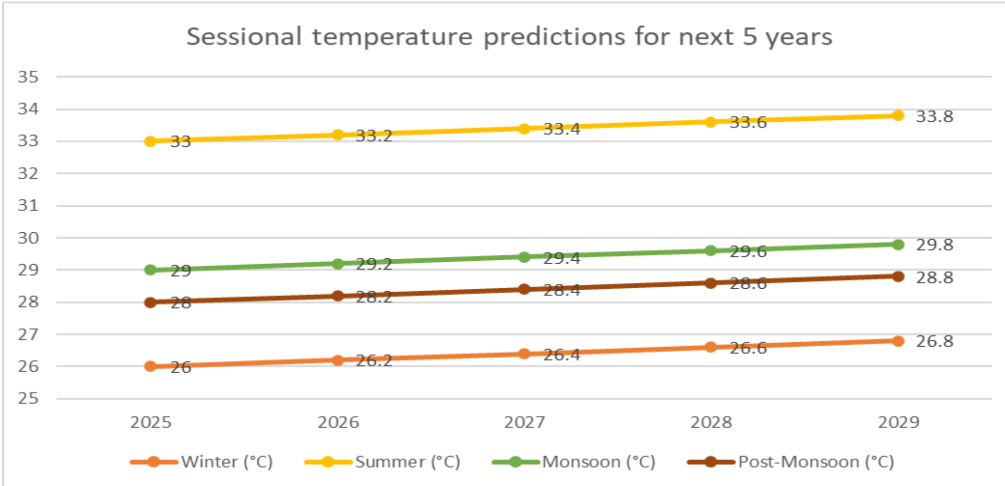

Figure 4.1.1 Sessional Projected Temperature

Using a linear regression model, temperature projections for 2025-2029 indicate a continued upward trend in average seasonal temperatures. Key insights include:

Pressing Climate Warming Across all Seasons

- Warmer Winters Ahead: By 2029, winter temperatures are expected to reach 26.4°C, indicating a trend towards increasingly mild winters.
- Summers will get hotter: In the future, summer temps will rise above 33.4°C, which will make high heat events more likely.
- Monsoon temperatures are rising: the monsoon season is projected to reach about 294°C, keeping the warming trend steady.

How Rising Temperatures Impact Our Lives

- More Intense Heat Waves: Summers are becoming hotter, increasing the chances of prolonged heat waves. These extreme conditions can affect health, strain water supplies, and put pressure on energy consumption, making day-to-day life harder.
- Unpredictable Rainfall: Increased temperatures in the monsoon season can disrupt rainfall patterns, resulting in intense storms in certain areas while causing reduced

precipitation in others. This could increase the chances of floods or droughts, making farming and water supply more uncertain.

Extended Warm Periods: After the monsoon, temperatures might stay elevated for an extended duration, influencing crop development, soil moisture, and humidity. This change may lead to a decline in agricultural output and disrupt ecosystems, affecting farmers and biodiversity alike.

Prolonged Effects of Climate Change

- Increased Drought Likelihood: Elevated evaporation rates may lead to more regular and intense drought conditions.
- Heightened Severe Weather: Cyclones and intense rainfall occurrences could grow more extreme as temperatures rise.
- Agricultural Challenges: Changing seasonal patterns could put pressure on crops, impacting yields and farming cycles.
- The observed trends underscore the importance of implementing proactive climate adaptation strategies to address the enduring impacts of increasing temperatures in Tamil Nadu.

Rainfall Data (2017-2022)

- Comprehensive research of rainfall, its impact on various crops, and approaches of managing unusual precipitation may assist one to the following key conclusions:

Variations in the pattern of precipitation in recent years

- Especially in 2020-21 (1232.8 mm) and 2021-22 (1131 mm), where recorded large excess rainfall of +26.7% and +23%, respectively, total rainfall has been growing.
- The rainfall of the rising North East and South West Monsoons suggests a recent monsoonal season pattern with increasing severity.
    - This points to changed climate patterns, most likely derived from global weather occurrences like La Niña, a big climatic occurrence drastically

affecting world temperature trends. Extreme rain and long-lasting drenches result from La Niña weather patterns upsetting ecosystems, agriculture, and daily life.

- Results: increased groundwater replenishment and more water available for agriculture.

Large Variability in Rainfall Across Seasons

- The South West Monsoon (June-Sept) fluctuated, dropping in 2018-19 (330.8 mm) but peaking in 2021-22 (477.7 mm).
- The North East Monsoon (Oct-Dec) showed unpredictable trends, with a peak in 2020-21 (512.2 mm) and a drop in 2021-22 (444.8 mm).
- Except for 2020-21, which had very high rainfall (154.6 mm), winter rainfall (Jan-Mar) was mostly modest.
- Rainfall during the hot weather season (Apr–May) has progressively risen; its high will be in 2021–22 (166.5 mm).
- The North East Monsoon helps create stable post-monsoon crops (rabi crops like wheat and pulses).
- Late-season crops like vegetables, mustard, and wheat may suffer from erratic winter precipitation.
- Results

Stable post-monsoon crops—rabi crops like wheat and pulses—are benefited by the North East Monsoon. Unstable winter rains might damage late-season vegetables, mustard, and wheat.

Drought and Flood Years Identified

Drought Years (Below-Normal Rainfall)

- 2018-19 (-37.4%) was a drought year, receiving significantly less rainfall (698.8 mm), far below the standard (959.9 mm).
- Reduced winter and pre-monsoon rain in 2019–20 affected soil moisture and pre-sowing operations.
- **Drought effects include**

- reduced agricultural output (pulses, rice, maize)
- Higher farmers' irrigation expenses
- Low supply-based higher food costs.

Flood Years (Excess Rainfall)

- 2020-21 (+26.7%) and 2021-22 (+23%) were excessive rainfall years.
- High monsoon rainfall in 2020-21 (1232.8 mm) led to waterlogging, floods, and crop damage.

Flood Years—Excess Rainfall

- Years with too high rainfall were 2020-21 (+26.7%) and 2021-22 (+23%).
- 2020–21's high monsoon rainfall—1232.8 mm—caused floods, waterlogging, and agricultural devastation.

Consequences of too much rain:

- Root rot in crops including pulses and oilseeds; flooding in paddy fields.
- Wheat delayed harvesting alters grain quality.
- Greater spread of fungal illnesses under humid environments.

Risks Specific to Crops Discussed

- Rice (Paddy) benefited from strong monsoon rains, but too much water brought fungal illnesses and lodging problems.
- Various winter rains caused by which wheat crops experienced degraded grain formation and quality.
- Excess rain greatly damaged pulses (lentils, chickpeas), which produced poor pod development and fungal rots.
- Low-rainfall years saw strong performance from millets (bajra, ragi, sorghum), which makes them a viable option for areas vulnerable to drought.
- Groundnut and mustard oilsseeds suffered under severe rain, therefore lowering their oil content and seed viability.

Solution:

Farmers should use smart irrigation and drainage systems and change to climate-resilient cultivars.

4.2 How to increase crop production?

Trends and insights on water irrigation and crop production between 2017 and 2022

- **Trends in Crop Production and Irrigation**
  - Increasing both gross and net area sown Indicating agricultural growth, the Gross Area Sown rose from 5730 ('000 Hec.) in 2017-18 to 6348 ('000 Hec-) in 2021-22.

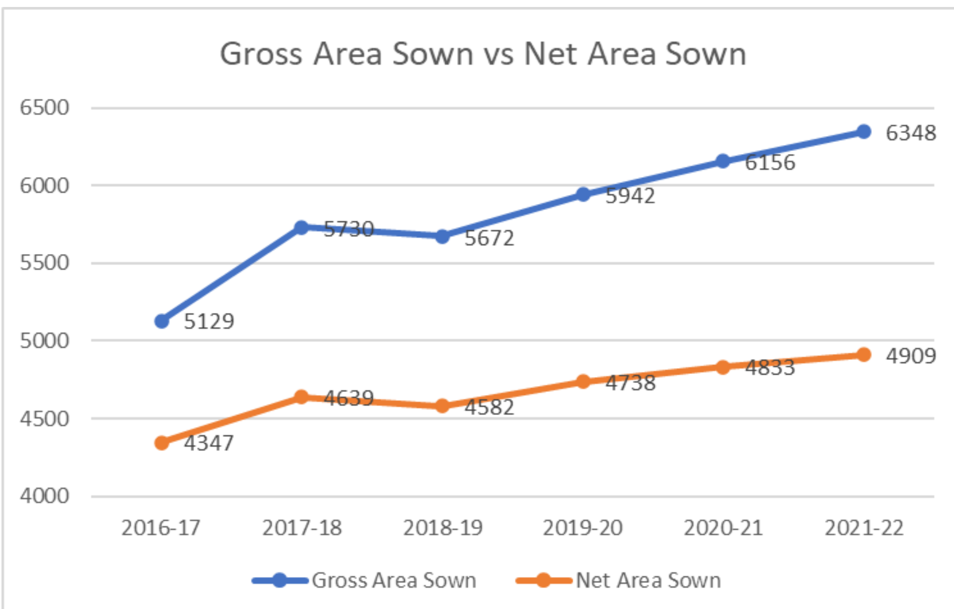

Figure 4.2.1 Gross Area Sown vs Net Area Sown

  - Enhanced Irrigation Coverage: Gross Area Irrigated increased from 3278 ('000 Hec.) to 3894 ('000 Hec.), therefore guaranteeing improved water availability for crops.

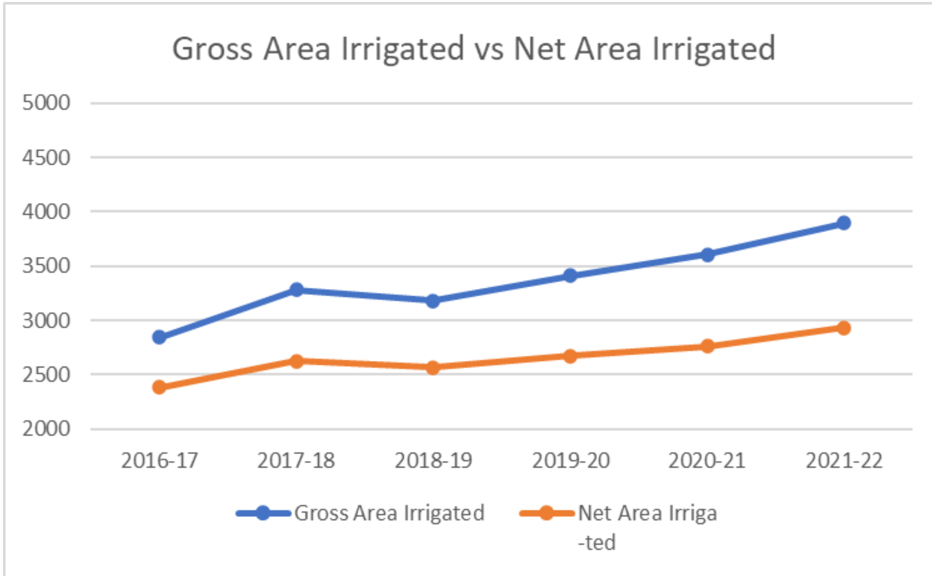

Figure 4.2.1.1 Gross Area Irrigated vs Net Area Irrigated

- Narrowing Gap Between Sown and Irrigated Area: The pattern demonstrates consistent improvement in irrigation infrastructure, hence lowering dependence on monsoon rain.
- Faster Growth in Net Area Irrigated – From 2627 (‘000 Hec%) in 2017-18 to 2930 (‘000 Hec%) in 2021-22, therefore guaranteeing better water security for farmed areas.

Trends in reservoir water release

- Changing Reservoir Water Releases: Affecting irrigation, Mettur saw a rapid increase in water release in 2018-19 (359.6 TMC) but a drop to 195.6 TMC in 2020-21.
- The significant oscillations in the Bhavanisagar and Papanasam Reservoirs revealed uneven water management or rainfall variances.

- Stable Water Releases from Vaigai Reservoir: Vaigai maintained a constant release despite reduced volume, therefore guaranteeing regular irrigation for the command area.

Important Learning Points

- More irrigation coverage helps to justify agricultural development.
- Reservoirs reveal inconsistent water release patterns, therefore showing ineffective water management.
- Further increasing agricultural production and water security include reservoir storage enhancement, irrigation technique optimization, and rainwater collecting improvement.

Strategies for increased crop production

Tamil Nadu may increase agricultural output by adopting the following plans: crop production; irrigation coverage; water discharge from reservoirs;

Enhancement in Irrigation Efficiency and Water Management

- Promoting micro-irrigation systems may help to lower water waste and guarantee improved crop hydration; using predictive release models will help to maximize water availability for farmers by means of reservoir water release.
- Build agricultural ponds, percolation tanks, and check dams to increase groundwater recharge and lower reliance on irregular monsoons, hence strengthening Rainwater Harvesting

Boost Rotation of Crop and Area Under Management

- Promote intercropping and multi-cropping as growing many crops in the same season increases soil fertility and stability of production.

- Make use of Fallow Lands: By means of organic composting and land reclamation, transform unproductive land into profitable farmland, therefore increasing the total agricultural production.

Add climate-resilient, high-yield crop varieties

- Encourage Short-Duration and Drought-Tolerant Crops: High-yield, climate-resilient cultivars help to lower crop loss brought on by erratic rainfall patterns.
- Promote pulses and millets in areas with little water; cholam, cumbu, and ragi may survive in dry circumstances, therefore guaranteeing sustainable agriculture.

Improve crop nutrition and soil fertility

- Apply organic farming and green manuring—using nitrogen-fixing crops, compost, and natural fertilizers enhances long-term output and soil condition.
- Promote precision farming by means of GPS-based soil mapping and artificial intelligence-driven nutrient analysis, thus enabling effective application of fertilizers, so lowering waste and raising output.

Strengthen Post-Harvest Infrastructure and Market Access

- Develop cold storage and warehouse facilities to reduce post-harvest losses by means of appropriate storage enhances marketable product and farmer profitability.
- Using eNAM (National Agricultural Market) and Farmer Producer Organizations (FPOs guarantees improved price realization and strengthens market linkages).

Advance Digital Farm Technology Adoption

- Use smart irrigation systems; weather predictions and artificial intelligence-based moisture sensors help to maximize water use.
  • Teach Farmers Advanced Techniques: Giving farmers digital tools and mobile-based consulting services would enable them to decide on irrigation and crops better.

Strategies of crop production enhancement

Tamil Nadu may increase agricultural output by adopting the following plans: crop production; irrigation coverage; water discharge from reservoirs;

Enhancement in Irrigation Efficiency and Water Management

- Encouragement of micro-irrigation systems helps to lower water waste and guarantee improved crop hydration by means of expandable drip and sprinkler irrigation.
- Using predictive release models and real-time water monitoring will help to maximize reservoir water availability for farmers.
- Build agricultural ponds, percolation tanks, and check dams to increase groundwater recharge and lower reliance on irregular monsoons, hence strengthening Rainwater Harvesting.

Boost Rotation of Crop and Area Under Management

- Promote intercropping and multi-cropping as growing many crops in the same season increases soil fertility and stability of production.
- Make use of Fallow Lands: By means of organic composting and land reclamation, transform unproductive land into profitable farmland, therefore increasing the total agricultural production.

Add climate-resilient, high-yield crop varieties.

- Encourage Short-Duration and Drought-Tolerant Crops: High-yield, climate-resilient cultivars help to lower crop loss brought on by erratic rainfall patterns.
- Promote pulses and millets in areas with little water; cholam, cumbu, and ragi may survive in dry circumstances, therefore guaranteeing sustainable agriculture.

Improvecrop nutrition and soil fertility

- Apply organic farming and green manuring—using nitrogen-fixing crops, compost, and natural fertilizers enhances long-term output and soil condition.
- Promote precision farming by means of GPS-based soil mapping and artificial intelligence-driven nutrient analysis, thus enabling effective application of fertilizers, so lowering waste and raising output.

Consolidate Market Access and Post-harvest Infrastructure

- Create cold storage and warehouse facilities to lower post-harvest losses by means of appropriate storage enhances marketable output and farmer income.
- Using eNAM (National Agricultural Market) and Farmer Producer Organizations (FPOs guarantees higher price realization by improving market linkages).

Advance Digital Farm Technology Adoption

- Use smart irrigation systems; weather predictions and artificial intelligence-based moisture sensors help to maximize water use.
- Teach Farmers Advanced Techniques: Giving farmers digital tools and mobile-based consulting services would enable them to decide on irrigation and crops better.

Comprehensive Agricultural Specific Plan to Boost Tamil Nadu's Production

Tamil Nadu has to implement a crop-specific plan emphasizing on climatic adaptation, irrigation efficiency, soil fertility, pest control, and market access if it is to increase agricultural output and sustainability. Here is a comprehensive schedule for the state's main farmed crops.

Rice Paddy Production Strategy

- Conventional flooding techniques cause a high water demand.
- Attacks from pests and diseases include blast disease, brown planthopper, stem borer.

- Low yield potential brought on by soil deterioration and incorrect fertilizer application.

Strategy to Reduce Production: Effective Water Resource Management

- Apply System of Rice Intensification (SRI):
  - Boosts production while cutting water usage by thirty to forty percent.
    - strengthens roots and increases aeration in soil.

• Encourage Alternate Wetting and Drying (AWD) Method: o 30% savings irrigation water while preserving yield.

• Extend drip and sprinkler irrigation in semi-dry rice fields.

High-Yield and Climate-Resilient Seed Varieties

- Use CO 51, ADT 47, CR Dhan 310—short-lived, drought-resistant.
- Add hybrid types to raise per hectare production.

Management of Pests and Diseases

- For environmentally friendly pest management use bio-pesticides, Pheromone traps, and Neem oil.
- Treat seed against fungal infections using Trichoderma biofungicide.

Balanced Fertilizer and Nutrient Use

- Soil health cards will direct tailored fertilizer application.
- Rich soil organically using Green Manuring (Sunhemp, Dhaincha).

Modern rice mills and cold storage facilities should be included into the market access and post-harvest management

- Establish Farmer Producer Organizations (FPOs) to support direct market selling. Millets (Cholam, Cumbu, Ragi); little irrigation help.
- Still in use are classic low-yielding cultivars.
- Comparatively to rice and wheat, weak market demand.

Reducing Strategy to Boost Manufacturing

Support drought-resistant variations

- Choose high-yielding varieties:
    - Cholam (COH 4, K 8); o Cumbu (CO 9, Hybrid BHB 146); o Ragi (Paiyur 2, GPU 28).
- Water-Efficient Agricultural Methods
- Use mulching and thorough plowing on your Dryland Farm.
- Increase water economy by use of sprinkler irrigation.

Raising Farmer Knowledge and Market Demand

- Start dietary initiatives to highlight millets as good substitutes.
- Promote processed millet product exports (flakes from millet, Ragi flour).
- Enhance Value Addition and Processing
- Establish millet-based food processing mills.
- Promote manufacture of ready-to-eat millet goods.

Black Gram, Green Gram, Red Gram—pulses

- Low production brought on by poor seed quality.
- Wilt, Pod Borer's pest and disease sensitivity.
- Significant post-harvest storage losses.

Strategies for Reducing Plan to Boost Production Seed and Pest Management

- Use certified seeds including: Black Gram (VBN 6, VBN 8); Green Gram (CO 6, VBN 3); Red Gram (Co 7, BDN 2).
- Treat seeds with Rhizobium culture and Trichoderma bio fungicide.

Good Intercropping and Soil Enhancement

- Intercrop pulses of paddy or millets to fix nitrogen in soil and boost output.
- Increasing soil fertility using farmyard manure and bio-fertilizers

Market linkages and processing

- Build storage and pulse milling systems to minimize losses.
- Support direct sales from farmers to consumers and bulk exporters.

Saccharine

- Water-intensive agricultural crop.
- Constant monocropping is reducing soil fertility.
- Strong bug infestations (early shoot borer, White grub).

Reducing Strategy to Boost Manufacturing

Strategies for Water Saving

- Increase Drip Irrigation to save 50% of water use.
- Advise trash mulching to help preserve moisture.

Introduce varieties with high yield.

- For enhanced sugar recovery use variants such Co-86032 and Co-11015.

integrated pest and nutrient control

- Use organic fertilizer made from vermi-compost and pressmud—sugar industry waste.
- Control pests using biological control agents—trichogramma and metarhizium fungus.

Strengthen logistic and processing systems

- Modernize sugar mills with highly efficient crushing systems.
- Create direct ethanol generating facilities in order to maximize profits.

Groundnut, Gingelly; oilseeds; rain-dependent farming producing uneven outputs.

• Common low-oil versions already in use.

- Reducing Strategy to Boost Output
- Promote Variations in High-Oil Content
- Groundnut CO-2, TMV-7, VRI-2; Gingelly VRI-2, TMV-3

Soil Enhancement and Water Conservation

• For improved moisture retention, use Broad Bed Furrow (BBF) technique.

• Increasing soil aeration with gypsum application

Processing and Export Concentration

- Establish cold-press oil extraction plants to produce superior food oils.

Promote exports of premium organic oils.

- Wool
- Pest resistance and bollworm infestations.

- Low fiber quality brought on by inadequate post-harvest processing.
    - Strategy for Reducing Conflict
    - Choose Varieties Resistant to Bollworms
- Support RCH-659, Bollgard II Bt Cotton varieties.

Fertilisation and pest control

- Apply bio-pesticides and neem oil sprays.
- Apply micronutrient-based balanced NPK fertilizers.

Create cotton processing facilities.

- Change the ginning and fiber grading systems to raise the cotton quality.

- Encourage tie-ups between the textile sector to maximize prices.

Horticulture (vegetables and fruits)

- Significant losses just after harvest.
- Bad cold storage facilities

Reducing Strategy to Boost Output

Practice Precision Agriculture

• Support greenhouse, polyhouse, and hydroponics growing.

• Promote organic vegetable growing for markets of luxury.

Build Cold Chain Infrastructure

- Extend cold storage facilities for perishable goods.
- Promote direct farm-to---retail relationships (eNAM, private stores).

4.3 Summary of Findings

What's Happening with Farming, Water, and Climate?

Farmers are seeing a shift in how water is available.

- There's more irrigation now than before, but ask any farmer, and they'll tell you—water doesn't always show up when they need it most. Some areas get too much, others barely any. It's a frustrating cycle.

Reservoirs don't always release water when needed.

- You ever notice how some fields are flooded while others are bone dry? That's because **water from reservoirs isn't managed well.** If it were, farmers wouldn't be left guessing when they'd get water.

Rainwater is slipping through our fingers.

- Every year, so much rainwater just **washes away.** If more of it was collected and stored, it could be a game-changer, especially during the dry months.

The heat? Yeah, it's getting worse.

- If you feel like summers are getting hotter—you're not wrong. Winters are barely hanging on, and even monsoon rains **feel different** than they used to.

Looking ahead? It's only getting hotter.

- By 2029, winters could **feel like spring**, and summers? Well, they might be downright unbearable. Farmers will need to **change how they plant and water their crops** just to keep up.

More extreme weather, more problems.

- **One year? Floods.** The next? **Drought.** It's hard to predict, and that's bad news for farmers who rely on stable weather.

Rainfall has been a wild ride these past few years.

- **2020-21 & 2021-22? Flooding.** Too much rain wrecked some farms.
- **2018-19? Drought.** Crops withered, and farmers suffered.

Some crops are tougher than others.

- **Rice:** Loves rain, but too much = fungal problems.
- **Wheat:** Needs steady winter rain, but lately? That's hit-or-miss.
- **Pulses:** Heavy rain? Bad news.
- **Millets:** The **survivors**—they do well in dry years.
- **Oilseeds:** Too much rain ruins their quality.

What's the best way forward?

- Farmers are already adapting by using **drought-resistant seeds** and **smarter irrigation** methods. But that's just the start.

Can we still grow enough food? Yes—but we need to be smart about it.

- **Water efficiency matters.** More drip irrigation, better rainwater storage.

- **Healthy soil = strong crops.** Less chemical dependence, more organic practices.
- **Markets need fixing.** Better storage, fewer food losses, stronger farmer networks.
- **Technology can help.** AI tools are helping farmers predict weather patterns and plan ahead.

Different crops need different approaches.

- **Rice?** Smarter planting techniques like **SRI (System of Rice Intensification)** can boost yield.
- **Millets?** More farmers should grow them—**they handle tough weather.**
- **Pulses?** Bio-fertilizers and mixed cropping keep them healthier.
- **Sugarcane?** Drip irrigation saves **tons of water.**
- **Oilseeds?** Choosing **high-oil content varieties** is the way to go.
- **Cotton?** Bt Cotton varieties **reduce pest damage.**
- **Fruits & Veggies?** Hydroponics and better storage **can reduce waste.**

What's next?

- Farmers can't tackle this alone. Scientists, policymakers, and local communities **must work together** to ensure stable food production.
- Even small changes—**better water use, smarter seeds, improved storage—can have a big impact.**

4.4 Conclusion

If you’ve been in Tamil Nadu lately, you’ve probably noticed—it’s getting hotter. Summers feel brutal, and winters? They don’t even feel like real winters anymore. Farmers are feeling the impact more than anyone. They rely on predictable weather, but these days, nothing is certain. One year, the fields are flooded, and the next, the soil is cracked and dry.

Rainfall isn’t what it used to be either. Some years, it pours non-stop, drowning crops and leaving farms underwater. That’s exactly what happened in 2020 and 2021—too much rain, too fast. But in 2018 and 2019, it was the opposite. **Hardly any rain fell, and farmers were left watching their crops wither away.** That kind of unpredictability is making farming more of a gamble than a livelihood.

It’s not just the rain, though. Cyclones, floods, and heatwaves are hitting harder and more often. The weather used to follow a pattern, but now it feels like chaos. This isn’t just a bad season—it’s becoming the new normal. If things keep going this way, farmers will need to rethink how they grow crops, manage water, and deal with extreme weather.

Take rice, for example. It thrives in wet conditions, but when there’s too much water, diseases spread fast, destroying yields. Pulses and oilseeds face the opposite problem—**too much rain ruins them, but so does too little.** That’s why many farmers are now looking for **climate-resilient seeds**—ones that can handle extreme shifts in weather.

But good seeds aren’t enough if there’s no water when farmers need it. **Drip irrigation, better reservoir planning, and smarter rainwater harvesting** could help ensure water isn’t wasted. Some farms have already started using **AI-powered moisture sensors** to track soil conditions and prevent overwatering. It’s small steps like these that could make a big difference.

Better farming techniques will help, but farmers also need better market access. **Cold storage, warehouses, and digital selling platforms** (like eNAM and FPOs) could prevent crops from going to waste and help farmers get fair prices.

At this point, waiting isn't an option. Tamil Nadu needs to **adapt now**—not next year, not in five years. That means shifting to **drought-resistant crops, using water wisely, and rethinking how farming is done.** Change is coming, whether we like it or not. The question is: **Will we be ready for it?**

CHAPTER V:

DISCUSSION

5.1 Discussion of Results

- Rising temperatures will affect agricultural cycles and yields, hence heat-resistant crop types will be developed.
- Trends in irregular rainfall need for better water storage and conservation methods.
- The increase of floods and drenches demands strong agricultural practices and infrastructural improvements.
- Crop selection and rotation strategies ought to prioritize drought-resistant and climate-adaptive varieties.
- Enhancing irrigation efficiency, particularly through the growth of drip and sprinkler systems, is crucial.
- Enhancements in storage, cold chain systems, and access to markets can help address post-harvest challenges.
- Innovative solutions like AI-powered weather forecasting, intelligent irrigation systems, and precision agriculture can boost productivity.
- Policies from the government ought to back climate-smart agriculture by providing incentives and subsidies for farming practices that adapt to changing conditions.

5.2 Discussion of How does climate and Rainfall impact agriculture?

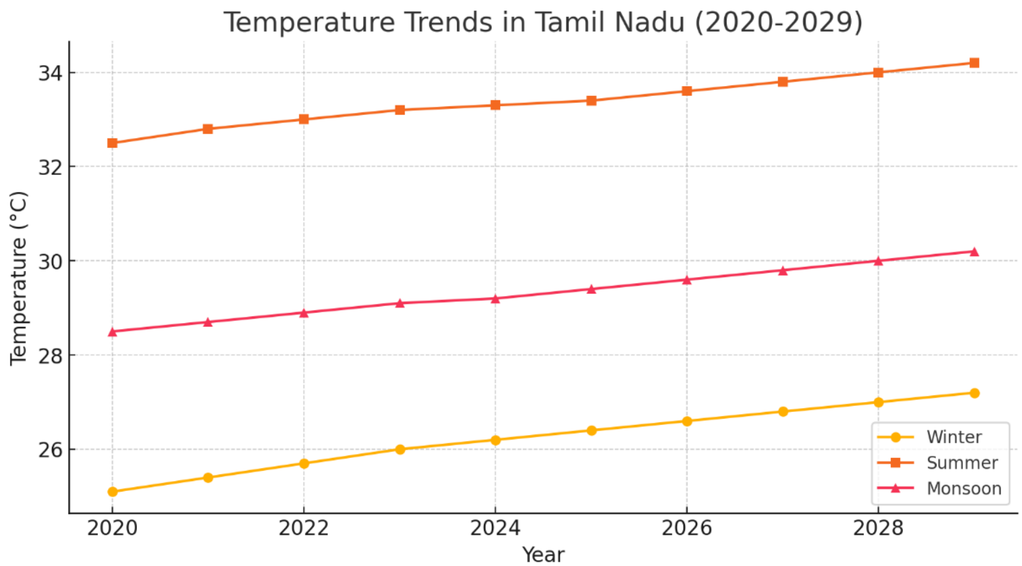

Figure 5.2 Tamil Nadu's 2020–2029 temperature trends

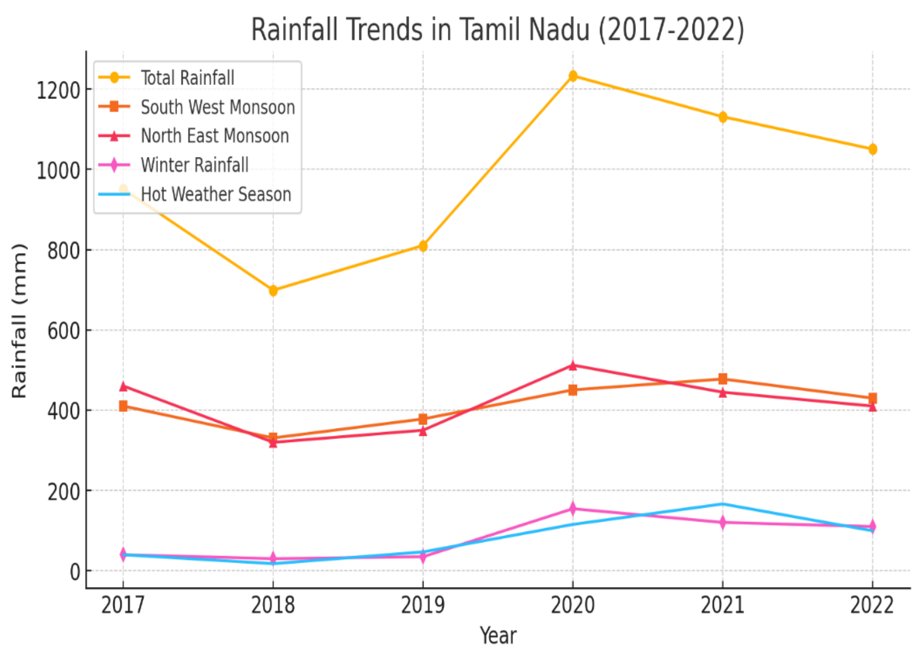

Figure 5.2.1 Tamil Nadu's rainfall trends, 2017–2022

The graphic representations show Tamil Nadu's temperature and rainfall trends:

2020–2029 Temperature Trends

- A slow increase in temperature all through the seasons.
- Winters heating up to anticipated 27.2°C by 2029.
- Summers become hotter, maybe up to 34.2°C, which increases the likelihood of major heat waves.
- Rising monsoon temperatures might affect patterns of rainfall.

Rainfall Trends 2017–2022:

- Rising rainfall in recent times; peak amounts will be seen in 2020-21 and 2021-22.
- Monsoons in the North East and the South West differ in their fluctuating patterns.
- Emphasizing great weather variation, drought in 2018-19 and floods in 2020-21
- Effect on agriculture; millets hold resilience in dry years whereas crops like pulses and oilseeds suffer from too much rain.

These revelations underline the importance of flexible plans including effective water management to address droughs and surplus precipitation.

- Urban greenering to fight growing heat.
- Plans for heatwave preparation help to safeguard sensitive groups.
- Sustainable agriculture's climate-resilient crop choices.

5.3 Discussion of How to increase crop production?

Trends and Insight: Water Irrigation and Crop Production (2017–22)

Irrigation and Crop Production Trends

- Gross Area Sown rose from 5730 ('000 Hec.) in 2017-18 to 6348 ('000 Hec-) in 2021-22.
- Gross Area Irrigation went from 3278 ('000 Hec.) to 3894 ('000 Hec%), thereby lowering monsoon reliance.
- Steady advances in irrigation infrastructure are narrowing the distance between sowed and irrigated sections.
- Growth in Net Irrigated Area: To guarantee more water security, the Net Irrigated Area grew from 2627 ('000 Hec.) to 2930 ('000 Hec.).

Trend in Reservoir Water Release

Fluctuating Water Releases:

- Mettur Reservoir: Affecting irrigation, increasing release in 2018-19 (359.6 TMC) but declining to 195.6 TMC in 2020-21.
- High swings in the Bhavansagar and Papanasam Reservoirs point to unequal rainfall or water management.
- Vaigai Reservoir: Guaranteed dependable irrigation by maintained constant water discharges.

Difficulties Revealed

- Unregular water discharge from reservoirs affecting agricultural development.
- Dependency on monsoon rain high even with better irrigation.
- Monocropping and incorrect fertilizer usage cause deterioration of soil.
- Post-harvest losses and insufficient cold storage compromising marketability.

Key Techniques to Boost Agricultural Production

a. Efficiency of Water Management and Irrigation

- Expanding drip and sprinkler irrigation helps to reduce water waste.
- Real-time monitoring helps reservoir water releases to be maximized.
- Check dams and strengthen Rainwater Harvesting over agricultural ponds.

b. Boost Multi-Cropping & Intercropping To Improve Soil Fertility; Increase Cultivated Area and Crop Rotation

- Land reclamation and organic farming may be done on Fallow Lands.

c. Provide variances in high yield and climate-resilient crops

- Advance drought-tolerant, short-lived crops (CO 51, ADT 47 for Paddy).
- Promote pulses and millets in areas with little water.

d. Fertility of Soil and Improvement of Crop Nutrition

- Support environmentally friendly manuring and organic farming.
- Apply precision farming with nutrition analysis powered by artificial intelligence.

e. Build cold storage and warehouses to minimize losses; strengthen post-harvest infrastructure and market access

- Via eNAM and FPOs, strengthen market linkages.
- Improve Market Linkages via eNAM & FPOs.

f. Advance digital farming and technology; make use of smart irrigation systems—based on artificial intelligence—based moisture sensors

- Teach Advanced Techniques to Farmers to Improve Decision-Making

g. Crops-specific production strategies

- Paddy: bio-pesticides, AWD technique, system of rice intensification (SRI).
- Millets: Sprinkler irrigation and high-yield drought-resistant variants Certified seeds, Rhizobium treatment, pulse milling infrastructure—pulses
- Sugarcane: Mulching, drip watering, high-yielding varietals.

- Groundnut, gingelly oilseeds: High-oil content cultivars and moisture retention methods.
- Cotton: Bt Cotton adoption, pest-resistant cultivation.
- Horticulture—Vegetables and Fruits: Cold chain development and precision farming.
- Cotton: Bt Cotton adoption, pest-resistant farming.
- Horticulture (Vegetables & Fruits): Precision farming, cold chain development.

CHAPTERVI:

SUMMARY, IMPLICATIONS, AND RECOMMENDATIONS

6.1 Summary

- The agricultural output in Tamil Nadu is significantly influenced by seasonal variations in rainfall patterns.
- Increasing Temperatures (2020–2024): Elevated heat levels across all seasons could impact water supply and agricultural productivity.
- Uncertainty in agriculture stems from erratic rainfall patterns, such as droughts in 2016–17 and excessive rain in 2018–19 and 2020–21.
- Millets such as cholam and cumbu rely on rainfall for their development, whereas rice and sugarcane require substantial irrigation.
- The increasing dependence on tube and bore wells prompts concerns regarding the sustainability of groundwater resources over the long term.
- In addition to enhancing water economy, micro-irrigation techniques, such as drip and spray systems, provide a substantial contribution to the improvement of crop resistance to damage.
- Despite the fact that a sizeable portion of land has been designated for agricultural uses, the bulk of the land's needs continue to be met by rainfall that occurs in the spring.
- The use of micro-irrigation methods, such as drip and spray systems, makes a substantial contribution to the enhancement of crop resistance to damage while simultaneously enhancing water efficiency.

6.2 Implications of Climate, Rainfall, Agriculture, and Irrigation Trends in Tamil Nadu

Altering Temperatures Increase Crop Susceptibility and Water Requirements

- In the case of water-intensive crops like rice and sugarcane, summer temperatures above 33°C result in greater water evaporation, lower soil moisture levels, and increased irrigation demands.

Erratic Precipitation Disrupts Agricultural Cycles

- Fluctuations in monsoon patterns, including drought (2016–17) and heavy rainfall (2018–19, 2020–21), create instability in planting and harvesting, thus impacting food production and farmers' livelihoods.

Groundwater depletion poses a significant threat to ecological irrigation

- The decrease in groundwater levels due to excessive dependence on tube wells and bore wells highlights the increasing importance of long-term agricultural sustainability.

Inconsistent Reservoir Water Levels Impacting Irrigation Stability

- Variations in reservoir storage (Mettur, Vaigai, Papanasam) affect agricultural water availability, resulting in irrigation shortages during critical phases of crop development.

Ineffective Water Distribution Strategies Result in Water Waste

- The prevalent application of traditional flood irrigation results in significant water loss, highlighting the critical need for modern irrigation technologies such as drip and sprinkler systems.

Rainfall Affects Yield in Crops

- Dependent on natural rainfall, millets such ragi, cumbu, and cholam have variable yields arising from fluctuating monsoon patterns, therefore influencing food security and farmer income.

Decline in Soil Fertility Threatens Agricultural Productivity

- Constant farming, too much chemical fertilizer used, and erratic rainfall patterns contribute to damage soil, therefore reducing long-term agricultural productivity.

Water & Climate Problems

- Change in crop prices, erratic weather, and rising irrigation costs create financial uncertainty for marginal and small-scale farmers that causes increased financial stress.

Rising urban and industrial water demands restrict agricultural supply

- Growing cities and enterprises are fighting for water supplies, thereby stressing Tamil Nadu's agriculture sector and reducing irrigation water availability..

Climate-Resilient Farming & Smart Irrigation Are Essential

- Adoption of drought-resistant crops, precision irrigation, and enhanced water management methods will help farmers to evolve with current trends. Climate-resilient farming and smart irrigation are very vital.

Policy & Infrastructure Deficit Affects Water Saving Initiatives

- Although modern irrigation techniques nevertheless reveal shortcomings even if irrigation infrastructure has expanded, rainwater gathering, efficient canal systems, and farmer education on them has improved.

Sustainable Water Management is Critical for Agricultural Growth

- Long-term agricultural sustainability relies mostly on enhancing groundwater recharge, reservoir utilization, micro-irrigation promotion, and climate change adaptation plan execution. Sustainable water management is thus very essential for agricultural development.

6.3 Recommendations for Future Research: Impact of Climate Change and Agricultural Productivity

- Research long-term temperature patterns and how they could affect crops such oilseeds, pulses, and rice.
- Evaluate how severe weather events—heat waves, drenches, and floods—may affect soil quality, agricultural output, and water availability.

Rainfall Variability and Water Resource Optimization

- Examine how groundwater depletion and erratic monsoon patterns interact.
- Create prediction models to evaluate changes in rainfall and how they affect agricultural output and irrigation design.

Improving Irrigation Effectiveness

- Analyze using drip, sprinkler micro-irrigation systems to maximize agricultural water use.
- Investigate how well watershed management, check dams, and rainwater collecting could increase water security.

Environmental Diversification of Sustainable Crops

- Discover the financial and environmental advantages of switching from water-intensive crops (paddy, sugarcane) to drought-resistant crops (millets, pulses).
- Analyze how crop rotation and intercropping affect soil fertility, water use, and climate resilience.

Reservoir and Canal Management

- Look at ways to improve reservoir water release plans for consistent irrigation assistance.
- Analyze how effective water distribution, desiluting, and canal modernizing affect irrigation sustainability.

Socioeconomic Implications of Climate and Irrigation Trends

- Examine how variations in climate could affect rural employment, farmer incomes, and migration trends.
- Analyze how well government programs like insurance plans, subsidies, and regulations promote farming that is robust to climate change.

AI and Data-Driven Decision-Making in Agriculture

- Create AI-based models for water availability, agriculture yields, and monsoon patterns.
- Real-time soil moisture, irrigation efficiency, and climate effect monitoring using IoT and satellite data.

Environmental Groundwater Management

- Evaluate over-extraction's long-term effects and suggest workable recharging techniques.
- Investigate community-led water conservation projects to reduce dependency on bore wells and advance groundwater sustainability.

Localized Climate Adaptation Strategies

- To find area-specific adaptation strategies, compare the climatic effect in many areas (coastal, delta, semi-arid).
- Record and expand on effective farming methods from significantly impacted areas.

Policy Enhancements for Climate-Resilient Agriculture

- Examine current water and agricultural policy to find areas lacking in encouragement of sustainable irrigation and climate adaption.
- Suggest focused policy proposals to improve water governance, infrastructure building, and farmer incentives.

6.4 Conclusion

Tamil Nadu's logical diagram: climate, rainfall, agriculture, and irrigation

Here is a logical model showing Tamil Nadu's links among climate, rainfall, agriculture, and irrigation

Figure 6.4 Tamil Nadu's logical diagram: climate, rainfall, agriculture, and irrigation
(Source: Adapted from Government of Tamil Nadu, 2020)

This is Tamil Nadu's logical map showing the relationships among climate, rainfall, agriculture, and irrigation.

Factors of Climate

- Water availability and agriculture are strongly influenced by temperature, humidity, and seasonal changes.

Rainfall Seasons

- Western areas get rainfall from the June–September Southwest Monsoon.
- The main source of rainfall for the state is the Northeast Monsoon (October to December).
- Extreme weather events and floods might result from cyclonic rainfalls (November–December).

Impact on Farmwork

- Rainfall patterns and temperature directly affect Tamil Nadu's agriculture.

Tamil Nadu's Crop Categories

- Cereals: Ragi (finger millet), Cumbu (Pearl Millet), Paddy, Cholam (Sorghum).
- Black grams, green grams, red grammes.
- Groundnut, Gingelly (Sesame) seeds are oilseeds.

Main Dependencies

- While millets (Cumbu, Ragi) are drought-resistant, rice need for considerable irrigation.
- Rainfall differences affect yield variations and planting trends.

Function of Irrigation for Support of Agriculture

Water Sources for Irrigation

- Distributing water from reservoirs to fields via canals
- Store rainwater for seasonal irrigation in tanks.
- Extract groundwater from tube wells and bore wells, but too much usage drains reserves.
- Open wells are the conventional approach, but unreliable in dry spells.
- Large-scale water storage enabling many districts comes from reservoirs.

Comparative Water Availability Against Crop Requirements

- High-water-demand crops (paddy, sugar cane) rely on irrigation.
- Because they need less irrigation, millet crops are climate-resilient.

Effect of Changing Climate

- Rising Temperatures: Summer and monsoon temperatures might change rainfall distribution.
- Extreme Variability in rainfall influences irrigation design either in excess or shortage.
- Challenges of Water Scarcity: Dependency on bore wells causes groundwater depletion.

Ecological Remedies

- Rainwater Harvesting improves water-storing capacity.
- In dryland crops, drip and sprinkler irrigation helps to reduce water waste.
- Researches reservoir management to provide appropriate irrigation water release
- Encouragement of millet farming helps to lower water demand via crop diversification.

APPENDIX A

SURVEY COVER LETTER

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APPENDIX B

INFORMED CONSENT

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APPENDIX C

INTERVIEW GUIDE

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REFERENCES

Abbott, D. (2014) *Applied Predictive Analytics: Principles and Techniques for the Professional Data Analyst*. Indianapolis, IN: Wiley.

Abbott, D. (2021) Predictive analytics: Algorithms and methods in the analysis of data trends. *Journal of Data Science*, 5(2), pp.34–49.

Afri BI. Big data Hadoop and its ecosystem. Available at: https://africanabi.com/services/corporate-it-training/big-data-hadoop-and-its-eco-system/

AgriTechTomorrow. AG Tech Decision and Management Apps. Available at: https://www.agritechtomorrow.com/article/2017/12/ag-tech-decision-and-management-apps/10407

Agricultural Science – HEGO. Agricultural Science. Available at: https://hego-project.com/archives/848/

Ali, A.M. et al. (2022) Crop Yield Prediction Using Multi Sensors Remote Sensing (Review Article). *The Egyptian Journal of Remote Sensing and Space Science*, 25(3), pp.711–716.

Argade, D. and Chavan, H. (2015) Improve Accuracy of Prediction of User's Future M-commerce Behaviour. *Procedia Computer Science*. https://doi.org/10.1016/j.procs.2015.04.234

Atheists for Human Rights. What is the most popular bug in Florida? Available at: https://www.atheistsforhumanrights.org/what-is-the-most-popular-bug-in-florida/

Ayars, J.E. et al. (2002) Subsurface drip irrigation of row crops: a review of 15 years of research at the Water Management Research Laboratory. *Agricultural Water Management*, 42(1), pp.1–27.

Biz4Intellia. Crop Health Monitoring with IoT-enabled Agriculture Solution. Available at: https://www.biz4intellia.com/blog/crop-health-monitoring-with-iot-enabled-precision-agriculture-solution/

Brouwer, C. et al. (1985) *Irrigation Water Management: Training Manual No. 1 - Introduction to Irrigation*. FAO, Rome.

BYJUS. Types of Soil in India - Alluvial Soil, Black Soil, Laterite Soil, Red Soil & More. Available at: https://byjus.com/free-ias-prep/classification-of-soil-in-india/

BYJUS. What Is Irrigation? - Types, Methods and Importance of Irrigation. Available at: https://byjus.com/biology/irrigation/

Climate-Data.org. Climate data for Tamil Nadu, India. Available at: https://en.climate-data.org/asia/india/tamil-nadu-759/

Davenport, T.H. (2013) *Analytics at Work: Smarter Decisions, Better Results*. Boston: Harvard Business Press.

Ferehan, N., Haqiq, A. and Ahmad, M.W. (2022) Smart Farming System Based on Intelligent Internet of Things and Predictive Analytics. *Journal of Food Quality*, pp.1–8. https://doi.org/10.1155/2022/7484088

FNB Tech. Cultivating the Future: How Wireless Farming is Revolutionizing Smart Agriculture. Available at: https://agritech.fnb.tech/wireless-farming-revolutioniz-smart-agriculture/

Focus Global Reporter. Reweighing Complete Water Security from Source to Tap? Available at: https://focusglobalreporter.org/reweighing-complete-water-security-from-source-to-tap/

Garg, A., Munoth, P. and Goyal, R. (2016) Application of Soil Moisture Sensors in Agriculture: A Review. *International Journal of Agricultural Engineering*, 9(1), pp.15–22.

Ge, L., Wolfert, S. and Bogaardt, M.-J. (2019) Digital twins in smart farming. *Agricultural Systems*, 176, p.102672.

Ge, Y. et al. (2019) Applications of sensing technology in precision agriculture. *Computers and Electronics in Agriculture*, 162, pp.613–626.

Geerts, S. and Raes, D. (2009) Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. *Agricultural Water Management*, 96(9), pp.1275–1284.

GRM Institute. Weather Risk Management Services. Available at: https://grm.institute/blog/weather-risk-management-services/

IBM (2022) IBM Watson Decision Platform for Agriculture. Available at: https://www.ibm.com/products/watson-decision-platform-for-agriculture

ICAR (2021) *Types of Soils in India*. Indian Council of Agricultural Research. Available at: https://icar.org.in

ICAR (2023) Sustainable Farming Practices and Climate Resilience Strategies in Tamil Nadu. New Delhi: ICAR Publications.

Iksch, J., Kastek, M. and Stoma, M. (2021) Development of Sensor Systems for Smart Farming Applications. *Sensors*, 21(13), p.4357.

Inoue, Y. (2020) Remote sensing of crop production using UAV-based platforms. *Field Crops Research*, 233, pp.123–134.

Intellias (2023) Smart Farming Solutions: Agricultural IoT, AI and Weather Forecasting. Available at: https://www.intellias.com

Kaur, B. and Saxena, S. (2024) Embracing Technological Advancements. *Advances in Hospitality, Tourism and the Services Industry*. https://doi.org/10.4018/979-8-3693-1978-9.ch012

Keller, J. and Bliesner, R.D. (1990) *Sprinkler and Trickle Irrigation*. New York: Van Nostrand Reinhold.

Kijne, J.W. (2003) Unlocking the Water Potential of Agriculture. Rome: FAO.

Lee, D. et al. (2014) Sensor-based pest detection and pest control systems: A review. *Journal of the Korean Society for Precision Engineering*, 31(2), pp.139–148.

Mendeley. Smart farming for improving agriculture: Preview & related info. Available at: https://www.mendeley.com/catalogue/6c58746e-6c81-3499-be65-4307246c709c/

Mendel, G. (1866) Versuche über Pflanzen-Hybriden. *Verhandlungen des Naturforschenden Vereins Brünn*, 4, pp.3–47.

Ministry of Agriculture & Farmers Welfare (2023) Agricultural Productivity and Climate Resilience in Tamil Nadu. New Delhi: Government of India. https://agricoop.nic.in

MoEFCC (2021) *India: Third Biennial Update Report to the UNFCCC*. Government of India.

Narayanamoorthy, A. (1997) Technical Efficiency in Paddy Production: An Analysis Based on Farm Level Data. *Indian Journal of Agricultural Economics*, 52(1), pp.169–178.

NASA (2023) Global Temperature Trends and Climate Variability. Available at: https://climate.nasa.gov

National Centre for Disease Control (2025) State Action Plan on Climate Change and Human Health: Tamil Nadu. Government of India. https://ncdc.mohfw.gov.in

National Geographic, n.d. *The Art and Science of Agriculture*. Available at: https://education.nationalgeographic.org

NWDA (2023) Water Resources and Irrigation in India. Government of India. Available at: https://www.nwda.gov.in

OAR@ICRISAT (2023) Integrated Weed Management for Sustainable Agriculture in India. *International Crops Research Institute for the Semi-Arid Tropics*. https://oar.icrisat.org

Pereira, L.S., Oweis, T. and Zairi, A. (2002) Irrigation management under water scarcity. *Agricultural Water Management*, 57(3), pp.175–206.

Perry, C. and Steduto, P. (2017) Does Improved Irrigation Technology Save Water?. *FAO Water Reports No. 41*. Rome: FAO.

Postel, S. et al. (2001) Drip irrigation for small farmers: A new initiative to alleviate hunger and poverty. *Water International*, 26(1), pp.3–13.

Robotics in Agriculture: Types and Applications, n.d. Automate. Available at: https://www.automate.org

Shanahan, J.F. et al. (2001) Use of remote sensing imagery to estimate corn grain yield. *Agronomy Journal*, 93(3), pp.583–589.

Shmueli, G. and Koppius, O.R. (2011) Predictive analytics in information systems research. *MIS Quarterly*, 35(3), pp.553–572.

SOUP Project (2022) Smart Optimization of Urban Farming Processes. EU Horizon Project. https://www.soup-project.eu

Tamil Nadu Government (2023) Statistical Handbook of Tamil Nadu. https://www.tn.gov.in/statistical-handbook

Vasily Dokuchaev (1883) Russian Chernozem. St. Petersburg: Imperial University Press.

WeatherSpark. Average weather in Chennai, Tamil Nadu, India - Year Round. https://weatherspark.com/y/110123/Average-Weather-in-Chennai-Tamil-Nadu-India-Year-Round/

Wild Willow Farm. Pests. https://www.wildwillowfarm.org/pests

World Bank (2020) Transforming Agriculture Through Digital Technologies. Washington, DC: World Bank.

World Bank (2023) Water Resources Management: Overview. https://www.worldbank.org

Wolfert, S. et al. (2017) Big Data in Smart Farming – A Review. *Agricultural Systems*, 153, pp.69–80.

APPENDIX A

SURVEY COVER LETTER

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APPENDIX B

INFORMED CONSENT

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APPENDIX C

INTERVIEW GUIDE

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REFERENCES

Abbott, D. (2014) *Applied predictive analytics: principles and techniques for the professional data analyst*. Indianapolis, IN: Wiley.

Agisoft (n.d.) *PhotoScan: 3D Mapping Software*. Available at: https://www.agisoft.com.

Ali, A.M., Abouelghar, M., Belal, A.A., Saleh, N., Yones, M., Selim, A.I., Amin, M.E.S., Elwesemy, A., Kucher, D.E., Maginan, S. and Savin, I. (2022) 'Crop Yield Prediction Using Multi Sensors Remote Sensing (Review Article)', *The Egyptian Journal of Remote Sensing and Space Science*, 25(3), pp. 711–716. doi: https://doi.org/10.1016/j.ejrs.2022.04.006.

Biz4Intellia (n.d.) *Crop Health Monitoring with IoT-enabled Agriculture Solution*. Available at: https://www.biz4intellia.com/blog/crop-health-monitoring-with-iot-enabled-precision-agriculture-solution/.

BYJUS (n.d.) *Types of Soil in India - Alluvial Soil, Black Soil, Laterite Soil, Red Soil & More [UPSC GS-I Notes]*. Available at: https://byjus.com/free-ias-prep/classification-of-soil-in-india.

BYJUS (n.d.) *What Is Irrigation?- Types, Methods and Importance of Irrigation*. Available at: https://byjus.com/biology/irrigation.

Climate-Data.org (n.d.) *Climate data for Tamil Nadu, India*. Available at: https://en.climate-data.org/asia/india/tamil-nadu-759/ .

Evans, R.G., Spomer, R.G. and Burke, E.J. (1996) 'Irrigation scheduling and water management', *Journal of Production Agriculture*, 9(2), pp. 257-265.

FAO (2021) *Smart Farming and Digital Agriculture: Opportunities and Challenges*. Rome: Food and Agriculture Organization of the United Nations.

FAO (2022) *Climate Change and Agriculture: Impact on Crop Productivity and Irrigation Systems*. Rome: FAO. Available at: https://www.fao.org/climatechange/agriculture.

Ferehan, N., Haqiq, A. and Ahmad, M.W. (2022) 'Smart Farming System Based on Intelligent Internet of Things and Predictive Analytics', *Journal of Food Quality*, 2022, pp. 1–8. doi: https://doi.org/10.1155/2022/7484088.

Garg, A., Munoth, P. and Goyal, R. (2016) 'Application of Soil Moisture Sensors in Agriculture: A Review', *International Journal of Agricultural Engineering*, 9(1), pp. 15-22.

Ge, L., Wolfert, S. and Bogaardt, M.-J. (2019) 'Digital twins in smart farming', *Agricultural Systems*, 176, 102672.

IBM (2022) *IBM Watson Decision Platform for Agriculture*. Available at: https://www.ibm.com/products/watson-decision-platform-for-agriculture.

IMD (2023) *Annual Climate and Rainfall Reports for Tamil Nadu*. Ministry of Earth Sciences, Government of India. Available at: https://mausam.imd.gov.in/.

IMD (2024) *Climate and Rainfall Trends in Tamil Nadu (2017-2022)*. New Delhi: IMD. Available at: https://www.imd.gov.in.

Indian Council of Agricultural Research (ICAR) (2021) *Climate Change and its Impact on Agriculture in Tamil Nadu: A Statistical Analysis*. ICAR Research Institute.

Indian Council of Agricultural Research (ICAR) (2023) *Sustainable Farming Practices and Climate Resilience Strategies in Tamil Nadu*. New Delhi: ICAR Publications. Available at: https://www.icar.org.in.

Inoue, Y. (2020) 'Satellite- and drone-based remote sensing of crops and soils for smart farming – a review', *Soil Science and Plant Nutrition*, 66(6), pp. 798–810. doi: https://doi.org/10.1080/00380768.2020.1738899.

Intellias (2020) *Weather Monitoring Technologies to Save Crops from Mother Nature*. Available at: https://intellias.com/weather-monitoring-technologies-to-save-crops-from-mother-nature/.

Mendel, G. (1866) 'Versuche über Pflanzen-Hybriden', *Verhandlungen des Naturforschenden Vereins Brünn*, 4, pp. 3-47.

Ministry of Agriculture & Farmers Welfare, Government of India (2023) *Agricultural Productivity and Climate Resilience in Tamil Nadu*. New Delhi: Department of Agriculture. Available at: https://agricoop.nic.in.

NASA (2023) *Global Temperature Trends and Climate Variability*. Washington, D.C.: NASA. Available at: https://climate.nasa.gov.

National Centre for Disease Control (NCDC) (2025) *State Action Plan on Climate Change and Human Health: Tamil Nadu*. Ministry of Health & Family Welfare, Government of India. Available at: https://ncdc.mohfw.gov.in/.

National Geographic (2022) *The Art and Science of Agriculture*. Available at: https://education.nationalgeographic.org/resource/agriculture.

NWDA (2023) *Irrigation Systems and Reservoir Management in Tamil Nadu*. New Delhi: National Water Development Agency. Available at: https://www.nwda.gov.in.

Ramasamy, C., Balasubramanian, R. and Chandrasekaran, M. (2020) 'Impact of Climate Change on Agriculture in Tamil Nadu: A Regional Perspective', *Journal of Agricultural Economics*, 15(3), pp. 45-62.

Tamil Nadu Government (2023) *Statistical Handbook of Tamil Nadu*. Available at: https://www.tn.gov.in/statistical-handbook.

Vasily Dokuchaev (1883) *Russian Chernozem*. St. Petersburg: Imperial University Press.

WeatherSpark (n.d.) *Average weather in Chennai, Tamil Nadu, India - Year Round*. Available at: https://weatherspark.com/y/110123/Average-Weather-in-Chennai-Tamil-Nadu-India-Year-Round.

Wolfert, S., Ge, L., Verdouw, C. and Bogaardt, M.-J. (2017) 'Big data in smart farming – A review', *Agricultural Systems*, 153, pp. 69-80.

APPENDIX A:

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