IoT based Irrigation and Fertilization framework for Smart Agriculture

*A **Thesis***

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by

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List of Abbreviations

.apk	Android Application Package
1-DCNN	One-dimensional Convolutional Neural Network
6LoWAN	IPv6 Low-power Wireless Personal Area Network
A_r	Adequate rainfall
AC	Alternate current
ACF	Autocorrelation function
ADF	Augmented Dickey-Fuller
AFT	Advanced Fusion Technique
AI	Artificial Intelligence
AIC	Akaike's Information Criterion
AIoT	Agricultural Internet of Things
AM	Alpine Meadow
AMQP	Advanced Message Queuing Protocol
ANN	Artificial Neural Network
ANOVA	Analysis of Variance
A_p	Atmospheric pressure
AR	Autoregressive
ARIMA	AutoRegressive Integrated Moving Average
AS	Alpine Steppe
BPNN	Back Propagation Neural Network
CISCO	Commercial and Industrial Security Corporation
CNCV	Computational Needs for Computer Vision
CNN	Convolutional Neural Networks
CoAP	Constrained Application Protocol
CRB	Crop Residue Burning
CRD	Completely Randomized Design
CV	Computer Vision
d	Non-seasonal differences

D_p	Deep percolation
DCGAN	Deep Convolutional Generative Adversarial Network
DDoS	Distributed Denial of Service
DDS	Data Distribution Service
DNN	Deep Neural Network
DSS	Decision Support System
EAS	Extension and Advisory Services
ECU	Electronic Control Unit
ES-ETHG	Electro-magnetic Triboelectric Hybrid Generator
Et_{crop}	Crop water needs
EU	European Union
FANET	Flying Ad Hoc Network
FBMS	Farm-Based Management Systems
FCI	Food Corporation of India
FMS	Farm Management System
GA	Genetic Algorithm
GDP	Gross Domestic Product
GeIS	Geographic Information Systems
GIS	Global Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRU	Gated Recurrent Unit
GSM	Global System for Mobile Communication
GUI	Graphical User Interface
H	Humidity
H2H	Human-2-Machine
HAN	Home Automation Networks
HRI	Human-Robot Interaction
HYV	High Yielding Variety
I	Integrated
IA	Identification and Authorization
IaaS	Infrastructure as a Service
IAS	Irrigation Advisory Services
ICT	Information, Communication, and Technology
IDE	Integrated Development Environment

IFFCO	Indian Farmers Fertilizer Cooperative Limited
IHDS	Intelligent Harvesting Decision System
IMB	International Business Machines
IN	Irrigation water needs
INoT	Internet of Nano Things
IoE	Internet of Everything
IMoT	Internet of Medical Things
IoS	Internet of Services
IoT	Internet of Things
IoT-Ai	IoT-Artificial Intelligence
IoT-GSI	IoT-Global Standards Initiative
IoUT	Internet of Underground Things
IP	Internet Protocol
IPV6	Internet Protocol
IS	Information Security
IT	Information Technology
ISAP	Indian Society of Agribusiness Professionals
IST	Indian Standard Time
IT	Information Technology
ITU	International Telecommunications Union
ITU-T	International Telecommunication Union - Telecommunication
K	Potassium
k-NN	k-Nearest Neighbors
kPA	**kilo-pascal**
KPSS	Kwiatkowski Phillips Schmidt Shint
L	Luminosity
LAI	Leaf Area Index
LD	Listwise Deletion
LG	Lucky-Goldstar
LoRA	LongRange
LR-WPAN	Low-Rate Wireless Personal Area Network
LSD	Least Significant Difference
LSTM	Long Short-Term Memory
LTE	Long Term Evolution
M2M	Machine-to-Machine

MA	Moving average
MAE	Mean Absolute Error
MCNN	Multi-path Convolutional Neural Network
MDI	Markov-Decision based Irrigation
$MDW\&F_bDSS$	Minimal Distribution of Water and Fertilization based Decision Support System
Mg	Magnesium
MILP	Mixed Integer Linear Programming
MIT	Massachusetts Institute of Technology
ML	Machine Learning
MLD	Maximum Likelihood Estimation
MLR	Multiple Linear Regression
MQTT	MQ Telemetry Transport
MSE	Mean Squared Error
MSER	Maximally Stable External Regions
N	Nitrogen
NFC	Near Field Communication
NFV	Network Function Virtualization
NPK	Nitrogen Phosphorus Potassium
P	Phosphorus
q	Autoregressive term
PA	Precision Agriculture
PaaS	Platform as a Service
PACF	Partial Autocorrelation Function
PAR	Photosynthetically Active Radiation
PCA	Principal Components Analysis
P_e	Plants Effectively
pH	potential of Hydrogen
PHOG	Pyramid Histogram of Oriented Gradient
PLSR	Partial Least Squares Regression
PP	Phillips-Perron
PSoC	Programmable System on Chip Technology
q	number of lagged forecast errors
QoS	Quality of Service
R_{off}	Runoff
R_bDSS	Requirement based Decision Support System

RFID	Radio-Frequency Identification Network
RFR	Random Forest Regression
RGB	Red-Green-Blue
RKVY	Rashtriya Krishi Vikas Yojna
RMSE	Root Mean Square Error
RNN	Recurrent Neural Network
RPAS	Remotely Piloted Aircraft System
RPL	Routing Protocol for Low-power and Lossy Network
RS	Remote Sensors
SA	Smart Agriculture
SaaS	Software as a Service
SASE	Secure Access Service Edge
SDN	Software Define Networking
SE	Software Engineering
S_m	Soil moisture
SMS	Short Message Service
SOC	Soil Organic Carbon
S_t	Soil temperature
SVM	Support Vector Machine
SVR	Support Vector Regression
T_r	Total amount of rainfall
TC	Task Controller
TCP	Transmission Control Protocol
TN	Total Nitrogen
UAV	Unmanned Aerial Vehicles
UDP	User Datagram Protocol
UN	United Nations
UWB	Ultra-wideband
VANET	Vehicular Ad-hoc Networks
WFS	Web Featured Services
XAMPP	Extensible Messaging and Presence Protocol
Z-Wave	Zensys Wave

Certificate

I hereby certify that the work which is being presented in this thesis entitled "**IoT based Irrigation and Fertilization framework for Smart Agriculture**", in partial fulfillment of the requirement for the award of degree of "**Doctor of Philosophy**" submitted in Computer Science and Engineering Department, Thapar Institute of Engineering and Technology (Deemed University), Patiala (India), is an authentic record of my own work carried out under the supervision of **Dr. Sanmeet Kaur** and refers other research works which are duly listed in the reference section.

The matter presented in this thesis has not been submitted for the award of any other degree of this or any other university.

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Abstract

In recent years, Internet of Things (IoT) has played a significant impact in transforming agricultural domain by virtue of which the concept of Smart Agriculture (SA) has emerged. This concept has helped in revolutionizing agricultural practices by automating, analyzing, and computing of various agricultural parameters. There is no denying in the fact that food demand has increased at an unprecedented pace due to accelerated population growth all over the world. Therefore, it is imperative to harness emerging technology like IoT in agriculture sector to ensure sustainable food production.

In order to understand the significant role of IoT in agriculture, a comprehensive literature review has been performed based on the framed research questions. Various research articles have been identified using the inclusion exclusion criteria from renowned electronic databases. Research articles were categorized on the basis of six different phases of agriculture's life cycle, *i.e.*, soil properties and sowing, irrigation and fertilization, growth and monitoring of plants, crop protection from various diseases and weeds, harvesting, and stubble management. In addition, some of the most prominent research articles published over the past few years in IoT domain have been discussed to understand the pragmatic approach of this term. Also various web portals and mobile applications catering the agricultural domain have been presented within the study. On the basis of extensive literature review, research gaps have been identified and objectives have been framed.

To achieve the framed objectives a framework namely, Minimal Distribution of Water & Fertilization based Decision Support System ($MDW\&F_bDSS$) has been proposed. The framework consists of two different hardware devices, *i.e.*, Libeliums Waspmote Plug and Sense device and NPK sensor mounted over Arduino Uno. Using first hardware device, dataset was collected on three different crops namely, Rice (paddy), Wheat, and Capsicum on various parameters, *i.e.*, Soil moisture (S_m), Soil temperature (S_t), Atmospheric pressure (A_p),

Humidity *(H)*, and Luminosity *(L)*. Whereas the second hardware device detected the existing presence of Nitrogen *(N)*, Phosphorus *(P)*, and Potassium *(K)* within the soil. The captured data on various parameters have been saved on cloud server for analysis.

For irrigation assessment, Time Series Analysis of collected datasets has been performed using Auto-Regressive Integrated Moving Average Model (ARIMA) and Long Short-Term Memory (LSTM) techniques. The proposed framework has been evaluated using different parameters, *i.e.*, Mean Absolute Error (MAE), Mean Squared Error (MSE), and Root Mean Squared Error (RMSE). It has been observed that the results of ARIMA model performed better than LSTM for weekly forecasting. For fertigation assessment, the existing presence of various fertilizers, *i.e.*, *N*, *P*, and *K* within the fields has been estimated. The proposed framework reflected accuracy, and it can be concluded that the existing framework can be used for other applications, such as irrigation scheduling, target fertilizer spray, *etc*.

To digitize the process of agriculture, two applications, *i.e.*, a web portal www.smartfasal.in and a mobile application Farm analyzer have been designed. These applications allow farmers to monitor and control agricultural activities remotely. The web application enables farmer to view real-time recordings for different parameters captured on various crops. Whereas Farm analyzer provides the user a Graphical User Interface (GUI) to view real-time readings captured by various agricultural sensors, along with weather api readings. In addition, precise estimation of water for irrigation requirement can be determined in advance by selecting the desired crop and entering the area field. Lastly, the mobile application provides an interface to remotely turn on/off irrigation value for the fields.

The work presented in this study has huge potential in transforming contemporary agricultural practices by enhancing yield productivity and conserving natural resources to maximum extent.

Chapter 1

Introduction

The term of agriculture has been derived from two Latin words, *i.e.*, *ager* (field) and *colo* (cultivate) [2]. In general terms, agriculture is multidisciplinary field that encompasses endeavor to reshape the surface of the earth through cultivation of plants and crops [3, 4]. The process of agriculture began independently in different parts of the globe 11,500 years ago [5]. Figure 1.1 depicts various parts of the globe where agricultural practices initially began.

Figure 1.1: Regions of the world depicting areas where the process of agriculture initially began [1]

Agricultural practices are of paramount importance as they are considered to be the backbone of any developing country [6]. Considering Indian agriculture in specific, India ranks second place worldwide in terms of farm output [7]. According to the studies, the agricultural domain contributes up to 25% Gross Domestic Product (GDP) globally, out of which 18% contribution is from its allied sectors, *i.e.*, forestry and fisheries [8, 9, 10]. Agricultural activities also help in enhancing industrial sector through various products, such as paper, cloth, rope, and other raw materials [11]. According to a study by Max Roser, agriculture contributes to a total of 28% global employment [12].

Based on the paramount importance of agriculture, various innovative techniques have been implemented with an aim to further explore and enhance this domain's capabilities. With the passage of time and constant innovations, the term of agriculture has evolved to "Smart Agriculture (SA)". This chapter provides a high level view of this thesis. The introductory section of this chapter discusses the background of agriculture, followed by an overview of the Internet of Things (IoT), its need, and various application areas. The concept of Smart Agriculture (SA) has also been discussed in this chapter. The role of IoT and its significant impact within the agricultural domain has also been discussed in detail, along with its needs, applications, techniques, various phases, and challenges of SA. It culminates with discussion of the organization of the rest of the thesis along with its contributions.

1.1 Background of Agriculture

Over centuries, agricultural practices have contributed towards the rise of civilizations [13]. People started learning how to grow grain and root crops around 11,500 years ago, and eventually settled down to a farming lifestyle [14, 15]. Gradually with time, they became completely dependent on agriculture. Various farming devices like stone, iron, bronze, and bones were incorporated in agricultural practices to made this process easier. With the passage of time cattle were introduced in the field of agriculture that helped in enhancing agricultural productivity [16]. In 5500 B.C., farmers in Mesopotamia devised basic irrigation systems that channelized water from streams onto their fields, allowing them to dwell in previously unsuitable agricultural areas [17]. These irrigation practices were further adopted by farmers of Egypt and China [18]. By 6000 BC, newer plant varieties were developed by farmers [19]. These agricultural practices were being followed for centuries until the 1700's when the first green revolution in growth and productivity took place [16]. This was the phase-changing era in the agricultural domain, as machines started playing a crucial role in enhancing agricultural productivity. Cotton gin, which Eli Whitney invented in 1794, was the first automated mechanical device that began to be used to separate cotton fiber from seed [20]. Cyrus McCormick's mechanical reaper in 1830 [21], John and Hiram Pitts' horse-powered thresher in 1835 [22], John Deere's steel plow [23] in 1837, *etc.*, were some of the oldest and most popular mechanical instruments that were introduced in the agricultural domain. It was in the year 1892 when the first agricultural tractor was developed by John Froelich in Clayton County, Iowa, United States of America (USA). This invention was the biggest leap in the domain, as it resulted in less human effort and more productivity. Scientists in early 1970s, discovered that they could rearrange genes and introduce new ones to enhance disease resistance, yield, and other desired crop qualities. Electricity became major power source to be used within farms of Japan and Germany, in early 1990s [24]. For the last quarter of 1990, agricultural domain has depicted a sharp inclination towards adaptation of Information Communication and Technology (ICT) and IoT rather than following the conceptual methods of farming practices [25]. Since then, for every passing year, there has been significant development in this domain, helping it attain higher benchmarks. Figure 1.2 depicts the pictorial representation of history of agriculture.

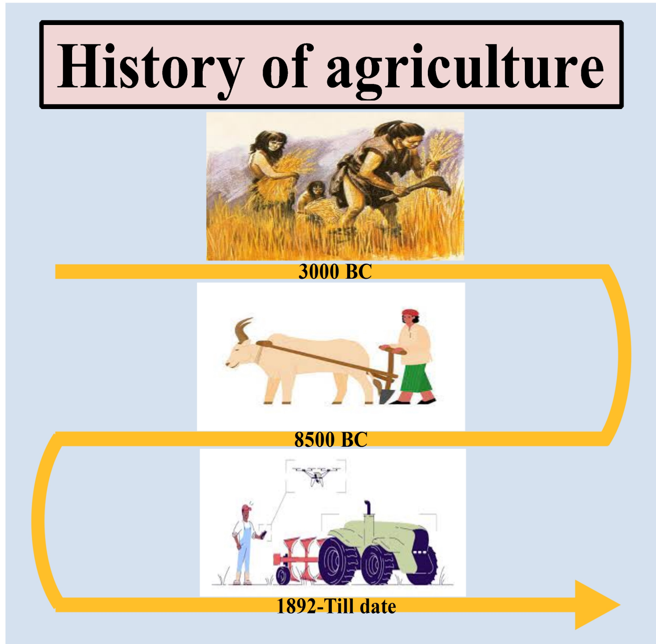


Figure 1.2: History of agriculture

According to a study conducted by Coldevin, with respect to an exponential population growth there would be an increased requirement of 70% food by the year 2050 [26]. Over the past few years urbanization has been witnessed on agricultural lands which followed depletion of finite natural resources, that further aggravated the problem of attaining required food requirements. Therefore, agricultural practices are now considered to be a mandatorily undertaken with the help of IoT solutions. IoT assists farmers in bridging the supply-demand gap by ensuring excellent yields, profitability, and environmental preservation. Since IoT is bound to play a vital role in enhancing agriculture's current state, the next section presents an over-view of IoT.

1.2 Internet of Things (IoT)

International Telecommunication Union - Telecommunication (ITU-T) has termed IoT as "A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving inter-operable information and communication technologies" [27]. In simple words, it is a technique of linking physical and virtual objects with an aim to capture data and later transfer it with the help of various communication capabilities. This infrastructure includes existing and evolving Internet and network developments. It tends to offer specific object-identification, sensor, and connection capability as the basis for developing independent cooperative services and applications. These are characterized by a high degree of autonomous data capture, event transfer, network connectivity, and interoperability.

Although, the term "Internet" was first coined by Vinton Cerf and Robert Kahn in 1974 [28], however the medium of communication was confined either to inland mail or voice message, that was attained through telephone lines in the mid-1980s [29]. In the early 1990s, Auto-ID Labs at Massachusetts Institute of Technology (MIT) introduced the initial notion of IoT [30]. In terms of practical implementation, Trojan Room coffee pot was the first IoT application that was developed in the year 1999 [31]. Later during the same year, the world's first Internet controlled device, *i.e.*, a toaster was designed that had the facility to be turned on/off remotely over the Internet [32, 33]. The main aim of inducting IoT was to synchronize things over the Internet and to reduce human intervention. The three aspects, *i.e.*, Internet, Human, and Things (Objects) play a significant role in attaining the objective of IoT. Figure 1.3 depicts the Tri-sectional relationship between all the three aspects of IoT.

In terms of communication, the Internet has unquestionably established a benchmark. IoT has assumed control of billions of gadgets in today's world by adding a variety of sensors that are based on their functional capabilities [34]. When these devices (sensors) are connected to the Internet, these devices generate massive amounts of data, on which decisions are made post analysis. Over the last few years, there has been an inclination towards adaptation of new-age communication techniques. Till date, the world is deployed with 05 billion smart

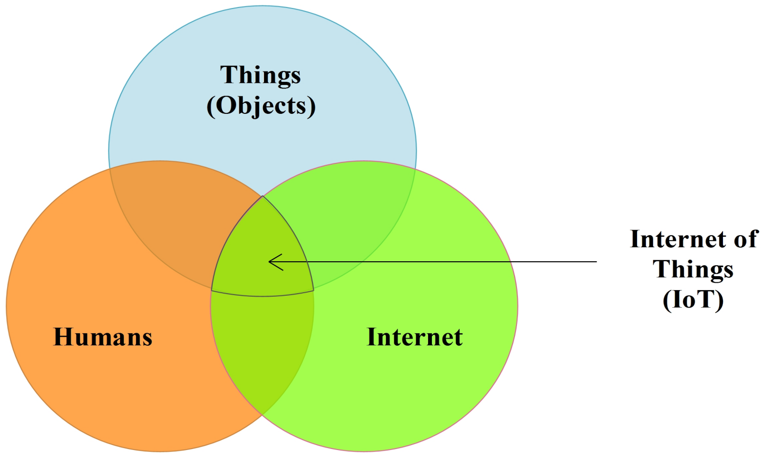


Figure 1.3: Tri-sectional relationship of IoT

devices [35]. The incremental value of IoT is expected to exceed $300 billion by the end of the decade [36]. This value heightens the potential for the development of newer communication technologies and the discovery of new techniques that helps in synchronization for various devices over the Internet.

Over the years, IoT has gained more popularity due to its wide range of usability. Figure 1.4 portrays the popularity of web searches over the last five years, as measured by Google search trends for both phrases.

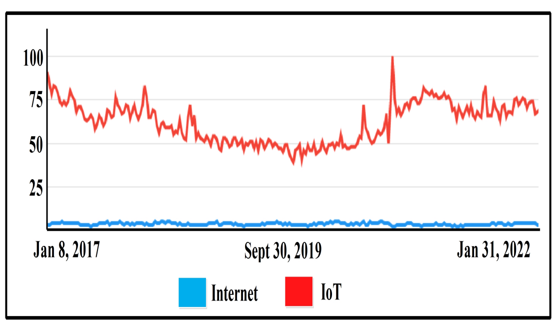


Figure 1.4: Google Trends response for keywords “Internet” and “IoT” for the last 5 years

For the last couple of years when the term of IoT became a trend, various applications have been associated with it. The next subsection sheds light on various application areas of IoT that developed on its journey of growth.

1.2.1 Applications of IoT

IoT's capabilities enable the development and implementation of a wide range of applications. Due to these features, the concept of IoT is now being looked upon as a road map for development in multiple areas of concern towards society. Some of the most prominent application areas are Smart Mobility, Smart Grid, Smart Homes/Buildings, Public Safety and Environment monitoring, Medical and Health care, Industrial processing, Agriculture and Livestock monitoring, Independent living. Figure 1.5 depicts some of the most prominent applications of IoT.

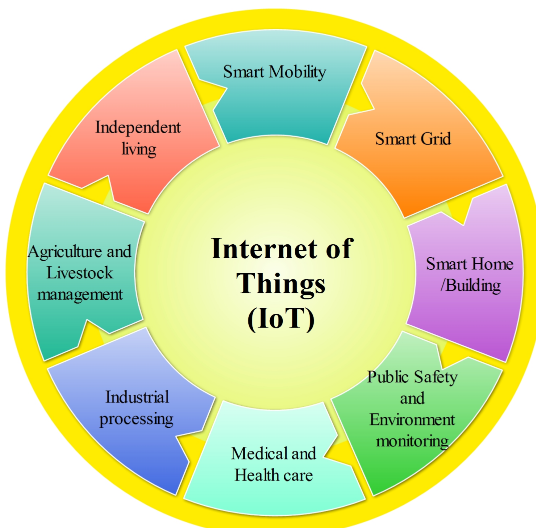


Figure 1.5: Prominent applications of IoT

i Smart Mobility

Smart Mobility is a technique of travel that is seamless, efficient, and flexible across several modes. With the passage of time and ever-increasing demands for various innovative techniques, *i.e.*, Vehicular Ad-hoc Networks (VANET) and Flying Ad Hoc Network (FANET) have been quite in limelight. As a result, it can be described as a paradigm that allows shifting toward a more flexible and multi-modal transportation system.

ii Smart Grid

A smart grid is an electrical distribution system, that uses digital communications technology to monitor and respond to changes in demand on a local level. It's also known as a digital technology, that permits two-way communication, where in the first phase observations are generated by incorporating various dedicated sensors and in the second phase, only required amount of energy is channelized, which is based on the evaluated demand.

iii Smart Home/Building

A smart home or building is a living environment, where home appliances like air-conditioning, lights within a room, heating elements are remotely managed over the smart-phone or a computer. The ability to manage them remotely enhances the quality of living by a greater prospective.

iv Public Safety and Environment monitoring

Incorporation of IoT in public safety and monitoring domain aims to monitor some of the most basic facilities that are closely associated with our environment, such as weather conditions, water quality, soil ,wind, and other environmental attributes.

v Medical and Health-care

Internet of Medical Things (IoMT) is a technique that aims at connecting health-care services and its various applications over the Internet. Medical gadgets have built-in Wi-Fi systems that enables Machine-to-Machine (M2M) communication in a faster and efficient manner.

vi Industrial processing

For the past few years, the concept of IoT has also flourished in industrial domain. Modern day industrial equipment and requirements are so complex that the functional capabilities of IoT are either designed or customized according to user's requirements to cater to the needs of the industrial sector.

vii Agriculture and Livestock monitoring

Agriculture is one of the most prominent application area where IoT has been incorporated. It is aimed at reforming and reorienting agricultural growth in light of the realities of climate change. Techniques and strategies for undertaking agricultural tasks have changed dramatically over the past few years due to numerous reasons. Modern day agricultural devices are IoT equipped that facilitates farmers to remotely monitor and undertake required agricultural decisions. Agricultural operations are carried out, according based on the observations and analysis. In addition, Livestock monitoring is also undertaken with the help of IoT. This technique makes use of IoT-enabled devices with an aim to track and monitor the health of livestock, most commonly cattle, to locate their precise locations within the fields, *etc.*

viii Independent living

Independent living attempts to assist elderly people as much as possible in their everyday activities, allowing them to live a self-sufficient and secure lifestyle.

Since the focus of the study is on the agricultural domain, it is visible that IoT plays a significant role in enhancing farming practices. Keeping the current scenario under consideration, this thesis proposes an IoT based irrigation and fertilization framework for SA within the study. Since there are no substantial differences between the terms "Smart Agriculture (SA)" and "Precision Agriculture (PA)"; "Fertilization" and "Fertigation", therefore, both have been used interchangeably in this thesis. The next subsection depicts an overview of IoT in SA.

1.2.2 IoT in Smart Agriculture

During the past few years, there has been an exponential growth witnessed of world population [37]. According to the United Nations (UN), agricultural domain will have to produce 70% more food in 2050, shrinking agricultural lands, and depletion of finite natural resources, the need to enhance farm yield has become critical [38, 39]. Limited availability of natural resources such as fresh water and arable land along with slowing yield trends in several staple crops, have further aggravated the problem. Another impeding concern over the farming industry is the shifting structure of agricultural workforce. Moreover, agricultural labor in most of the countries has declined. As a result of the declining agricultural workforce, adoption of Internet connectivity solutions in farming practices has been triggered, to reduce the need for manual labor.

Hence, incorporation of IoT based solutions are looked upon by various researchers to aid farmers to minimize the supply demand gap, by ensuring high yields, profitability, and protection of environment. The approach of using IoT technology to ensure optimum application of resources to achieve high crop yields and reduce operational costs is called "Smart/Precision Agriculture. IoT in agriculture technologies comprise specialized equipment, wireless connectivity, software and Information Technology (IT) services. Agricultural practices based on IoT technologies enables farmers to enhance productivity and enabling efficient utilization of resources such as water, electricity, fertilizers, *etc*. Some of the advantages of incorporating IoT concepts in agriculture are as under:

i Farm Management Systems

   Farm management systems are specifically designed to collect precise location based information within the fields, that makes the process of farming lot more easier among farmers enabling to manage their farms. These systems typically come with analytical, reporting, and accounting features. FarmLogs is an example of a Farm Management

System that analyzes and monitors the entire farm, helps farmers in making reports, and drawing up accounting [40].

ii Resource optimization

IoT in agriculture focuses on optimizing the use of land, energy, and water by first capturing the associated parameters and them evaluating them as per the requirement.

iii Cleaner process reducing the carbon footprint

Smart farming using IoT is genuinely the solution to decrease the use of fertilizers and pesticides. Precision farming helps farmers save energy and water and make farming a greener activity. The approach ensures a more organic and cleaner final product compared to conventional agricultural methods and reduces carbon footprint [41].

iv Accentuated product quality

By utilizing IoT solutions, smart farming is able to meet the growing demand for crops while providing the highest quality standards. With more and more solutions being designed and introduced, nations can decrease the necessity to import and increase the chances of exporting their products. As decisions are taken beforehand, the product quality remains pristine.

The next section depicts a vivid description of Smart agriculture.

1.2.3 Smart Agriculture

"Smart Agriculture (SA) is a management strategy that gathers, processes, and analyzes temporal, spatial and individual data and combines it with other information to support management decisions according to estimated variability for improved resource use efficiency, productivity, quality, profitability, and sustainability of agricultural production" [42]. Agriculture used to be a long, arduous, and difficult task that lasted from dawn to dusk. With time, various advancements took over the conceptual procedure of farming. Nowadays, it has become relatively easier to perform these activities with the help of various agricultural devices.

SA is a new age technique that helps in guiding actions that are required to transform and remodel agriculture systems to ensure food security, irrespective of climate change and other related factors to agriculture. SA's main aim is to tackle two main objectives, namely, sustainability by increasing agricultural productivity and building a resilience model towards climate change. SA process entails farm management operations that are based on observing, quantifying, and responding to inter- and intra-field crop variability. An another important aspect of SA is to synchronize to the ability of automated systems based on decisions taken by a Decision Support System (DSS) to ensure adequate returns on inputs while preserving resources [43].

With the change in time and constant advancements in agricultural domain, there has been a lot of inclination towards adaptation of sensor-based devices, which has created a new wave of change in farming concepts. Cultivation is dependent upon numerous factors like soil conditions, climatic variations, availability of water, *etc*. All the agriculture-related factors ran parallel and had an equivalent amount of significance in agriculture. It has been observed that there has been a rise in demand for agricultural facilities; however, there is a lack of resources [44]. Hence there is a requirement to adopt new-age practices for farming. Smart agriculture keeps track of almost all the parameters that were earlier looked over while performing agricultural activities [45].

Last few years have witnessed incorporation of various hardware devices (sensors) while performing agricultural practices. These devices help in determining some of the prominent parameters, such as Soil moisture (S_m), Soil temperature (S_t), Humidity *(H) etc.* in advance [46, 47, 48]. The results of predictions enable farmers to perform agricultural practices according to the requirements, that result in better yields. Apart from induction of agricultural sensors, various other devices, such as Global Positioning System (GPS) and Global Navigation Satellite System (GNSS) receivers, and drones have also been considered within the domain that help in navigating precise locations within the fields for collection of soil samples, crop monitoring, examining crop yield, terrain topography, evaluating the presence of nitrogen, potential of hydrogen (pH), magnesium (Mg), Electrical Conductivity *(EC)*, and Potassium *(K)* levels within the fields [49, 50]. In addition, cloud computing techniques make the process of agriculture much more easier for farmers, by giving them a facility to access agricultural data remotely. These practices, not only enhance farmer's capability, but also result in better crop yields [51]. All these techniques have helped agricultural domain in taking a gigantic leap. These techniques have also benefited farmers in numerous ways. With better land-use optimization, modern-day agricultural devices (sensors) enable farmers to ensure that every fertile bit of arable land on a farm is optimized for the best growing conditions [52]. In addition to the above, evaluations are also performed to estimate the precise water requirement for irrigation and fertilizer distribution within the fields [53]. IoT sensors are now being deployed within the fields with an aim to enhance green efficiency [54]. This domain has captured interest for both academic and industrial sector. Over the past few years, there has been a constant increase in number of publications. Figure 1.6 depicts the publication of research articles on SA for the last two decades.

The next subsection presents the significant importance of ICT and IoT in agricultural domain.

1.2.4 Significant importance of ICT and IoT in agricultural domain

The process of SA revolves around the general advancement made in the 21^{st} century to help farming be more prosperous by incorporating various ICT and IoT techniques. There are

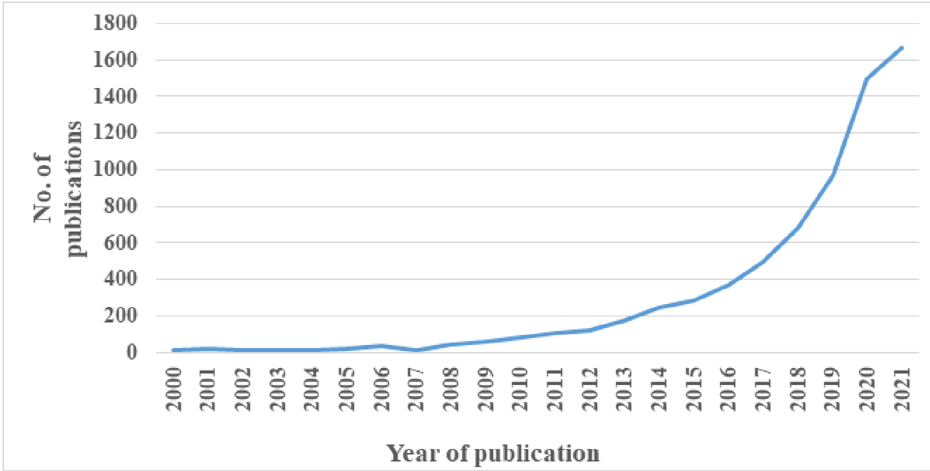


Figure 1.6: Year-wise publications on Smart agriculture domain (2000-2021)

numerous reasons to implement SA's practices into commercial and local farming. Some of the most prominent reasons for incorporating these practices are as under.

i Increasing global population

According to a United Nations (UN) study, the world's population will exceed 8.5 billion by 2030 and 9.7 billion by 2050 [55, 56, 57]. With an increase in population, the demand for food supplies will also incredibly enhance. Hence, to cater to the ever-increasing requirements, it is very much important to adopt new-age agricultural practices.

ii Water conservation

Water is a natural resource and has significant importance in agricultural domain. Blind practice of irrigating the fields will lead to its cessation [58]. Hence, estimating agricultural parameters in advance with the help of agricultural sensors help in evaluating the precise requirement of this resource as and when needed.

iii Lightens the workload, reduces human intervention, saves time and cost effective

Induction of IoT within the agricultural domain benefits farmers through a number of prospectives [59]. It not only enables the farmer to remotely monitor farm activities, but also helps in reducing human effort, provides real-time data evaluation of farms, saves time, making this process more effective [60, 61, 62, 63, 64]. Implementation of IoT in agricultural farms requires deployment of Artificial Intelligence (AI) within the proposed framework [65].

iv Reduces environmental footprint

Using IoT based agricultural techniques enables farmer to make minimal usage of fertilizers, provides efficient irrigation management strategies, and reduces livestock methane emissions which in return enhances soil's health [66, 67].

v Results in better yields

When computations are performed over sensed data, necessary decisions are made with an aim to enhance the yields. Based on the results, suggestive actions are undertaken that result in better yields and enhanced profits [68].

vi Eases the process of Decision Support System

ICT has the capability to deliver precise and accurate information among farmers at the desired time, allowing them to use it and reap the benefits. Farmers can improve upon field's yield by using ICT's decision support system so as to implement good agricultural techniques for cultivating, harvesting, post-harvesting, and marketing their produce [69, 70].

vii Widens Market Access

One of the primary limitations of the agriculture sector is the complexity of its distribution routes for agricultural output marketing. Farmers are unaware of current commodity pricing, the best locations for marketing their inputs, and consumer trends. For optimal benefit, ICT offers the ability to expand farmers' marketing horizons directly to customers or other appropriate users. Farmers can communicate directly with a large number of people and learn about current commodity pricing. They can access the market from the comfort of their own homes. Furthermore, it reduces the middle man profit, which will benefit the farmers. This can increase a farmer's cash stream, as well as empower them to make informed decisions regarding future crops and commodities, as well as marketing channels through which they can sell their produce and obtain inputs [71].

viii Strengthens and empower farming community

Through extensive networking and collaborations with various institutes, non-governmental organizations, and the corporate sector, ICT technologies can facilitate in the strengthening of farming communities. Farmers can also improve their own capabilities by accessing up-to-date knowledge and broad exposure to the scientific, farming, and trade communities [72].

ix Soil Quality Assessment

Soil quality can be assessed at the farm level as well as at the regional level. It can be done at the regional level based on soil, climate, and land usage. Some useful technologies aid in comprehending the nature of soil and the difficulties that it faces as a result of management techniques. ICT has undergone numerous transformations in recent years. The scope of the assessment of natural resource status has also broadened. Some relevant technologies are used to analyse soil quality, such as surface ponding, soil structure and consistency, soil porosity, *etc* [73].

Hence, from the above key points it evident that both ICT and IoT have a significant impact towards improving the current standings of agricultural domain. The next subsection highlights some of the most prominent key technologies used in SA.

1.2.5 Key technologies used in Smart Agriculture

Smart agricultural practices has got recognition over the years mainly due to its distinct key technologies, that has enabled this domain to scale newer benchmarks [74]. Some of the most prominent key technologies have been discussed as under.

i Remote sensors

Agricultural sensors is considered to be a mature technology as it is indeed one of the oldest and safest technique to be incorporated within the domain. Over the years agricultural sensors have been deployed within the fields for providing timely spectral information which can be used for various parameters that are directly or indirectly associated with crop growth and management [75, 76]. These agricultural sensors are paired over the Internet, that enables them to transmit the sensed data timely for further course of action.

ii Agricultural drones

Since technology upgrades itself every passing hour, Drones for agriculture are a good example of this trend. In the agricultural sector, drones are being used to improve farming methods. Farmers can use drones to get information on plant health indices, plant counting and yield prediction, plant height measurement, canopy cover mapping, field water ponding mapping, scouting reports, stockpile measuring, chlorophyll measurement, nitrogen content in wheat, drainage mapping, weed pressure mapping, and other topics. Figure 1.7 depicts an agricultural drone being put to use within fields.

Some of the most popular drones that are used within agricultural domain are Matrice 22 v2, eBee SQ, and PHX Senetra [77, 78, 79].

iii Cloud computing

With the help of agricultural sensors data is captured. However, storage of this data is of paramount importance. Cloud computing technique are then incorporated within

Figure 1.7: An agricultural drone spraying nutrients upon field

agricultural domain to store this data and retrieve it as and when required. Cloud computing service incorporated within the study offers services like Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS) at relatively cheaper costs [80, 81]. Figure 1.8 depicts a pictorial representation of Cloud computing services for the domain.

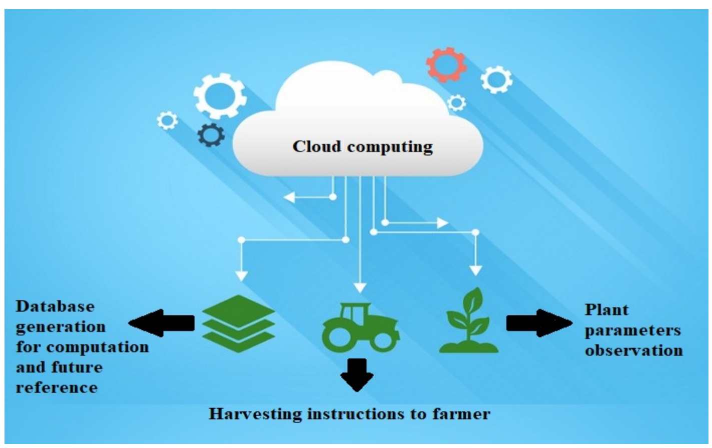


Figure 1.8: Cloud computing services for agricultural domain

iv Big data analysis

Data processing is an important tool for data capturing and securing. With the help of big data analytics it has become easy to identify the hidden patterns within the data. Mainly, big data analytics is used in agricultural domain for supply chain management of agro products with an aim to minimize the overall costs [82, 83, 84].

v Global Positioning System (GPS) and Global Information System (GIS)

Usage of GPS in agricultural practices provides its farmers to accurately navigate to precise locations within their fields, year after year, to collect soil samples, monitor crop conditions, *etc*. This technique allows farmers to remotely access and obtain the required information [85, 86]. On the other hand, GIS is all about analyzing the land, visualizing data on a map, mapping the acquired data to work, *etc*. Powered by GIS, SA enables informed actions and decisions by virtue of which farmers get the most out of each acre without damaging the environment [87, 88, 89].

vi Thermal imaging

In agricultural domain, thermal imaging is technique for precise identification, measurement, and visualization of heat patterns. This technique is used specifically in environments where there is lack of visible light. In addition, this application is incorporated to determine crop water stress, pathogen and disease detection among plants, irrigation scheduling, and maturity evaluation of fruits [90, 91].

vii Robotics

Agricultural robots are specialized articles that are capable of assisting farmers with a wide range of operations. These autonomous devices are programmed to carry out a multitude of functions mainly evolving them within the domain to match the requirements or to undertake tedious tasks on behalf of farmers [92, 93, 94]. Autonomous tractors, weeding devices, spraying machines, *etc.* are some of the most prominent and automated robotic devices that are used in agricultural domain [95].

viii Variable rate fertilizer

According to variations in soil type, there is a significant difference in fertilizer requirement among crops within the fields. Hence, to estimate the same requirement, computations are performed. This helps in a precise distribution of fertilizers within the fields, for better yield [96].

ix Sprinkler irrigation

This type of irrigation is similar to rainfall. In this technique, water is pumped using a pipe system and then sprayed uniformly with the help of sprinkler heads. The advantage of this type of irrigation technique is that areas, irrespective of their size, can be covered efficiently. Although, the trend of this type of irrigation technique is hardly seen within the fields these days due to over-and-above costs involved in the overall process as well as due to lack of knowledge of this technique among farmers. Secondly, its limited use can also be due to the mechanical aspect involved for installation of hardware devices within the fields.

x Drip irrigation

It is defined as the method in which water drips slowly via a pipe system to the roots of the plants either from above or below the soil surface. An another name given to this type of technique is micro-irrigation, by which both water and soil nutrients can be saved. Valves, tubes, pipes, and emitters are the various hardware used in this type of irrigation technique [97].

Incorporation of all these key technologies have not only helped agricultural domain in meeting the enhanced requirements for global food securities, but they have also revolutionized the way agricultural practices were earlier undertaken. The next subsection sheds light on various phases involved in SA domain.

1.2.6 Phases of Smart Agriculture process

Over the past few years, automation in agricultural domain has completely revolutionized the entire process. The generic process of agriculture begins with sowing the fields till harvesting of crops. This process transits through various phases. Each phase amalgamates with the new age technology, that ensures the correct usage of natural resources and involves practices to forecast potential problems that usually go unseen while performing traditional farming practices. This is only possible by correctly identifying the potentials of each phase, and then schedule future course of action. There are four essential phases in SA as depicted in Figure 1.9. The four phases of SA have been explained as under.

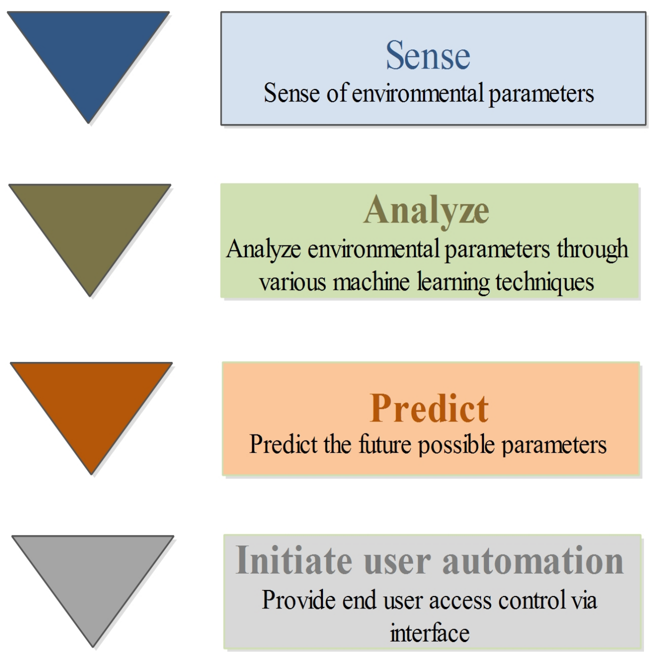


Figure 1.9: Essential phases of Smart agriculture process

i Sense

This is the first phase for the SA process. In this, various agricultural sensors are deployed within the fields, that generate observations on various parameters. As the data is observed, it is simultaneously transferred to the second phase, *i.e.*, the analyze phase.

ii Analyze

It is the second phase, where all the observations are analyzed over designated Machine Learning (ML) technique. Data is split in training and testing sets and computations are performed in the third phase, *i.e.*, the predict phase.

iii Predict

In this phase, final conclusions on the dataset are drawn and the most feasible solution is finally presented to its end user for consideration. This phase is the most important phase among all the four phases, as the outcome of the framework completely depends upon accuracy of predicted results.

iv Initialize user automation

This is the fourth phase, where necessary actions are undertaken by the end user (farmer) implements according to the outcome predicted by the proposed framework.

The next subsection highlights some of the most prominent challenges in SA domain.

1.2.7 Challenges in Smart Agriculture domain

Along with added advantages of new-age technology, there are several challenges that the agricultural domain has to face. Some of the most important challenges have been listed out as under.

i Interoperability of different standards

Interoperability is quickly becoming a source of worry, as newer devices are being introduced to the domain to further ease the process. Different tools and technologies don't always adhere to the existing technology standards or platforms. As a result, there is a lack of consistency in end-users' final analysis. Creating additional gateway(s) for translating and transporting data across standards becomes necessary in many cases. SA is currently scattered to a great extent, despite its rapid evolution. The difficulty is converting smart standalone devices and gateways into comprehensive farmer-friendly systems [98].

ii Adaptability of newer techniques and agricultural practices

Smart farming entails the use of cutting-edge technology to boost crop production. Setting up the proper IoT architecture and sensor network for farmer's field sometimes turns out to be a very difficult task. Before moving further with the implementation, it's critical to familiarize farmers with the concept of smart farming and the tools/devices [99, 100].

iii Internet connectivity in rural areas

Solid and consistent Internet access is lacking in most regions of the world, particularly in distant rural areas (specially in developing countries). As a result, attempts to use smart implement, smart agricultural techniques in such areas is a big challenge. Digital farming remains a challenge unless network performance and bandwidth speeds are greatly increased. Since many agro-sensors/gateways rely on cloud services for data transmission and storage, it is mandatory that cloud computing techniques should be improvised. Furthermore, GPS signal reception becomes a major challenge in farmlands with tall, dense trees and/or mountainous terrains [101].

iv Extracting vital information from Big data in agriculture

Big data is mainly characterized by some of the most unique features, *i.e.*, variety, volume, variability, and versatility. This vast reservoir mostly accumulates information in unstructured form. Information on agriculture in Big data is mainly in form of images (Red-Green-Blue (RGB) and multi-spectral), videos, sensor data. All this information is in abundance volumes and it becomes a challenging task to process this data [102].

v Lack of scalability and configuration problems

Agricultural farms come in a variety of sizes. A single owner can own a large crop-growing plot of land as well as multiple smaller plots. In a country like India, only 5% of the total number of farms account for approximately 33% of the entire area under cultivation, clearly demonstrating the unequal nature of farm sizes [103, 104]. In other words, on a huge commercial farm and a little plot of personal garden/cropland, same technology and benefits should be available. Another potential source of concern is the necessity to manually configure the devices. Self-configurable technology is required for agricultural domain to become totally autonomous [105].

vi Loss of manual employment

The sector employs approximately four out of every ten people [106]. As IoT in agriculture continues to grows more mainstreamed and things become more automated, a huge portion of the agricultural workforce is expected to lose their jobs. Other industries must be able to absorb this personnel, yet many developing and undeveloped countries' economies are not strong enough to do so. Although there is no reason to question the benefits of precision agriculture, the large-scale displacement of manual workers may cause public displeasure.

vii Benefits don't reflect spontaneously

Users, presumably have no idea on how better the returns they can capture from a "new technology" like smart farming. Indeed, there is absolutely no way to predict precise long-term benefits of SA, as they do not appear immediately. As a result, many landowners still term modern technology in agriculture as "risky" and "an uncertain" process, and therefore are hesitant towards implementation of these techniques. Such anxieties should dissipate when people have a better understanding of agri-tech and receive adequate training.

Hence, it is very much important to first clearly identify the possible challenges and eliminate all the identified ones in a systematic manner. Based on identified challenges, research gaps within the study have been drawn. The next section depicts the identified research gaps for the study.

1.3 Research Gaps

Agricultural industry has been experimenting largely for a makeover from the contemporary mode towards new age techniques. However, there are indeed some of concern areas, where proper observation and evaluation needs to be done before practicing newer methods. Some of the research gaps that have been identified are as under.

i Lack of soil health monitoring

Soil is an important natural resource just as the air and water. Over the years, this aspect has been completely been overlooked. There has been a constant downfall in crop yields across the regions, as there is no formal practice undertaken for monitoring soil's health.

ii Excess usage of water for irrigation

Various crops have their individual water needs. However, farmers blindly practice water distribution within the fields, which not only harms the crops, but also has adverse effects on soil and finally results in water crisis.

iii Usage of excess amount of fertilizers

Quite similar to excess water usage within the fields, another prominent issue in agricultural domain is the over and above distribution of fertilizers. This practice not only leads to depletion and exhaustion of the soil, but also results in low productivity, environment, and health concerns.

iv Lack of data analytics system available

Taking farm parameters into consideration is one of the most important aspects in agricultural domain. However, due to numerous reasons, this practice is overlooked by farmers. Understanding farm requirements and providing timely resolutions to all the addressable issues can certainly help in increasing farm yields.

v Existing solutions are complex and costly

In present scenario, all the existing solutions are too complex to understand and costly as well. Due to this reason, farmers hesitate to adapt these solutions and opt to practice farming activities through traditional techniques. Hence, there is a need for a low-cost solution to facilitate farmers.

vi Unavailability of user friendly interface

There are no dedicated web interface and mobile applications available among farmers for monitoring and controlling of various agricultural parameters on real-time basis. There is a dire requirement for proposing a low-cost architecture, that can provide suggestions enabling farmers to take timely decisions undertaking various agricultural practices.

From the aforementioned research gaps, following research objectives have been framed.

1.4 Objectives

Main objectives of this work are as follows.

i To study the existing automated techniques for irrigation and fertilization in Punjab.

ii To propose an IoT-based smart irrigation and fertilization framework to optimize the use of water and fertilizers in agriculture.

iii To develop a data analytics system for decision making.

iv To validate the proposed smart irrigation and fertilization framework.

1.5 Research Methodology

The following methodology has been followed to achieve the objectives of the research work.

i *To achieve the first objective*

- An extensive literature review has been done to gain in-depth knowledge for both the aspects, *i.e.*, IoT and SA.
- A review study related to the research work on various renowned electronic database (national and international conference(s), journals, workshops, letters to editors, and magazines) were focused.
- Initially the process of agriculture was categorized into six different phases. Furthermore, IoT's role in each phase was identified and explored in detail. An overview of all the phases of agriculture and the role of IoT in each phase has been discussed as under:

  (a) Soil properties and Sowing

  This is the initial phase that deals with evaluation of soil properties and the process related to sowing of seeds. IoT plays an important role in predicting the soil attributes and overcoming the manual process of sowing seeds through agricultural sensors, GPS co-ordinates, Spectroscopy techniques, and Unmanned Aerial Vehicles (UAV).

  (b) Irrigation and Fertilization

  The second phase deals with irrigation and fertilization distribution system.

IoT helps in maintaining optimum water level and yielding high quality crops through smart irrigation system, AI enabled technology, use of high-tech softwares, and modeling techniques.

(c) Growth and monitoring of plants

This phase focuses on the process of plant's growth and monitoring. In order to make the current process more efficient, Graphical User Interface (GUI) based image processing, ML techniques, 3D imaging technique, and IoT based bot notification technique have been discussed within the study by length.

(d) Crop protection

The fourth aspect in agriculture aims to monitor pest and disease control along with the detection of weeds in crops. Deep Convolutional Generative Adversarial Network (DCGAN) modeling technique, Deep Neural Network (DNN) technique, Completely Randomized Design (CRD) technique, and Advanced Fusion Technique (AFT) are some of the techniques evaluated within the study.

(e) Harvesting

This stage deals with the harvesting of crops. The use of Mixed Integer Linear Programming (MILP) technique, harvesting robot, Intelligent Harvesting Decision System (IHDS) mechanism, Multi-path Convolutional Neural Network (MCNN) technique, Principal Components Analysis (PCA) technique, Electro-magnetic Triboelectric Hybrid Generator (ES-ETHG) technique help in bringing automation and minimizing human intervention in the harvesting process.

(f) Stubble management

This phase deals with managing the farm residue burned by farmers to clear land and preparing the field for the next sowing season. Use of IoT-based techniques help in providing alternative measures to overcome the difficulties involved within the procedure associated with this process.

Based on the above reported key points, first objective is achieved.

ii *To achieve the second objective*

- A test bed in Malwa region of Punjab, *i.e.*, Patiala was developed to capture values related to identified parameters.
- Minimal Distribution of Water and Fertilization based Decision Support System ($MDW\&F_bDSS$) framework for optimization of irrigation and fertilization distribution within the field were proposed respectively.
- Prominent parameters associated with irrigation practices *i.e.*, Soil moisture (S_m), Soil temperature (S_t), Humidity *(H)*, Atmospheric Pressure (A_p), and Luminosity *(L)* were identified.
- To capture values, Libelium's Waspmote Plug and Sense device was deployed in the fields and various sensors were mounted over the hardware device.
- An IoT-based hardware system that consisted of relay (an electrical device) pump for initiating and disconnecting water supply within the fields was also proposed and implemented within the study.
- NPK sensor was deployed within the fields over Arduino Uno to capture values for evaluating the existing presence of fertilizers.

Based on the above reported key points, second objective is achieved.

iii *To attain the third objective*

- Data was captured using a variety of sensors was uploaded over a cloud server.

- On datasets associated with irrigation parameters, AutoRegressive Integrated Moving Average (ARIMA) and Long Short-Term Memory (LSTM) modeling techniques were implemented.
- An android based Farm Analyzer (weather data analytics) application has also been developed that provides live readings for various parameters under consideration and provides manual turn on/off of water valve.

Based on the above reported key points, third objective is achieved.

iv *To attain the fourth objective*

- Evaluated results of ARIMA and LSTM modeling techniques were compared among each other, with an aim to determine the best modeling technique among them.
- The results of the best technique identified were further compared with the results of other standard systems.
- To validate the functioning of the proposed system(s) and android application, testing was done on other fields.

Based on the above reported work, fourth objective is achieved.

A pictorial representation of various objectives and their attainment criteria(s) have been presented in Figure 1.10.

1.6 Research Contributions

Major contributions of this work are as follows.

- The present research study contributes to a great extent in the domain of IoT and SA. A significant contribution has been made in form of extensive literature review,

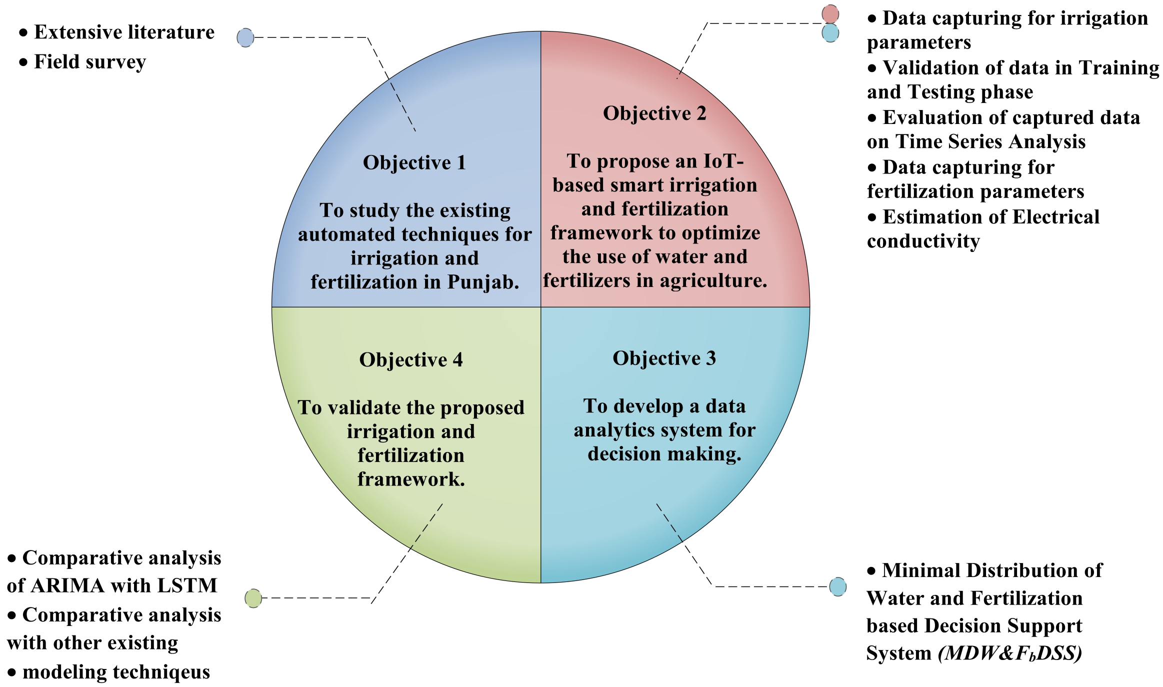


Figure 1.10: Objectives and their attainment criteria(s)

highlighting the various applications and challenges of IoT. In addition to this, a state-of-the-art survey has been carried out reflecting the impact of IoT on SA.

- Minimal Distribution of Water and Fertilization based Decision Support System ($MDW\&F_bDSS$) framework has been proposed within the study for monitoring and optimizing the irrigation requirement within the fields.

- Libelium's Waspmote Plug and Sense device has been deployed within the fields and dataset about different crops on various parameters, such as Soil moisture (S_m), Soil temperature (S_t), Humidity *(H)*, Atmospheric pressure (A_p), and Luminosity *(L)* have been collected. These datasets have been made publicly available for researchers to make computations using different modeling techniques.

- AutoRegressive Integrated Moving Average (ARIMA) and Long Short Term Memory (LSTM) modeling techniques have been implemented on the collected datasets and time series prediction has been done. The evaluated results are comparable with state-of-the-art techniques.

- NPK sensor was deployed within the fields to capture readings on various parameters to assess the existing presence of fertilizers.
- A web based application www.smartfasal.in has been developed that enables farmers for storing datasets, viewing real-time farm statistics, and their computed results.
- An android application Farm Analyzer has been developed that provides ability to remotely monitor farm statistics. This application in addition, provides information related to weather statistics and allows the farmer to remotely turn on/off the water valve for his fields.

1.6.1 Thesis Organization

The thesis has been structured into seven chapters. Figure 1.11 depicts pictorial representation for thesis organization. A brief overview of these chapters is as follows.

Chapter 1: Introduction

This chapter introduces the background of agriculture along with an overview of IoT and its various application areas. Also, a detailed description on SA has been presented in this chapter including the significant importance of ICT and IoT within the domain. Followed by the significant importance, key technologies, phases and challenges faced within the domain have also been discussed in detail. On the basis of detailed study on SA domain, various research gaps have been identified and objectives for the study have been framed. In the end of this chapter, research methodology has been discussed along with thesis contribution and organization.

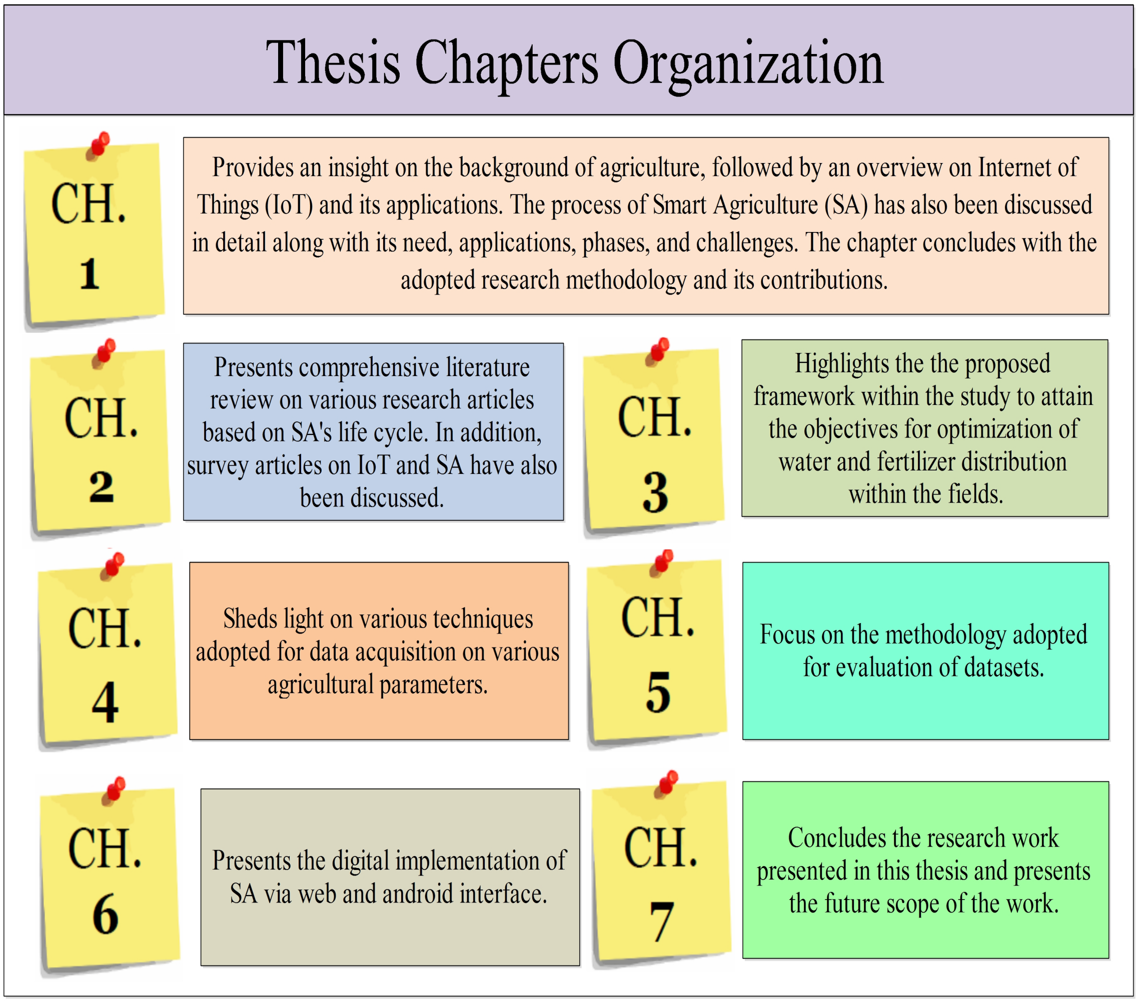


Figure 1.11: Thesis chapters organization

Chapter 2: Literature Review

This chapter includes a systematic review on various research articles published over the past few years based on IoT's impact on various phases of agriculture's life cycle. This chapter starts with the identification of gaps based on research questions based on IoT and SA domain. Furthermore, a review methodology has been followed to conduct this systematic review. To clearly reflect the interdependency of agricultural domain on IoT, the study first presents an overview of IoT along with its various communication techniques. The study then discusses research articles according to agriculture's life cycle, *i.e.*, soil properties and sowing, irrigation and fertilization, plant's growth and monitoring, crop protection from various diseases and weeds, harvesting, and stubble management. In addition, various survey articles published for IoT and SA have also been discussed within this chapter. At the end of this chapter some of the existing web portals and mobile applications have been discussed.

Chapter 3: IoT-based Smart Irrigation and Fertilization Framework

This chapter presents a detailed description about the proposed architecture within the study to optimize the process of irrigation and fertilization. This chapter starts with the discussion on the overview of IoT-based Smart irrigation and fertilization framework for the existing study. Minimal Distribution of Water and Fertilization based Decision Support System ($MDW\&F_bDSS$) framework has been proposed within the study for monitoring and optimizing the irrigation requirement and fertilizer distribution within the fields. The working of all the three different phases, *i.e.*, Sensor Network/Data Acquisition Layer (Phase 1), Storage and Computation Layer (Phase 2), and Menu-driven interface (Phase 3) within the proposed framework has been discussed in detail. In addition to this, evaluation of irrigation water needs for the soil and effective rainfall determination has also been discussed in this chapter. The concluding section of this chapter, highlights the proposed framework and working an IoT-based automatic water mechanism for irrigation. The study also sheds light on the hardware devices incorporated for practical implementation of the proposed framework.

Chapter 4: Data acquisition

This chapter highlights the strategy adopted to capture data on various agricultural parameters. A detailed description for geographical locations for various fields (testbeds), have been presented in this chapter. In addition, a detailed description related to technical and generic specifications for various hardwares devices incorporated along with their sensors has also been discussed. This chapter also presents a detailed description on various datasets for different crops taken into consideration. Post dataset collection, its storage strategy and pre-processing process has been discussed in the last section of this chapter.

Chapter 5: Time Series Analysis for evaluation of irrigation and fertigation requirement

This chapter presents a detailed discussion on various models available under Time Series Analysis. The preceding part of this chapter presents a detailed discussion on the results obtained by implementing ARIMA and LSTM modeling techniques on various datasets captured with the help of agricultural sensors to optimize the irrigation requirement within the fields. Results obtained after performing computations on both the modeling techniques have been compared and the best modeling technique among the two has been determined. The concluding section of this chapter presents a detailed discussion on technique adopted to evaluate the precise fertigation requirement within the fields.

Chapter 6: Web and Mobile applications for Smart agriculture

This chapter presents a web application for SA, available at www.smartfasal.in. The interface of the portal has been designed to host datasets for various fields (testbeds). In addition, the web interface also provides technical specifications on the hardware device incorporated within the study for conducting experimentation to optimize the process of irrigation. The user of the interface can view live readings and results of the predictions done by the incorporated ML technique. This chapter also discusses the interface for the android application Farm Analyzer. Similar to the web interface, the user can view live readings and results of computations in the form of values and graphs for all the parameters. The interface also provides a calculative value for the precise requirement of water within the fields for various crops. Lastly, the interface provides a toggle button that enables the farmer to turn on/off the water valve according to the field's current statistics.

Chapter 7: Conclusion and Future Scope

This chapter concludes the research work presented in this thesis and presents the future implications. It has been concluded that the results given by the system are very promising as the practical implementation reflects a reduced consumption in water and fertilizer requirements. In future, various new techniques can be incorporated such as image dataset processing to identify crop disease, identification of weed among crops and plants, targeted spray treatment on infected crops, optimization of the irrigation pattern and its advance scheduling.

Chapter Summary

This chapter sheds light on the background of agriculture and its significant importance has been discussed in its introductory section. From the basics of agriculture, the focus of the study also provides an insight on the significance of IoT. Furthermore, its need, various applications, and challenges faced on its deployment have been discussed extensively. After an overview of IoT, the focus of the study again shifts to SA providing its importance and current standings. The next section of this chapter depicts the inter-dependence of SA on IoT, followed by its need, applications, various techniques for performing SA practices, different phases involved within the process, and challenges encountered in its implementation. On the basis of in-depth study, routes the flow of the study towards identification of potential gaps. Based on identified gaps, objectives for the study have been laid. The next section discusses the methodology adopted to attain the goals laid for the study. The concluding part of this chapter is thesis organization that presents an outline overview for all the thesis chapters.

Chapter 2

Literature Review

In this chapter, a systematic review on SA has been presented relating to its various phases of life cycle. Since IoT plays a significant role in SA's implementation, the initial sections of this chapter focus on the clear identification of gaps based on some prominent research questions. This chapter furthermore presents significant documentation that eliminates doubts on IoT's considerable impact over agricultural domain's, followed by a detailed description on various communication techniques. This chapter also highlights various survey articles published over the past few years. On the basis of detailed discussion on various research articles, the concluding sections of this chapter highlights some of the most prominent web portals and mobile applications that are of paramount importance in agricultural domain. Lastly, issues based on extensive literature review have also been discussed in this chapter.

The next section discusses the analytical methodology that has been followed to carry out this systematic review.

2.0.1 Review methodology followed

A systematic review for both the aspects, *i.e.*, IoT and SA have been conducted on the basis of following steps.

Development of review protocol

A systematic evaluation has been carried out by determining potential research studies after reviewing plethora of manuscripts from various journals, national and international conferences, and edited volumes. After identification of potential articles, to narrow down the total count of selected studies, inclusion and exclusion criteria has been followed. The final research studies considered for the existing study has been selected based on the formulation of research questions as discussed in Table 2.1 and various phases of SA's life cycle. Extraction of research articles has been done by querying scholarly databases by searching keywords such as "Internet of Things", "IoT", "Smart Agriculture", and "Precision Agriculture". Since there are no substantial differences between both the terms, "Smart Agriculture" and "Precision Agriculture", therefore both the terms has been used to identify potential research articles for extensive literature review. Final research studies have been selected based upon the relevance of content, and its significant impact on the domain under consideration.

Identification of gaps based on research questions

The intent of conducting literature review was to identify IoT and SA's individual roles and to classify queries related to both the domains. In the same context, some of the most prominent research questions that help in the proper planning and implementation of the survey article have been listed in Table 2.1.

Table 2.1: Research questions taken into consideration for conducting the systematic review on IoT and SA

Research Questions
RQ 1. What is the development/evolution track of IoT?
RQ 2. What are the various communication mediums under IoT's preview?

Research questions were taken into consideration for conducting the systematic review on IoT and SA. (continued)

Research Questions
RQ 3. What is the significant importance of IoT?
RQ 4. What sort of prominent work has been done in the field of IoT?
RQ 5. What is the significance of IoT in agricultural domain?
RQ 6. What sort of prominent work has been done in the field SA?
RQ 7. What are the different parameters considered for performing SA?
RQ 8. Which are the available on-line web portals and mobile applications catering SA domain?

Sources of information

This systematic survey has been carried out in accordance to the recommendations suggested by Kitchenham *et al.* (2007) [107]. A systematic keyword-based advanced search has been used to extract significant research studies from several e-databases (2002 onwards) as depicted in Table 2.2.

Table 2.2: Keyword-based advanced search for SA,PA, IoT, and Internet of Things
C: Conference; J: Journal; W: Workshop; L: Letters; M: Magazines

Source	**Publication type**	**No. of publications**
Google Scholar *(www.scholar.google.co.in)*	C, J, W, L, and M	312
ACM Digital Library *(www.acm.org/dl)*	C, J, W, L, and M	108

Keyword-based advanced search for SA,PA, IoT, and Internet of Things (continued)
C: Conference; J: Journal; W: Workshop; L: Letters; M: Magzine

Source	**Publication type**	**No. of publications**
IEEE Xplore *(www.ieeexplore.ieee.org)*	C, J, W, L, and M	121
Springer *(https://link.springer.com)*	C, J, W, L, and M	120
Elsevier *(https://www.elsevier.com/en-in)*	C, J, W, L, and M	92
Wiley Online Library *(https://onlinelibrary.wiley.com)*	C, J, W, L, and M	58

Before beginning the search, a suitable set of e-databases were selected to identify relevant as well as potential research publications. The electronic databases that have been used for locating research studies are Google Scholar *(www.scholar.google.co.in)*, Science Direct *(www.sciencedirect.com)*, ACM Digital Library *(www.acm.org/dl)* and IEEE Xplore *(www.ieeexplore.ieee.org)*. Majority of the articles selected for the existing study are published in National/International Conference(s), Journals, Proceedings, Transactions, Databases, and Magazines. The redundant papers on Science Direct, ACM Digital Library, and IEEE Xplore have been excluded before the final selection of research articles. A total of 310 papers out of a complete database of 811 papers have been shortlisted weighing the pros and cons of variables and parameters. Each paper was analyzed, discussed, and then it was further classified to a specific domain category. Figure 2.1 depicts the selection procedure for the extraction of research articles based on abstracts, title, and keywords.

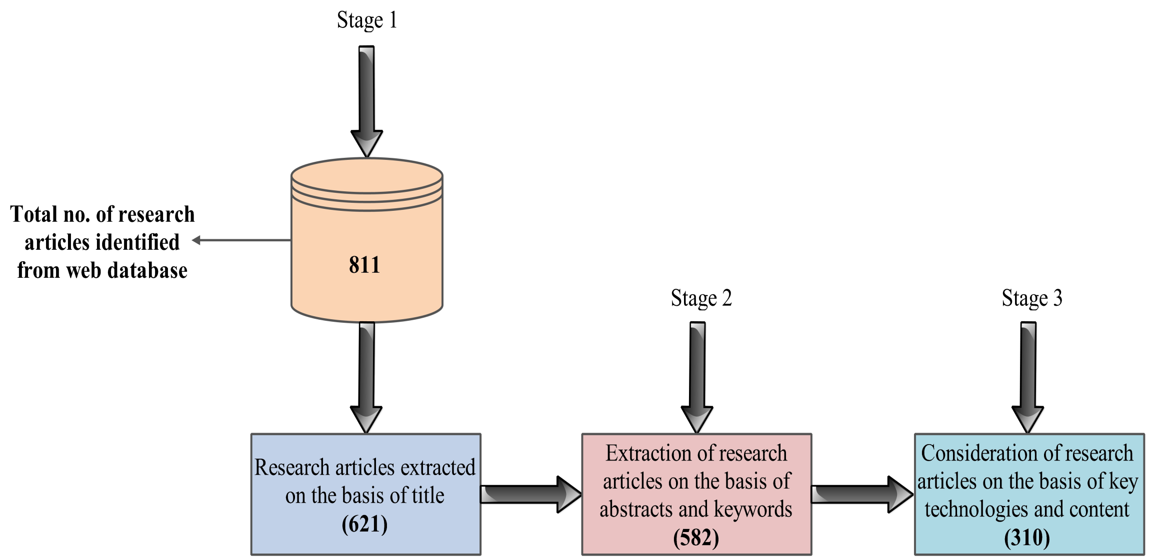


Figure 2.1: Study selection procedure

The next section presents an insight on the development/evolution track of IoT over the past few years.

2.1 IoT - An era of transformation

Over the years, IoT has become the backbone for numerous applications. Initially, it was considered as a newer version of Information Technology (IT), which was designed to pair with hardware devices. Gradually, this concept was incorporated into various streams, *i.e.*, Software Engineering (SE), Data science, visual analysis, application development, *etc.* Over the years, IoT has witnessed a significant change in conceptual functioning. The proceeding subsections present an insight about its evolution and transformation over past few years.

2.1.1 Evolution of IoT

During the last few years, IoT has steadily seized control of billions of devices by adding sensor(s) based on their functional capabilities [108]. When sensor(s) are connected over the Internet, massive amounts of data are generated, which is further used for processing and decision-making. There has been a steady increase in the adoption of new-age communication technology over the years. To date, the world is deployed with 5 billion smart devices [35]. It has been predicted that over 50 billion devices will be connected over the Internet by the year 2025 [109]. The incremental value of IoT is expected to exceed $300 billion by the end of the decade, as per the estimates. This expands the possibilities for developing new communication technologies and discovering new ways to connect newer gadgets and sensors over the Internet. However, evaluating the practical capabilities of IoT without first knowing its working strategy, time-to-time updates, and developments may be inaccurate. Figure 2.2 depicts the constant increase of devices associated over the Internet during the last few years and an estimated projection till 2025.

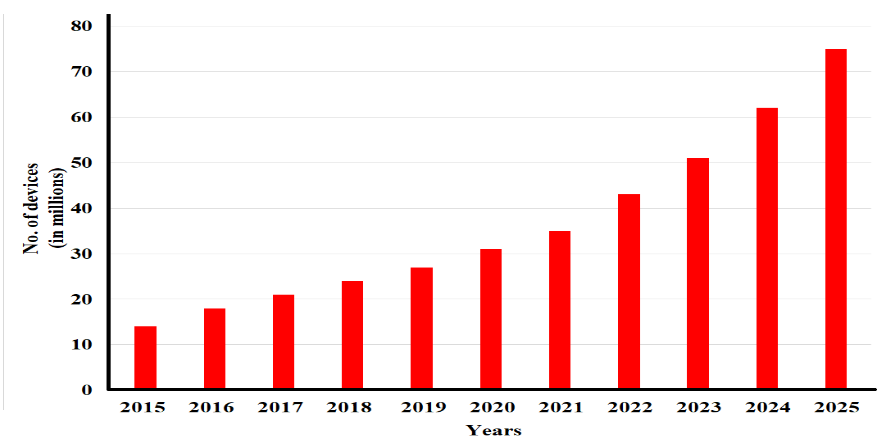


Figure 2.2: Projection in number of devices being associated over the Internet (2015-2025) [110]

In the early 1990s, the term of IoT was initially proposed [111]. However, in 1999, the term was coined for the first time by Kevin Ashton [112]. The very first IoT application that researchers had developed was Trojan Room Coffee Pot. A year later, *i.e.*, in 2000 Lucky-Goldstar (LG) launched Internet Digital DIOS (an IoT based refrigerator). In 2003, Radio-Frequency Identification Network (RFID), a communication technique under IoT was deployed for the very first time. Two years later, in 2005 International Telecommunications Union (ITU) published its first report that focused on IoT [113]. Two years later, a group of companies launched IPSO Alliance to promote Internet Protocol (IP) within networks of "Smart Objects" to enable the IoT. During the fourth quarter of 2008, IoT gained formal recognition from European Union (EU), and after a year's gap the first IoT conference was also held. Chinese premier Wen Jiabao stated IoT as the key industry for their nation in 2010. Taking note of the gaining popularity of IoT in 2011, IoT-Global Standards Initiative (IoT-GSI) was established, that aimed to cater to the promotion of an unified approach for the development of technical standards on global basis. Commercial and Industrial Security Corporation (CISCO), Ericsson, and International Business Machines (IBM) initiated the development of large-scale educational and marketing initiatives for IoT in the year 2012. In 2013, various hardwares, *i.e.*, Arduino, Raspberry Pi, and other hardware platforms took center stage and started making IoT-based devices, that helped in expansion of IoT's usability by all possible means. In 2014, 3^{rd} party devices, such as, Drones, RFID, *etc.* were incorporated with IoT extensibility. By the year ending 2016, IoT products were available in market, portraying as gimmicks in various forms and shapes. An year later, *i.e.*, in 2017, the first IoT malware was identified [114]. By 2018, the concept and usage of IoT had flourished majorly as the government initiated various policies to regulate and scrutinize IoT security. In the year 2019, IoT's focus has been shifted to crypto-currency. Lastly, in 2020, Secure Access Service Edge (SASE) initiated the future of network security over IoT. Figure 2.3 depicts IoT's evolution and its achievements during the recent years, whereas Table 2.3 depicts references for Figure 2.3.

Since the term Internet has witnessed a significant transformation, it can be co-related to a

Table 2.3: References for IoT's evolution for various years as depicted in Figure 2.3

Year of Evolution	Terminology derived	Reference
1990	IoT's concept was proposed.	[115]
1999	IoT's term coined for the very first time.	[116]
1999	First IoT application was developed, *i.e.*, a Trojan Coffee Pot in the year 1999.	[117]
2000	First Internet refrigerator, Internet Digital DIOS was launched by LG.	[116]
2003	Commercial deployment of RFID for the very first time.	[118]
2005	ITU's first report on IoT.	[119]
2005	Group of companies launched IPSO Alliance to promote the use of IP within networks of "Smart Objects" to enable the IoT as a service platform.	[120], [121]
2008	EU gives recognition to IoT.	[122]
2010	Chinese premier Wen Jiabao termed "IoT" as the key industry for China's development.	[123]
2011	IoT-GSI, a standardization group was established.	[124]
2012	Cisco, Ericsson, and IBM started developing large scale educational and marketing initiatives on IoT.	[125]
2013	Arduino, Raspberry Pi and other hardware platforms matured and started making IoT accessible devices.	[126], [127], [128], [129], [130]
2014	Usage of 3^{rd} party devices *i.e.* Drones, RFID, *etc.*, were incorporated with IoT extensively.	[131]
2016	IoT products were available in the market potreying as marketing gimmix.	[132]
2017	First IoT malware identified.	[133], [134]
2018	Government initiates policies to regulate IoT security.	[135]
2019	Crypto-currencies focus on IoT.	[136], [137], [138]
2020	SASE initiates the future of network security over IoT.	[139], [140]

series of phases. The next subsection sheds light on various transformation phases.

2.1.2 Transformation from Pre-Internet to IoT

The term of IoT gained recognition with the passage of time and constant advancements within the domain. The term's initial name transformed from, "Internet" to "IoT" after passing a series of phases, as depicted in Figure 2.4.

The initial phase was the Pre-Internet phase, where communication was possible only over a fixed telephone line or via Short Message Service (SMS). Later this communication medium was upgraded with mobile telephony services, *i.e.*, Global System for Mobile Communi-

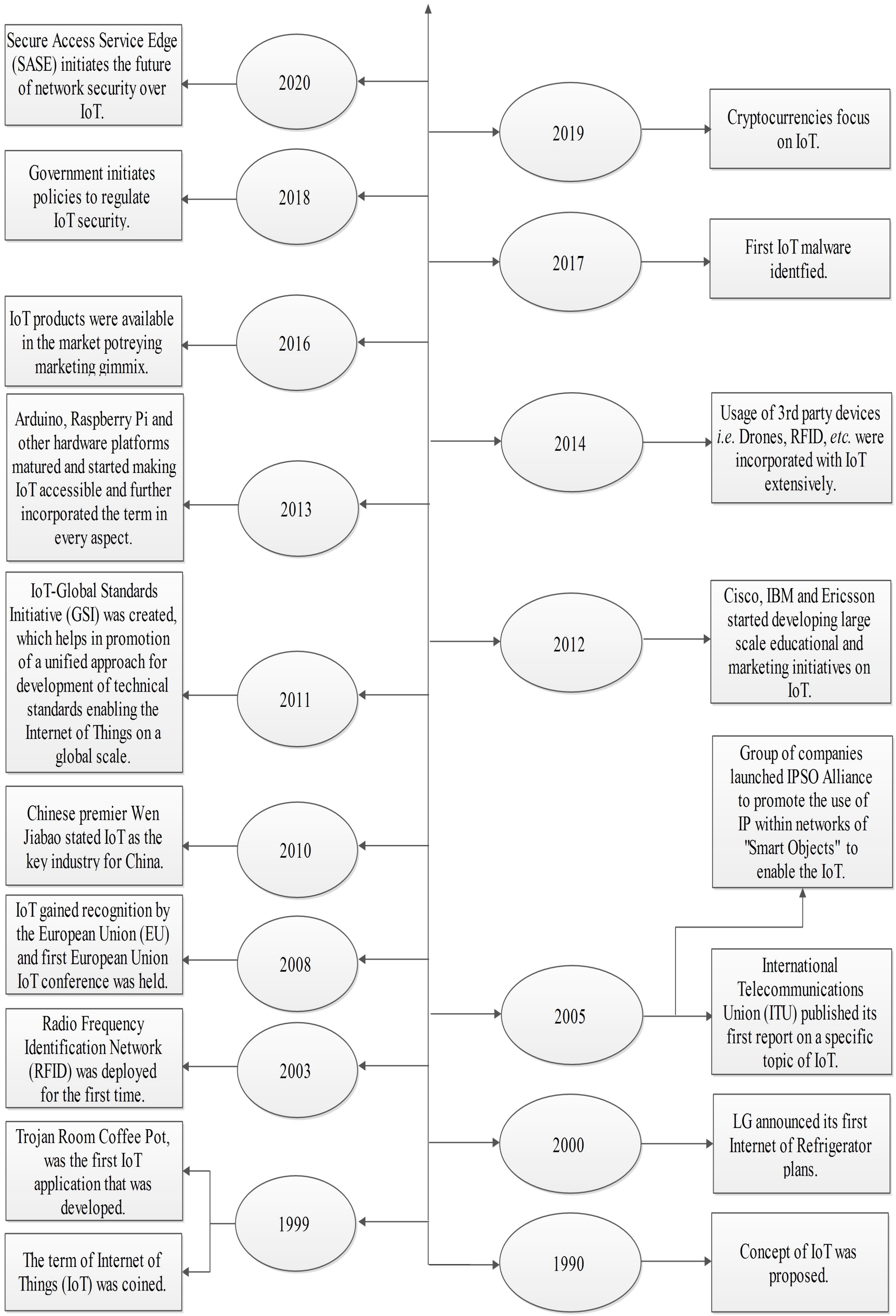


Figure 2.3: Evolution of IoT

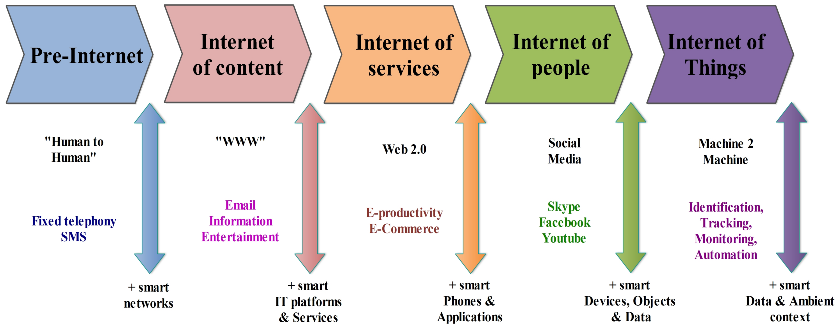


Figure 2.4: Transformation of Internet from Pre-Internet to IoT

cation (GSM). The second phase was of content based over the Internet. This phase was capable of sending large-sized messages, *i.e.*, an e-mail, which was capable of associating attachments. Information sharing, entertainment access, *etc*. were some of the basic possibilities within this phase. The third phase was of Internet of Services (IoS), that focused on bridging a communication source over various electronic applications, such as, e-commerce, e-productivity, *etc*. The fourth phase was termed as Internet of people. In this phase people got associated with each other through social media and numerous other mediums, such as, Facebook, Orkut, Skype, YouTube, *etc*. The ongoing era is the IoT phase. The functional aspect of this phase is that it has the capability of connecting and communicating various devices over the Internet. Hence, these devices enables themselves and communicate with each other to perform several activities as directed/programmed by the its user.

However, the present era may not be treated as the concept's final destination. Researchers are attempting to embed AI principles with these interconnected gadgets so that they can make necessary decisions and take immediate action without the human intervention. It is possible that the next phase of IoT will be powered by IoT-Artificial Intelligence (IoT-AI), which will increase the demand and dependency even further.

Significantly, IoT has gained a good reputation within the agricultural domain due to its continuous advancements over the past few years. The interdependency of both aspects gives space to several significant gaps for a further scope of research. The next subsection highlights various communication techniques incorporated by various hardware devices to transmit data over the Internet.

2.1.3 Communication techniques

There exists an almost bewildering choice of connectivity options for modern-day devices and applications. These communication devices vary primarily in terms of size and capability. Communication devices are chosen based on the end-product and its service horizon. These communication devices enhance the functional capability of the device and enables the device to be remotely connected to its end-user. Some of the most prominent communication technologies in IoT have been discussed under and a diagrammatic description for the same has been reflected in Figure 2.5.

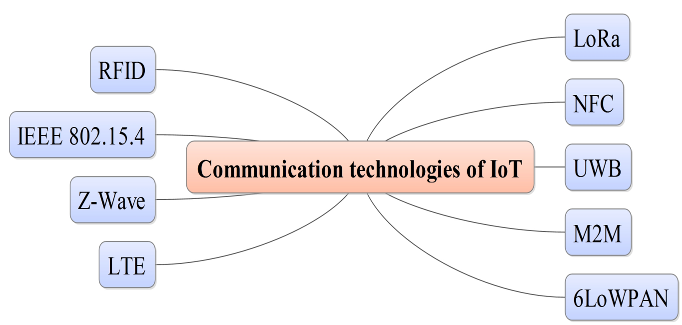


Figure 2.5: Communication technologies of IoT

i RFID

RFID tags are identified by a unique address and attached to various hardware devices. They transfer data associated with an object via radio-frequency electromagnetic waves [141].

ii IEEE 802.15.4

It is a standard for Low-Rate Wireless Personal Area Network (LR-WPAN) that specifies the physical layer and media access control. The working model of IEEE 802.15.4 supports a 2.4 GHz ISM band, whereas the original version supported 826 and 915 MHz frequency bands. The fundamental architecture specifies a communications range of 10 metres and a transfer rate of 250 kbit/s [142].

iii Zensys Wave (Z-Wave)

For Home Automation Networks (HAN), Z-Wave is a low-power wireless communication standard. It is commonly utilized in remote control applications for smart homes and small businesses. It uses 868.42 MHz bandwidth in Europe, while 908.42 MHz bandwidth is used in Canada and the United States of America. Between two nodes, the distance should not exceed more than 30 meters.

iv Long Term Evolution (LTE)

LTE is a standard wireless communication protocol which is based on GSM network technologies, that is mainly used for high-speed data transport between mobile phones. This technique is capable of handling speeds of up to 100 MHz. During data upload and download, the latency rate is frequently lower [143].

v LongRange (LoRa)

LoRa is a digital wireless data communication technology invented by Cycleo in Grenoble, France [144]. This technique was later acquired by Semtech in 2012. This technique is mainly used in rural, remote, and offshore businesses for long-range communication among various IoT devices. Apart from the aforementioned applications, LoRa is also used in supply chain management, transcontinental logistics, mining, natural resource management, and many more applications to say the least [145].

vi Near Field Communication (NFC)

NFC and RFID are quite similar in terms of functioning. NFC is a unique type of radio communication technology that is enabled on mobile devices either by tracing innate settings that need to be engaged or by two devices being in close proximity to each other [146].

vii Ultra-wideband (UWB)

UWB communication technology is similar in terms of functioning to NFC. It is meant to facilitate communications within low-range coverage zones. High-bandwidth applications, on the other hand, are utilized to connect sensors for transmission. It can handle a maximum bandwidth of 500 MHz. It was earlier referred as Radio pulse technique.

viii Machine to Machine (M2M)

Intern-communication between two computers, embedded processors, smart sensors, actuators, or mobile devices is referred to as M2M. During the previous few years, the use of M2M communication has increased at a rapid rate [147].

ix IPv6 Low-power Wireless Personal Area Network (6LoWPAN)

6LowPAN is an IP based technology. Encapsulation and header compression methods are defined in this as network protocol. The standard allows for frequency range and physical layer flexibility, and it can also be utilized on a variety of platforms, including Ethernet, Wi-Fi, IEEE 802.15.4, and sub 1 GHz ISM.

Table 2.4 depicts technical specifications for various communication technologies used for IoT communication.

Some of these communication devices are incorporating in agricultural domain, to transmit various agricultural parameters for analysis. Since the focus of the study is on the SA domain, the next section presents a detailed literature review on some of the most prominent research articles of the agricultural domain based on SA's life cycle.

Table 2.4: Overview of various communication technologies used for IoT communication

Technology	Standard	Year of Discovery	Downlink /Uplink	Range (in metres)	Operating Frequency (in MHz)
RFID	Wireless	1973	100 kbps	2	0.125-5876
IEEE 802.15.4	6loWPAN	2003	250 Kbps	30	826 and 915
Z-Wave	Wireless	2013	100 kbit/s	30	868.42, and 908.42
LTE	3GPP, LTE, and 4G	1991	100 Mbps	35	400 - 1900
NFC	ISO 18092	2004	106, 212 or 424 Kbits	0.2	13.56
UBW	IEEE 802.15.3	2002	11- 55 Mbps	10 - 30	2400
M2M	Open for all communication protocols	1973	50 - 150 Mbps	5 - 20	1 - 20
6loWPAN	Wireless	2006	250 Kbps	30	915

2.2 State-of-the-art work on various phases of agriculture's life cycle

The process of agriculture consists of six phases majorly, as depicted in Figure 2.6.

Every phase of agriculture is of paramount importance and plays significant role. The next subsection discusses the state-of-the-art research work done for each phase based on IoT's prospective. The first phase of agriculture's life cycle is evaluation of soil properties and sowing of seeds.

2.2.1 Soil properties and Sowing

Soil is a crucial element of agriculture domain. It helps to regulate the key ecosystem processes, *i.e.*, fertilizer intake, decomposition, and water availability. Predicting soil qualities is an initial and most significant aspect, as it determines the procedure required to prepare the

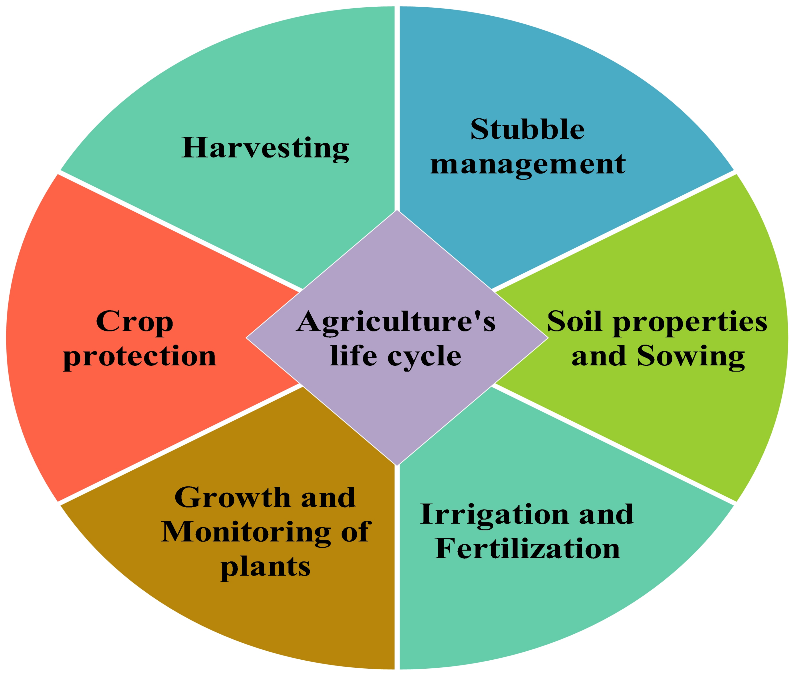


Figure 2.6: Various phases of agriculture's life cycle

land, crop selection, seed selection, crop yield, and fertilizer/manure selection. Predicting soil nutrients, humidity level for the soil surface, meteorological conditions, *etc.* during the crop's life cycle are all necessary soil attributes.

Seed also has a significant importance in agricultural domain. Hence, it is essential to minimize seed loss and maintain a proper germination condition for growing a seed to grow healthy and high crop productivity, proper seed placement, seed rate, and uniformity of seed is desired. To attain a higher percentage of yield, an economical and effective solution is the deployment of agricultural sensors within the domain. This technique provides a proper depth sowing, uniform seed germination throughout the field, and eliminates the problem of seed blockage. Various agricultural sensors, such as Ultrasonic sensors, Linear variable differential sensors, *etc.* are some of the most prominent agricultural sensors which can measure the depth of the sowing in dusty field conditions. An infrared sensor or photoelectric sensor is ideal for calculating the seed rate and status of the seed tube [148]. Based on the usage of these agricultural sensors, several experimentations and studies have been conducted during the past recent years. Some of the most prominent research findings under this category are discussed as follows.

Chaudhry *et al.* (2011) in their study proposed the usage of WSN within a Greenhouse environment. Furthermore, the study suggests evaluation of various agricultural parameters, *i.e.*, soil type, atmospheric pressure, soil temperature, humidity and presence of CO_2 within soil. Control on air vents and heating devices were administered through various sensors to control the variations in soil properties within greenhouse. The study proposes induction of Programmable System on Chip Technology (PSoC) within agricultural practices as a part of WSN, that helped in controlling and monitoring of various parameters of greenhouse and soil properties [149].

Chen *et al.* (2012) in their study highlighted the popularization of IoT within the agricultural domain. To overcome issues related to communication while evaluating soil properties, Routing Protocol for Low-power and Lossy Network (RPL) technique was proposed within the study. Two case studies, *i.e.*, ContikiRPL and TinyRPL have been discussed within the article. Furthermore, the results obtained after performing simulation experiments over RPL capable COOJA simulator further helped in the evaluation of soil properties [150].

Gomez *et al.* (2014) in their study proposed usage of GPS coordinates generation to determine the positioning points for crop distribution within the fields. The proposed system generated information related to path planning within the fields, that helped in determining the drones traversing path in advance without damaging the crops. On this travel route, the drone sprayed liquid fertilizers upon crops in a well controlled and an efficient manner [50].

Ojha *et al.* (2015) in their study highlighted the advent of WSN techniques that spurred a new direction of research within the field of agricultural domain. The study focused on highlighting the functional potentials for various WSN applications, challenges, and issues associated with its deployment for improved farming practices. Numerous case studies have been explored within the study that highlights the current standings in the field of agriculture. In addition, various solutions have been proposed concerning associated problems [151].

Maia *et al.* (2017) in their study highlighted issues related to the evaluation of soil properties to sow appropriate crop within the fields. Furthermore, the study depicted evaluation of various measures to prevent soil erosion and overuse of artificial as well as natural resources. A real-time, in-situ agricultural IoT based device was proposed within the study to monitor soil and other associated environmental parameters. Experiments were conducted within the fields of Sao Paulo, Brazil on various parameters, such as conductivity, humidity, soil temperature, *etc.* to evaluate soil conditions. Climate parameters have also been taken into consideration for evaluating crop's health [152].

Diwate *et al.* (2018) in their study discussed issues related to the process of sowing while performing agricultural practices. Since the process is tedious, time-consuming, and requires a huge amount of workforce, therefore to overcome these issues, the study suggested usage of agricultural drones for sowing of cotton seeds at a designated location, that took less time to complete the process. Quad-copter, a UAV was deployed for performing experimentation. The drone was controlled via bluetooth and Wi-Fi. The drone incorporated for experimentation had 3-axis gyro (ITG3205), 3-axis accelerometer (BMA180), 3-axis magnetometer (HMC5883L), Barometer (BMP085), GPS receiver (MTK3329), and 2-Ultrasound distance sensors (HC-SR04) [153].

Gowrishankar *et al.* (2018) in their study proposed sowing and spraying of pesticides using Agribot (an IoT based robot). The robot was designed to keep the safety and health of agricultural workers on priority. The aim of developing this autonomous robot was to minimize human intervention, ensuring enhanced yield and efficient utilization of available resources [154].

Huuskonen *et al.* (2018) in their study focused on the paramount importance of soil sampling. Various sensors were deployed within the fields that captured information on agricultural parameters enabling them to make proper decisions on improving agricultural practices. A novel approach to determine the locations for soil samples based on a soil map through an autonomous mode was created through drone imaging after ploughing the fields. A wearable augmented reality technology was incorporated within the study that guided the user precisely at generated sample points. To attain the objective, DJI Phantom 4 Pro (a drone) was incorporated within the fields that helped in capturing of images for evaluation purpose with the help of a RGB camera mounted beneath the incorporated drone [155].

Coutinho *et al.* (2019) in their study proposed evaluation of sampling density as an important parameter with an aim to identify the spatial variability properties within soils. To attain the objective, soil sensors and spectroscopic techniques were considered for the experimentation. Evaluation of results depicted some limitations in characterizing the chemical fertility of soils. Furthermore, the study aimed to evaluate the effect of sieving and drying temperature, based on the determination of nitrogen, phosphorus, and potassium presence within soil by using two different spectroscopy techniques, *i.e.*, Vis-NIR and Mid-Infrared [156].

Jin *et al.* (2019) in their study highlighted issues related to estimated concentration of carbon dioxide ($_eC0_2$) on grain nutrient. Since, soil types are often misunderstood by farmers, therefore gain enhanced nutritional quality, rotation in crop cultivation among wheat, field pea, and canola were practiced. Experimentations resulted in decreased concentrations of Nitrogen Phosphorus Potassium (NPK), specially for canola and wheat crops [157].

Pang *et al.* (2020) in their study proposed the potentials of Hyperspectral imaging technology and Convolutional Neural Networks (CNNs) technique to predict maize seed viability within the fields. Hyperspectral imaging information (for 144 samples) was collected for 10 hours before the process of germination of four vigor level seeds. Support Vector Machine (SVM) and One-dimensional Convolutional Neural Network (1-DCNN) were considered within the study to model the spectral data set. The results of the outcome helped in comparing the effects of multi-dimensional scattering correction, and principal component analysis [158].

Yamunathangam *et al.* (2020) in their study focused on usage of UAV within the agricultural domain. To overcome the manual and tedious process of sowing seeds, Pixhawk Flight Controller, a UAV, was incorporated within the study for seed dispensing at desired locations within the fields. Automation through UAV reduced human intervention and saved time [159].

Table 2.5 depicts a comparative analysis of various articles discussed under the process of Soil properties and Sowing.

Table 2.5: Comparative analysis of various articles discussed under the process of Soil properties and Sowing

Author, Year of Publication, & Citation	**Objective**	**Application proposed/ Hardware device incorporated for study**
Chaudhry *et al.*, (2011), & [149]	Evaluation of climatic conditions	PSoC
Chen *et al.*, (2012), & [150]	Perform simulation on soil properties based on COOJA simulator	RPL
Gomez *et al.*, (2014), & [50]	Automation in sowing of seeds within fields	GPS+GIS based automatic sowing mechanism
Ojha *et al.*, (2015), & [151]	To improve farming practices from sowing to harvesting	Proposed design and implementation related parameters

Comparative analysis of various articles discussed under the process of Soil properties and Sowing (continued)

Author, Year of Publication, & Citation	**Objective**	**Application proposed/ Hardware device incorporated for study**
Maia *et al.*, (2017), & [152]	Evaluation of soil properties to sow appropriate crop within fields, and prevention of soil erosion	In-situ Agricultural Internet of Things (AIoT)
Diwate *et al.*, (2018), & [153]	Sowing of cotton seeds	Automatic UAV based seed sowing mechanism
Gowrishankar *et al.*, (2018), & [154]	Automation in sowing of seeds	Agribot, an IoT based robotic device
Huuskonen *et al.*, (2018), & [155]	Determination of soil properties	Remotely Piloted Aircraft System (RPAS)
Coutinho *et al.*, (2019), [156]	Evaluation of soil samples for distribution of fertilizers	Diffuse Reflectance Spectroscopy
Jin *et al.*, (2019), & [157]	Effect of 7-year CO_2 treatment on grain nutrients	Optima 8000 and CHNS/O analyser
Pang *et al.*, (2020), & [158]	Estimation and prediction of corn seeds	Hyperspectral imaging technique
Yamunathangam *et al.*, (2020), & [159]	Distribution of seed sowing pattern	Payload seed sowing technique

The next subsection presents articles related to the second aspect of SA's life cycle.

2.2.2 Irrigation and Fertilization

Water management approaches are mainly taken into consideration due to an increased threat on its scarcity and to ensure its availability for agricultural production. By incorporating IoT-driven WSN platform in SA, it can revolutionize the significance of information. Smart irrigation systems are now being deployed across the globe to reduce water consumption while performing agricultural activities. Controlling and monitoring of irrigation situation can now be done through on-line platforms and various mobile applications. Smart irrigation system saves precious resources without subjecting plants to moisture deficiency that can be measured with the help of a digital hygrometer or through various agricultural sensors [160]. It helps in efficient use of water and thus enables farmers achieve a high yield of crops by using minimum resources. This management relies on deployment of sensors within the fields. Thus, smart irrigation helps enhanced root growth and maximized input use across the fields. During the past few years, WSN has taken agricultural domain by storm. WSN consists of a variety of agricultural sensor network, that constantly tests external stimuli and communicate real-time data across short distances through wireless links. These sensors collect data on various agricultural parameters and result of analysis of these high-volume data sets enable farmers to make quick decisions with long-term benefits. Additionally, these IoT-enabled sensors have low maintenance costs, quick setup time, and long-term battery life.

Fertigation is a type of fertilizer delivery technique in which fertilizers are mixed in water and later dispensed within the fields during the process of irrigation. It is an application of water-soluble solids and liquid fertilizers through irrigation. Fertilizer is passed directly to the plant or to the soil instead of spreading it to the air. With AI-enabled technology, fertigation gives the ability to distribute accurate rates. This application results in less wastage of fertilizer, thus becoming economically and beneficially processed. The automation process of applying fertilizer to the crops helps in reduced input costs and increases the yield.

Using high-tech equipment such as injectors and computer control systems; advanced fertigation systems achieves high accuracy. There agricultural practices are meticulously calibrated and regulated. High precision fertilization and irrigation can be obtained by selecting the best-suited system for crop and field circumstances and constructing it correctly. Over the years, numerous research papers and experiments have been conducted. Some of the most prominent research findings under this category are discussed below.

Pokrajac *et al.* (2001) in their study experimented on acquired dataset over Matlab software with an aim to observe the growth of crops by obtaining their images after a specific interval of time. Comparison was done on images from different intervals and results were derived. During observations, suggestions for the requirement of spray of fertilizers was also proposed. It was observed that some crops did not require fertilizer spray as improvement in its growth was visible on comparing the different set of images. The observations also depicted various stages and behavior of the crop with respect to available soil and other attributes related to agricultural activities [161].

Morais *et al.* (2005) in their study proposed a technique where evaluations were done to assess the percentage level of moisture presence within open fields and greenhouse. The study further compared the soil temperature and solar radiation effect on similar crops when cultivated in an open field and greenhouse. Sensor applications were characterized by low to medium resolutions, with a bandwidth below 2khz. The evaluations provided a significant difference in behavior among similar crops when cultivated at two different locations, giving a fair and square comparison among variations that takes place [162].

He *et al.* (2011) in their study highlighted the issues related to over and above utilization of fertilizers within the fields. To overcome this issue, the study proposed an integrated optimal fertilization DSS by incorporating wireless sensors using IEEE 802.11 protocol, to assess both the parameters actual availability and future requirement from the fields [163].

Li (2012) in his study has focused towards the transformation of conventional agricultural practices with modern agricultural cultivation and management perspective by incorporating WSN techniques. The study incorporated a SA irrigation system based on crop water requirement [164].

Savci (2012) in his study focused on the importance of growing demand for food due to increasing population, precise estimation for agricultural land per unit area required to achieve maximum efficiency and highest quality product. The study further highlighted that farmers seldom fertilized and irrigated their fields to make the agricultural field more efficient. This in return, hampered the land. The study concluded that apart from excessive fertilization practices, heavy metal accumulation, soil salinity, water eutrophication, and nitrate accumulation were the sole reasons for air pollution within the experimental area. A review to assess the environmental and health problems caused due to improper fertilization practices among plants has also been discussed in the study. Lastly, the study provided adequate solutions with an aim to overcome these problems [165].

Yan *et al.* (2012) in their study focused on the effect of various fertilizers on the growth and development of Stevia Rebaudiana Bertoni. The study highlights the significant change in stem's thickness, plant's growth rate and its height. The study also provides significant results in plant's grooming while using organic cultivation and chemical fertilization at two different occasions [166].

Kaewmard *et al.* (2014) in their study proposed a portable measurement technology that consisted of various sensors for measuring soil moisture, air humidity, and temperature sensors. On acquiring data from various agricultural sensors, irrigation process was controlled by actuators, that were paired over the smartphone. The proposed framework passed instructions to the automated irrigation system that helped in precise estimation on required amount of water within the fields. The proposed methodology aimed to reduce the overhead costs and to control the irrigation process [167].

Kaivosoja *et al.* (2014) in their study proposed a framework that detected threats to agricultural data from external sources. They emphasized a proper message transfer system that was reliable enough to transfer the data to Electronic Control Unit (ECU) of the incorporated component. ISOBUS Task Controller (TC) was proposed in the methodology to control data transfer in a standardized way. Transfer Controller used XML-based formats for communication with Farm-Based Management Systems (FBMS) to monitor the data. Web Featured Services (WFS) and Web Map Services (WMS) were used to acquire data on different parameters. Acquired data was later analyzed on the basis of different domains, *i.e.*, evaluation of groundwater, flood risk, weather, and forecasting. The aim of proposing such a system was to integrate multiple data sources for the creation of a dynamic application for SA [168].

Kaloxylos *et al.* (2014) in their study emphasized on the usage of cloud-based services for uploading information pertaining to various parameters within the fields. The study suggested on creating a user-friendly environment for end-users. The cloud services distinguished Farm Management System database from system-specific, *i.e.*, Greenhouse database. By using programming and other scripting languages, a graphic user interface was created for front-end users, in the form of a web portal, where information was uploaded. The interface later transferred to cloud for future reference basis [169].

Bendre *et al.* (2015) in their study emphasized additional insights from SA through big data approach. Suggestions for ICT usage for big datasets pertaining to agriculture has been proposed. In addition, the proposed approach incorporated the study to evaluate weather prediction with the help of GPS, Remote Sensors (RS) and Geographic Information Systems (GeIS). The proposed technique ws indeed expensive for farmers. An emphasis was given to remote sensing devices that were considered to play a vital role in data collection and real-time decision-making. Forecasting of weather was done based on obtained data using a regression model that can predict rainfall or temperature of a certain area. Relying on the results, a farmer could decide the crop pattern and water management [170].

Xiao *et al.* (2015) in their study proposed a methodology to evaluate the most prominent applications available within agricultural domain.in addition, the study also proposed a self-designed moisture wireless sensor to monitor the presence of moisture content and water height within the field. The proposed technique implemented smart irrigation control system in an autonomous mode based on real-time evaluation of captured parameters . The study proved to be applicable and feasible for the growth of rice. The study provided a visionary approach towards making use of soil moisture sensors for sensing the dryness of land and irrigating the fields thereafter [171].

Zaier *et al.* (2015) in their study proposed a technique for controlling the usage of ground and sea water for irrigation. This was attained by capturing moisture and conductivity parameters through various sensors and then evaluating the presence of required amount of water. The methodology was based on a calculation of various parameters pertaining to moisture calculating sensors. Hence, the evaluation results were determined the further usage of groundwater by regulating the required amount of water for irrigation purpose [172].

Ferrandez *et al.* (2016) in their study focused on the importance of information technologies in the precision agricultural domain. Issues related to correct identification of requirement-based sensors for various parameters. A low-cost sensor/actuator internetwork platform based on IoT that had an integrated M2M and Human-2-Machine (H2M) interface protocol was proposed within the study [173].

Jayaraman *et al.* (2016) in their study focused on the collection of agricultural data through various IoT devices, *i.e.*, WSN, cameras, network-connected weather stations, *etc.* for their systematic evaluation. Furthermore, the study also proposed Smart FarmNet (an IoT-based platform) that automated the process of data collection from various parameters related to agriculture, *e.g.*, soil, environmental, irrigation, and fertilization. The proposed framework was also capable of correlating the data and filtering out invalid data from the perspective of assessing crop performance and further computation crop forecasts [174].

Duhan *et al.* (2017) in their study focused on blind distribution of chemical fertilization techniques and pesticides within the fields. The study concluded that over and above distribution of pesticides and fertilizers practices not only resulted in loss to soil biodiversity, but also developed resistance against pathogens and pests within the fields. Hence, in order to overcome these prominent issues, the study proposed usage of Nano-encapsulated conventional fertilizers, herbicides and pesticides that helped in slow and sustained release of nutrients and agrochemicals within the fields that resulted in precise dosage distribution among plants. Their potential benefits were also discussed in detail within the study. The study provided experimentation results by using Nanotechnology-based plant viral disease detection technique, such as witche's broom with the help of kits. The final outcome and results of the study proved to be very useful in early detection of viral diseases. Lastly, the study also highlighted a detailed explanation on some of the most commonly used Biosynthesis of nanoparticles and their vital use in agriculture. Results of the study depicted that the coated fertilizers proved to be advantageous in resolving issues related to soil microflora. Methyl parathion detection model was proposed within the study to evaluate the toxic contents within the soil [175].

Tian *et al.* (2017) in their study focused on understanding the nutrient cycling process at high-altitude ecosystems, *i.e.*, at grassland of the Tibetan Plateau. The study revealed that vertical distributions of soil nutrients were closely evaluated along with their associated influencing factors within 1 meter of soil, using dataset of 68 individual soil profiles. The study concluded that Total Nitrogen (TN) and Soil Organic Carbon (SOC) stocks decreased with depth in natural habitat at different high altitude, *i.e.*, both Alpine Meadow (AM) and

Alpine Steppe (AS). Different soil profiles were evaluated over Trigonometric Transformation Method. Furthermore, One-way Analysis of Variance (ANOVA) and Least Significant Difference (LSD) tests on samples were also conducted to estimate whether soil nutrients at each depth increment differed significantly among various vegetation types [176].

Houng *et al.* (2018) in their study proposed on retaining water, as it being a valuable resource. To make minimal use of water within agricultural domain, the study proposed a generic irrigation model that was relatively similar to Markov Decision Processes and termed it as Markov-Decision based Irrigation (MDI) which was similar to any other automatic and precise irrigation process. The outcome of the proposed model outperformed the common threshold-based irrigation method by 40% [177].

Islam *et al.* (2018) in their study proposed an IoT-based smart monitoring system for performing agricultural practices based on a smart monitoring system. The proposed framework had three components, a client application, web application, and an android application. Collectively the proposed framework monitored irrigation module within the field [178].

Peerlinck *et al.* (2018) in their study focused on adapting a sophisticated method to improve agricultural practices. A Mathematical and Machine learning models have been proposed within the study to evaluate the fertilization distribution within the field based on the existing presence of nitrogen fertilizer within the fields. Furthermore, a comparative analysis has been undertaken based on multiple regression and neural networks to assess the performance of the proposed model [179].

Berge *et al.* (2019) in their study emphasized the limitation to correctly identify and explore minimum input requirements of macro-nutrients, *i.e.*, Phosphorus (P), Nitrogen (N), and Potassium (K) required to achieve full self-sufficiency in maize crop in nine countries of the African continent, *i.e.*, Nigeria, Faso, Mali, Ghana, Tanzania, Kenya, Burkina, Ethiopia, Uganda, and Zambia. Experimentations were conducted over a genetic equilibrium model, that was proposed within the study to estimate the minimum input requirements of NPK for cereal crops efficiently. The proposed methodology also incorporated Global Yield Gap Atlas data, with an aim to target the Geospatial distribution of the model's inputs and outputs for evaluating the minimal input requirement of fertilizers within the target region [180].

Bonfante *et al.* (2019) in their study focused on coping one of the most significant agricultural challenges, *i.e.*, DSS and Irrigation Advisory Services (IAS). To overcome both these challenges, a fully transferable DSS for irrigation support, which was based on three different methodologies that represented various state-of-the-art irrigation management tools, *i.e.*, W-Tens, IRRISAT, and W-Mod has been considered for the experimentation purpose. The proposed LCIS-DSS tool has been proposed within the study to support the farmer on irrigation management. The experimentation was conducted on maize crop, that was grown on Andosols in a private farm in southern Italy [181].

Peng *et al.* (2019) in their study focused on the shortage of water to meet irrigation needs. Hence, to overcome this issue, a prompt and effective crop water demand prediction model was proposed that helped in estimation of precise water requirement during the growth period of crop was proposed within the study. Parameters such as soil electrical conductivity, soil moisture, air temperature, and light intensity were considered as prominent factors for the study. A water demand prediction model which was based on Back Propagation Neural Network (BPNN) was also proposed within the existing study. The proposed model had an added feature that carried out optimized layout and hydrodynamic analyses for drip irrigation network and also identified the best pipe network arrangement within the field [182].

Zaragoza *et al.* (2019) in their study focused on irrigation and fertilizer distribution of olive crop. REUTIVAR model was proposed that helped in determining real-time irrigation and fertilization for the crop by applying treated waste water. Furthermore, the fertigation process was considered using weather information (both historical and forecast data), soil characteristics, tree nutrient status, and irrigation water quality level. The proposed model made use of treated wastewater, saving additional fertilization, which lead to significant environmental benefit [183].

Lin *et al.* (2020) in their study addressed issues related to irrigation and fertilizers management, based on an IoT-enabled precision agriculture for achieving sustainable management technique. To overcome the issue, a framework based on IoT-based irrigation and fertilization system has been proposed in which both long and short-term planning have been considered. Based on the proposed framework, an integer linear programming model was integrated within the study that aimed at allocating the distribution of limited resources among multiple crops with an aim of maximizing the economic profits and environmental benefits. Furthermore, a hybrid genetic algorithm has also been integrated within the proposed framework that aimed to solve the issues related to optimization model. Lastly, associated management implications have been obtained from sensitivity analysis to support managers' decision-making, involving planting structure design, strategies selection of water and fertilizer storage and replenishment [184].

Khanna *et al.* (2020) in their study emphasized on evaluation and precise usage of fertilizer distribution within the fields. Various parameters such as soil temperature, humidity, moisture, VWC, and EC were considered. ECH_2O5TE soil moisture sensor was incorporated within the study along with DHT-11 sensor for generation of various parameters considered. k-NN classification technique was implemented on the dataset using R software to estimate the presence of EC within the soil. Based on the evaluation of results, a future requirement of fertilizer distribution was estimated [185].

Hasaan *et al.* (2021) in their study proposed automation of irrigation within their study with the help of a wireless controlled robot. Soil moisture, humidity, and ph were the main parameters considered for the study. Acquired data was collected with the help of EC-4744 humidity and moisture sensor. Naive Bayes classification technique was implemented to the acquired dataset. A GSM-based prototype was proposed within the study that achieved water distribution within the fields more efficiently than the existing practice undertaken by farmers [186].

Khanna *et al.* (2021) in their study focused on the importance of water and its precise distribution within the fields. To attain the objective, a testbed was set up and parameters such as soil temperature, humidity, moisture (at three different levels), *i.e.,* 10 cm, 45 cm, and 80 cm were considered. Data on various parameters were acquired with the help of Libelium's Waspmote Plug and Sense device. ARIMA modeling technique was applied to the recorded dataset to predict the future possible values for various. Based on the results of the analysis, prediction of water distribution within the fields was determined [187].

Table 2.6 depicts comparative analysis of various articles discussed under the process of Irrigation and Fertilization.

Table 2.6: Comparative analysis of various articles discussed under the process of Irrigation and Fertilization

Author, Year of Publication, & Citation	**Objective**	**Application proposed/ Hardware device incorporated for study**
Pokrajac *et al.*, (2001), & [161]	Fertilization optimization	OLS linear model
Morais *et al.*, (2005), & [162]	Irrigation pattern determination	Wireless network with a top-down hierarchy
He *et al.*, (2011), & [163]	Fertilizer distribution within field	GIS spatial analysis technique

Comparative analysis of various articles discussed under the process of Irrigation and Fertilization (continued)

Author, Year of Publication, & Citation	**Objective**	**Application proposed/ Hardware device incorporated for study**
Li (2012), & [164]	Irrigation control	Automated irrigation module
Savci (2012), & [165]	Fertilizer effect on plants	Sampling technique
Yan *et al.*, (2012), & [166]	Fertilizer effect on Stevia Rebaudiana Bertoni	Manual and organic fertilizer distributor
Kaewmard *et al.*, (2014), & [167]	Irrigation pattern scheduling	Smart phone monitoring & controlling model
Kaivosoja *et al.*, (2014), & [168]	Environmental parameters evaluation for irrigation schedule determination	FMBS
Kaloxylos *et al.*, (2014), & [169]	Crop specific irrigation pattern determination and scheduling	Farm Management System (FMS) User-centric design model
Bendre *et al.*, (2015), & [170]	Data processing and weather forecasting	Map-reduce modeling technique
Xiao *et al.*, (2015), & [171]	Monitoring moisture content and water height of field soil	Context-centric data construction technique

Comparative analysis of various articles discussed under the process of Irrigation and Fertilization (continued)

Author, Year of Publication, & Citation	**Objective**	**Application proposed/ Hardware device incorporated for study**
Zaier *et al.*, (2015), & [172]	Irrigation pattern discovery and control of ground and sea water for irrigation	Automated precision irrigation system
Ferrandez *et al.*, (2016), & [173]	Field optimization for evaluating field's irrigation and fertilization requirements	Penman-Monteith technique
Jayaraman *et al.*, (2016), & [174]	Irrigation pattern determination	Query Access Performance Latency technique
Duhan *et al.*, (2017), & [175]	Nutrient evaluation & distribution and Plant disease detection	Methyl parathion detection model
Tian *et al.*, (2017), & [176]	Soil nutrient evaluation	Divergence distribution technique
Houng *et al.*, (2018), & [177]	Evaluation of water requirement	MDI
Islam *et al.*, (2018), & [178]	Irrigation monitoring & assessment	Agro filed monitoring and irrigation controlling system

Comparative analysis of various articles discussed under the process of Irrigation and Fertilization (continued)

Author, Year of Publication, & Citation	**Objective**	**Application proposed/ Hardware device incorporated for study**
Peerlinck *et al.*, (2018), & [179]	Prediction of winter wheat based on fertilization prescriptions	Nutrient concentration and fertilization rate evaluating model
Berge *et al.*, (2019), & [180]	Soil nutrient estimation	Past intensification trajectories module
Bonfante *et al.*, (2019), & [181]	Irrigation distribution pattern determination	LCIS irrigation model
Peng *et al.*, (2019), & [182]	Irrigation patter determination & water retrenchment technique	W-Tens & W-Mod techniques
Zaragoza *et al.*, (2019), & [183]	Fertilization scheduling & estimation	REUTIVAR Model
Lin *et al.*, (2020), & [184]	Fertilization distribution management	IoT-based fertilization system
Khanna *et al.*, (2020), & [185]	Fertilization distribution estimation	Requirement based Decision Support System (RB_dDSS) modeling technique

Comparative analysis of various articles discussed under the process of Irrigation and Fertilization (continued)

Author, Year of Publication, & Citation	Objective	Application proposed/ Hardware device incorporated for study
Hasaan *et al.*, (2021), & [186]	Irrigation pattern control	IoT based irrigation control technique based on Genetic Algorithm (GA)
Khanna *et al.*, (2021), & [187]	Water distribution estimation	RB_dSS model

The next subsection presents articles related to the third aspect of SA's life cycle.

2.2.3 Growth and Monitoring of plants

Plant health monitoring technology is a key to enable efficient resource management within agricultural domain. The efficiency of farming needs improvement as the global population continues to rise. The biggest challenge in agricultural domain is the size of the fields and the inefficiency of crop monitoring. With weather conditions becoming increasingly unpredictable, it makes monitoring of plants more difficult. Traditional methods have also proved limited approach and effectiveness. With the help of SA practices, the ability to predict plant's growth is critical for optimizing production. Crop monitoring technique has recently been added as a new feature that aims to analyze crop's health during its growth. Along with crop monitoring this technique also monitors all the associated parameters that are countable for plant's growth, such as humidity, temperature, *etc.* and timely alerts farmers with suggestive measures with an aim to enhance yields.

Currently, researchers are working on Computational Needs for Computer Vision (CNCV) and ML-based systems. The ML-based techniques have the ability to model plant's growth and predict its dynamics. With these new age technologies being experimented and implemented, researchers extract high-resolution data from plants, soil, and weather parameters. The data is then transferred along with complementary weather data to the cloud via communication protocols and is later analyzed. The algorithms applied then generate results, predictions, and recommendations of the actions. Some of the most prominent researches conducted under this category are as follows.

Bauer *et al.* (2016) in their study emphasized on monitoring various bio-physical crop parameters, which are crucial for the efficiency and sustainability while performing modern agricultural practices. The study highlighted the usage of Photosynthetically Active Radiation (PAR) sensor, as it significantly enhances the practical usage of WSN technology for non-destructive in-situ Leaf Area Index (LAI) assessment. LAI-2200, one of the most widely established standard instruments, along with PAR sensors, has been incorporated within the study for conducting experimentation [188].

Saputra *et al.* (2017) in their study focused on monitoring plant growth through an image processing technique. The study aimed to monitor the plant's growth based on GUI that helped in nondestructively predicting the plant's age and fresh weight. Five web-cams were deployed at distinct locations within the fields on an image-capturing box, that captured plant's image once in 3 days for a total of 48 days. Artificial Neural Network (ANN) technique was implemented to examine the captured images that predicted the age and weight of the plants. The proposed architecture consisted of a total of four layers with five input neurons, first hidden layer with five neurons, second hidden layer with five neurons, and output layers with one neuron [189].

Alhnaity *et al.* (2019) in their study highlighted the importance of evaluating plant's growth to estimate yield prediction within greenhouse. The proposed study was evaluated on ML and DL techniques that aimed to predict yield's growth based on two different scenarios, *i.e.*, tomato yield forecasting and Ficus benjamina stem's growth within a greenhouse environment. Furthermore, Recurrent Neural Network (RNN) using LSTM neuron model was implemented for predictions and formulations. Three different parameters, *i.e.*, stem diameter values, yield growth, and the micro-climate conditions have been used by the proposed architecture, with an aim to model the targeted growth parameters. To evaluate the performance of the proposed technique, a comparative study has also been presented within the study using various ML methods, such as Random Forest Regression (RFR) and Support Vector Regression (SVR) by utilizing the mean square error criterion, to evaluate the performance achieved by different methods [190].

Bernotas *et al.* (2019) in their study focused on evaluation on growth of different plants in different environments. PS-Plnat, a low-cost and portable 3D plant pheno-typing platform that was based on an imaging technique to evaluate the plant's phenotyping over the day-night cycle was incorporated within the study. Furthermore, the study investigated the growth of plants under a variety of conditions to illustrate the dramatic effect of the environment on plant's phenotype. Furthermore, a bespoke computer vision algorithm was developed and it was evaluated over DNN architecture to automate the segmentation of rosettes and individual leaves, with an aim to extract basic and more advanced traits from PS-derived data. The evaluation also emphasized on extraction that included the tracking of 3D plant's growth and diel leaf hyponastic movement [191].

Kitpo *et al.* (2019) in their study focused on evaluating early disease monitoring and detection system for tomato. Experimentations were performed in a greenhouse named Shinchi Agri-Green, located in Fukushima, Japan. The study highlighted the detected regions, and they were further classified into sim stages of fruit growth for using visible wavelength as a feature in SVM classification with the weight accuracy of 91.5% [192].

Table 2.7 depicts a comparative analysis of various articles discussed under the process of Growth and Monitoring of plants.

Table 2.7: Comparative analysis of various articles discussed under the process of Growth and Monitoring of plants

Author, Year of Publication, & Citation	**Objective**	**Application proposed/ Hardware device incorporated for study**
Bauer *et al.*, (2016), & [188]	Evaluation of Leaf Area Index LAI-2200	Distributed WSN application based on a simplified model of light transmittance
Saputra *et al.*, (2017), & [189]	Evaluation of growth of mustard plant	GUI based image processing
Alhnaity *et al.*, (2019), & [190]	Evaluating Ficus benjamina stem growth	ML and DL techniques to predict yield and plant growth variation
Bernotas *et al.*, (2019), & [191]	To study the growth of Arabidopsis thaliana	Passive 3D imaging technique
Kitpo *et al.*, (2019), & [192]	Evaluation of growing states of tomato	IoT based bot notification technique

The next subsection presents articles related to the fourth aspect of SA's life cycle.

2.2.4 Crop protection from various diseases and weeds

The fourth aspect in SA's life cycle aims to monitor pest and disease control in open-air (arable farming) and greenhouse environment. The detection and treatment of weeds is vital for agriculture since they are often considered the most harmful in crop production. Due to the difficulty of identifying and differentiating weeds from crops, the precise detection of weeds is necessary for successful yield in agriculture.

By using DL models and Computer Vision (CV) techniques, various diseases and weeds are detected and controlled in open-air and greenhouse environment in advance. Serious yield loss can be caused due to excessive weed and diseases, but the financial and significant environmental cost caused by it is quite large. AI, an integrated part of precision agriculture, has made this task relatively easy and efficient by spraying pesticides over the infected portions of crops with the help of drones. Using object detection, CV techniques can use either fully autonomous or semi-autonomous equipment like an UAV and other agricultural robots that can be used to identify disease in plants. With ML algorithms and sensors precise weed identification and discrimination may be achieved at a cheap cost, without any side effects. Some of the most prominent researchers conducted under this phase are as follows.

Arsenovic *et al.* (2019) in their study highlighted issues related to plant disease and their adverse effects on crops. Within the study, the limitations and flaws for several existing plant diseases and their detection methods had been explored. Furthermore, image processing technique was incorporated and a total of 79,265 images taken into consideration for evaluation purpose. These images were taken in various weather conditions, angles, and daylight hours with an inconsistent background mimicking practical situations. Two individual approaches, *i.e.*, Traditional Augmentation Methods and Style Generative Adversarial Network were taken into consideration for evaluation purpose. The study concluded that the proposed image processing technique helped in detection of multiple diseases in a single leaf [193].

Maimaitijiang *et al.* (2020) in their study proposed usage of UAV and sensor technology for evaluation of plant disease detection for soybean crop. Network of DNN, Partial Least Squares Regression (PLSR), RFR, SVR, input-level feature fusion based DNN (DNN-F1), and intermediate-level feature fusion based DNN (DNN-F2) were used to extract and combine multi - modal information such as canopy spectral, structure, thermal, and texture features to predict crop grain yield (DNN-F2). The conclusion of the revealed that multi-modal data fusion employing a low-cost UAV within a DNN framework resulted in a relatively accurate and robust estimation of crop yield and disease [194].

Surampalli *et al.* (2020) in their study proposed evaluation of disease detection by evaluating tomato leaves by incorporating DL techniques. In addition, the study also made use of image processing techniques based on clustering and image segmentation [195].

Velasquez *et al.* (2020) in their study proposed a technique to identify coffee leaf rusting (a fungal epidemic disease) with the help of WSN, remote sensing, and DL technique. The study was conducted in the fields of Colombia, where the most common way to detect this disease was done through visual inspection by walking throughout the crop field. To overcome the issue, a diagnostic model in the Coffea arabica, technological integration was done with the help of remote sensing (through drone capable multi-spectral cameras), WSN (multi-sensor approach), and DL technique, *i.e.*, ANN [196].

Nasir *et al.* (2021) in their study emphasized the importance of timely identification of plant disease. With the help of AI, parameters such as fruit color, shape, texture data, *etc.* were analyzed to detect infections. To attain the objective, CNN technique was proposed, which evaluated the data over image classification technique. A plant dataset was used to retrain a fine-tuned, tailored deep learning model (VGG19), from which relevant features were retrieved. Then, using a serial-based technique, contour features were retrieved using Pyramid Histogram of Oriented Gradient (PHOG) and merged with the deep features. A few pieces of redundant information were introduced in the form of features during the fusion process. Finally, the best characteristics from the fused vector were chosen for the final classifications using a “relevance-based” optimization technique. The use of multiple classifiers resulted in accuracy of up to 99.6% [197].

Table 2.8 depicts comparative analysis of various articles discussed on the process of Crop protection from various diseases and weeds.

Table 2.8: Comparative analysis of various articles discussed under the process of Crop protection from various diseases and weeds

Author, Year of Publication, & Citation	**Objective**	**Application proposed/ Hardware device incorporated for study**
Arsenovic *et al.*, (2019), & [193]	Detection of plant disease based on leaf's image evaluation	DCGAN modeling technique
Maimaitijiang *et al.*, (2020), & [194]	Growth progress & disease detection for soybean crop	Fusion-based DNN technique
Surampalli *et al.*, (2020), & [195]	Detection of disease in tomato crop	Image segmentation & clustering technique
Velasquez *et al.*, (2020), & [196]	Detection of coffee leaf rust	CRD technique
Nasir *et al.*, (2021), & [197]	Identification of fruit diseases	Advanced fusion technique

The next subsection presents articles related to the fifth aspect of SA's life cycle.

2.2.5 Harvesting

Newer technological innovations in the agriculture field, such as AI and IoT, help in increase of yields. SA is primarily reliant on automation. Electronic data collection systems, accurate field positioning systems such as GPS and variable rate application controller play an important role within the domain. Deployed agricultural sensors capture data for various parameters such as bio-molecular, chemical, optical, thermal, electrical, radiation, and biological metrics to provide a 360-degree perspective of a crop's health. They play an essential role in collecting data and sense the type of soil. A variety of sensors are developed for different purposes. Precision agriculture benefits the most from network protocols. Cellular connections, LoRaWAN, LPWAN, and others are some of the most extensively used connectivity protocols in intelligent farming. A variety of agricultural devices (sensors) are commonly used to assess soil water content, crop biomass, and other variables. Robots are now being designed to handle critical agricultural tasks which help in intelligent harvesting by reducing human efforts, optimizing crop yield, and cost-efficient production. AI and ML-based techniques are used to better understand the crops, allowing farmers to harvest their crops to their full potential, resulting in greater output. AI-enabled robots can harvest crops at a much faster rate and in larger quantities. Robots are also trained to check the quality of crops and detect weed and execute other agricultural tasks independently, such as irrigation, protecting fields to produce accurate reports, ensuring that adverse environmental conditions do not affect production, increasing precision, and managing individual plants in novel ways. Once the crops are grown, the process of harvesting is done. Over the years, contemporary harvesting process was followed. With the passage of time, automation has also been implemented in this phase. Some of the most prominent research work conducted have been discussed as follows.

Kong *et al.* (2019) in their study focused on a mathematical optimization model, that aimed to evaluate on real-time data with precision to enhance the process of decision-support and to optimize short-term farming operation. The focus of the research has been on evaluating the precise time for harvesting of crops. To attain the objective, two meta-heuristic algorithms, *i.e.*, a tailored genetic algorithm and a hybrid genetic-tabu search algorithm have been implemented. The main aim of the study was to optimize sugarcane harvesting in the KwaZulu Natal region of South Africa [198].

Onishi *et al.* (2019) in their research focused on using a single deep neural network technique to adapt automated techniques for picking crops via robot. The article proposed a unique method for identifying fruits and automated the process of harvesting with a robot arm as the initial step. A stereo camera was used to detect a three-dimensional location of the fruit, and a single shot multi-box detector was used to detect the precise position of the fruit. Based on the observations, the robot arm moved towards the target, *i.e.*, fruit's position after inverse kinematics calculates the angles of the joints at the detected position. The robot then rotated the hand axis to harvest the fruit. The experiment concluded that more than 90% of the fruit was spotted within the fields, and the robot harvested one fruit in under 16 seconds resulting in time utilization [199].

Faisal *et al.* (2020) in their study proposed IHDS technique for harvesting of date fruit using DL and image processing. The experimentation was conducted in the Kingdom of Saudi Arabia. Detection of seven different maturity stages for date fruit were trained over DL. On evaluation of DL, each one produced different accuracy levels in terms of the seven aforementioned maturity stages [200].

Mao *et al.* (2020) in their study proposed recognition of cucumber and its harvesting robots by using DL and multi-feature fusion through image processing. The study proposed a new cucumber region detection method, that combined MCNN with Color Component Selection and SVM to accomplish the goal. In addition, the cucumber images were captured and later converted into color space to acquire 15 color components, and I-RELIEF technique was implemented to evaluate the weight information of significant characteristics. In parallel, the OSTU technique was used to segment the G-component and Maximally Stable External

Regions (MSER) was utilized to obtain the mask image to exclude part of the background area [201].

Zhang *et al.* (2020) in their study proposed identification of key canopy parameters for mass mechanical apple harvesting that made use of supervised machine learning, *i.e.*, PCA and weighted k-Nearest Neighbors (k-NN). The initial ML technique was adopted to determine the key canopy parameters by calculating the coefficients of principal components [202].

Zhang *et al.* (2021) in their study focused on automation of harvesting of crops with the help of a self-sensing device. To attain the objective, an ES-ETHG was designed and incorporated within the study to attain the objective. Parameters such as wind speed and wind level were determined for performing computations. The main aim of the study was to minimize human intervention within the fields by completely automating the existing process [203].

Table 2.9 depicts a comparative analysis of various articles discussed under the process of Harvesting.

Table 2.9: Comparative analysis of various articles discussed under the process of harvesting

Author, Year of Publication, & Citation	**Objective**	**Application proposed/ Hardware device incorporated for study**
Kong *et al.*, (2019), & [198]	Identification of precise harvesting time for sugarcane	MILP technique
Onishi *et al.*, (2019), & [199]	Evaluation for best time to harvest apple fruit	Single-shot Multi-box detector harvesting robot
Faisal *et al.*, (2020), & [200]	Harvesting of date fruit & its maturity level	IHDS mechanism

Comparative analysis of articles discussed under the process of Harvesting (continued)

Author, Year of Publication, & Citation	**Objective**	**Application proposed/ Hardware device incorporated for study**
Mao *et al.*, (2020), & [201]	Harvesting of cucumber	Multi-path Convolutional Neural Network technique
Zhang *et al.*, (2020), & [202]	Harvesting of apple fruit	PCA technique
Zhang *et al.*, (2021), & [203]	Harvesting of crops	ES-ETHG technique

The next subsection presents articles related to the sixth aspect of SA's life cycle.

2.2.6 Stubble management

Although the process of agriculture is considered from sowing of seeds to harvesting of crops. Yet post harvesting of crops, farm residue burned by farmers to clear land for new crops, produces large volumes of greenhouse gas emissions and causing a spike in pollution levels, as well as degrades the soil's organic content, vital nutrients, and microbial activity. This lowers the long-term productivity of the soil. Stubble-burning is outlawed or forbidden in several nations but is still used widely in major parts of the world.

Farmers prefer the conventional method of stubble-burning because it is less expensive and less time-consuming than alternatives that require more time, effort, and labour. Stubble retention has several advantages, but it necessitates a systemic strategy to disease, insect, and weed control. An equal distribution of residue and by applying the right stubble cutting height at harvest are the foundations of effective stubble management. Hence, it becomes an essential aspect to evaluate. Using an AI-powered platform using satellite data, the exact information of stubble burning can be provided to government agencies for timely action.

AI-based applications are competent enough to provide data related to burning predictions, expected crop waste and calorific value, emissions, fire counts, and other data that can be used to monitor and impose regulations on stubble burning. Some of the most prominent research articles under this category are as follows.

Dubey *et al.* (2019) in their study highlighted similar issues of burning detection using IoT based techniques and ANN. The present study proposed an early fire detection model with the help of the Raspberry Pi micro-controller and fire detecting sensors. Feed-forward fully connected neural network is used for prediction purpose within the study [204]. Malik *et al.* (2019) in their study focused on significant concerns associated to Crop Residue Burning (CRB), specially for rice and wheat crops. The results of the study revealed that crop burning caused severe air pollution, in addition to some other prominent issues, such as emitting traces of carbon dioxide, methane, carbon monoxide, nitrous oxide, and other harmful particles release within the atmosphere. This emission of various harmful gases causes respiratory and other health concerns, along with prime cause of regional polluter. Furthermore, the results of the study revealed that the practice of stubble burning causes loss of vital nutrients, resulting in a loss of soil fertility. To combat this noxious practice with best management practices and capacity building of the farmer community in order to conserve the climate for the sustainable development of agriculture, the study recommends the adoption of various agronomic management reforms, new machineries such as zero drills, happy seeder, and straw baler [205].

Dheeraj *et al.* (2020) in their study focused on the role of AI and IoT in managing stubble burning issues. The study aimed at highlighting various techniques by which these practices can be improved. Furthermore, Blue sky analytics technique, that makes use of Zuri satellite data has been incorporated within the study. This device helps to analyze the allocation of crop waste as raw material for use in other industries. Lastly, Zuri an application that records data on farm fires as it happens for every district and state has also been discussed [206].

Keil *et al.* (2021) in their study highlighted issues related to crop residue burning's adverse effects on humans and on fields. To address the problem, the researchers devised the "Happy Seeder", a tractor-mounted machine that mulches rice residues while at the same time sowing wheat. The results of the study indicate that the device constitutes a practice that avoids stubble burning and enhances farmer profits [207].

Kulkarni *et al.* (2021) in their study proposed and IoT-based firefighting system to protect farm from stubble burning. The proposed system deployed fire sensors as when surrounding farms catch fire, then the hardware senses the fire and starts water sprinklers to put out the fire and share this data on IoT to know the status of farm [208].

Table 2.10 depicts comparative analysis of various articles discussed under the process of Stubble management.

Table 2.10: Comparative analysis of various articles discussed under the process of Stubble management

Author, Year of Publication, & Citation	**Objective**	**Application proposed/ Hardware device incorporated for study**
Dubey *et al.*, (2019), & [204]	Timely identification of fire within forests	Feed-forward fully connected neural network
Malik *et al.*, (2019), & [205]	Impact of crop residue burning for rice & wheat crops	Agronomic management, Zero drill, Happy seeder, and Straw baler as current alternative management practices

Comparative analysis of various articles discussed under the process of Stubble management (continued)

Author, Year of Publication, & Citation	**Approach**	**Application proposed/ Hardware device incorporated for study**
Dheeraj *et al.*, (2020), & [206]	Management of stubble burning	Blue Sky Analytics & Zuri app
Keil *et al.*, (2021), & [207]	Harvesting and management of stubble	Happy Seeder tractor
Kulkarni *et al.* (2021), & [208]	IoT based farm fire-alarm generating technique	IoT based technology

Apart from the above, there have been various survey articles that have been published over the past few years. Next subsection presents some of the most prominent survey articles published over the past few years under IoT and SA domain.

2.2.7 Survey articles

Since the enhancement in agricultural practices is only possible by incorporating IoT techniques, therefore emphasis has been given to identify the most prominent research conducted in IoT the domain. Hence, this section highlights the most prominent survey articles published for IoT and SA domain, respectively.

Survey articles on IoT

Dlamini *et al.* (2009) in their study focused on Information Security (IS) as a significant concern in context of IoT's deployment in various walks of life. The article aimed towards taking a leap forward to pro-actively highlight various types of threats that IoT were likely to encounter in the future. Lastly, the study highlighted, how a botnet of stoves could bring down an entire power grid and how Distributed Denial of Service (DDoS) could be implemented to beat the competition and increase revenues of Telcos [209].

Atzori *et al.* (2010) is one of the oldest and most innovative survey article under IoT domain. The article highlights enabling factor of a promising paradigm, *i.e.*, IoT's integration with several other technologies and its related communications solutions. Different visions of this IoT paradigm have been reported and enabling technologies have been reviewed. Furthermore, various applications, open issues, and security challenges for the domain has also been discussed [210].

Agarwal *et al.* (2013) in their study focused on successful enabling of various communication technologies in different domains, since they play a pivot role. Lastly, various applications, security, and prominent issues has also been discussed within the study [211].

Gubbi *et al.* (2013) in their study focused on Cloud-centric vision for the deployment of IoT globally. For its implementation Aneka, which is based on the interaction of private and public cloud framework was proposed within the study. Furthermore, Dynamic Resource Provisioning and Application Scheduler in Aneka for various IoT applications were also reviewed in the study. Lastly, various applications, open challenges, and future directions have also been highlighted as a part of the study as they had significant importance towards the domain [212].

Riahi *et al.* (2013) in their study highlighted issues related to the security of IoT devices and its various networks. Furthermore, role of each actor (entity) and its interactions with another actor (entity) have been presented. IS has been shortlisted under for various categories, *i.e.*, Identification and Authorization (IA) Security, Design and configuration, *etc.* has also been discussed within the study [213].

Said *et al.* (2013) focused the importance of implementing the concepts of IoT in the field of commerce, industry, and educational domains. History of IoT, applications, various architectures, *i.e.*, 3-Layer architecture, 5-Layer Architecture, and Special Purpose Architectures, research challenges and open problems have been highlighted within the study [214].

Perera *et al.* (2014) in their study emphasized on the correct deployment of sensors, with an aim towards the data collection, modeling, reasoning, and distribution of context. Various challenges were also discussed within the study. Context-aware computing has been the focus area for the study, as the most prominent aspect towards evaluating acquired sensor data. Furthermore, its awareness with respect to IoT's prospective has been projected within the study, to clearly understand the aspect and its importance. The survey aimed at addressing a broad range of techniques, functionalities, methods, applications, models, systems, and middle-ware solutions related to context awareness with respect to IoT domain [215].

Madakam *et al.* (2015) in their study highlighted the basic IoT concepts, through a systematic review of scholarly research papers published over the past few years under different domains. Various architectures of IoT such as, European FP7 Research Project, ITU, Kun Han, Shurong Liu, Qian Xiaocong & Zhang Jidong, Dacheng Zhang & Ying Han were some of the most prominent ones that have been discussed within the study along with their communication technologies [216].

Miraz *et al.* (2015) In their study presented the current and future possibilities of IoT, Internet of Everything (IoE) and Internet of Nano Things (IoNT). The study highlights a basic difference between IoT and IoE, which is wrongly considered to be a single entity by its users. In addition, current advancements in various fields of IoT, IoE, and IoNT have been highlighted, along with its possible future expansion of existing applications. Various challenges on deployment of communication technique via Internet Protocol (IPv6) has been discussed. Lastly, the future of Internet has also been presented within the study [217].

Whitmore *et al.* (2015) in their study highlighted current trends of IoT, various challenges, some of the most prominent research questions that target the most prominent hurdles towards future inclination of IoT have been discussed. Furthermore, various communication techniques of IoT have been discussed along with available architectures, and applications have also been highlighted within the study. Lastly, various challenges and privacy issues were also discussed with a pragmatic approach [218].

Kang *et al.* (2017) in their study emphasized on communication gateways as key elements empowering IoT. Their importance towards bridging the communication gap among various field control/sensor nodes and cloud has been discussed, along with its automation being the key focus within the study. Three different IoT gateways, *i.e.*, Passive, Semi-automatic, and Fully-automatic gateways has been given a significant importance within the study. A self-configurable gateway featuring real-time detection and configuration over smart things was proposed and experimented with the help of a wireless network. The key features of the proposed device included a dynamic discovery of home IoT devices, automatic updates of hardware changes, connection management of smart things connected over AllJoyn framework. Implementation of Constrained Application Protocol (CoAP) protocol for the proposed autonomous gateway has been experimented [219].

Mendez *et al.* (2017) in their study highlighted various challenging issues related to security for devices and networks on which these devices are either inter-connected to each, or connected over devices via Internet. The study focused primarily on devices connected over the ad-hoc network in specific. Challenges in context of various technologies and their architecture have also been discussed. The study primarily aimed at IoT intrinsic vulnerabilities and security challenges for various communication layers that were based on the principles of data availability, confidentiality, and integrity. Lastly, a comparative analysis for various articles published under the security domain for IoT has also been presented within the study [220].

Ngu *et al.* (2017) in their study focused on the importance of IoT as a middleware, binding functional capabilities of Internet to objects. The importance of IoT as a middleware has been discussed in various applications. Specific focus has been on real-time monitoring and future prediction of blood alcohol within a human body with the help of smart watch sensor data. Lastly, a systematic analysis has been performed within the study that highlights various enabling technologies and challenges in developing IoT as a middle-ware that embraces heterogeneity for various IoT devices. This furthermore enables them to support the essential ingredients required for correcting identification of adaptability, composition, and security aspects of an IoT system [221].

Yassein *et al.* (2017) in their study highlighted various protocols and standards proposed by different standardization organizations in message passing within a session layer. Main emphasis was on the discussion of two different protocols, *i.e.*, Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) used by numerous IoT applications for data transmission. Most widely used application protocols, *i.e.*, Extensible Messaging and Presence Protocol (XMPP), CoAP, MQ Telemetry Transport (MQTT), Data Distribution Service (DDS), and Advanced Message Queuing Protocol (AMQP) have been discussed within the study. In specific, MQTT has been given the highest priority among other documented protocols due to its unique architectural design, messaging format, scope, and Quality of Service (QoS) for various levels. A comparative analysis among various research articles on about MQTT in terms of their vision and methodologies have been discussed within the study by length [222].

Williams *et al.* (2019) in their study focused on a detailed description of security issues related to IoT. Furthermore, the study indicated that increasing the number of networks will gradually increase the intrusion percentage. The systematic review first highlighted various features of IoT. In addition, the study aimed at providing possible answers to two main questions, *i.e.*, security features offered by the device and to make a well-informed decision prior to integration to devices over the network. Lastly, the study aimed to highlight the paramount importance of integrating various security features in development and design aspects for IoT, rather than re-iterating the designs, after-through. In addition to the above-stated issues, the background of IoT, various documented security incidents since 2010, and vivid approaches are taken to tackle the threats have been presented within the study [223].

Alkhabbas *et al.* (2020) in their study focused upon automation of industrial hardware through IoT. Furthermore, the inclusion of the Edge-Cloud continuum was also considered for the study. Various challenges were discussed in this context. Issues related to extra-functional requirements for a system, its heterogeneity among other hardware resources, concern over their processing and storage capabilities, constraints like legal issues, and various other direct/indirect operational costs have also been discussed within the study. In addition, an industrial survey was conducted with 66 IoT practitioners from 18 countries across the world, *i.e.*, Bangladesh, Brazil, Denmark, France, Iran, Ireland, Israel, Luxembourg, Poland, Spain, Sweden, Tunisia, Turkey, and United Kingdom. Cost, performance, reliability, and security were the four major parameters that were taken under consideration. To acquire the responses, Convenience and Snowball sampling techniques were adopted. Horizontal and Vertical analysis were performed on the feedback acquired. Results of evaluation depicted a higher percentage inclination towards issues related to deployment decisions concerning IoT systems in practice and the factors that influence those decisions [224].

Dehkordi *et al.* (2020) in their study focused on various issues that helped in the elimination of data redundancy. The study also aimed at various key points for the improvement of energy efficiencies that helped in increasing the lifespan of WSN deployed within a specific framework. Furthermore, the study emphasized on the deployment of an efficient data aggregation protocol as it helped in reducing network traffic. The study helped in binding the basic foundations, that aimed to develop new advanced designs based on data integration and clustering techniques. In addition, the study presented various applications, advantages, and disadvantages for a sensor network covering ground, underground and underwater sensor networks [225].

Khanna *et al.* (2020) in their study focused on eight different domains, *i.e.*, Smart Mobility, Smart Grid, Smart Home/Building, Public Safety and Environment monitoring, Medical and Health care, Industrial Processing, Agriculture and Breeding, and Independent Living having wide usage of IoT. Articles for the domains had been selected based on highest number of citations over the past few years. Furthermore, the article sheds light on the evolution of IoT, its objectives, various communication technologies, open issues, challenges, and future research directions in the field of IoT. Furthermore, comparative analysis for various aspects, and application domains under IoT were discussed on various parameters, *i.e.*, observations over the past few years, impact of proposed methodology, costs involved to develop the proposed framework within the study, area for experimentation, possibility for implementation of proposed methodology on related platform, and future expansion of proposed methodology [226].

Stoyanova *et al.* (2020) in their highlighted recent advancements in hardware and information technology over the Internet for last few years under different domains, *i.e.*, environment control, health, home automation, and transportation. Issues related to complex process of IoT-based investigations, cloud security challenges, legal, and privacy were also highlighted within the study. Furthermore, an overview of different past and current theoretical models under digital forensics science were discussed within the study. Special attention was paid to frameworks that were designed to extract data in a privacy-preserving manner or secure the evidence integrity using decentralized block chain-based solutions [227].

Lafontaine *et al.* (2021) in their study focused on the drastic change in lifestyle through automation of various day to day devices, with the help of IoT. Evaluations were made to assess the elicit people's attitude and concern towards adopting IoT in their day to day lives. Focus of the study was based on evaluating the perception of three different geographic regions, *i.e.*, Europe, India, and United States of America (USA). Data was collected through an online survey from 232 participants. Pearson's Chi-Square test was performed on the responses to analyze the relationship between ordinal and qualitative variables. Furthermore, Fisher's exact test was implemented when minimum expectancy counts were not met to compute the statistical difference. Outcome study concluded that user concerns need to be addressed on a priority basis, especially for Indian customers, and to enhance their trust towards adaptation of IoT [228].

Table 2.11 depicts a comparative analysis for various aspects discussed in various survey articles under IoT domain.

Table 2.11: Comparative analysis for various aspects discussed in survey articles under IoT domain
A: Applications; B: Challenges; C: Communication techniques; D: Comparative Analysis; E: Inclusion of other technologies; F: Implementation costs for IoT's deployment; G: Security issues

Author, Year of Publication, & Citation	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Dlamini *et al.*, (2009), & [209]	-	✓	✓	-	-	-	✓
Atzori *et al.*, (2010), & [210]	✓	✓	✓	-	-	-	✓
Agarwal *et al.*, (2013), & [211]	✓	✓	✓	-	✓	-	✓
Gubbi *et al.*, (2013), & [212]	✓	✓	✓	-	✓	-	✓
Riahi *et al.*, (2013), & [213]	-	✓	-	-	-	-	✓
Said *et al.*, (2013), & [214]	✓	✓	✓	-	-	-	✓

Comparative analysis for various aspects discussed in survey articles under IoT domain (continued)
A: Applications; B: Challenges; C: Communication techniques; D: Comparative Analysis; E: Inclusion of other technologies; F: Implementation costs for IoT's deployment; G: Security issues

Author,Year of Publication, & Citation	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Perera *et al.*, (2014), & [215]	-	✓	-	✓	-	-	✓
Madakam *et al.*, (2015), & [216]	✓	✓	✓	-	✓	-	✓
Miraz *et al.*, (2015) , & [217]	✓	✓	✓	-	-	-	✓
Whitmore *et al.*, (2015) , & [218]	✓	✓	✓	-	-	-	✓
Kang *et al.*, (2017), & [219]	-	-	✓	✓	✓	-	✓
Mendez *et al.*, (2017), & [220]	✓	✓	-	✓	-	-	✓
Ngu *et al.*, (2017), & [221]	✓	✓	-	-	✓	-	✓
Yassein, *et al.*, (2017), & [222]	-	-	✓	✓	-	-	✓
Williams *et al.*, (2019), & [223]	-	✓	-	-	-	-	✓
Alkhabbas *et al.*, (2020), & [224]	-	✓	-	-	✓	✓	-
Dehkordi *et al.*, (2020) , & [225]	-	-	-	-	✓	✓	-

Comparative analysis for various aspects discussed in survey articles under IoT domain (continued)
A: Applications; B: Challenges; C: Communication techniques; D: Comparative Analysis; E: Inclusion of other technologies; F: Implementation costs for IoT's deployment; G: Security issues

Author,Year of Publication, & Citation	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Khanna *et al.*, (2020), & [226]	✓	✓	✓	✓	✓	✓	✓
Stoyanova *et al.*, (2020), & [227]	-	-	✓	-	✓	-	-
Lafontaine *et al.*, (2021), & [228]	-	-	-	✓	✓	-	✓

Survey articles on SA

There are several prominent survey articles published within the domain. Some of the most significant are as follows.

Kamilaris *et al.* (2018) in their survey focused on 40 research articles based on DL techniques that were applied on various challenges related to agriculture and food production. In addition, particular agricultural problems under DL domain, various sources, specific models and frameworks employed, nature and pre-processing of data used, and overall performance achieved were some of the parameters considered for the study. Furthermore, a comparative analysis in DL with other existing popular techniques were projected within the study. The conclusions of the study indicated that DL provided high accuracy percentage rate and outperformed over commonly used image processing techniques [229].

Drury *et al.* (2019) in their study focused on the impact of semantic web technologies within the agricultural domain. A survey was conducted to motivate further research to be carried out specifically on semantic web technologies for agricultural problems by making self-contained reference. Various architectures for semantic web methods, data interchange standards, and current applications of semantic web technologies were discussed within the existing study [230].

Khanna *et al.* (2019) in their study the focused on the significant impact of IoT in the agricultural domain. Various communication technologies, open issues, and challenges were discussed within the study. The study also focused on 10 prominent articles published under SA domain, highlighting various techniques/methodologies adopted to overcome these issues [231].

Vasconez *et al.* (2019) in their study focused on various Human-Robot Interaction (HRI) approaches for solving complicated problems faced within agricultural domain. The study further highlights industrial areas that benefit the domain by applying HRI strategies in their applications [232].

Lezoche *et al.* (2020) in their study focused on the importance of data real-time information processing and its impact on the process of decision-making. Various information techniques were also discussed at length. Furthermore, the incorporation of Big data analytics, IoT, Knowledge model approaches, and Artificial Intelligence techniques were also presented as an important aspect within the study. Induction of robotics in performing precision agricultural activities to reduce human intervention was also an agenda that was highlighted within the study. Lastly, upcoming models of Agri-food supply chains were discussed [233].

Patel *et al.* (2020) in their study focused on various agricultural techniques followed for monitoring of parameters associated in the agricultural process. A survey was conducted on various 53 prominent articles. Issues related to communication barriers, challenges, and their remedial solutions were discussed within the study [234].

AlKameli *et al.* (2021) in their study focused existing applications and their significant impact of machine learning in SA. The focus was on the impact of Deep Reinforcement Learning techniques. A comparison between conventional solutions for agricultural machine learning decision-making problems are further supervised via this approach [235].

Balaji *et al.* (2021) in their study focused on the paramount importance of evaluating plant's health from time to time. Various monitoring sensors, *i.e.*, soil health, *pH*, temperature, air quality, humidity, *etc.* were considered important factors affecting plant's health. Logistic Regression algorithm technique was proposed within the existing study to evaluate plants health. Lastly, various contributions and limitations for plant-soil monitoring using WSN, implementation of AI and IoT, agricultural sensors, and various predictive analyses were also been discussed within the study [236].

Bhat *et al.* (2021) in their study highlighted various techniques for making cultivation more productive, proficient, and well-regulated with the help of IoT. Concepts and functional importance of Big data were highlighted within the study and were considered to be most vital in today's date. These techniques had a huge data analytical capabilities. With the help of evaluated results, farmers are able to comprehend farming practices well. The study's aim was to document the latest applications under Big data for SA and be acquainted with related financial and social challenges. The study further depicted various data creation methods, accessibility techniques of data, available software for computations, and analytic methods. Challenges faced during implementation of Big data techniques in the agricultural domain have also been highlighted within the study [237].

Devi *et al.* (2021) emphasized reducing human labor within agricultural fields by implementing various agricultural techniques. The study aims at highlighting various smart farming techniques using IoT concepts. Crop monitoring was another aspect and its management techniques were also discussed. Lastly, key challenges of IoT were also highlighted in the study [238].

Friha *et al.* (2021) in their study presented a comprehensive review of emerging technologies of IoT. The focus of the study was on usage of wireless technologies, open-source IoT platforms, Software Define Networking (SDN), UAV, Network Function Virtualization (NFV) technologies, Cloud & Fog computing, and Middleware platforms within agricultural domain. Various IoT-based applications on intelligent monitoring, agro-chemicals applications, disease management, smart water management, smart harvesting, supply chain management, and smart agricultural practices have also been discussed and presented within the study. In addition, a state-of-the-art methods towards supply chain management based on the block chain technology for agricultural IoT has been highlighted within the study. Lastly, real ongoing projects that have the most vivid use of the aforementioned technologies have also been listed within the study [239].

Gaspar *et al.* (2021) in their study conducted a survey on 21 micro, small and medium agrofood companies, belonging to bakery and pastry, coffee, fruticulture, milk, honey, olive oil, jams, meat, and wine sectors in the central region of Portugal. The aim of the study was to identify various opportunities for IoT's proper implementation in Portugals agro-industry. A questionnaire consisting 21 questions was prepared. Responses were acquired from 21 companies in the central region of Portugal. Evaluation of results revealed a stage of maturity, potential, level of sophistication, solutions, opportunities, and barriers for the implementation of IoT. In addition to the responses, various suggestions and recommendations to improve practices were also presented within the study [240].

Kalyani *et al.* (2021) in their study focused on the influence of Cloud, Fog, and Edge computing techniques in the field of SA. Various issues of cloud computing, *i.e.*, high bandwidth, ultra-low latency, real-time analytics, and security has been discussed within the study. The study further presents research work conducted under agricultural domain using Cloud,Edge, and Fog computing applications since 2015. The study proposed a new architecture model that had combinations of Cloud-Edge-Fog based on existing studies. Various agricultural application domains, research approaches, and applications of used combinations have also been presented within the study. Lastly, various communication protocols used to interact from one layer to another within different computing techniques have also been highlighted within the study [241].

Mishra *et al.* (2021) in their study emphasized the importance of IoT within the domain. Various agricultural communication techniques, aspects involved in agricultural practices, data analytics of IoT, open issues, and future challenges have been discussed within the study by length [242].

Pandiarajaa *et al.* (2021) in their study presented the most conventional methods to the advanced technology with the advent of the technology. Various ML and Text processing techniques has been discussed within the study. Most prominent startups in public-private sector undertaking agricultural practices have also been highlighted within the study. An integrated research to develop a bottom-up participatory technology extension approach using new technologies has been suggested for sustainable development in agriculture. In addition, applications, developments, limitations, and future parameters has also been presented within the study [243].

Raj *et al.* (2021) focused on the adoption of various emerging technologies like IoT, *i.e.*, Internet of Underground Things (IoUT), Data analytics, and UAV in agricultural domain with an aim to fulfill the increasing demand for food supplies across the world. The study further presents a comprehensive overview as to how multiple technologies such as IoT, IoUT, ML, DL, and UAVs can be adequately developed to manage various farm-related operations. Relevant technologies, their use cases, existing case studies, research works, potential research gaps were also highlighted within the study [244].

Shali *et al.* (2021) in their study highlighted various advancements achieved during the last few years with the help of IoT in SA. Security issues faced in IoT while performing farming activities has also been presented, along with a rundown of most prominent sensor-based applications [245].

Setiaji *et al.* (2021) in their study conducted a survey on the recent implementation of IoT based monitoring systems within agricultural domain. Scale of adoption, cost, and its benefit with respect to IoT's adaptation are some of the key objectives that were discussed within the study. Lastly, various strategies to adopt an IoT-based monitoring tool pertinent to irrigation systems implementation in Indonesia were also proposed within the study [246].

Tang *et al.* (2021) in their study visualized and presented the leap that could possibly be taken in the agricultural domain on implementing 5G network as the medium of communication. Furthermore, advantages of Cloud Computing service in the 5G network were also discussed for providing efficient and flexible solutions for farming practices. Benefits and applications of 5G for data analytics, predictive maintenance, real-time monitoring, virtual consultation, and cloud repositories have also been highlighted within the study [247].

Sinha *et al.* (2022) in their study focused on the significant impact of IoT in the agricultural domain over the past few years. The study focused on major components, challenges, new technologies, security issues, and future trends involved within the domain. Requirements based on specific applications have also been discussed so that researchers within the domain can clearly identify problems related to IoT's deployment and adopt available resources efficiently. Lastly, the significant importance of data analytics for SA has also been discussed within the study [248].

Table 2.12 depicts a detailed description on various surveys published over the past few years on Smart agriculture domain.

Table 2.12: Comparative analysis for various aspects in survey articles discussed under SA domain published over the past few years
A: Communication technique; B: Security; C: Challenges; D: Comparative analysis; E: Taxonomy

Author, Year of Publication, & Citation	**Domain of research article**	**A**	**B**	**C**	**D**	**E**
Kamilaris *et al.*, (2018), & [229]	Implementation of deep learning techniques	✓	✓	✓	✓	-
Drury *et al.*, (2019), & [230]	Implementation of Semantic web technologies	✓	✓	✓	✓	-
Khanna *et al.*, (2019), & [231]	Impact of IoT	✓	✓	✓	✓	-
Vasconez *et al.*, (2019), & [232]	Implementation of HRI	-	✓	✓	-	-
Lezoche *et al.*, (2020), & [233]	Impact of IoT	✓	-	-	-	✓
Patel *et al.*, (2020), & [234]	Monitoring of various techniques in agriculture domain	✓	✓	✓	✓	-
AlKameli *et al.*, (2021), & [235]	Impact of machine learning in SA	-	-	-	✓	✓
Balaji *et al.*, (2021), & [236]	Plant's health monitoring	-	✓	✓	-	-
Bhat *et al.*, (2021), & [237]	Productivity enhancement by incorporating IoT techniques	✓	-	✓	-	-

Comparative analysis for various aspects in survey articles discussed under SA domain published over the past few years (continued)
A: Communication technique; B: Security; C: Challenges; D: Comparative analysis; E: Taxonomy

Author, Year of Publication, & Citation	**Domain of research article**	**A**	**B**	**C**	**D**	**E**
Devi *et al.*, (2021), & [238]	IoT concepts implementation	✓	-	✓	-	-
Friha *et al.*, (2021), & [239]	Emerging technologies of IoT	✓	-	-	✓	✓
Gaspar *et al.*, (2021), & [240]	Identification to barriers of IoT's implementation	✓	-	✓	✓	-
Kalyani *et al.*, (2021), & [241]	Influence of Cloud, Fog, and Edge computing		-	-	✓	✓
Mishra *et al.*, (2021), & [242]	Importance of IoT	✓	-	✓	-	✓
Pandiarajaa *et al.*, (2021), & [243]	Implementation of technology through most conventional methods	✓	-	-	-	✓
Raj *et al.*, (2021), & [244]	Implementation of IoT, UAV, IoUT	✓	-	✓	-	✓
Setiaji *et al.*, (2021), & [245]	Implementation of IoT based monitoring systems	✓	-	-	-	✓
Shali *et al.*, (2021), & [246]	IoT in SA	-	✓	-	-	✓

Comparative analysis for various aspects in survey articles discussed under SA domain published over the past few years (continued)
A: Communication technique; B: Security; C: Challenges; D: Comparative analysis; E: Taxonomy

Author, Year of Publication, & Citation	**Domain of research article**	**A**	**B**	**C**	**D**	**E**
Tang *et al.*, (2021), & [247]	Enhancement of advanced communication technologies, *i.e.*, 5G	-	✓	✓	-	-
Sinha *et al.*, (2022), & [248]	Impact of IoT	✓	✓	✓	✓	-

The next section sheds light on some of the most vital web portals and mobile applications for the subjected domain.

2.3 Existing Web portals and Mobile applications catering agricultural domain

As an extension to agricultural practices over the years, various web portals and mobile applications have been launched to facilitate farmers on various prospects. Web portals provide information, service, and resources pertinent to agriculture among farmers, agricultural entrepreneurs, extension workers, scientists, and other agricultural development stakeholders. On the other hand, Mobile applications within the domain help to enhance agricultural productivity and connect farmers to their farms remotely by using ICT concepts. Some of the most prominent features within a mobile application aims at providing information related to Weather forecasting, Farm statistics (agricultural parameters), agricultural news and updates, control over actuators deployed within fields, *etc.*

In the context of Agricultural Extension and Advisory Services (EAS), there are two predominant types of portals. These are as follows.

i One that provides technical and market knowledge to end users at the grassroots level.

ii Second that provides help with capacity development of extension personnel.

Similarity, there are three different types of agricultural moblie applications available on android and iOS, mainly Agronomy apps, Commodity pricing apps, and Agriculture automation apps. Table 2.13 depicts an overview of various web portals for the domain.

Table 2.13: List of prominent web portals and their web links

Name of portal	**Web link**
Rice Knowledge Bank	http://www.knowledgebank.irri.org/
e-Agriculture	http://www.e-agriculture.gov.gh/
Agri Market	http://www.agmarknet.nic.in/
Digital Green	https://www.digitalgreen.org/
Vikaspedia	https://vikaspedia.in/
TNAU Agritech Portal	www.agritech.tnau.ac.in
Indian Society of Agribusiness Professionals (ISAP)	https://isapindia.org/
India Agro Net	http://www.indiaagronet.com/
Food Corporation of India (FCI)	www.fciweb.nic.in
*e*Kisaan	www.krishiworld.com/
Department of fertilizers, Govt. of India	https://fert.nic.in/

List of prominent web portals & their web links (continued)

Name of portal	**Web link**
Fertindia	https://www.fertindia.com/
Farmer India	https://farmer.gov.in/
*m*kisan	https://mkisaan.gov.in/
Krishi	https://krishi.icar.gov.in/

An overview of the most prominent web portals discussed in Table 2.13 and their services have been discussed as under.

i Rice Knowledge Bank

This domain provides information on pre-planting, growth, and post-production for rice crop. The domain caters 13 Asian countries and 3 African countries in specific. This domain also includes training resources, fact sheets, and various participatory research workshops enabling farmers to enhance rice productivity.

ii *e*-Agriculture

This web portal is managed by Food and Agricultural Organization of the United Nations. This portal aims to bring together farmers from all across the world for the exchange of information and ideas on agricultural practices. Blogs, webinars, online training sessions, *etc.* are also held for its members. There are a total of 73 countries as permanent members of this domain. Lastly, this portal also aims to provide updates on the latest trends in the agricultural domain related to incorporating ICT and IoT concepts.

iii Agri Market

It is a portal hosted by the Government of India providing information on price and stock availability of various crops and fruits in different country states. Apart from the above, this domain also provides important guidelines and information related to agricultural activities that needs to be undertaken for various crops and fruits. Lastly, this domain also provides regular SMS to its registered users on updates and market trends on prices for various commodities.

iv Digital Green

It is a domain hosted jointly by the Indian and Euthopian governments that aims at providing interactive video sessions on agricultural practices for uplifting the agricultural economy in both the nations. This domain also hosts an application, FarmStack enabling farmers to post their queries related to their agricultural practices and get timely reverts from experts.

v Vikaspedia

This is another domain that is hosted by the Government of India, providing information on agricultural practices and updates on various crops and fruits in 23 different Indian languages. This domain also provides farmers with helpful links on National policies related to agricultural practices and various beneficial schemes. Lastly, this domain also provides link enabling farmers for Agricultural loans directly from government banks.

vi Tamil Nadu Agricultural University (TNAU) Agritech Portal

This portal is hosted and maintained by Tamil TNAU, which provides the latest information on farm machinery, Bio-energy, food processing, conservation of seeds, *etc.* Furthermore, this portal also provides financial aids to needy farmers under Rashtriya Krishi Vikas Yojna (RKVV) aided by the Department of Agriculture and Farmers Welfare, Government of India.

vii Indian Society of Agribusiness Professionals (ISAP)

ISAP aims at providing sustainable agricultural solutions by incorporating the latest technical advancements. This domain also provides skill development programs from time to time for needful farmers.

viii India Agro Net

This domain aims at providing information on various agricultural equipment. This portal also has an interface for sale and purchase of various seeds at subsidized prices. It also provides a platform for its registered users to share their ideas and experiences within the domain on various crops.

ix Food Corporation of India (FCI)

This web portal provides information on effective price support, food security, price stabilization, and distribution of food grains through a public distribution system, benefiting both farmers and consumers. This domain also aims at providing on-line and offline training sessions to farmers regarding latest agricultural trends and practices. Lastly, the central government has also started to motivate Indian farmers on the adaptation of ICT and IoT enabled agricultural practices.

x *e*Kisaan

*A*part from being a portal, eKisaan is a non-profitable organization that aims at leveraging technology to improve agriculture, health, nutrition and education among Indian farmers. Namma Raitha and Namma Halli - Smart Village are some of the aided programs undertaken by this organization. There are a total of 1,300 villages and 20,000 farmers connected to this portal.

xi Department of fertilizers, Govt. of India

This portal provides information on different aspects of fertilizer, its consumption requirement among various crops, its adverse effects on crops have also been discussed. Furthermore, price fluctuation of various fertilizers is also regulated. Lastly, it also has a sale/purchase window enabling various farmers to perform transactions.

xii Fertindia

This portal also provides detail about fertilizer statistics in India, its prices, and fertilizer marketing. This domain also hosts an interface for sale and purchase of a variety of IoT-based devices that help in the detection of NPK's presence within soil.

xiii Farmer India

This domain provides information and directions on crop management, online soil health card, and risk management directions based on crop. This also has a 24*7 call support center that aims at eliminating farmer's agricultural issues.

xiv *m*Kisaan

*m*Kisan SMS-based portal, enabling all central and state government organizations in the agricultural domain, along with various other allied sectors to give information/services/advisories to farmers via SMS in their regional language. This portal also hosts a 24*7 call support center for farmers.

xv Krishi

This portal provides services related to coordinates identification and manages the latest content in research and education for the agricultural sector, including horticulture, fisheries, and animal sciences. Furthermore, it also has a dashboard where farmers can share their experiences. Lastly, this portal also hosts information on a variety of modern-day agricultural sensors, their prices, information of distributors and dealers giving beneficial deals on these devices.

Similarly, a variety of mobile applications are also available over android and iOS, enabling farmers to perform agricultural activities remotely. Table 2.14 depicts the list of most prominent web portals and their availability platforms.

Table 2.14: List of prominent mobile applications

Name of Mobile application	**Availability platform**
Krishe	Android and iOS
Iffco Kisan App	Android and iOS
Agri Media Video App	Android
FarmBee - RML Farmer	Android
Kisan Yojana	Android
Agronote	Android and iOS
AkerScout	Android
Crop Nutrient Advisor	Android and iOS
Cloud farmer	Android and iOS
Soil Study	Android and iOS

An overview of the most prominent mobile applications discussed in Table 2.14 and their services have been discussed as under.

i Krishe

This application leverages the combination of technology and experience to provide crop information that improves the crop yield for each farmer. This application also features consulting services and useful agriculture information for various crops that boost crop yield. The application also features a personalized calendar that provides information for each farm based on farm location, crop, season, farm size, planting material, sowing date, and other parameters that are unique to the farm and to crops.

ii Indian Farmers Fertilizer Cooperative Limited (IFFCO) Kisan app

This application is specifically designed to cater the needs of an Indian farmer, enabling him to take informational decisions based on accessing customized agricultural information related to his/her needs. In addition, this application also provides latest and updated information relating to market (mandi) agricultural advisory, best practices tips related to animal husbandry, weather forecast, and horticulture. Information is shared in the form of audio clips that are available in 11 different Indian languages.

iii Agri Media Video app

It is an Indian application designed to impart agricultural education and extension of agricultural practices among farmers. There are numerous informational videos loaded in three different languages, *i.e.*, English, Hindi. and Gujrati providing complete scientific crop cultivation process from land preparation to harvesting.

iv FarmBee - RML Farmer

This application is also referred as FarmBee - The Pomegranate Expert. This application is specially designed to grow good-quality pomegranates by managing farm functions remotely. This application also provides an interface to its users for having interactive chats among other experts that fall under a similar crop domain.

v Kisan Yojana

This application is designed specifically to cater to the needs of Indian farmers. This application provides information about various government schemes for farmers from their respective states. This application also has a database that provides contact points and numbers of all the resourceful persons available region-wise.

vi Agronote

This application provides a user-friendly interface to record farm income and expenses entries. In addition, this application also allows farmers to create expenses and revenue record for livestock and machinery procedures and access this information with ease.

vii AkerScout

This is a directed crop scouting application that helps farmers in timely identification of damaged crops. The application works on standalone mode; however various important features are enabled within the application, when a user loads high-resolution aerial vegetation imagery. Furthermore, this application also saves a comprehensive database for the identification of diseases among plants, pests, and plant limiting stress. Uploaded data over this application, provides full support of web dashboard with data analytics.

viii Crop Nutrient Advisor

This application provides information on crop nutrient deficiencies product recommendations and compares spray tank. Lastly, this application also allows users to pair the application with the cloud server to record and save observations for future reference.

ix Cloud farmer

This is a cloud sync application that allows the farmer to record farm parameters over the cloud via on-line and off-line mode. Weekly planner, stock records, farm diary, purchases and sales, health and safety, time-sheets, animal treatment records, jobs list, upload pictures of documents, and locations are some of the other available features on this application.

x Soil study

This application enables the farmer to locate his fields over the map provided by google maps by using GPS measurement tool. In addition, this application has a feature called "accurate navigation" that allows farmer to reconnect to the same pick-up position every time the application is excessed. When aiming for productivity, this application also provides fertilizing analysis of different crops, such as wheat, corn, soybean, *etc.* before seeding to determine the existing soil's nutrition level. This technique helps farmers and agronomists in determining fertilization rates before seeding, planting or sowing.

After referring to a number of articles within the domain, it has been considered that agricultural parameters and selection of hardware devices for generating observations to various parameters play a vital role. In parallel, correct identification of best fit ML technique for computations further enhances the current standings of the domain. In addition, there are a couple of concern areas from the farmers' perspective, discussed in the next section.

2.4 Issues identified based on extensive literature review

Irrespective of numerous advancements in the agriculture domain, there are numerous issues faced among farmers within the agricultural domain. Figure 2.7 depicts a pictorial representation of the prominent issues identified after conducting literature review.

Figure 2.7: Issues identified after conducting literature review

Some of the most prominent issues faced by farmers on adaptation of IoT practices under agricultural domain are as follows.

i Lack of infrastructure

Due to lack of connection infrastructure, farmers are unable to avail benefits from IoT technology. This is mainly due to lack of Internet services in remote areas. Connection troubles would render a sophisticated monitoring system ineffective because a farmer requires reliable access to agricultural data at all times and from every location. [249].

ii Higher hardware costs

The technology required to integrate IoT in agriculture is very costly. Despite the fact that sensors are the least expensive component, equipping complete area of a farmer's field, can cost over a thousand dollars. In addition, farm management software and cloud access to record data are included as an automated machinery, which costs more than manually run machinery. Farmers should invest in these technologies to increase their revenues; nevertheless, they may find it difficult to make the first expenditure to set up IoT equipment on their farms [250].

iii Security issues

Since IoT devices interact with paired hardware equipment, there is an utmost requirement of an active Internet connection. Hence, there need to be a secured system for performing this task uninterruptedly. Moreover, an enormous amount of data is collected by IoT agricultural systems, which is sometimes difficult to procure and transmit. [251].

iv Instability of seasonal showers

Climate change profoundly impacts agriculture and its allied sectors, as planted crops are highly sensitive to climate change. The interaction and synchronization between agricultural performance and weather have been an important area of concern for research since last few decades. It has gained momentum due to the awareness of the adverse effects of climate change during the last recent years. For example, the state of Punjab gets winter rainfall because of westerly depression (Temperate Cyclones) that often originate from the Mediterranean sea in the Atlantic Ocean, as they lie in the temperate zone and therefore are in the pathway of this depression. Hence, the crops cultivated in the state often get harmed due to seasonal showers' instability. This variation in season can be monitored via agricultural sensors, but farmers find it hard to put on use because of their limitations with respect to knowledge and usability [252, 253, 254].

v Cropping pattern

With the introduction of the green revolution, the agricultural domain has witnessed a considerable change in cropping patterns. Crops that are grown within the fields are divided into two broad categories:

- Food crops
- Non-food crops

A fine example in this case is the area under cultivation for cotton and sugarcane remains relatively stable. Although High Yielding Variety (HYV) seeds have replaced multi-cropping with a mono-culture of wheat and rice. Yet the state's natural resources, particularly water and soil, have been majorly exploited, and floral biodiversity has been lost. As a result of the varied pattern of farming, the land fertility frequently deteriorates, leaving no time for natural rejuvenation [255].

vi Land ownership

Although agricultural land ownership in majority of states is reasonably evenly distributed, there is some concentration of land holding. The fact that land ownership changes frequently across the state contributes to inequity in land allocation. Large tracts of land within the state are thought to be owned by a tiny group of wealthy farmers, landlords, and moneylenders. While the vast majority of farmers in the state own either very little or no land at all. Furthermore, the majority of holdings are either modest or unprofitable. As a result, the benefits of large-scale farming are unavailable, and the cost per unit for "uneconomic" holdings is rather high. As a result, the output per hectare is quite low. Hence, the peasants cannot generate a sufficient marketable surplus. Consequently, the farmers across the state are not only poor but often in debt as well.

vii Farmland leasing

There is a trend of giving agricultural land on lease within the state, *i.e.*, the land is given to farmers on a contractual basis for a yearly cycle. The borrowers perform agricultural activities on the land without giving much concern towards understanding the soil's fertility rate, land usage technique, and availability of groundwater. Hence, as a result, the fertility rate of the land decreases year by year [256].

viii Issues of agricultural labour

Agricultural labour are the ones who work on the land on day-to-day basis. They can be classified into two different categories:

- Bonded or Semi-Free labour
- Dwarf-Holding labour
- Under-Employed Landless labour
- Full Time Land-Less labour

One of the major issues associated with agricultural labour is either the absence of skill required to carry out agricultural activities or the lack of knowledge. Hence, there is hardly any change in level during the regime of motivation. Issues related to their illiteracy, ignorance towards the adoption of newer agricultural techniques are some other factors under consideration [257].

ix Unawareness and non-availability of modern-day agricultural equipment

Unawareness and non-availability on the usage of modern-day agricultural equipment is one of the major concerns in deteriorating the agricultural domain. The farmers are hardly aware of precision agricultural equipments and their correct usage. Although the state and central government disseminate information through agricultural seminars and exchange programs for motivating farmers to adopt modern-day agricultural equipment and practices. Farmers across the state avert adopting these techniques either due to financial constraints or due to lack of knowledge [231, 258].

x Unavailability and over-priced cost of seeds and manures

Unavailability and overpriced cost of quality seeds and manures is a big matter of concern for farmers across the state. As stated earlier, financial constraints are often encountered by farmers. Hence as a chain result, they keep their investments in seeds and manures at a marginal level leading to a compromise with traditional agricultural practices [259].

xi Unavailability of electricity for initiating water supply

Specifically for all the states of Indian sub-continent, availability of electricity is a major concern. Although, the state of Punjab is blessed with 3 prominent rivers, *i.e.* Beas, Sutlej, and Ravi. Even then, the agricultural land of Punjab faces acute scarcity of water due to the unavailability of 24*7 electricity for initiating water supply through tube-wells [260]. Moreover, the water level in the state has drastically decreased over the past few years [261, 262]. Farmers often compare the electricity rates at which they are acquiring electricity in contrast to other states nearby Punjab. Hence, the variation in electricity cost is also a matter of concern among farmers [263, 264].

xii Use of contaminated water for irrigation purpose

Drainage of industrial waste into rivers has long-term effects on humans and plants. During recent years, issues related to the usage of contaminated water for irrigation purpose has become a source of major concern [265].

xiii Unaware regarding modern-day agricultural practices

Due to lack of knowledge, most of the farmers across Punjab are unaware of new-age devices and techniques. Over the years, newer techniques like drip irrigation, sprinkler irrigation, furrow irrigation, soil moisture evaluation, issues related to soil temperature, effects of humidity upon crops, *etc.* have gained a lot of significance in the field of agriculture [266, 267, 268, 269, 270].

With the change farming practices, now a days, agricultural activities are performed on the basis of evaluating various parameters such as soil temperature, soil moisture, soil humidity, luminosity, wind speed, estimation of rainfall, *etc.* [271, 272, 273, 274, 275].

All the issues highlighted in Section 2.4 are based on the prominent shortcomings identified from the literature review and from farmer's perspective. Based on the identification of prominent issues from an extensive literature review, problem formulation for the present study has been derived, that are co-related with the objectives for the present study.

2.4.1 Problem formulation

Agriculture is an important aspect and it is directly associated towards the growth of country's economy. In addition, this domain provides a vast horizon of job possibilities to a huge section of the people. The final outcome of agricultural process provides food and raw materials. Hence, this domain is of paramount importance and it must be ensured that this domain should never be in stagnation state. To overcome this issue an extensive study on existing agricultural practices have been performed within the present study.

In our preliminary investigation performed on various agricultural practices in existing scenario, some of the most prominent research gaps had been identified and listed in Section 1.3. Later, while performing an extensive literature review based on various phases of agriculture's life cycle and evaluating numerous survey articles on IoT and SA, additional relevant issues have been identified and listed in Section 2.4. All these prominent issues have significant impact while performing agricultural practices. In addition, these issues are also countable for experiencing stagnation within the domain. Based on the identification of the most prominent issues, that are required to overcome on priority have been made as the objectives for the present study.

Chapter Summary

The growth of research work in the field of IoT and SA has motivated to conduct this systematic survey. There are several issues that the farmers face during performing agricultural activities. The research work in this field is continuously growing due to ever-increasing demands and expectations. Till now, the research focus has only been on proper implementation of agricultural sensors, data transmission to the cloud, and control over agricultural sensors and actuators remotely. Therefore, this chapter is a significant contribution in the literature of SA, which includes the systematic survey over – research studies published (Till the year-mid of 2020). However, it has been concluded from the study that farmers feel hesitant about implementing new-age agricultural practices. Majority of studies discussed in literature review shed light on various web portals and mobile applications developed by researchers enabling farmers to undertake the agricultural activities with some added advantage. The next section aims at discussing some of the most prominent web portals and mobile applications used within the domain.

The next chapter proposes an IoT based smart irrigation and fertilization framework, to ensure minimal use of water and fertilization distribution within the fields.

Chapter 3

IoT-based Smart Irrigation and Fertilization Framework

Conceptual framework is the most crucial aspect of building an architecture for any research study, as it acts as a foundation for the development of the research's various components. Developing a framework helps the researcher in arriving at a specific position for or against a phenomenon [276]. Various phases within a conceptual framework integrate towards lucrative functioning of the framework. In context of the proposed study, two aspects, *i.e.*, water and fertilizers are of paramount importance. The presence of water is a basic necessity for the functioning of all forms of life that exist on earth. Excessive distribution of water is pernicious for crops and for the environment. When the crop is not properly irrigated, the tips and edges of the leaf get dry and change their colour from green to brown. Gradually, with the passage of time, the leaves of the plant die. On the other hand, when water is distributed in excess within the fields, it often results in water-logging. Due to this phenomenon, the process of germination gets initiated, *i.e.*, roots either don't grow properly or the standing crops get destroyed. In addition to it, the amount of salt on the surface soil also enhances.

Similarly, fertilizer also holds an important aspect within agricultural domain. Mineral fertilizers are mainly used as supplements which are quickly absorbed by soil for crop's proper growth. Excessive usage of fertilizers is harmful to both crops and the environment alike excessive water distribution. It often results in chemical burns to crops, enhances air pollution, and acidification of soil's surface resulting in mineral depletion of the soil. Hence, it becomes necessary to first evaluate the precise requirement for both the aspects before their distribution within the fields. In order to attain the objective of optimizing the use of water and fertilizers, Minimal Distribution of Water and Fertilization based Decision Support System ($MDW\&F_bDSS$) framework has been proposed within the existing study. The next section presents the overview of IoT-based Smart irrigation and fertilization framework for the proposed system.

3.1 Overview of IoT-based Smart irrigation and fertilization framework for the proposed system

Using a structured framework approach is indeed the best technique that not only provides a complete information of the overall working of the framework, but also enables the developer and user to further improve on individual modules. To attain the objective of optimizing water consumption and fertilization distribution within the fields, Minimization Distribution of Water and Fertilization based Decision Support System ($MDW\&F_bDSS$) has been proposed. A pictorial representation for the proposed framework has been depicted in Figure 3.1. The proposed framework is clefted into three different phases. Each phase has its own significant importance and a unique function to perform. A detailed description on internal working for each phase has been presented below.

Phase 1: Sensor Network/Data Acquisition Layer

This is the initial phase of the proposed framework that emphasizes on deployment of various agricultural sensors within the fields with an aim to capture readings on multiple parameters. These parameters are Soil moisture (S_m), Soil temperature (S_t), Atmospheric pressure (A_p), Humidity *(H)*, and Luminosity *(L)* and Volumetric-water-Content *(VWC)*. Agricultural sen-

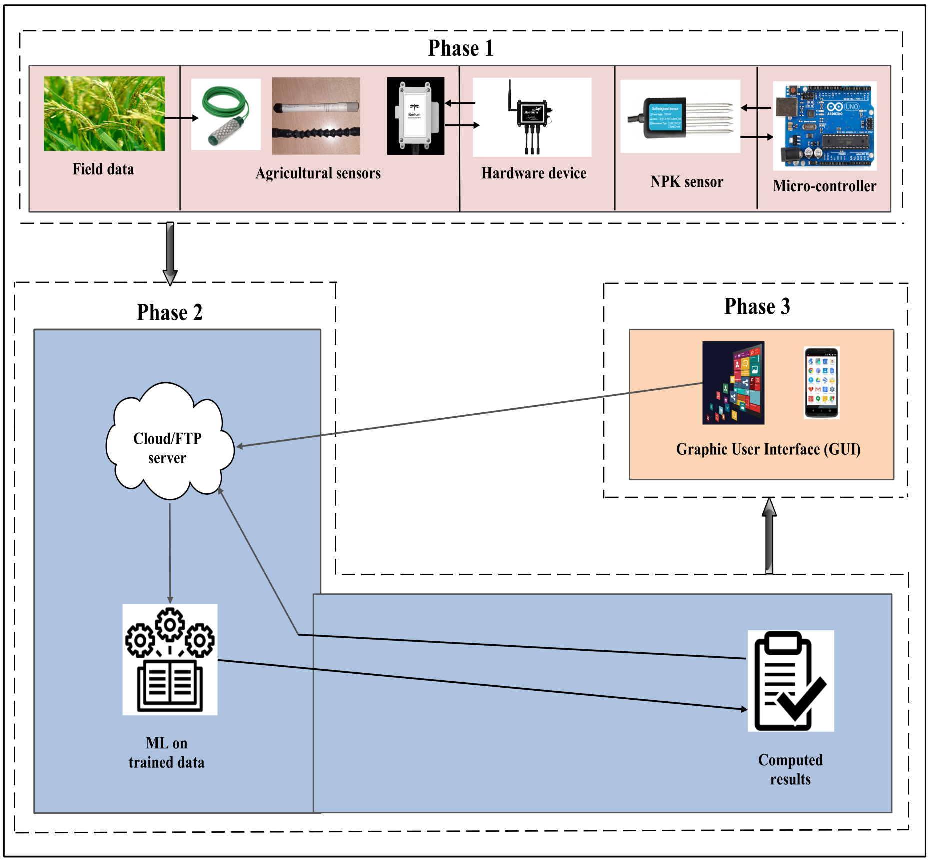


Figure 3.1: Proposed framework for Minimal Distribution of Water & Fertilization based Decision Support System ($MDW\&F_bDSS$)

sors were mounted over two different hardware devices, *i.e.*, Libelium's Waspmote Plug and Sense device and Arduino Uno to capture the above said parameters. Furthermore, to enable the hardware device to capture readings on various parameters, two different codes have been uploaded on both the hardware devices, that further enabled the associated device(s) to generate signals after regular intervals to capture readings on various parameters. Figure 3.2 depicts the work-flow of Phase 1 for the proposed framework.

Once the agricultural sensor captured the information, the data was transmitted to the second phase of the proposed framework as input. Data transmission from the first phase to the second phase was performed with the help of SS7 protocol stack (for GSM module) for Libelium's Waspmote Plug and Sense device. For the second aspect, data was captured with the help of NPK sensor mounted over Arduino Uno. The readings were transmitted over the

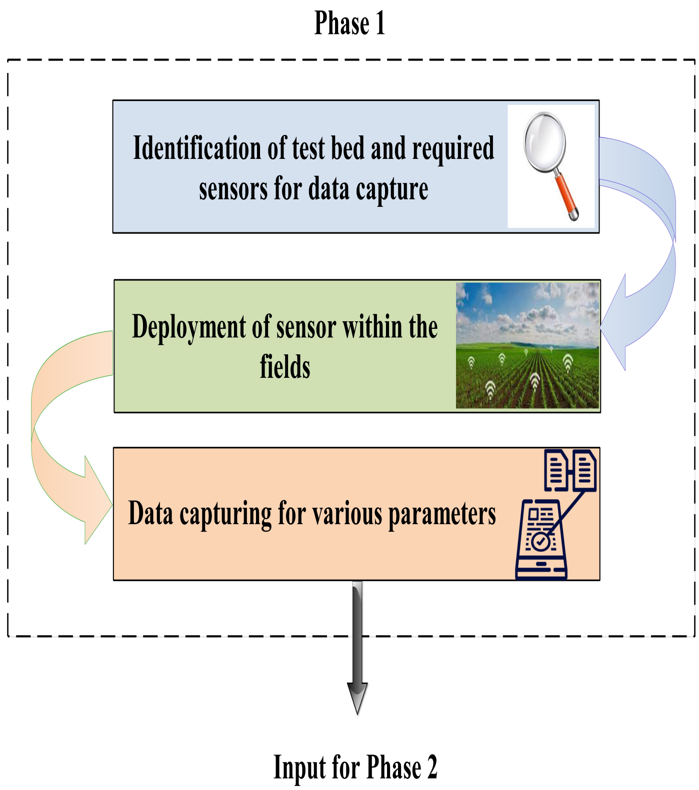


Figure 3.2: Workflow of Phase 1 for the proposed framework

cloud on real time basis and an OLED display module was also attached within the designed circuit to view the readings.

Phase 2: Storage and Computation Layer

This is the second and the most prominent phase of the proposed framework. Input is taken from the previous phase, where data is initially captured. At the very first step of the second phase, the data captured by Libelium's Waspmote Plug and Sense device is stored over the cloud server. The second step post storage of data is its pre-processing. Once the data was pre-processed, *i.e.*, identification of missing and repeated values were performed, the data was transferred to the incorporated ML technique. The ML technique splits the data into two portions for training and testing purpose and later computations were performed. Results of the computations were transmitted back to the cloud server for storage and future reference purpose. In addition, these results are also transmitted to the third phase of the proposed architecture. Figure 3.3 depicts the internal working for Phase 2 of the proposed framework.

Phase 3: Menu-driven interface

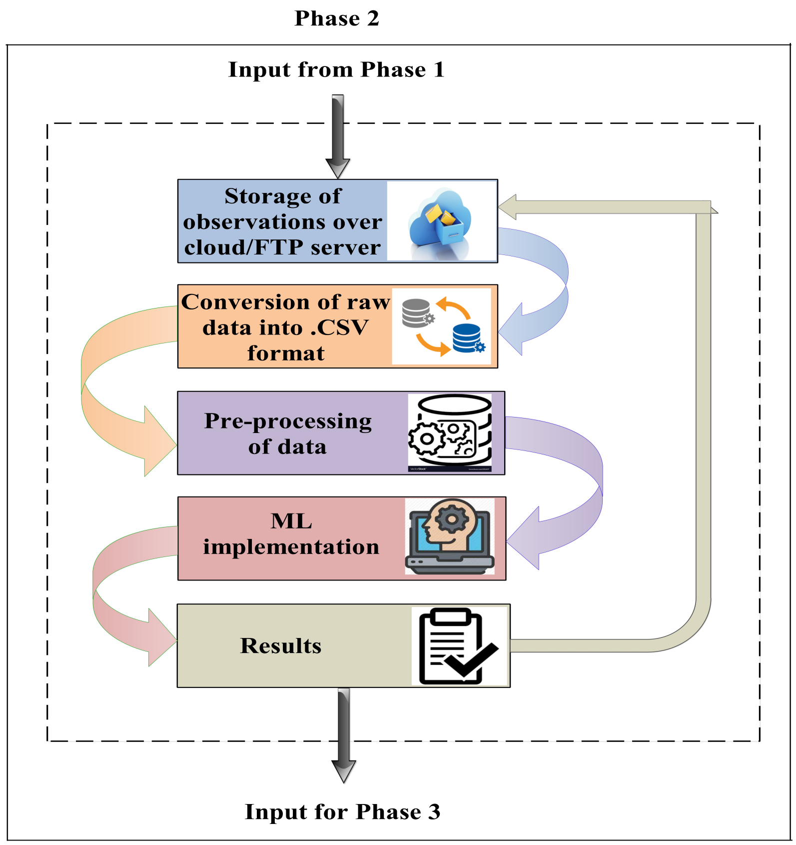


Figure 3.3: Workflow of Phase 2 for the proposed framework

This is the third and the last phase of the proposed framework. The main aspect of this layer is to provide a GUI, that enables the end-user to view the final computed results. The interface also has a facility to view live farm statistics when the process of data capturing was being performed. This GUI supported both mobile-based and web-based interface. It enabled the user to view results either on mobile or over the laptop. Based on the results of the computations, it facilitated the end-user to take feasible and timely action in the context of agricultural practices. Additionally, the interface of the GUI also provided facility to view the captured data. Figure 3.4 depicts the internal working of Phase 3 for the proposed framework.

With the help of computations, a precise estimation of water and fertilizer distribution is

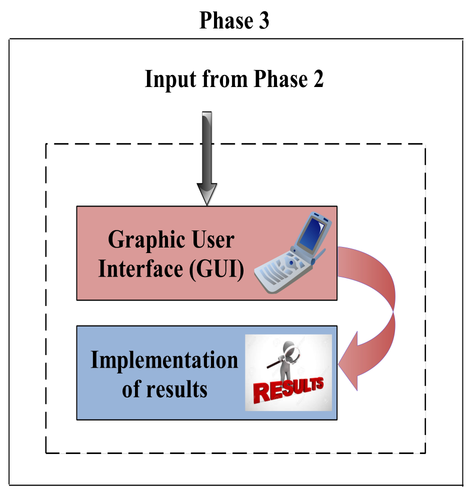


Figure 3.4: Workflow of Phase 3 for the proposed framework

determined in advance. In architectural domain, different variety of crops are sown within the fields and hence requirement of water for irrigation varies. In addition, at different geographical locations, the variety of soil also changes. Therefore, the process of evaluating agricultural parameters in advance is of paramount importance.

In addition to the above factors, the determination of effective rainfall also plays a vital role in determining the precise amount of water distribution within the fields as it is also considered to be a source of irrigation. The next section presents the evaluation technique acquired by researchers for estimating water requirements based on soil and rainfall determination.

3.2 Evaluation of irrigation water needs for the soil and effective rainfall determination

Water is a critical input for agricultural production and plays an important role in food security [277, 278]. It is required by both soil and crop. Water is distributed within the fields in three different ways, *i.e.*, irrigation, rainfall, and a combination of irrigation and rainfall. In scenarios where all the water requirements for optimal crop's growth is compensated by rainfall only, irrigation is not required, hence the value of Irrigation water needs *(IN)* is assigned as 0, as depicted in equation 3.1

$$IN = 0 \tag{3.1}$$

In the second scenario, when there is no rainfall during the growing season of the crop, the water requirement is fulfilled by irrigating the fields. Consequently, *IN* equals the Crop water need (ET_{crop}), as formulated in equation 3.2.

$$IN = ET_{crop} \tag{3.2}$$

In the third case, when rainfall partially irrigates the fields and deficit irrigation is done by further irrigating the fields. In such cases, there arise a difference between ET_{crop} and that part of the rainfall Plant's Effectively *(Pe)*. Hence, *IN* is determined through equation 3.3.

$$IN = ET_{crop} - Pe \tag{3.3}$$

Rainfall is a key factor having dramatic effect on agriculture, as it fulfills the water requirements of the crops. Estimation of rainfall before hand not only helps in strategic decision making related to irrigation, but also helps in determining crop's growth [279]. In order to evaluate the precise estimation of effective rainfall, it is always recommended to evaluate the possibility of rainfall so that fields do not get over irrigated [280]. The determination of adequate rainfall involves two important factors, *i.e.*, Evaporation and Precipitation. Figure 3.5 depicts the process of evaporation and precipitation of rainwater within the fields.

As depicted in Figure 3.5, when rainfall takes place (1), droplets of water falls the soil surface (2), while a proportional amount of water stagnates on the surface (3), some amount of water flows over the surface as runoff (4). In addition, some amount of stagnated water evaporates into the atmosphere (5), while the remaining amount of water slowly infiltrates into the soil (6). The infiltrated water percolates below the root zone (7), while the rest remains stored at the root zone (8).

To put it another way, it can be stated that adequate rainfall (A_r) is the total amount of rainfall

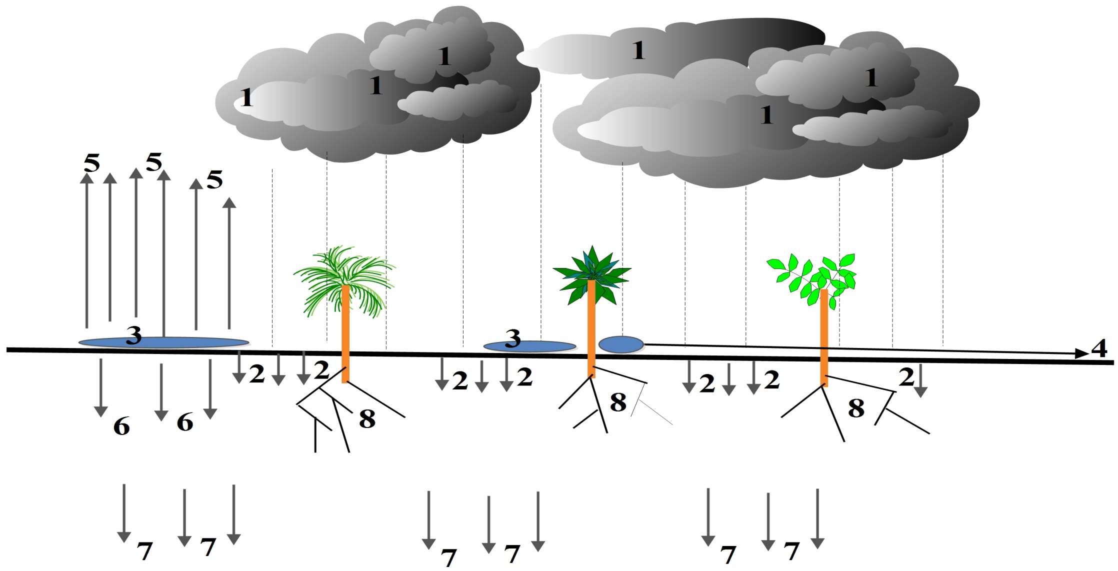


Figure 3.5: Process of evaporation and precipitation of rain water

(T_r) minus runoff (R_{off}) minus evaporation *(e)* minus deep percolation (D_p). This has been formulated through equation 3.4.

$$A_r = T_r - R_{off} - e - D_p \tag{3.4}$$

Hence, by virtue of this formulation, an estimation of effective rainfall is determined and deficit irrigation is calculated.

For the purpose of present study, water requirement for wheat crop in the summer season was estimated. During this season, a spell of rainfall was experienced thrice. Effective rainfall based on above formulation was evaluated and accordingly amount of water for deficit irrigation was determined in advance. The same process has been followed for calculating water requirement, effective rainfall, and deficit irrigation for two other crops, *i.e.*, rice (paddy) and capsicum. While evaluating the irrigation water needs for the soil, it has been observed that every crop grown within the field has its own water requirement. With the help of IoT, irrigation system can also be controlled remotely to maximize irrigation efficiency [281, 282]. The next section presents the proposed IoT-based automatic water relay mechanism to turn on/off the water supply within the fields.

3.3 IoT-based automatic water relay mechanism for irrigation

It is evident from a number of studies that water is of paramount importance in the agricultural domain [283]. Both over-or under-irrigation have adverse effects on crop as well as on soil's health. Numerous studies conducted over the past few years in relation to the above depict similar results [284, 285, 286]. The process of smart irrigation is possible only by deploying various actuators that can be remotely. This implementation overall results minimal wastage of water, thereby reducing the costs.

For the purpose of optimum distribution of water within the fields, an IoT-based automated water-valve control system has been designed and implemented. Wireless sensors and actuators with low-power wide-area networking radio technology have been incorporated. The proposed device allows farmer to remotely control the irrigation for the field. The working of the proposed mechanism was tested on all the three testbeds. The hardware device deployed within the test bed consisted of a single sensor node, a gateway, a server application, and a mobile-based interface. The conceptual working of IoT-based automatic water relay mechanism for irrigation has been depicted in Figure 3.6.

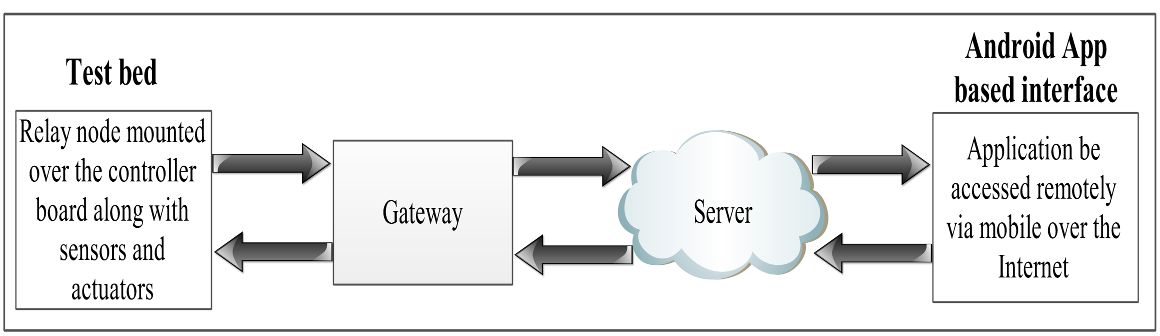


Figure 3.6: Conceptual working of IoT-based automatic water relay mechanism for irrigation

The functioning of the proposed mechanism is as follows.

- A controller board, agricultural sensors, and actuators are the devices that were deployed within the test bed. The primary function of the agricultural sensor was to capture values for various parameters *i.e.*, Soil moisture (S_m), Soil temperature (S_t), Atmospheric pressure (A_p), Humidity *(H)*, and Luminosity *(L)*. With the help of Internet, captured values were transmitted to the computation machine and results were drawn. A minimum and maximum threshold was calculated for Soil moisture (S_m) parameter. Based on evaluation of all the agricultural parameters, minimal irrigation requirement was determined.

- The router within the proposed mechanism worked as a gateway. It allowed wireless communication between the sensor node and a web-based server application.

- Captured data was stored on the cloud that also hosted the mobile application.

- The mobile application allowed the farmer to remotely view the farm parameters, evaluated results, and provided a control to turn on/off the water valve remotely via mobile application.

The aim of developing an automated mechanism was to minimize water consumption within the fields. It is needless to say that the proposed mechanism is incomplete without incorporating hardware devices. Various hardware devices and software platforms used within the proposed mechanism are:

- **ESP32**

  It is a low-cost, low-power system on a chip micro-controller with an integrated Wi-Fi and a dual-mode Bluetooth capabilities. The ESP32 series employs a single-core and dual-core microprocessor. This module has built-in antenna switches, RF Balun, power amplifier, low-noise receive amplifier, filters, and various power management modules. This incorporated device helped in performing computations. The calculated threshold was fed in the micro-controller (ESP32) device. Based on the continuous observations by agricultural sensors, when the moisture level reached the minimum threshold, the micro-controller used to send a signal to initiate the solenoid valve and when the threshold reached maximum limit, disengage signal was transmitted.

- **Solenoid valve**

  It is an electrically controlled valve that allows the hardware device to control the flow of water. It features an electric coil in its center which creates a magnetic field. The magnetic field exerts an upwards pressure that pulls the valve to open or close the valve gates. Solenoid valve received disengage signal to turn off the water supply when maximum Soil moisture (S_m) was attained and vice-versa.

- **Heroku**

  It is a cloud based PaaS that enables various applications to communicate information and to provide remote access on various services for remotely administering the obtained datasets [287]. The cloud also used to send alert messages via SMS on user's registered mobile number.

The proposed mechanism was attained with the help of a framework that consisted of two phases as depicted in Figure 3.7, whereas Figure 3.8 depicts the practical implementation of solenoid valve deployed at rice crop's test bed. The next chapter shed light on various data acquisition techniques incorporated within the study for the proposed objectives.

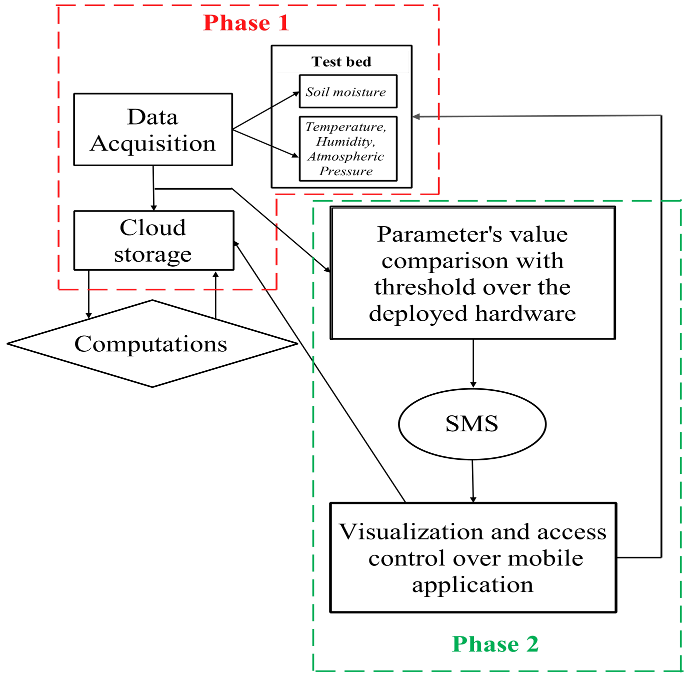


Figure 3.7: Workflow for IoT-based automatic water relay mechanism

Figure 3.8: Pictorial representation of IoT-based automatic water valve mechanism's deployed at rice crop's test bed

Chapter Summary

This chapter presented an in-depth detail and working of the proposed framework, *i.e.*, IoT-based irrigation and fertilization framework, that aims to minimize the consumption of water and fertilizers within the fields. Since rainfall also contributes to the process of irrigation, this chapter also provides an in-depth discussion on determination of effective rainfall within the fields and its evaluation strategy. The last section of the study sheds light on the conceptual working of IoT-based automatic water relay mechanism that enables the farmer to remotely engage and disengage the process of irrigation based on the evaluation results of various agricultural parameters.

The next chapter sheds light on various data acquisition techniques adopted within the present study to capture associated parameters for determining precise requirement of water and fertilization distribution within the fields.

Chapter 4

Data Acquisition

The process of acquiring data is the most important component and one of the essential aspects for building a SA system. For the proposed SA system, data acquisition is done by deploying sensors within the fields. These sensors generate values on various parameters, which are further used for evaluation purpose. To optimize the process of irrigation and fertilization, three different locations (fields) for rice (paddy), wheat, and capsicum crops were identified for conducting experimentation. Libelium's Waspmote Plug and Sense device had been deployed in the fields to capture readings on various parameters with an aim to optimize water requirement. Similarly, NPK sensor was another hardware device that was deployed over Arduino Uno to capture readings of various parameters to optimize the fertilizer distribution within the fields. Figure 4.1 depicts the process of data acquisition on various parameters for different crops. Details for both the hardware devices and their associated sensors have been discussed in subsection(s) 4.2.1 and 4.2.2 respectively.

The next section depicts a detailed demographic description for various fields identified for conducting experimentations.

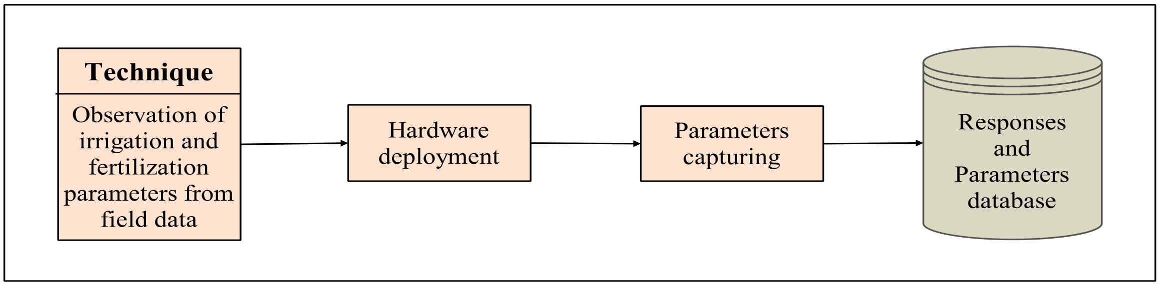


Figure 4.1: Process of data acquisition on various parameters for different crops

4.1 Demographic details of the fields used for experimentation

The framework to estimate the precise water requirement has been tested at three locations in the Malwa region of Punjab, *i.e.*, Patiala. The details of testbed(s) are as under:

- The first testbed is setup at Thapar Institute of Engineering and Technology's Center of Research and Excellence (CORE) having coordinates 30^o3564^oN, 76^o3647^oE. In this field, rice crop was used for experimentation.
- The second testbed is a field of village Dandrala, Dist. Patiala, having field coordinates as 30^o4667^oN, 76^o3190^oE. In this field, experiments were conducted on wheat crop.
- The third testbed is established in a vegetable field, with coordinates 30^o 2211^oN, 76^o2335^oE. In this testbed, capsicum crop was cultivated.

All the agricultural sensors were deployed within these three testbeds to capture readings on various parameters. The details of collected datasets have been discussed in Section 4.3. In the next section, a detailed description on technical specifications for various hardware devices and agricultural sensors incorporated within the study has been presented.

4.2 Hardware devices incorporated

Agricultural sensors provide data which further assist farmers to monitor and optimize crops by adapting to changes in the environmental conditions. Therefore, selection of hardware and its correct deployment are the most important aspects in SA domain. To capture readings, two hardware devices, *i.e.*, Libelium's Waspmote Plug and Sense device and Arduino Uno have been used for this experimentation. Figure 4.2 provides an overview of various hardware devices and agricultural sensors used for capturing values.

```
Hardware devices and sensors deployed within the test bed
├── Libelium's Waspmote Plug and Sense device
│   ├── Temperature, Humidity, and Pressure (BME280) sensor
│   ├── Soil moisture sensor
│   └── Luminosity sensor
└── Arduino Uno
    └── NPK sensor
```

Figure 4.2: Various hardware devices and agricultural sensors deployed within the fields

A detailed description for all the hardware devices and sensors incorporated for the study have been depicted in the subsections below.

4.2.1 Hardware used for irrigation assessment

The first aspect of conducting experimentation is estimating the precise requirement of water for irrigation within the fields. To obtain values of parameters like Soil moisture (S_m), Soil temperature (S_t), Atmospheric pressure (A_p), Humidity *(H)*, and Luminosity *(L)*, Libelium's Waspmote Plug and Sense device has been used. The proposed hardware captured data on a real-time basis. A variety of sensors had been mounted on the hardware device to capture readings for various parameters. A pictorial image of the hardware device has been depicted in Figure 4.3.

Libelium's Waspmote Plug and Sense hardware is a sophisticated device, that empowers the user to deploy and manage an end-to-end digitalization solutions. The main reason to use this specific hardware is its ability of low power consumption, autonomous work, modu-

Figure 4.3: Libelium's Waspmote Plug and Sense device and its sockets where sensors can be mounted

lar architecture, portability, easy to use, valuable and simple interface of IDE, and its high flexibility to perform operations in every season. It is made up of polycarbonate material, that is a resistance-free metal and powered by an alternate current (AC) and requires a 3.7V to recharge the battery. In addition, the rechargeable lithium-ion battery (solar power) consists of electric storage of 6600 mAh. The device has a battery backup of up to 70 hours to perform the operations in the field. This device is a portable instrument, and it can easily be deployed anywhere within the field. Generic specifications for the hardware device have been listed in Table 4.1. Table 4.2 highlights the technical specifications, whereas Table 4.3 depicts the description for various sockets available on the hardware device.

The mode of operation for nodes to optimize the energy requirements of the hardware has been given below.

- The sleep mode

  In this mode, the current consumption of the nodes is the smallest and is 30μA.

Table 4.1: Generic specifications for Libelium's Waspmote Plug and Sense device

Operational Description	Value
Power source (Battery)	3.7V
Power Source (Solar)	12V
12 voltage	6600 mAh
Total sensor nodes	06
Portable	Yes
Upgradeable	Yes
GSM slot	4G
USB connection	Yes
SD Card	Micro SD (supported)
IDE version	Waspmote Version 12

Table 4.2: Technical specifications for Libelium's Waspmote Plug and Sense device

Specifications	
Weight	20g
Dimensions	73.5 x 51 x 1.3 mm
Temperature Range	[- 20°C, 65°C]
Electrical characteristics	
Board power voltages	5V
Sensor power voltages	5V
Maximum admitted current (continuous)	200 mA
Maximum admitted current (peak)	400 mA

Table 4.3: Slots description for Libelium's Waspmote Plug and Sense device

Slot	Sensor	Description
Socket A	NA	Reserved for other sensors such as GPS, Barometers, *etc*.
Socket B	Soil moisture sensor	First slot where soil moisture sensor can be mounted.
Socket C	Soil moisture sensor	The third sensor slot for soil moisture sensor.
Socket D	Temperature, Humidity, and Pressure (BME280) sensor	Three readings such as atmospheric temperature, humidity level, and pressure in the air of the environment are fetched from the sensor of the BME series.
Socket E	Soil moisture sensor	The second sensor slot that can be deployed at different depth in soil.
Socket F	Luminosity sensor	Readings of the light and its intensity power.

- The heating mode for sensors

  In the second mode, the current is transmitted from the hardware device and consumed by each sensor. The total amount of current provided by the hardware device is 18 mA.

- The mode of transferring the captured values to the server

  In this mode, the observed information is transferred to serer. Here, the current consumption is 351 mA.

The hardware device has a total of six ports, where different agricultural sensors were plugged in. Out of them, three ports are reserved for soil moisture sensors (that can be dug at different soil depths). The 4^{th} port is for BME280 sensor, which helped in capturing readings for temperature, humidity, and pressure attributes. In the 5^{th} port, luminosity sensor was mounted, to capture associated parameter values. A detailed description for all the sensors that can be plugged within the hardware device are as under:

i Temperature, Humidity, and Pressure BME280 sensor

  As the name suggests, this sensor module had three-in-one sensor unit. This sensor required 5V to function. The sensor fetched information for three variables in the format of ^{o}C for the temperature, percentage value for humidity, and the pressure's value was measured in kilo-pascal (kPa). Figure 4.4 depicts pictorial image of BME280 sensor.

Figure 4.4: Temperature, Humidity, and Pressure (BME280) sensor

ii Soil moisture sensor

The soil moisture sensor is the most vital sensor for the unit. It measures the percentage presence of water within the soil. The sensor has three individual ports for each depth. At the upper level of the soil, moisture is recorded relatively low due to the presence of humidity, evaporation process, *etc.*, whereas it is relatively high at different depths of soil. A snapshot of the soil moisture sensor has been depicted in Figure 4.5.

Figure 4.5: Soil moisture sensor

The sensor comprises non-resistance material to the water and the soil. An advantage of the sensor was, it remained rust-free when dipped in soil for a longer span. Hence, it had an enormous validity and a good accuracy score. These rust-free sensors are deployed in a sequence order, as depicted in Figure 4.6.

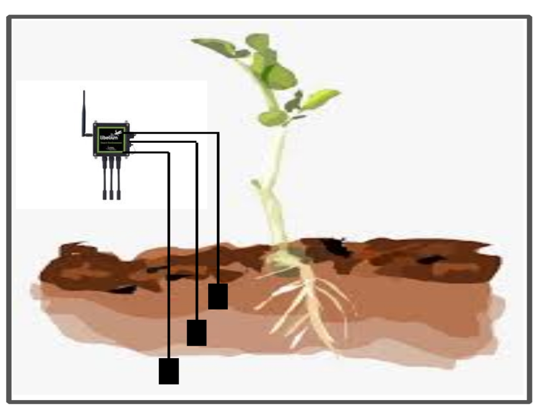


Figure 4.6: Deployment of soil moisture sensor within the soil

iii Luminosity sensor

It is the third sensor of the experiment that is used to fetch the information of the available light in the environment. The technical specifications of this sensor has been highlighted in Table 4.4. Figure 4.7 depicts the pictorial image of the luminosity sensor.

Table 4.4: Description of the Luminosity sensor

Characterstic	Range
Supply Voltage	2.7 - 3.6V
Unit	lux
Measurement Range	0.1 - 40,000 lux
Operational Temperature Range	-30degC - 70degC
Accuracy Range	±1 lux
Response Time	± 1 seconds

Figure 4.7: Luminosity sensor

Individual specifications for various sensors that have been attached to the device have been discussed in Table 4.5.

The next subsection highlights the technical details for NPK sensor. This device is incorporated within the study to evaluate the precise requirement of fertilizer and its required distribution within the fields.

Table 4.5: Individual specifications for various sensors mounted on Waspmote's Plug and Sense device

Temperature, Humidity and Pressure sensor (BME280)	
Supply voltage	5V
Sleep current typical	0.1 μA
Sleep current maximum	0.3 μA
Temperature sensor	
Operational range	- 40°C ∼ + 85°C
Full accuracy range	0°C ∼ + 65°C
Accuracy	± 1°C (range 0°C ∼ 64°C)
Response time	1.65 seconds (63% response from + 30 ∼ + 125°C)
Typical consumption	1 μ A measuring
Humidity sensor	
Measurement range	0 ∼ 100% of Relative Humidity
Accuracy	<± 3% RH ((at 25°C, range 20 ∼ 80%)
Hysteresis	±1% RH
Operating temperature	-40 + 85°C
Response time	1 second
Typical consumption	1.8 μA measuring
Maximum consumption	2.8 μA measuring
Pressure sensor	
Measurement range	30 - 110 kPa
Operational temperature range	40 ∼ + 85°C
Full accuracy temperature range	0 ∼ + 85°C
Absolute accuracy	± 0.1 kPa (0 - 65°C)
Typical consumption	2.8 μA measuring
Maximum consumption	4.2 μA measuring
Soil moisture sensor	
Measurement range	0 - 200 cb
Frequency Range	50 ∼ 10000 Hz approximately
Diameter	22 mm
Length	76 mm
Terminals	AWG 20
Soil temperature sensor	
Measurement range	55 ∼ 125°C
Accuracy	± 0.5 from 10°C ∼ + 85°C
Diameter	7 mm
Length	26 mm
Cable	1.8 m
Luminosity sensor	
Dynamic range	0.1 ∼ 40000 lux
Spectral range	300 ∼ 1100 nm
Voltage range	2.7V ∼ 3.6V
Supply current typical	0.24 mA
Operating temperature	- 30 ∼ + 70°C

4.2.2 Hardware used for fertilization assessment

To fetch readings related to various parameters associated to assess the precise usage of fertilizer distribution within the fields, NPK sensor was deployed in the fields. This device is one of the most reliable, efficient, instant, and relatively economical to capture readings on precise presence of various fertilizers, *i.e.*, Nitrogen (N), Potassium (P), and Phosphorous (K) presence within soil. This device overcomes the limitations of Spectral Analysis Method whose results are considered to be 60-70% valid. Based on its existing presence, future possible estimation is done. Figure 4.8 shows the pictorial representation of the sensor device taken into consideration, whereas Technical specifications for the hardware have been presented in Table 4.6.

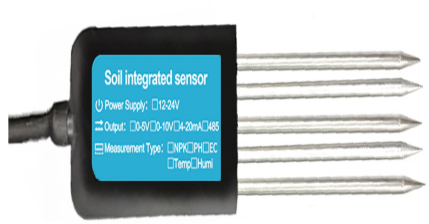


Figure 4.8: Pictorial representation of NPK sensor

The next section presents a data description for three different crops taken into consideration for evaluation purpose.

4.3 Dataset collection for various crops

Since the state of Punjab is considered to have one of the most fertile soil across the Indian sub-continent [288], there are a variety of crops that are cultivated within this region. Some of the most prominent crops are paddy, wheat, cotton, maize, capsicum, *etc.* One of the most important criteria while performing agricultural process is the estimation of precise irrigation within the fields. This aspect is directly associated with various parameters, *i.e.*,

Table 4.6: Technical specifications for NPK sensor

Power supply	12-24V DC
Output Singal	RS485/4G/NB-IoT/LoRA
Protection level	IP68
Temperature measuring range	$-45^oC - 115^oC$
Moisture measuring range	0-100%RH
pH measuring range	3-9 *pH*
NPK measuring range	0-1999 mg/kg
EC measuring range	0-10000 us/cm
Temperature precision	$\pm 0.5^oC$
Moisture precision	$\pm 3\% in 0 - 53\% range; \pm 5\% in 53 - 100\% range$
pH precision	$\pm 0.3 pH$
NPK precision	2% F.s
EC Resolution	10 us/cm
Response time	$< 1s$

Soil moisture (S_m), Soil temperature (S_t),Atmospheric pressure (A_p), Humidity *(H)*, and Luminosity *(L)*. Among all of these parameters, soil moisture is a key parameter, as it depicts the quantity of water that resides within the gap of the soil particles. Soil moisture values differ based on the type of crop, soil type, and the season. Therefore, to evaluate the water requirement among different crops, datasets pertaining to three crops, *i.e.*, rice, wheat, and capsicum were taken into consideration. The next subsections depict a detailed description for all three datasets.

4.3.1 Rice (Paddy)

Rice is the second largest cultivated crop within the Punjab region. Rice is grown in land that is flooded, either through rain or irrigated with canal or tube-well water. Water is run into the fields to a depth of 05 inches, to improve the rice plants' ability to compete against weeds for nutrients and sunlight, reducing the need for herbicides. Since the amount of water required for irrigation is excessive, it was the second crop identified for experimentation. A testbed was established with an area of 170 m^2 (10*17 meters) to capture readings on various parameters. The hardware device used to generate a reading after an interval of ninety seconds. The dataset consisted of 42,666 rows and 07 columns. A total of 2,98,662 readings were taken into consideration. Figure 4.9 depicts the hardware device deployed within rice (paddy) test bed for generating observations.

Figure 4.9: Hardware device deployed within rice (paddy) test bed

Reading of the acquired dataset were captured for complete crop cycle.

4.3.2 Wheat

Wheat is the highest cultivated crop in the Punjab region, and also across the world [289]. The roots of this crop grow 73 - 83 cm deep within soil. To minimize water consumption for this crop, real-time observations were recorded. The hardware device was deployed in a field of village Dandrala, Dist. Patiala. An area of 440 m^2 (20*22 meters) The hardware device is used to capture reading after an interval of fifteen minute. This dataset consisted of 4,213 rows and 07 columns. A total of 29,491 readings were taken into consideration. Figure 4.10 depicts the hardware device deployed within the field for generating observations.

Readings related to various parameters for wheat crop were taken into consideration for complete crop cycle. The next subsection presents an overview of the capsicum crop dataset.

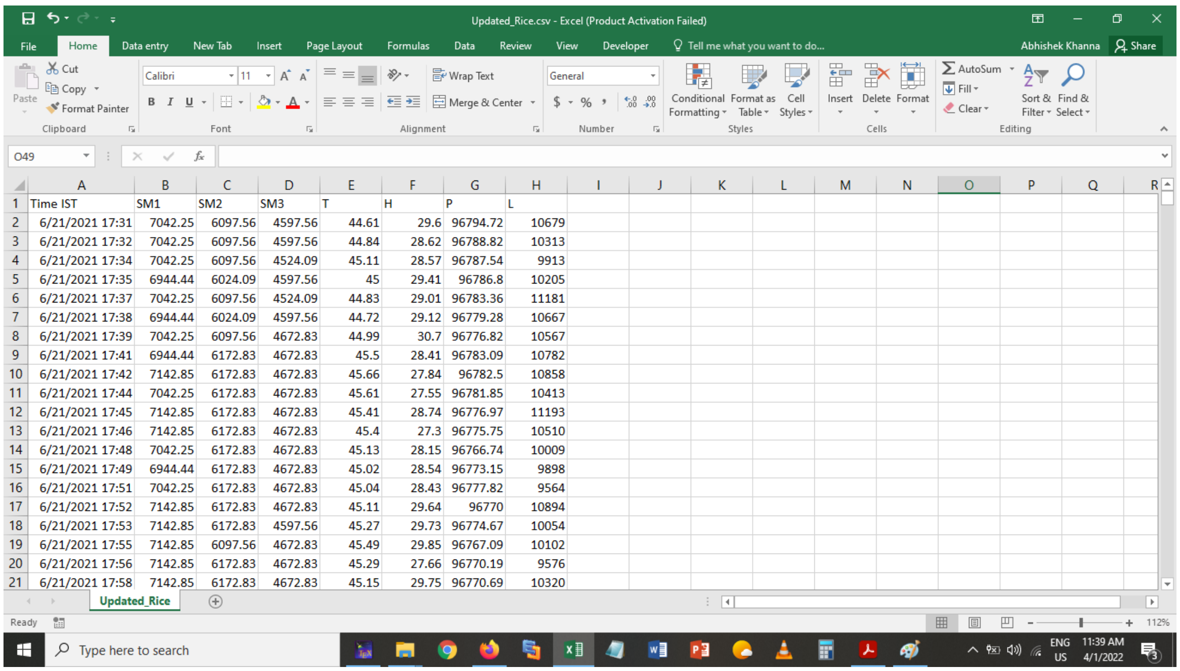
Figure 4.10: Hardware device deployed within wheat test bed

4.3.3 Capsicum

The third experimentation was conducted on capsicum crop. To capture readings on real time environment, a testbed was developed, with an area of 80 m^2 (8*10 meters). The roots of this crop grows about 20 - 27 cm deep, making it an ideal crop for experimentation. The hardware device was programmed in such a manner that it fetched a reading after an interval of one hundred and fifty seconds. The dataset for capsicum crop consists of 7,188 rows and 07 columns. A total of 50,316 readings were taken into consideration. Figure 4.11 depicts the hardware device deployed within capsicum test bed for generating observations.

Figure 4.11: Hardware device deployed within capsicum test bed

Dataset for capsicum crop was also recorded for full season alike the other two crops. The dataset for each of the above said crop captured values on 07 different parameters, *i.e.*, Soil moisture at 10 cm, Soil moisture at 45 cm, Soil moisture at 80 cm, Soil temperature, Atmospheric pressure, Humidity, and Luminosity. In addition another column was created within the dataset that depicted the time stamp of the recorded data as per Indian Standard Time (IST). Figure 4.12 depicts screen shot of the dataset captured for rice crop. Datasets created for other crops also had similar columns as of rice crop dataset.



Time IST	SM1	SM2	SM3	T	H	P	L
6/21/2021 17:31	7042.25	6097.56	4597.56	44.61	29.6	96794.72	10679
6/21/2021 17:32	7042.25	6097.56	4597.56	44.84	28.62	96788.82	10313
6/21/2021 17:34	7042.25	6097.56	4524.09	45.11	28.57	96787.54	9913
6/21/2021 17:35	6944.44	6024.09	4597.56	45	29.41	96786.8	10205
6/21/2021 17:37	7042.25	6097.56	4524.09	44.83	29.01	96783.36	11181
6/21/2021 17:38	6944.44	6024.09	4597.56	44.72	29.12	96779.28	10667
6/21/2021 17:39	7042.25	6097.56	4672.83	44.99	30.7	96776.82	10567
6/21/2021 17:41	6944.44	6172.83	4672.83	45.5	28.41	96783.09	10782
6/21/2021 17:42	7142.85	6172.83	4672.83	45.66	27.84	96782.5	10858
6/21/2021 17:44	7042.25	6172.83	4672.83	45.61	27.55	96781.85	10413
6/21/2021 17:45	7142.85	6172.83	4672.83	45.41	28.74	96776.97	11193
6/21/2021 17:46	7142.85	6172.83	4672.83	45.4	27.3	96775.75	10510
6/21/2021 17:48	7042.25	6172.83	4672.83	45.13	28.15	96766.74	10009
6/21/2021 17:49	6944.44	6172.83	4672.83	45.02	28.54	96773.15	9898
6/21/2021 17:51	7042.25	6172.83	4672.83	45.04	28.43	96777.82	9564
6/21/2021 17:52	7142.85	6172.83	4672.83	45.11	29.64	96770	10894
6/21/2021 17:53	7142.85	6172.83	4597.56	45.27	29.73	96774.67	10054
6/21/2021 17:55	7142.85	6097.56	4672.83	45.49	29.85	96767.09	10102
6/21/2021 17:56	7142.85	6172.83	4672.83	45.29	27.66	96770.19	9576
6/21/2021 17:58	7142.85	6172.83	4672.83	45.15	29.75	96770.69	10320

Figure 4.12: Snapshot of dataset for rice crop

Libelium's Waspmote Plug and Sense device used for capturing data on various agricultural parameters had an inbuilt GSM module, by virtue of which data transmission used to take place. Captured data was initially uploaded on a cloud server, *i.e.* Thingspeak. A domain www.smartfasal.in was designed that hosted the readings related to various parameters for all the three crops taken into consideration.

Chapter summary

This chapter presents an insight on various data acquisition techniques adopted to attain the objectives laid for the study. In the initial section, the test field's demographic details have been presented, followed by a detailed description on various hardware devices incorporated within the study for generating observations related to various parameters. Since, there are a variety of crops that are practiced within the fields, the next section, highlights a detailed description on datasets related to three crops taken into consideration for the study, *i.e.*, rice, wheat, and capsicum have been discussed. Furthermore, data collection strategy adopted for storage strategy adopted to procure the observed data has also been discussed.

The next chapter presents a detailed discussion on evaluation technique considered for the present study to optimize the process of irrigation and fertilization within the fields.

Chapter 5

Time Series Analysis for evaluation of irrigation and fertigation requirement

Data analysis is the process of evaluating data, which helps in cleaning and transforming huge amount of data by making it efficient and meaningful. For this purpose, identification and implementation of a reliable model is of paramount importance. To attain the objective for the existing study, the process of data analysis has been incorporated for evaluating various associated parameters. Since the objective of the present study is to minimize the consumption of water and fertilizer distribution within the fields, it is essential to evaluate parameters, *i.e.*, Soil moisture (S_m), Soil temperature (S_t), Atmospheric pressure (A_p), Humidity *(H)*, and Luminosity *(L)*. For this purpose, Time Series Analysis has been implemented within the present study to evaluate associated parameters. In Time Series Analysis two forecasting models, *i.e.*, Auto-Regressive Integrated Moving Average Model (ARIMA) and Long Short-Term Memory (LSTM) techniques have been employed and results have been acquired. To determine the precise distribution of fertilizer within the fields, NPK sensor was deployed to evaluate the existing presence of fertilizers within the fields. Based on the existing presence, the deficit amount of fertilizers required was calculated. The next section sheds light on the basics of Time Series Analysis.

5.1 Time Series Analysis

Time Series Analysis is a statistical technique that deals with analyzing the sequence of observations of a well-defined data items, that are obtained over a regular interval of time. In this technique, there are no suggested limit on minimum or maximum amount of time that must be included to capture observations [290, 291]. In particular, this technique highlights the associated factors, that influence certain variables between the starting and ending period. This methodology is considered to be different in contrast to other methodologies as each data point within the series is inter-dependent towards its previous data point [292]. Figure 5.1 depicts a Time Series graph for captured values at regular intervals.

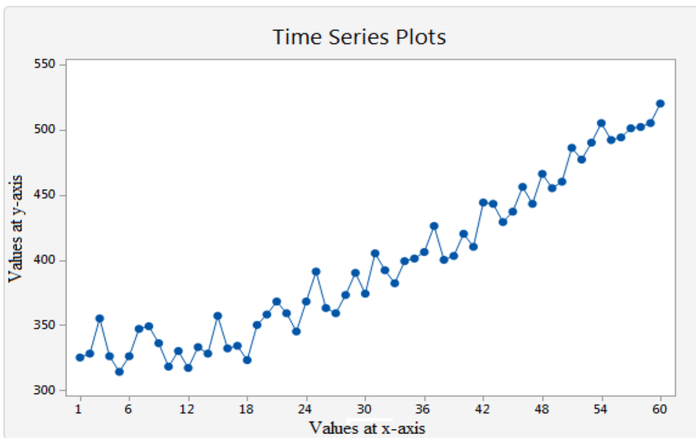


Figure 5.1: Time Series graph for captured values at regular intervals

The basic aim of implementing Time Series Analysis techniques is as follows.

- Clearly understand and identify the underlying forces that produce the observed data.
- Fit a model and proceed to the process of monitoring and forecasting.

Time Series Analysis is one of the most prominent technique practiced, that not only helps in the prediction of future values, but also helps to understand past behavior in an efficient manner. Some of the most prominent applications, where Time Series Analysis is used are economic forecasting, weather analysis, yield projection, health-care analysis, *etc.* There are four important components of Time Series Analysis as follows.

i Trend

A trend prevails when there is a long-term increase or decrease in the data. This data need not to be linear. The trend can either be an increasing trend or a decreasing trend.

ii Seasonality

A seasonal pattern is encountered when a time series is affected by seasonal factors such as a specific time within a year or day of the week. The seasonality component is always fixed and has a known frequency.

iii Irregularity

This component is also termed as residual. This component is often faced when the trend is either erratic and unsystematic. This is observed for short durations and observed dissimilar at different timestamps.

iv Cyclic

When the collected data is observed, there is a scenario encountered when the data captured either rises and falls. This occurs due to some external factors that have direct association with the observed values.

There are various methods to forecast data with the help of Time Series Analysis. The next subsection highlights these various methods for the same.

5.1.1 Various methods for evaluating data over Time Series forecasting

Time Series forecasting is one of the most commonly applied data science technique in today's world [293]. Various techniques of Time Series Forecasting have been described as under.

i Naive approach

This forecasting technique involves using of previous observation directly as the forecast value without making any change. This technique is also termed as Persistence forecasting.

ii Simple average

This is the simplest technique in Time Series analysis. The next value is calculated by taking the average of all the previous values.

iii Moving average

This technique is an improvement over simple average method, as the average of ‘n’ previous points is taken to be the predicted value [294].

iv Weighted moving average

A Weighted Moving Average puts more weight on recent data values and less on past data values [295].

v Simple exponential smoothing

This time series forecasting method is considered to be best for univariate data. This technique requires a single parameter, called alpha (a), also called the smoothing factor or smoothing coefficient [296].

vi Holt’s linear trend model

Holt’s linear trend method is a valuable extension of Exponential smoothing technique that helps in dealing with trending data. The forecast function in this method is a function of level and trend [297].

vii Holt’s winter method

Holt’s winter method is a modeling technique that has three aspects of the time series as given below.

- A Typical value (average)
- A slope (trend) over time
- A cyclical repeating pattern (seasonality)

Both these aspects are applied for simple projection techniques [298].

viii AutoRegressive Integrated Moving Average (ARIMA)

It is one of the most popular technique for time series modeling, as it describes the correlation between different data points and takes into account the difference of values. The two different points are Autoregressive (AR) and Moving Average (MA). AR model is forecast series that is based solely on the past values within a series. These values are also referred as lags. On the other hand, MA is a forecast series that is based solely on the past errors within the series. These series are called as error lags.

ix Long Short-Term Memory (LSTM)

It is an application that is designed where the input is an ordered sequence. In this type of modeling technique, information from an earlier sequence is considered to predict the next possible variable. LSTM is similar to all the other neural networks that reuses the output from a previous step as an input for the next step. The nodes of LSTM have an internal state that is used as a working memory space, *i.e.*, information is stored and retrieved as an input value. Taking this as an advantage for the modeling technique, both the approaches, *i.e.*, ARIMA and LSTM have been discussed in detail in the consecutive sections of this chapter.

5.2 ARIMA model

ARIMA is a statistical analysis model that forecasts data to evaluate and predict future trends. This is one of the best models to work with time series data. This model is considered to be a combination of two models, *i.e.*, AutoRegressive *(AR)* and Moving Average *(MA)*. ARIMA is known to be a a form of regression analysis, that gauges the strength of one dependent variable relative to other changing variables. The model's goal is to predict future possible values by examining the differences between values in the series instead of through actual values. There are three main components in ARIMA, *i.e.*, AutoRegression *(AR) model*, Integrated *(I)*, and Moving average *(MA)* as discussed below.

i AutoRegression *(AR) model*

In an AR model, correlation is determined between the data at previous time stamps and the current time stamp. Thus, an autoregressive model of order p can be calculated using equation 5.1:

$$Y_t = \alpha + \beta_1 Y_{t-1} + \beta_1 Y_{t-2} + ... + \beta_p Y_{t-p} + \varepsilon_1 \tag{5.1}$$

where $Yt-1$ is the lag1 of the series. $\beta 1$ is the coefficient of lag1 that the model estimates and α is the intercept term, also estimated by the model.

ii Integrated *(I)*

The use of differencing of raw observations, *i.e.*, subtracting an observation from an observation at the previous time step is done in order to make the time series stationary.

iii Moving average *(MA)*

In this model, MA is obtained to smoothen the data and average the noises and irregularities identified within the dataset. It is parameterized with q, called moving average term. Calculation of *MA* has been depicted by virtue of equation 5.2.

$$Y_t = \alpha + \varepsilon_t + \phi_1 \varepsilon_{t-1} + \phi_2 \varepsilon_{t-2} + ... + \phi_q \varepsilon_{t-q} \tag{5.2}$$

where the error terms are the errors of the autoregressive models of the respective lags. The errors ε_t and $\varepsilon(t_1)$ are the errors as depicted in equation 5.3.

$$\begin{aligned} Y_t &= \beta_1 Y_{t-1} + \beta_2 Y_{t-2} + ... + \beta_0 Y_0 + \varepsilon_t \\ Y_{t-1} &= \beta_1 Y_{t-2} + \beta_2 Y_{t-3} + ... + \beta_0 Y_0 + \varepsilon_{t-1} \end{aligned} \tag{5.3}$$

These two models are then integrated with a degree of differencing *(d)* from previous *(p)* time intervals. Two plots are used to determine three different values, *i.e.*:

- The number of autoregressive terms *(p)*
- The number of nonseasonal differences needed for stationarity *(d)*

- The number of lagged forecast errors in the prediction equation *(q)*

These can be determined by following two techniques.

i Autocorrelation function (ACF)

It is a measure of the correlation between the Time Series (TS) with a lagged version of itself.

ii Partial Autocorrelation Function (PACF)

This measures the correlation between the TS with a lagged version of itself but after eliminating the variations already explained by the intervening comparisons.

The next subsection highlights various steps that are required for ARIMA's implementation.

5.2.1 Steps for ARIMA's implementation and its working

There are a total of nine steps to implement ARIMA modeling technique on a particular dataset. These steps are described as under.

i Loading of data

In the initial process of model building, the dataset is loaded onto the computing machine.

ii Pre-processing

Depending on the dataset, the steps of pre-processing are defined. This step includes creating of timestamps, converting the *d*-type of date/time column, making the series univariate, *etc.*

iii Making the series stationary

In order to satisfy the assumption, it is necessary to make the existing series stationary. This process includes thorough cross checking of the series and performing required transformations.

iv Determining d-values

For making the series stationary, the number of times the difference operation is performed. This is considered as the d value.

v Creating of ACF and PACF plots

This is the most important step in ARIMA implementation. ACF and PACF plots are created, that are further used to determine the input parameters for our ARIMA model.

vi Determining p and q values

In this step, reading of values p and q from the plots within the previous step are determined.

vii Fit ARIMA model

Using the processed data and parameter values, that are calculated from the previous steps, the best fit ARIMA model is fitted.

viii Predicting values for validating the set

In this step, future values are predicted based on validation set.

ix Calculating Root Mean Square Error (RMSE)

In the last step, in order to evaluate the performance of the model, the RMSE value is calculated using the predictions and actual values on the validation set.

The working of ARIMA has been summarized in Algorithm 5.1.

In Algorithm 5.1, the initial step is the splitting of the loaded dataset into respective variables of the dataset. These acquired columns are transformed into an interval of a 15-minute based dataset in the following phase. The next process is counting the maximum observations in the dataset which is required for the creation of the training and testing datasets. Modeling on the ARIMA is the next step in which the variables are trained. The trained model fits the dataset as well as predicts the acquired model. These acquired observations are compared

```
Begin
    Procedure (Prediction):
    Load the dataset
    Split into columns
    Convert data into 15 minutes interval data
    Total rows ← count max rows
    Training, Testing ← split the dataset into training and testing subsets
        For i in range (column)
            model = ARIMA (column)
           model fit ← fitting of the model
        predictions ← predict values using the model_fit()
    Eval_metric = Error (Testing, predictions)
        If Eval_metric < previous Eval_metric
            forecasting = next 7 days forecasting of model_fit()
        else
            goto 7
end
```

Algorithm 5.1: Model building phase for ARIMA

with the actual values using the validation tests. If the model passes the validation tests, the model predicts the values for the next 7 days.

- Working of ARIMA model

  This model is a regressive and an average based model that depends on a unique variable to forecast the data. The first step in ARIMA modeling is to acquire a dataset for an experiment and pre-process the data using feature selection techniques of machine learning. Afterward, the differencing order of the dataset is computed to make a dataset in stationary form. The "Stationarity" implies that the dataset remains at a constant level over time. It has a notation of integration, which means differencing the raw data with a lag order. The "Stationary" data can be availed by using differencing of the data observations. This allows the model to be independent of the other observations, removes the trend and stabilize the means value of the time-series-based dataset.

  After converting a non-stationary data into a stationary data, the next step is to fetch the *(p, q)* parametric values for the ARIMA model. These values can be acquired using the ACF function for p, and the PACF for q, where p is used for the Auto-regression model and *q* is used for the Moving Average model. These *p, q* values are in the range of integers datatype. Like as a sample model the ACF and PACF values are observed in the range 01 to 03 in a dataset. Hence all these parametric values are required to be used one by one for the model. As an example, ARIMA (0, 1, 0), ARIMA (1,2,1), and ARIMA (1,1,2) are used to build the model using the parametric values and these can be changed for the better performance of the model. Different parametric values help the model to forecasts the best results of observations. Figure 5.2 represents the workflow of ARIMA model.

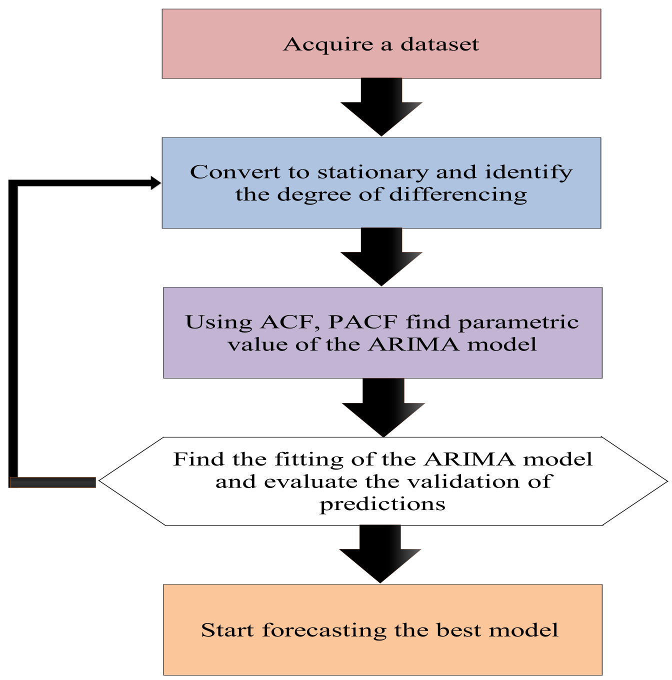


Figure 5.2: Workflow of ARIMA model

- Validation strategy for ARIMA modeling technique

  The validation of the proposed model is a very crucial component to evaluate the performance of the model. There are several tests that can be used to evaluate the model's performance, such as Augmented Dickey-Fuller (ADF) test, Phillips-Perron (PP) test, Kwiatkowski Phillips Schmidt Shint (KPSS) test. For the existing study, ACF and PACF plot techniques have been incorporated to validate the study. ACF and PACF plots helps to determine *AR* and *MA* terms needed in a systematic way after the time series has been stationarity. The next section presents the second modeling technique incorporated within the study.

5.3 Long Short-Term Memory (LSTM)

The second model used for evaluating the observed parameters is LSTM. The functional concept of LSTM is RNN. RNN is a kind of Artifical Neural network, whose conceptual purpose is to identify patterns in a sequences of data. RNN use their internal state (memory) to process variable length sequences of inputs [299]. This makes the technique easily applicable to tasks such as unsegmented, connected handwriting recognition, speech recognition, numerical times series data emanating from sensors. RNN uses Back-Propagation algorithm for training, but it is applied for every time-stamp.

LSTM are special kind of RNN, that have the capability of learning long time dependencies, *i.e.*, most of the time only recent data is required by the model to perform operations. High volumes of data when taken into consideration (during evaluation of LSTM model) helps to overcome issues like Vanishing and Exploding Gradients, making LSTM more versatile by handling long-term dependencies easily. LSTM cell has four components, *i.e.*, Input gate, Forget gate, Output gate and the Cell state [300], in addition to two non-linear activation functions, *i.e.*, *tanh* and *sigmoid* respectively. Information in LSTM is stored, written, or read via the three gates. These gates accumulate the memory in the analog format. Structure of LSTM cell has been depicted in Figure 5.3.

In Figure 5.3, σ refers to *sigmoid*, *tanh* refers to *tanh* function, $\otimes$ refers to point-by-point multiplication, $\oplus$ refers to point-by-point addition. t refers to time-stamp, $f^{(t)}$ is *forget gate* at t, $X^{(t)}$ is the input at t, h^{t-1} is the previous hidden state, $C^{\sim(t)}$ is the value that is generated at *tanh*, $C^{(t)}$ is the cell state information at t, $C^{(t+1)}$ is the previous time-stamp, $O^{(t)}$ is the output gate at t, and $h^{(t)}$ is the LSTM's output. The conceptual functioning for the various

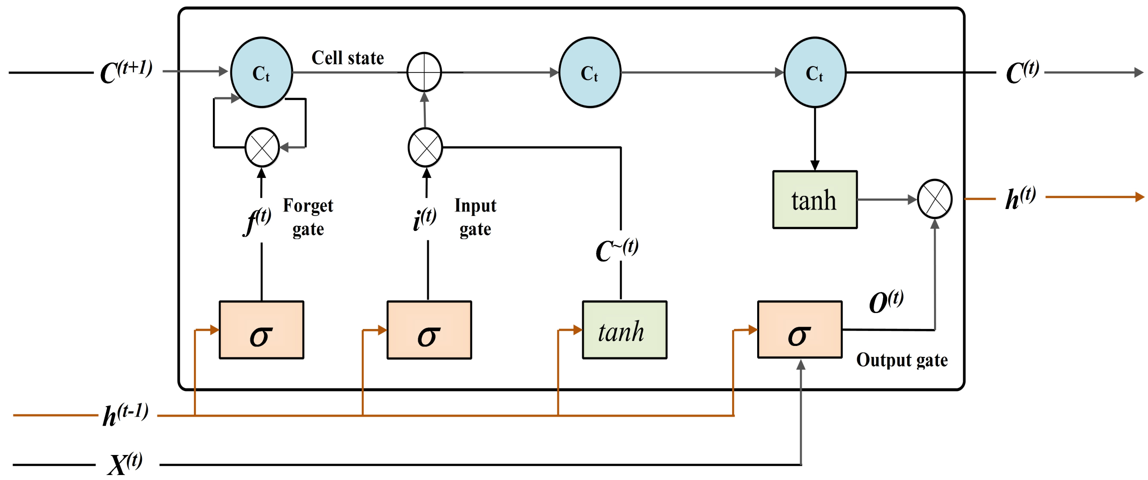


Figure 5.3: Structure of LSTM cell

functions, *i.e.*, three gates and two non-linear activation function areas as follows.

i *tanh*

tanh is a non-linear activation function. It regulates the values flowing through the network, maintaining the values between -1 and 1. To avoid information fading, a function is needed whose second derivative can survive for longer. There might be a case where some values become enormous, further causing values to be insignificant [301].

ii *sigmoid*

This function belongs to the family of non-linear activation functions. Unlike *tanh*, sigmoid maintains the values between 0 and 1. It helps the network either to update or to forget the data. If the multiplication results in 0, the information is considered forgotten. Similarly, the information stays if the value is 01 [302, 303].

iii Forget gate

The forget gate decides which information needs attention and which can be ignored. Information from the current input $X^{(t)}$ and hidden state $h^{(t-1)}$ are passed through the sigmoid function. Sigmoid generates values between 0 and 1. It concludes whether the part of the old output is necessary (by giving the output closer to 1). This value of f_t will later be used by the cell for point-by-point multiplication. The mathematical formulation to obtain value of f_t at this gate is given in equation 5.4.

$$f_t = \sigma(W_f.[h^{(t+1)}, x^{(t)}] + b_f) \tag{5.4}$$

where, W_f between forget gate and input gate and b_t is connection bias at t.

iv Input gate

This gate performs the following two operations to update cell status.

- Firstly, the current state $X^{(t)}$ and previously hidden state $h^{(t-1)}$ are passed into the second sigmoid function. The values are transformed between 0 (important) and 1 (not-important).
- Secondly, the same information of the hidden state and current state will be passed through the *tanh* function. To regulate the network, the *tanh* operator will create a vector $C^{\sim(t)}$ with all the possible values between -1 and +1. The output values generated form the activation functions are ready for point-by-point multiplication [304].

  The mathematical formulation to obtain value of i_t and $C^{\sim(t)}$ at this gate are given in equation 5.5.

$$\begin{aligned} i_t &= \sigma(W_i.[h^{(t+1),X^{(t)},} + b_i) \\ C^{\sim(t)} &= tanh(W_c.[h^{t-1}, X_1]) + b_c) \end{aligned} \tag{5.5}$$

where, W_i is the weight matrix of *sigmoid* operator between input gate and output gate, W_c is the weight matrix of *tanh* operator between cell state information and network output, and b_c is the bias vector at t, *w.r.t.* W_c.

v Output gate

The output gate determines the value of the next hidden state. This state contains information on previous inputs. Initially, the values of the current state and previous hidden state are passed into the third sigmoid function. Then the new cell state generated from the initial cell state is passed through the *tanh* function. Both these outputs are multiplied point-by-point. Based upon the final value, the network decides which information the hidden state should carry. This hidden state is used for prediction. Lastly, the new cell state and new hidden state are carried over to the next time step [304]. The mathematical formulation to obtain value of $o^{(t)}$ and $h^{(t)}$ at this gate are given in equation 5.6.

$$\begin{aligned} o^{(t)} &= \sigma(W_o[h^{(t+1)}, X^{(t)}]) + b_o \\ h^{(t)} &= o^{(t)} * tanh(C^{(t)}) \end{aligned} \tag{5.6}$$

where, W_o is weight matrix of the output gate, b_o is the bias vector, *w.r.t* W_o.

In addition, there is a *Cell state operation*, in LSTM modeling technique. The network has enough information from the forget gate and input gate. The next step is to decide and store the information from the new state in the cell state. The previous cell state $C^{(t-1)}$ gets multiplied with forget vector $f^{(t)}$. If the outcome is 0, then values will get dropped in the cell state. Next, the network takes the output value of the input vector $i^{(t)}$ and performs point-by-point addition, which updates the cell state giving the network a new cell state $C^{(t)}$ [305]. The mathematical formulation to obtain value of $C^{(t)}$ is given in equation 5.7.

$$C^{(t)} = f^{(t)} * C^{(t+1)} + i^{(t)} * C^{(\sim t)} \tag{5.7}$$

The next subsection highlights various steps required for LSTM's implementation.

5.3.1 Steps for LSTM's implementation and its working

The six steps to implement LSTM modeling technique on a particular dataset are described as under.

i Import the dependencies and code the activation functions

  To import dependencies following libraries are to be installed in the python environment.

  (a) import numpy

  (b) from keras.models import Sequential

  (c) from keras.layers import Dense

  (d) from keras.layers import Dropout

  (e) from keras.layers import LSTM

  (f) from keras.utils import np_utils

ii Initializing the biases and weight matrices

iii Multiplying forget gate with last cell state to forget irrelevant tokens.

iv Activation of *Sigmoid* to decide which values to take in and *tanh* transforms new tokens to vectors

v Calculate the present cell state

vi Calculate the output state

- Working of LSTM model

  LSTM is a Neural Network based model that uses deep learning approaches such as RNN with an aim to forecast the observations. The first step in LSTM is to acquire dataset for the experiment and then pre-process the data using feature selection technique of Machine Learning. After acquiring the dataset, it has been scaled on the scale of 0 to 1 integer for the efficient performance of the model. Further, the scaled dataset has been reshaped to the three-dimensional format to observe the unique variance of the data.

This manipulated dataset is passed to the LSTM to build the model for the forecasting of the observations. The keras library is used for the LSTM, it has several different parameters such as number of LSTM and Dense layers, neurons and the epochs to be used for the model building of this proposed study. The LSTM is tuned with different values of these parameters to achieves the best accuracy of the model. This tuned model is fitted with the dataset of the soil moisture and observation are predicted. The workflow of LSTM model has been depicted in Figure 5.4.

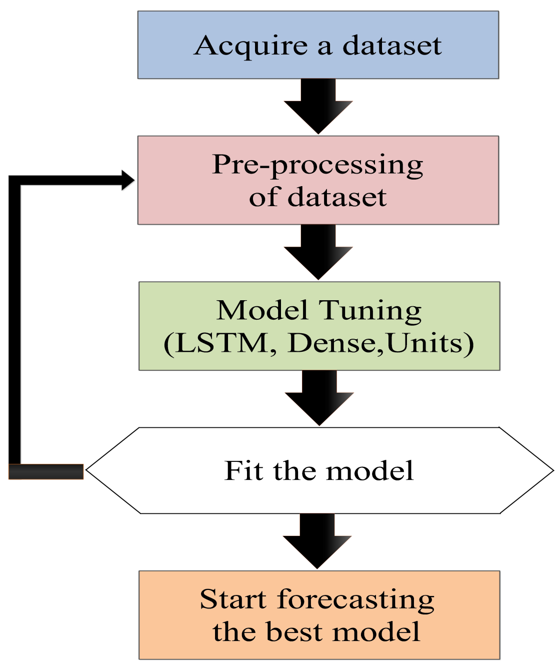


Figure 5.4: Workflow of LSTM model

- Validation strategy for LSTM modeling technique

  Data in LSTM is divided into two sets, *i.e.*, training (80%) and validation (20%) sets so that the model fit can be evaluated independently of the training. Cross-validation is an approach to divide the training data into multiple sets that fit separately. The parameter consistency is compared between the multiple models. While performing the validation of LSTM results, it is relatively important to determine how the model performs without measurements when it uses prior predictions to forecast the future outcome.

5.4 Results and discussion for irrigation assessment

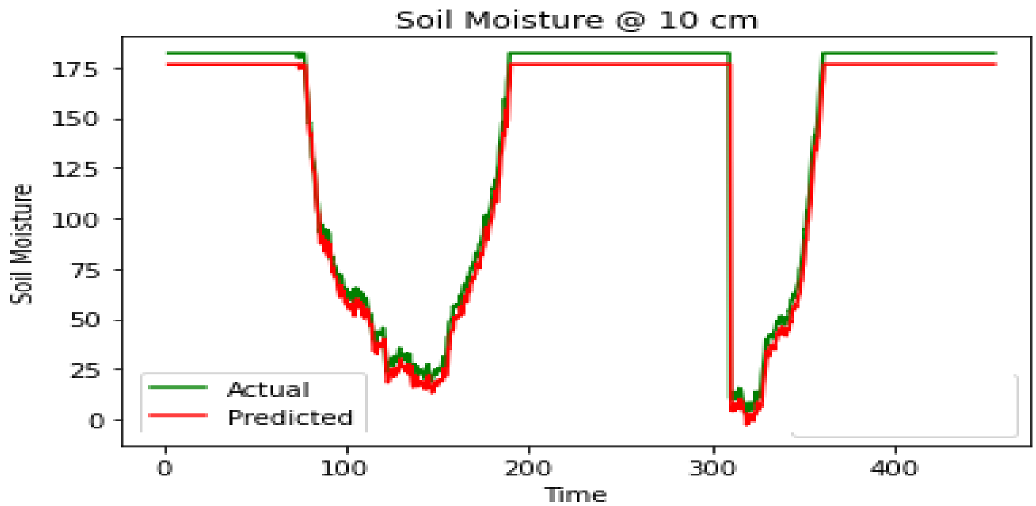
The results for the three datasets have been derived by using Spyder *IDE* software application. The computing machine had an *i5* processor, 16GB RAM, and a *64-bit* Windows Operating system.

5.4.1 Evaluation of Rice (Paddy) crop dataset on ARIMA and LSTM model

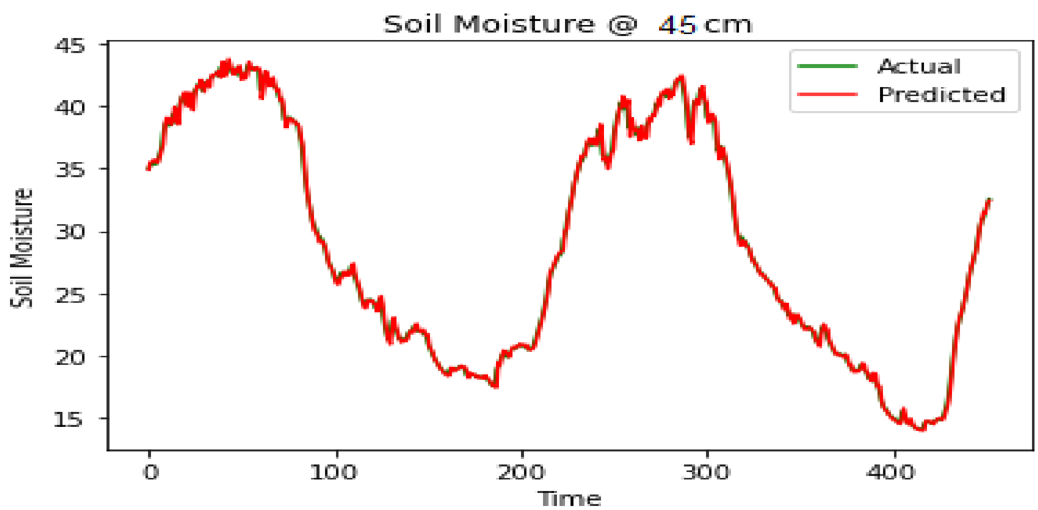
a **Evaluation of ARIMA model**

Rice is crop that requires enormous amount of water. The seeds of this crop need water right from the sowing stage, as they remain submerged in water, while the process of germination is underway. Due to the process of evaporation, there is a continuous requirement for re-irrigating the fields as water level needs to be maintained. Keeping this constraint in mind, the dataset of this crop has been evaluated. The ARIMA modeling technique was implemented to optimize the irrigation requirement for rice crop. The univariate ARIMA was trained with different hyper-parameter, *i.e.*, Autoregressive term *(p)*, Non-seasonal differences *(d)*, and number of lagged forecast errors *(q)* in order to acquire the best possible results. Each trained model ends with an Akaike's Information Criterion (AIC) score. This score is useful in selecting for determining the order of an ARIMA model. The best possible AIC scores for rice crop dataset has been summarized below in Table 5.1.

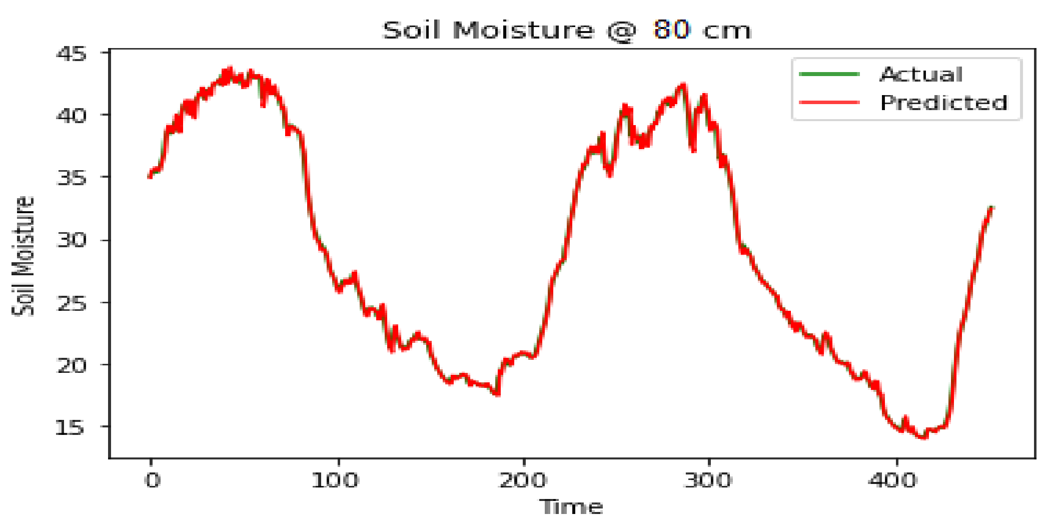
The graphical plot results of these validated and predicted models for various Soil moisture levels have been depicted in Figure 5.5, whereas predicted models for Atmospheric pressure, Humidity, Luminosity, and Soil temperature have been depicted in Figure 5.6.



(a) Soil moisture at 10 cm

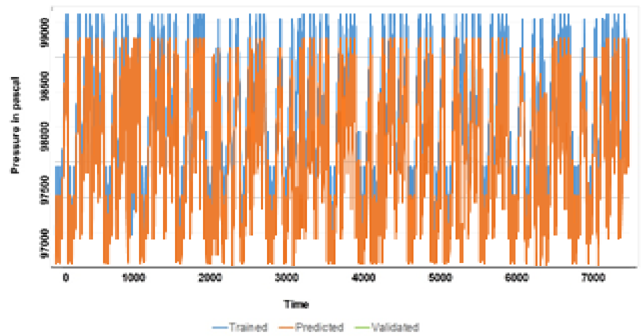


(b) Soil moisture at 45 cm

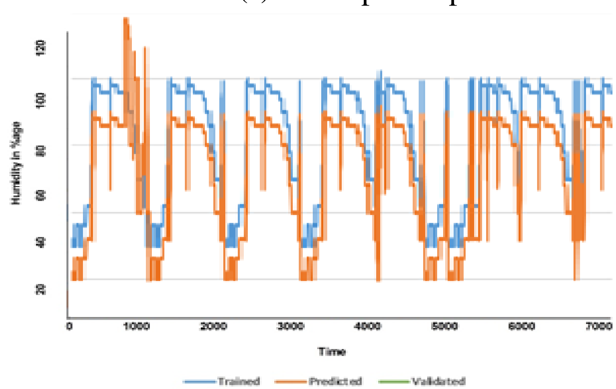


(c) Soil moisture at 80 cm

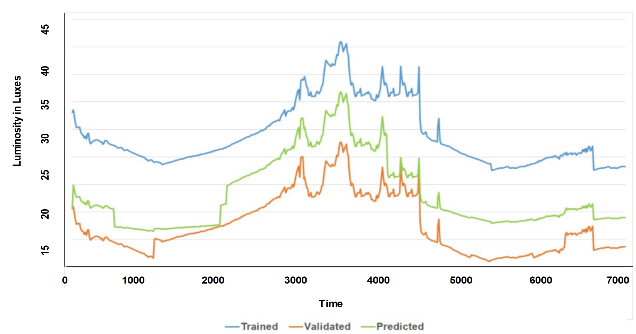
Figure 5.5: Validated and predicted graphical plots of Soil moisture parameter for ARIMA model with respect to rice crop



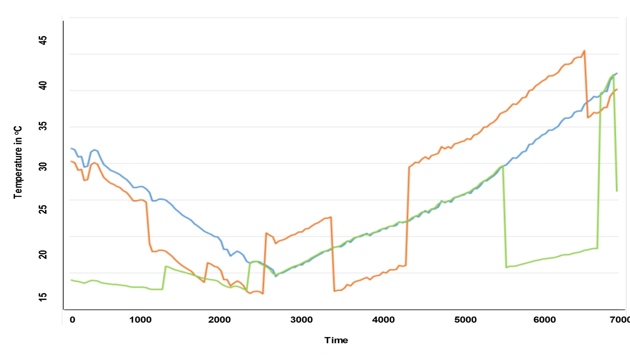
(a) Atmospheric pressure



(b) Humidity



(c) Luminosity



(d) Soil temperature

Figure 5.6: Visualization of validated and predicted graphical plots of remaining four parameters for ARIMA model with respect to rice crop

Table 5.1: Evaluation of ARIMA model on different hyper-parameters for rice crop

Variable	Univariate hyper-parameters (p,d,q)	AIC
Soil moisture 10 cm	order= (3,1,0)	AIC=78224.5970
Soil moisture 45 cm	order= (5,1,2)	AIC=69581.5126
Soil moisture 80 cm	order= (3,2,1)	AIC=77986.9412
Atmospheric pressure	order= (0, 1, 0)	AIC=32115.5924
Humidity	order= (0,1,1)	AIC=61226.2686
Luminosity	order= (7,1,1)	AIC=87223.5795
Soil temperature	order= (0,1,0)	AIC=-18964.5879

b **Validation of ARIMA model for rice crop**

The acquired dataset was trained with three different parameters *i.e.* Mean Absolute Error (MAE), Mean Squared Error (MSE), and Root Mean Squared Error (RMSE). The analyzed results indicate that R^2 scores depict that all the seven variables (Soil moisture 10, Soil moisture 45, Soil moisture 80 cm, Atmospheric pressure, Humidity, Luminosity, and Soil temperature) have performed more than 98%. Table 5.2 depicts the validated results for rice crop.

Table 5.2: Results of the best-suited ARIMA model for rice crop

Variable	Units	*p*	*d*	*q*	MAE	MSE	RMSE	R^2
Soil moisture 10 cm	Proximity	3	1	0	2.250	161.904	12.724	0.9927
Soil moisture 45 cm	Proximity	5	1	2	2.252	144.911	12.037	0.9815
Soil moisture 80 cm	Proximity	3	2	1	2.115	103.584	10.177	0.9855
Atmospheric pressure	Pascal	0	1	0	2.495	12.185	3.491	0.9821
Humidity	Percentage	0	1	1	4.665	34.144	5.843	0.9965
Luminosity	Luxes	7	1	1	2.495	12.185	3.491	0.9820
Soil temperature	^oC	0	1	0	2.102	14.552	3.814	0.9855

c **Evaluation of dataset on LSTM modeling technique**

Analysis of variables associated to rice crop were evaluated on LSTM modeling technique on similar parameters as of ARIMA model. The results of the modeling technique depicted relatively low values for four parameters. AIC scores obtained for rice crop dataset based on LSTM modeling technique have been summarized in Table 5.3.

Table 5.3: Evaluation of LSTM model on different hyper-parameters for rice crop

Variable	Univariate hyper-parameters (p,d,q)	AIC
Soil moisture 10 cm	order= (4,2,3)	AIC=77221.5512
Soil moisture 45 cm	order= (4,2,3)	AIC= 64235.2281
Soil moisture 80 cm	order= (3,3,1)	AIC= 72115.5539
Atmospheric pressure	order= (1,0,0)	AIC= 29696.8525
Humidity	order= (1,0,1)	AIC= 65983.2781
Luminosity	order= (6,2,4)	AIC= 81259.3496
Soil temperature	order= (0,0,1)	AIC= 18221.9862

d **Validation of LSTM model for rice crop**

Table 5.4: Results of the best-suited LSTM model for rice crop

Variable	Units	MAE	MSE	RMSE	R^2
Soil moisture 10 cm	Proximity	22.34	2111.10	45.946	0.9211
Soil moisture 45 cm	Proximity	29.14	2434.83	49.343	0.9251
Soil moisture 80 cm	Proximity	17.46	2423.81	49.232	0.9556
Atmospheric pressure	Pascal	8.91	318.55	17.847	0.9746
Humidity	Percentage	2.56	9.368	3.060	0.8954
Luminosity	Luxes	6.17	212.089	14.563	0.9311
Soil temperature	^oC	3.69	4.48	2.116	0.9578

The results obtained from LSTM model for rice crop were compared with the results of ARIMA model and predictions were made on the basis of R^2 scores. The analyzed results indicate that R^2 scores for three variables, *i.e.*, Soil moisture 80 cm, Atmospheric pressure, and Soil temperature attained 95% ,97%, and 95% respectively. The range of R^2 scores for remaining variables ranged between 89% - 93%. Since R^2 scores for all the variables of LSTM model found to be comparatively less than R^2 scores of ARIMA model, it has been concluded that the results obtained by ARIMA model were relatively better. Table 5.4 depicts the results for LSTM modeling evaluated scores on various variables for rice crop.

5.4.2 Evaluation of Wheat crop dataset on ARIMA and LSTM model

a **Evaluation of ARIMA model**

Wheat was the second crop was considered for evaluation. Although the root system of wheat crop grows approximately only half the length of rice crop, therefore there is not much requirement to irrigate the fields in contrast to rice crop. To optimize the irrigation requirement for wheat crop, similar parameters were considered for evaluation alike rice crop. For this purpose, seven different features of the dataset were trained. Acquired AIC scores of seven different models for wheat crop have been summarized in Table 5.5.

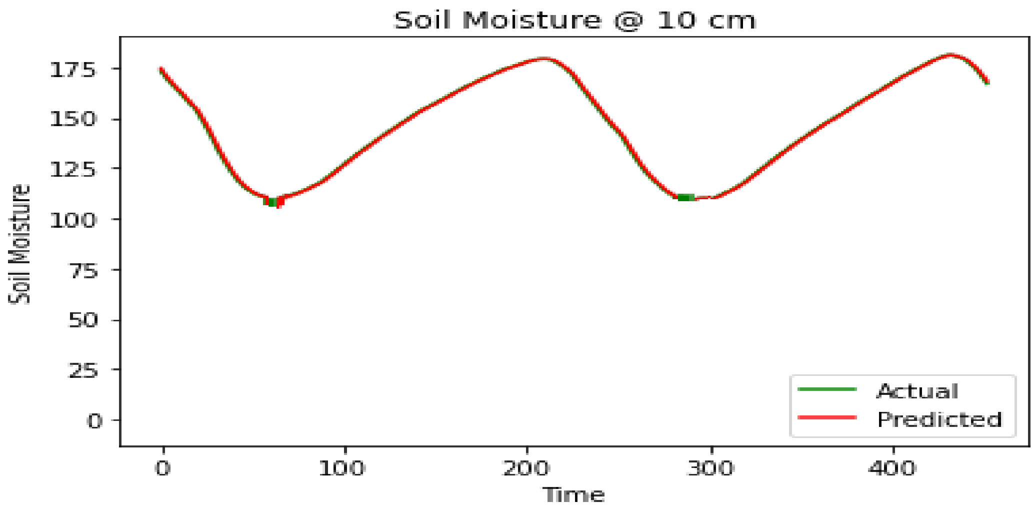
Table 5.5: Evaluation of the ARIMA model on different hyper-parameters on wheat crop

Variable	**Univariate hyper-parameters (p,d,q)**	**AIC**
Soil moisture 10 cm	order= (3,1,0)	AIC=71225.4530
Soil moisture 45 cm	order= (0,1,3)	AIC=68551.2590
Soil moisture 80 cm	order= (1,0,4)	AIC=75906.447
Atmospheric pressure	order= (1,0,6)	AIC= 78224.597
Humidity	order= (1,0,6)	AIC=294439.504
Luminosity	order= (1,0,1)	AIC=87221.6004
Soil temperature	order= (1,0,6)	AIC=-176311.8624

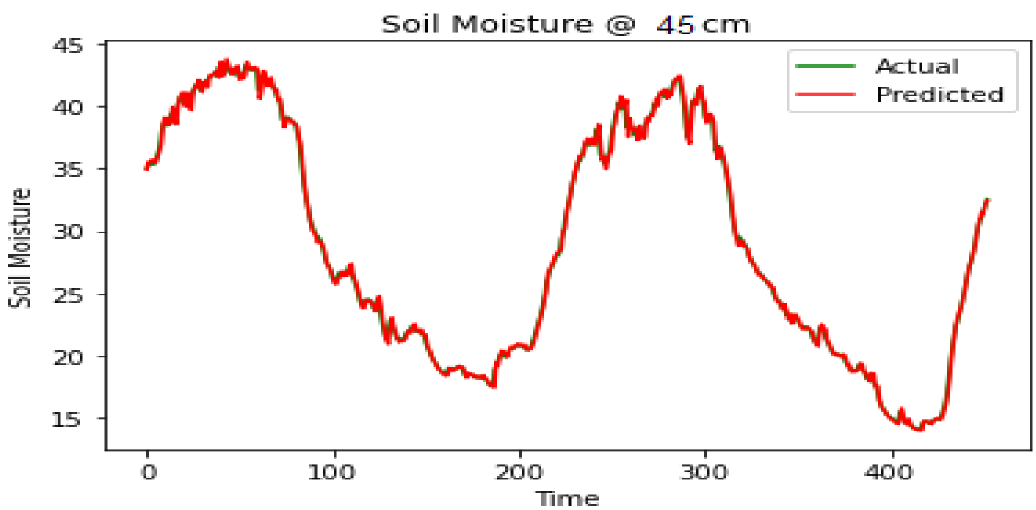
Figure 5.7 and 5.8 depicts the graphical plot results of these validated and predicted models for wheat crop.

b **Validation of ARIMA model for wheat crop**

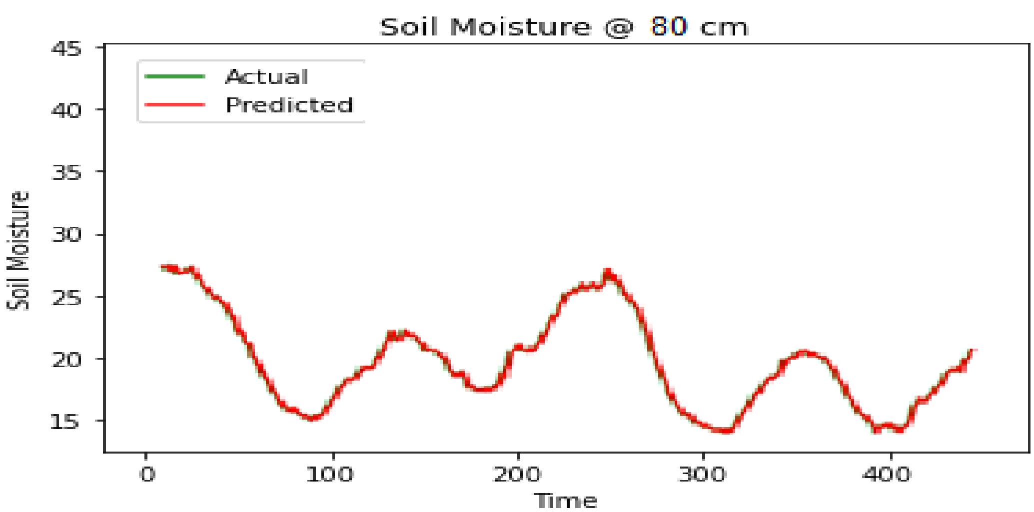
The acquired dataset on wheat crop was trained on three different parameters. In context of the outcomes as depicted in Table 5.6, it has been observed from the R^2 scores that three out of seven variables, *i.e.*, Soil moisture 10 cm, Soil moisture 45 cm, and Atmospheric pressure have performed more than 99% while the remaining four variables have scored between 96% and 98%.



(a) Soil moisture at 10 cm

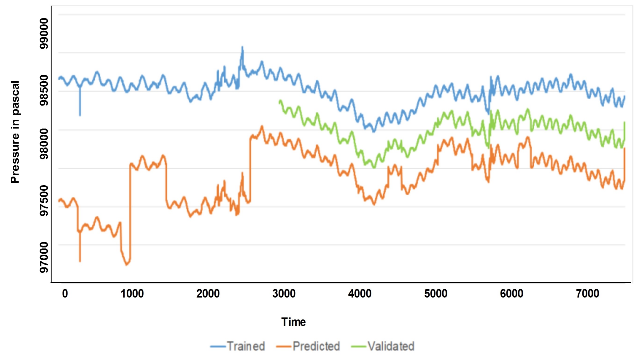


(b) Soil moisture at 45 cm

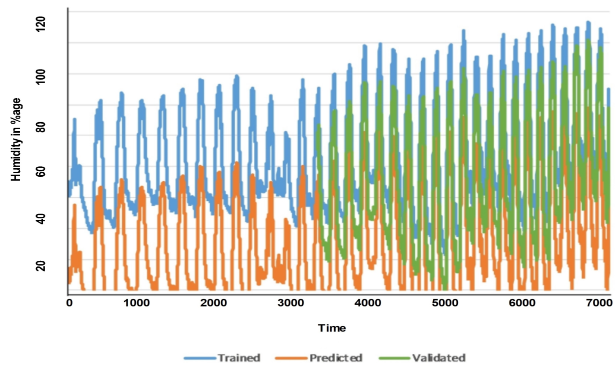


(c) Soil moisture at 80 cm

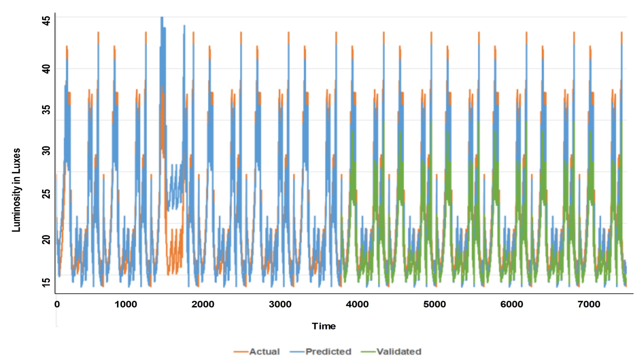
Figure 5.7: Validated and predicted graphical plots of soil moisture parameter for ARIMA model with respect to wheat crop



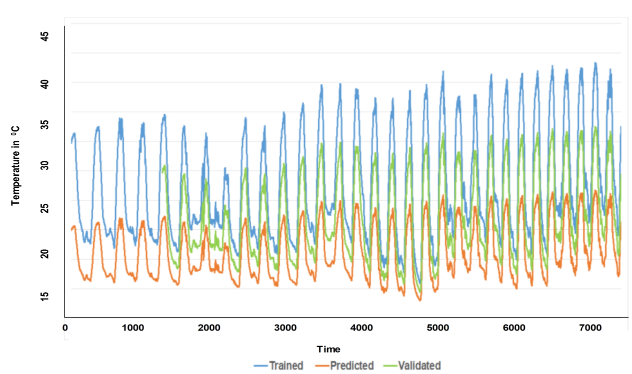
(a) Atmospheric pressure



(b) Humidity



(c) Luminosity



(d) Soil temperature

Figure 5.8: Visualization of validated and predicted graphical plots of remaining four parameters for ARIMA model with respect to wheat crop

Table 5.6: Results of the best-suited ARIMA model for wheat crop

Variable	Units	*p*	*d*	*q*	MAE	MSE	RMSE	R^2
Soil moisture 10 cm	Proximity	3	1	0	121.685	14.118	3.757	0.9914
Soil moisture 45 cm	Proximity	0	1	3	149.693	12.235	3.497	0.9978
Soil moisture 80 cm	Proximity	1	0	4	127.833	7.096	2.663	0.9855
Atmospheric pressure	Pascal	1	0	6	169.543	6.551	2.559	0.9956
Humidity	Percentage	1	0	6	121.075	8.401	2.898	0.9684
Luminosity	Luxes	1	0	1	194.757	13.993	3.740	0.9857
Soil temperature	^oC	1	0	6	111.005	18.049	4.248	0.9789

c **Evaluation of dataset on LSTM modeling technique**

Analysis of variables associated to wheat crop were evaluated on LSTM modeling technique on similar parameters as of ARIMA model. The results of the modeling technique depicted relatively low values for two variables, *i.e.*, Humidity and Soil temperature. AIC scores obtained for wheat crop dataset based on LSTM modeling technique have been summarized in Table 5.7.

Table 5.7: Evaluation of LSTM model on different hyper-parameters for wheat crop

Variable	Univariate hyper-parameters (p,d,q)	AIC
Soil moisture 10 cm	order= (2,1,3)	AIC= 69885.38125
Soil moisture 45 cm	order= (1,0,4)	AIC= 669358.4496
Soil moisture 80 cm	order= (1,1,6)	AIC= 746389.7592
Atmospheric pressure	order= (1,2,5)	AIC= 736981.3296
Humidity	order= (1,0,5)	AIC= 29221.6006
Luminosity	order= (1,1,4)	AIC= 74812.5540
Soil temperature	order= (1,2,6)	AIC= 17631.0052

d **Validation of LSTM model for wheat crop**

A similar process of comparing the derived results for R^2 was performed to determine the results for the better suited model for wheat crop. The analyzed results indicate that R^2 scores for four variables, *i.e.*, Soil moisture 10 cm, Soil moisture 45 cm, Soil moisture 80 cm, and Soil temperature ranged between 94% - 97%. The range of R^2 scores for remaining variables ranged between 91% - 92%. Since R^2 scores for all the variables of LSTM model found to be comparatively less than R^2 scores of ARIMA model, it has been concluded that ARIMA model **suits** better for wheat crop. Table 5.8 depicts the results for LSTM modeling evaluated scores on various variables for on wheats crop.

Table 5.8: Results of the best-suited LSTM model for wheat crop

Variable	Units	MAE	MSE	RMSE	R^2
Soil moisture 10 cm	Proximity	28.44	2511.10	50.110	0.9495
Soil moisture 45 cm	Proximity	28.82	2954.63	54.365	0.9522
Soil moisture 80 cm	Proximity	24.81	2727.26	52.223	0.9659
Atmospheric pressure	Pascal	4.97	212.35	14.572	0.9227
Humidity	Percentage	5.22	10.038	3.167	0.9254
Luminosity	Luxes	8.47	265.221	16.285	0.9198
Soil temperature	^oC	1.37	0.58	0.761	0.9788

5.4.3 Evaluation of Capsicum crop dataset on ARIMA and LSTM model

a **Evaluation of ARIMA model**

Capsicum was the third crop that was evaluated over the proposed model. The best possible AIC scores for capsicum crop dataset has been summarized below in Table 5.9.

Table 5.9: Evaluation of the ARIMA model on different hyper-parameters on capsicum crop

Variable	Univariate hyper-parameters (p,d,q)	AIC
Soil moisture 10 cm	order= (1,1,1)	AIC=77570.343
Soil moisture 45 cm	order= (0,1,1)	AIC=69570.534
Soil moisture 80 cm	order= (0,1,1)	AIC=75906.447
Atmospheric pressure	order= (0, 1, 1)	AIC=69570.534
Humidity	order= (3,1,2)	AIC=32175.262
Luminosity	order= (4,1,4)	AIC=60790.866
Soil temperature	order= (1,1,1)	AIC=-13798.666

In Table 5.9, best-suited Hyper-parameters *(p, d, q)* and their AIC score have been summarized. The AIC score depicts the level of generosity for the model. The graphical plot results of validated and predicted models for various soil moisture levels have been depicted in Figure 5.9, whereas results for best suited models for Atmospheric pressure, Humidity, Luminosity, and Soil temperature have been depicted in Figure 5.10.

b **Validation of ARIMA model for capsicum crop**

The acquired dataset was trained with three different parameters, *i.e.*, MAE, MSE, and RMSE. In Table 5.10, it has been observed that five out of seven models have performed more than the R^2 score of 99% while the remaining two variables such as Temperature and Humidity have R^2 scores of 98% and 97% respectively.

Table 5.10: Results of the best-suited ARIMA model for capsicum crop

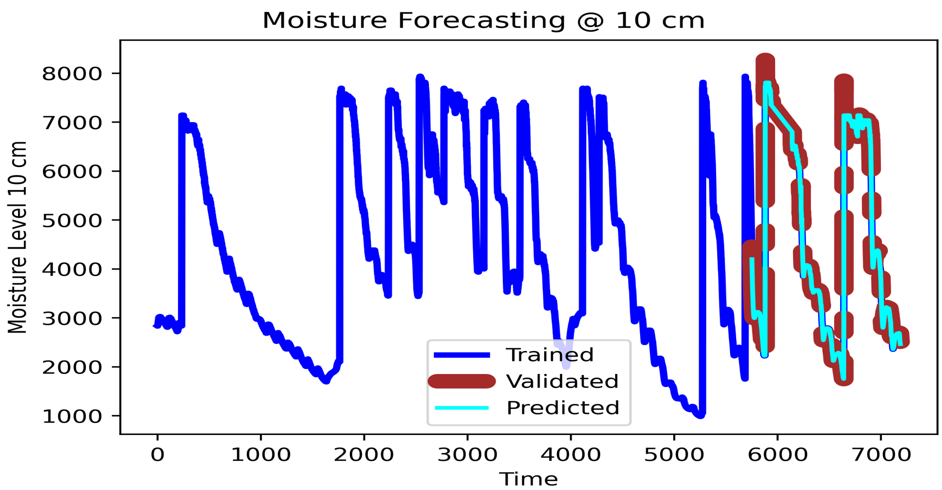
Variable	**Units**	***p***	***d***	***q***	**MAE**	**MSE**	**RMSE**	R^2
Soil moisture 10 cm	Proximity	1	1	1	25.24	20115.60	141.83	0.9940
Soil moisture 45 cm	Proximity	0	1	1	23.48	3121.83	55.87	0.9984
Soil moisture 80 cm	Proximity	0	1	1	26.34	25785.23	160.58	0.9935
Atmospheric pressure	Pascal	0	1	1	9.95	355.92	18.87	0.9956
Humidity	Percentage	3	1	1	1.78	13.09	3.61	0.9752
Luminosity	Luxes	4	1	4	9.68	414.87	20.68	0.9984
Soil temperature	^oC	3	1	3	0.35	0.50	0.71	0.9818

c **Evaluation of dataset on LSTM modeling technique**

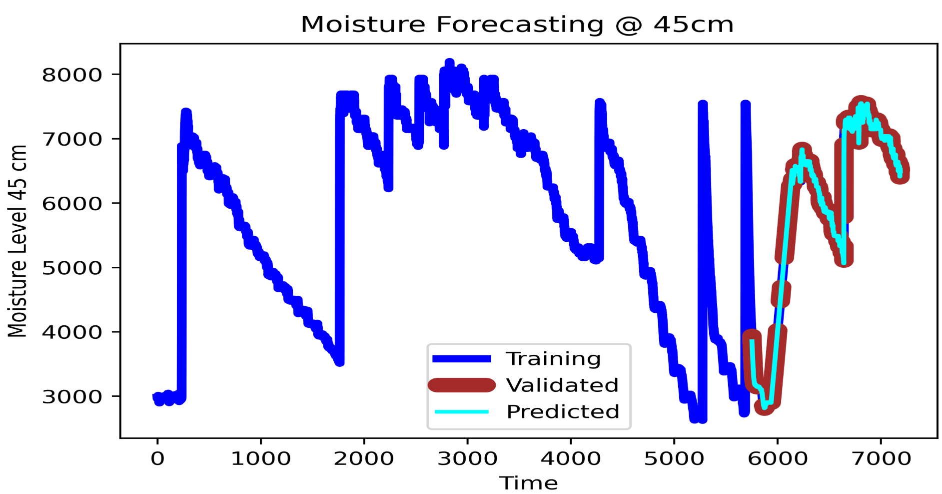
Analysis of variables associated to capsicum crop were evaluated on LSTM modeling technique on similar parameters as of ARIMA model. The results of the modeling technique depicted relatively higher values for three parameters. AIC scores obtained for capsicum crop dataset based on LSTM modeling technique have been summarized in Table 5.11.

d **Validation of LSTM model for capsicum crop**

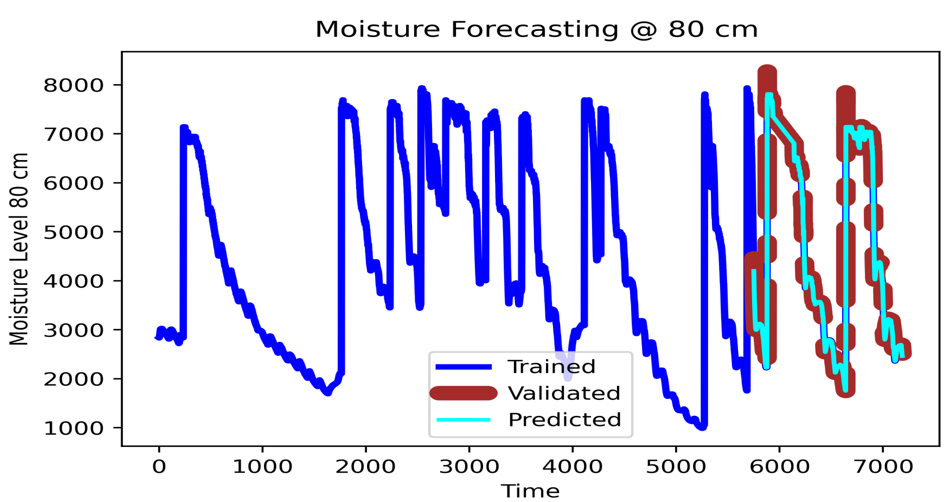
The results obtained from LSTM model for capsicum crop were compared with the results of ARIMA model and predictions were made on the basis of R^2 scores. The analyzed results indicated that R^2 scores for all the seven variables ranged between 95% - 97%. Since R^2 scores for all the variables of LSTM model found to be comparatively less than



(a) Soil moisture at 10 cm

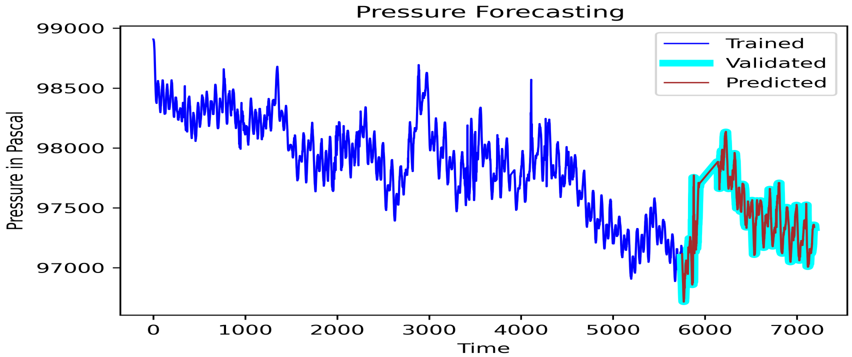


(b) Soil moisture at 45 cm

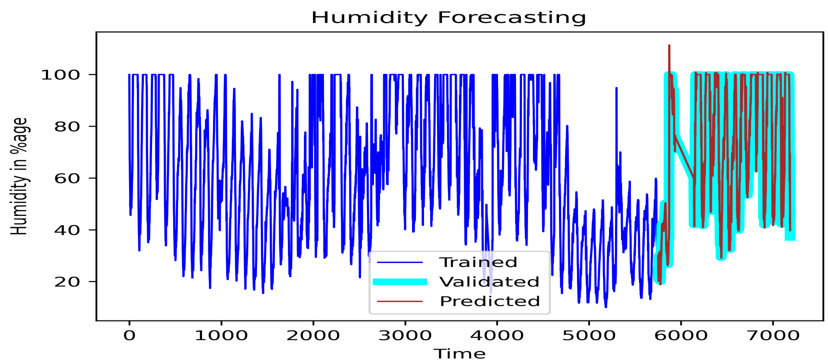


(c) Soil moisture at 80 cm

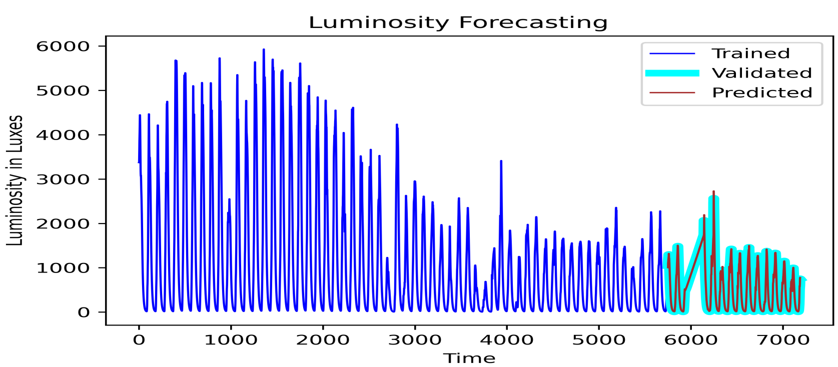
Figure 5.9: Validated and predicted graphical plots of soil moisture parameter for ARIMA model with respect to capsicum crop



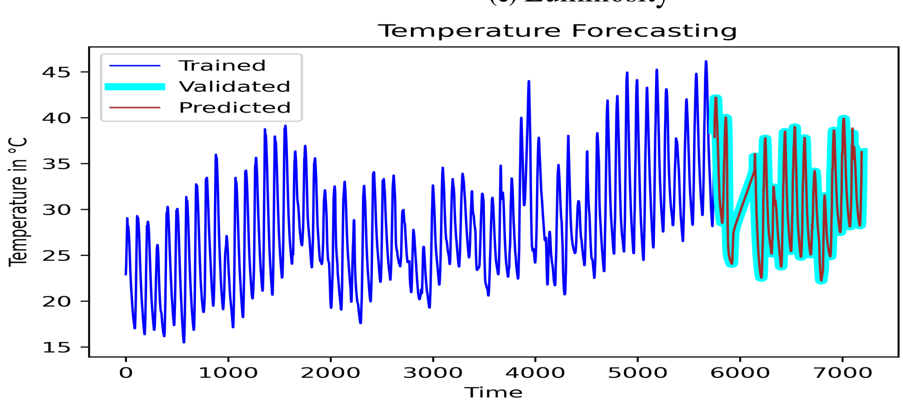
(a) Atmospheric pressure



(b) Humidity



(c) Luminosity



(d) Soil temperature

Figure 5.10: Visualization of validated and predicted graphical plots of remaining four parameters for ARIMA model with respect to capsicum crop

Table 5.11: Evaluation of LSTM model on different hyper-parameters for capcicum crop

Variable	Univariate hyper-parameters (p,d,q)	AIC
Soil moisture 10 cm	order= (3,1,0)	AIC= 71225.4530
Soil moisture 45 cm	order= (0,0,5)	AIC= 58649.5267
Soil moisture 80 cm	order= (4,1,6)	AIC= 48552.9826
Atmospheric pressure	order= (4,4,0)	AIC= 298763.5583
Humidity	order= (1,0,1)	AIC= 87221.6004
Luminosity	order= (1,0,6)	AIC= 78224.5971
Soil temperature	order= (0,1,5)	AIC= 35226.7156

R^2 scores of ARIMA model, it has been concluded ARIMA model were relatively better. Table 5.12 depicts the results for LSTM modeling evaluated scores on various variables for capsicum crop.

Table 5.12: Results of the best-suited LSTM model for capsicum crop

Variable	Units	MAE	MSE	RMSE	R^2
Soil moisture 10 cm	Proximity	27.14	26185.10	161.81	0.9895
Soil moisture 45 cm	Proximity	26.86	3552.13	59.59	0.9563
Soil moisture 80 cm	Proximity	29.11	28484.23	168.77	0.9625
Atmospheric pressure	Pascal	6.26	275.12	16.58	0.9722
Humidity	Percentage	1.52	11.52	3.39	0.9529
Luminosity	Luxes	9.68	299.47	17.30	0.9595
Soil temperature	^oC	0.37	0.43	0.65	0.9802

Interpretation of results derived from ARIMA and LSTM model for various crops in the present study

The results derived from ARIMA and LSTM model for rice, wheat, and capsicum crop. Based on the results, ARIMA model has out-performed in terms of precision and accuracy in predicting the next lags of time series in contrast to LSTM model with less error rate. The average reduction in error rates obtained by ARIMA was between 74% - 77% when compared to LSTM indicating the superiority of ARIMA model.

Further the evaluated results of ARIMA and LSTM models for the above crops have been compared with the results of similar studies. It has been found that the R^2 scores for the existing study are more than the results of derived in similar studies with various forecasting models [306, 307, 308, 309]. A comparative analysis of the present study with other existing studies has been summarized in Table 5.13.

Table 5.13: Comparative analysis of the proposed framework with other approaches
Models abbreviations: Multiple Linear Regression (MLR), SVR, ANN, and Gated Recurrent Unit (GRU)

Sr. No	Author, Year of Publication, and Citation	Proposed approach	Model	Results
1.	Nugroho *et al.* (2021) & [306]	Forecasting of solar radiance using the ARIMA Model for luminosity	ARIMA	R^2 = 0.8045 to 0.85902
2.	Guilln-Navarro *et al.* (2020) & [307]	Predictions of the Soil temperature using Neural Network	LSTM	R^2 = 0.9928
3.	Jin *et al.* (2020) & [308]	Deep Learning-based predictions of Temperature and Humidity for sustainable agriculture	GRU	RMSE = 2.4431 and 13.3041
4.	Prakash *et al.* (2020) & [309]	Predictions of the Soil moisture using Neural Networks	MLR, SVR, and ANN	R^2 = 0.92, 0.92, and 0.95
5.	Current study	Future predictions of agricultural parameters	ARIMA and LSTM	R^2 score more than 0.99

5.5 Evaluation of fertigation

Fertilizers are chemical substances or synthetic origin that are distributed within the fields with an aim to enhance the productivity. Fertilizers contain some of the most essential nutrients, that are required by the plants. Distribution of fertilizers among plants helps them to enhance their water retention capacity and also increases soil's fertility. In context of most modern agricultural practices focus on three main macro nutrients, *i.e.*, Nitrogen *(N),* Phosphorus *(P)*, and Potassium *(K)*. It is essential to determine the existing presence of fertilizers within the fields. To attain this objective, NPK sensor has been incorporated in the present study. It is a portable sensor that is low on cost, quick, responsive, highly precision device that works with Modbus RS485 that specifies electrical characteristics for multi-point. The proposed framework consisted of three modules.

i NPK sensor

This sensor is suitable for detecting existing presence of *N*,*P*, and *K* within soil. This sensor can be buried in soil over a long time. The accuracy of the hardware sensor is 2% upward with a measuring resolution is upto 1mg/Kg (mg/l). This sensor has high quality probes, rust resistant, electrolytic resistance, salt, and alkali corrosion resistance that ensures long-term operation of the probe, making it suitable for all kinds of soil.

ii Arduino Uno

Arduino is an open-source electronics platform that is based on easy-to-use hardware and software. These devices are capable enough to be paired with a variety of sensors for reading inputs and can be used to have control over associated devices. Figure 5.11 depicts the pictorial representation of the hardware device.

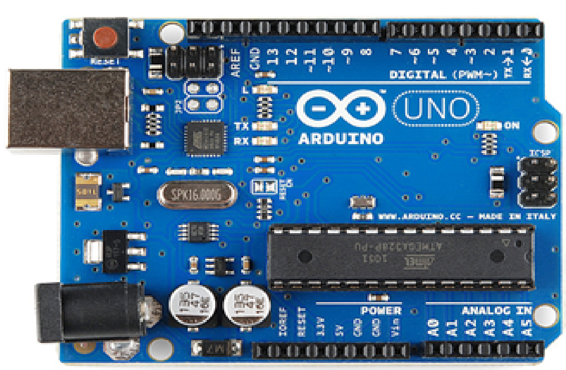


Figure 5.11: Pictorial representation of Arduino Uno

iii MAX485 TLL to RS-485 Interface module

This interface helps in enhancing the differential signaling for robust long-distance serial communications within a rage of 1200 meters or in soil electrically noisy environments. It supports upto 2.5 MBit/Sec data rates, but as the distance increases, the maximum data rate that can be supported comes down.. A pictorial image of the device has been presented in Figure 5.12.

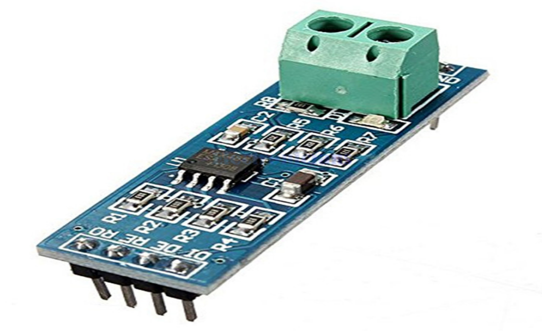


Figure 5.12: MAX458 TTL to RS-485 interface module

Figure 5.13 depicts hardware's interface with Arduino Uno. The next subsection discusses

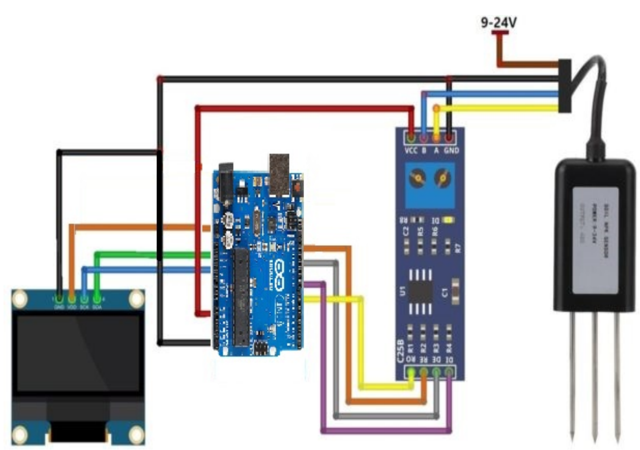


Figure 5.13: Hardware's interface with Arduino Uno

the Modbus commands used for performing observations.

5.5.1 Modbus commands used within the proposed framework

Modbus commands are used by the device to instruct the device for following actions.

i To change the value in one of its registers, which is initially written in Coil and Holding registers.

ii To read the information on an I/O port.

iii To command the device to send back one or more than one value contained in its Coil and Holding register.

A Modbus command contains the Modbus address of the device it is intended for (1 to 247). The modbus address is also referred as inquiry frame. When the device was put to use, only the addressed device responded and acted on the command. NPK sensor had three different frames for inquiry frames for reading the value of *N*, *P*, and *K*. Once code is uploaded on Arduino Uno, the hardware device used to get intialized. The phobes of the NPK sensor were dugged within soil to acquire NPK readings. The readings were displayed as mg/Kg. An 0.96" OLED display (I2C module) was also connected over the breadboard, to view the readings of the probe on real-time basis.

The use of the proposed framework was to check the existing presence of *N*, *P*, and *K* within soil. Based on the readings of the acquired value, further requirement of fertigation was determined.

Chapter Summary

This chapter presents the results of evaluation on various datasets that helps to optimize the process of irrigation requirements within the fields. The obtained results from ARIMA and LSTM modeling technique were firstly compared among each other. In order to further validate the results, similar studies were taken into consideration and the acquired results were compared with the results of other promising models. The second aspect, *i.e.*, optimization of fertilization distribution was also attained by evaluating the existing presence of various fertilziers within the fields with the help of NPK sensor.

The next section highlights the web-based portal and an android based mobile application designed to automate the existing study.

Chapter 6

Web and Mobile applications for Smart agriculture

Agricultural industry has radically transformed with the implementation of ICT and IoT based technologies. With the passage of time various techniques, *i.e.*, AI, Data mining, Data analytics, and Cloud computing have facilitated agricultural domain in scaling new heights. These emerging technologies not only have the capability to enhance agricultural yields, but also helps in reducing cost of labor, and assist farmers in easing their work. By using these techniques, farmers can now remotely monitor their fields and take proactive decisions. In the present study, digital implementation of SA has been taken into account. For this purpose, two different applications have been implemented. These applications are web based portal and an android based mobile application. This chapter deals with two sections. The first section sheds light on the functional aspects of web portal, whereas second section of the study presents the GUI for the android based mobile application and its working on real-time basis.

6.1 Web portal

A web portal is a platform that allows its user to host large volumes of information which is updated from time-to-time or on real-time basis. It not only helps in storage of data, but also facilitates to connect masses. Information on the web portal can be accessed by the end users depending upon their convenience and requirement. Keeping these aspects in mind, www.smartfasal.in, a web portal was developed to simplify and digitize the existing process of SA. This portal has been designed with an aim to improve the irrigation and fertilization system while performing agricultural practices using IoT and cloud infrastructure. This portal hosts a variety of features that can provide realistic solutions to existing changeless faced in agricultural domain. This portal stores datasets for three different crops taken into consideration for the existing study. Additionally, this portal provides a detailed information on technical specifications for the hardware device used for experimentation purpose within the existing study, and various agricultural sensors that can be mounted over the hardware device. Furthermore, the portal also provides a digital interface to view the results of evaluated datasets captured to obtain the objectives for the existing study. Apart from the above stated features, the portal also hosts a variety of similar datasets enabling keen researchers to perform their choice of ML techniques. Lastly, this portal also facilitates various researchers and farmers enabling the interconnectivity between potential researchers. Figure 6.1 depicts the interface of the web portal.

The main objective of this web portal is to monitor and manage agricultural activities remotely with the help of the incorporated hardware device. The hardware device deployed within the test bed is capable of capturing the data and also has the ability to upload the data onto cloud. The observed data is analyzed precisely over the ML technique, which helps in the estimation of irrigation requirement. The user of the domain can click on the dataset web-link and choose the option to download the recorded data from the drop down menu of the second tab on the interface page of the web portal. Figure 6.2 depicts the drop down option for viewing various datasets from 2^{nd} hyperlink on the interface of the web portal, whereas Figure 6.3 depicts the list of various datasets uploaded on the web portal respectively.

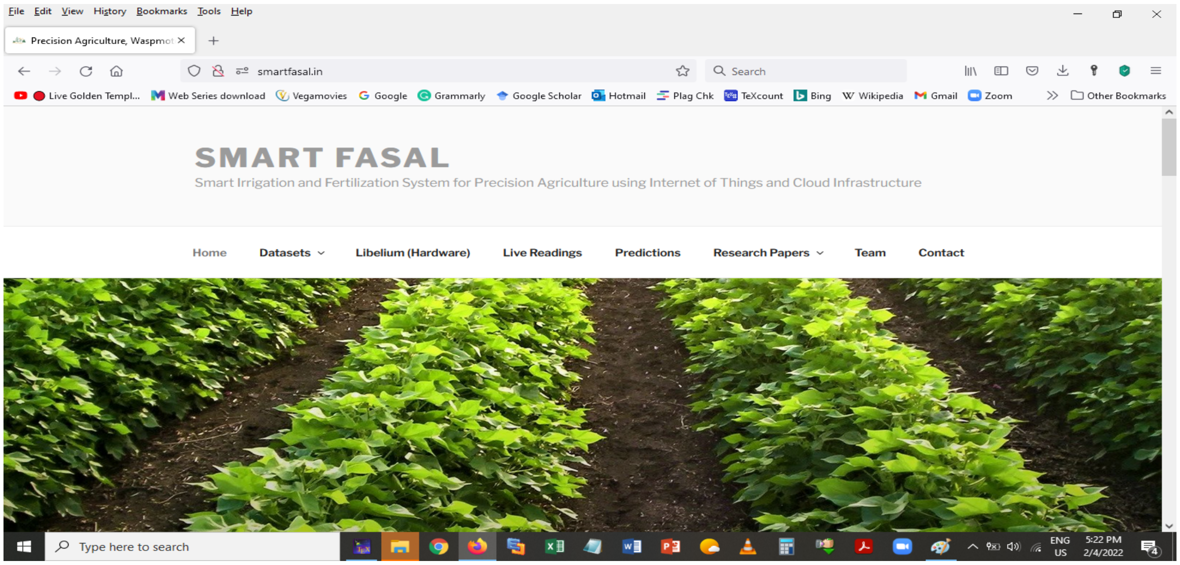


Figure 6.1: Interface of www.smartfasal.in

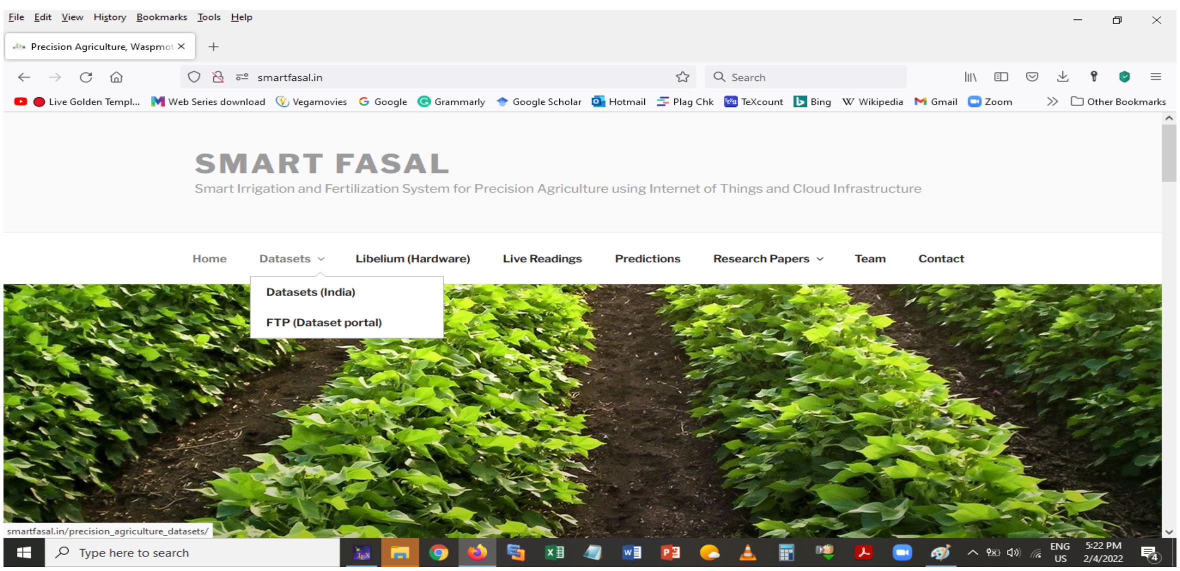


Figure 6.2: Drop-down option for selection of various crop datasets

By clicking on any of the dataset links, a .CSV file download gets prompted. On downloading it, the user can view the attributes for various datasets. The third link of the website routes to the web page, where live readings that are being captured from the deployed hardware device can be can be viewed. This web page is connected to the server's Mirror link

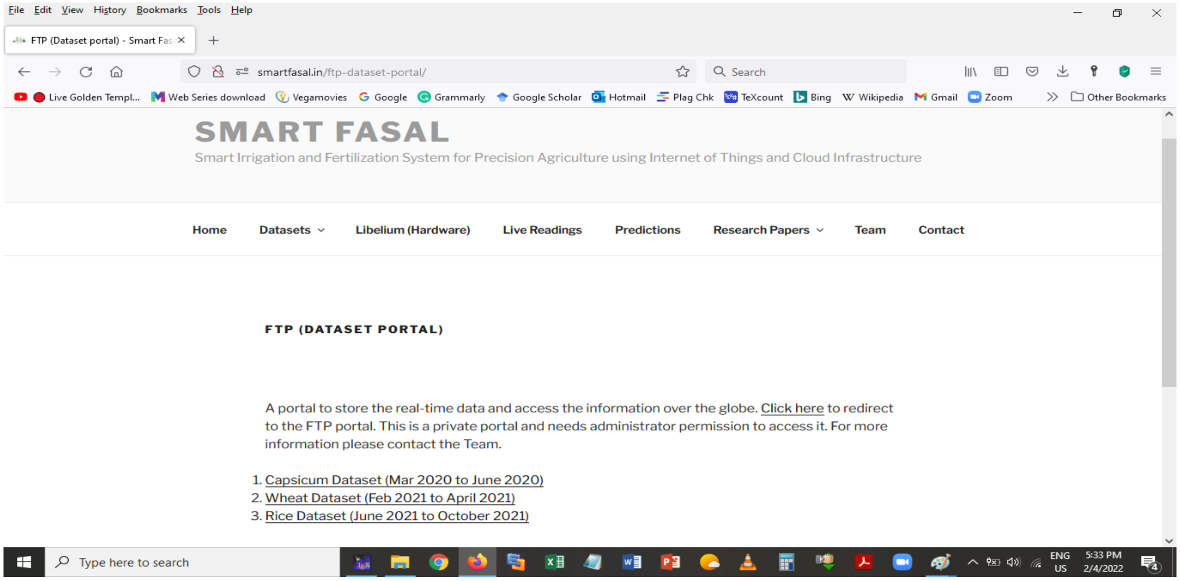


Figure 6.3: List of datasets available for download from the FTP link

1. This link enables the user to view the real-time recordings for various parameters that are being captured by the deployed sensors. Figure 6.4 delineates real-time recordings for various parameters captured in graphical mode.

In this entire process deploying agricultural sensors, capturing readings, uploading these readings over the cloud, their prediction is one of the most important aspect. Prediction is only considered to be valuable when it is well understood. Hence, the next tab on the domain enables the user to view the evaluated results, *i.e.*, the predicted values. Evaluations performed on various ML techniques incorporated within the study and the results acquired from the best suited model's output have been reflected in this web portal. Figure 6.5 portrays the predicted values for the current recorded parameters.

Lastly, the web portal not only facilitates the viewers with farm statistics remotely, but also provides a medium to share self experiences and innovative techniques globally with a better and bigger outer-reach.

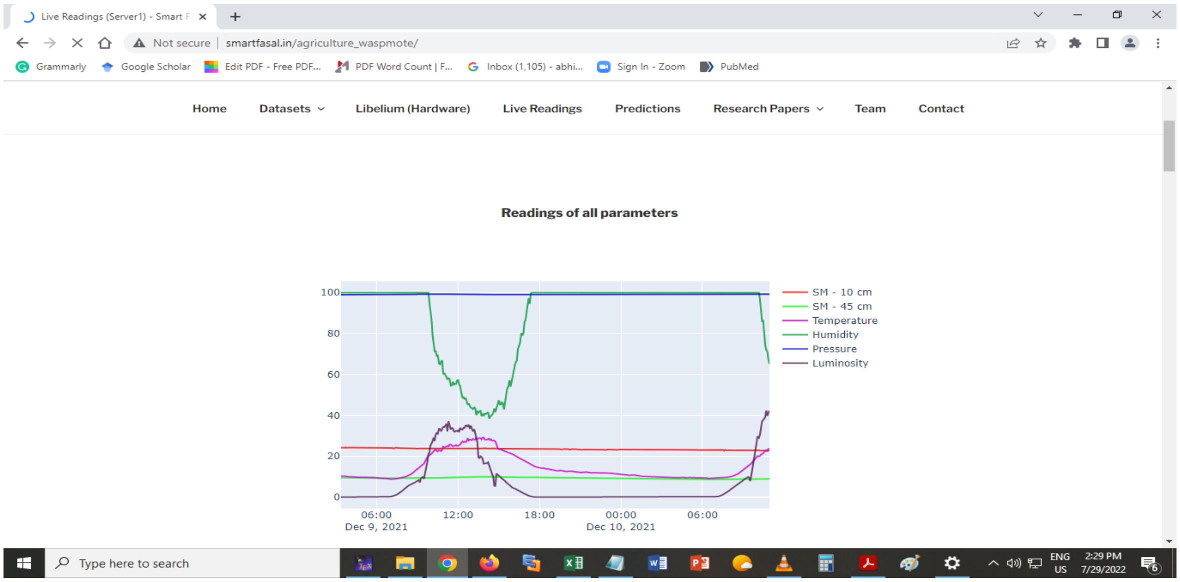


Figure 6.4: Webpage that routes to view real-time recordings for various parameters captured in graphical mode

6.2 Farm Analyzer- An android based mobile application

During the past decade, mobile application usage has increased many folds throughout the world [310]. Though, the primary goal of a mobile application is to provide a user friendly interface so that the user can conveniently and remotely perform the needful tasks. Over the years, the trend of generating an access control over the mobile phone has also picked up pace. Keeping this aspect in mind, Farm Analyzer, an android based mobile application has been developed to facilitate the farmer on account of performing agricultural activities. This application has been designed in such a manner that it provides real-time updates on weather data and sensor generated observations. The interface of this application also enables the user by viewing the final results of the computations performed on the observed data over the cloud, both in numerical as well as in graphical form. The application also provides an estimate on precise requirement of water required for irrigating the fields. An added feature of the hardware deployed within the field, generates an automated SMS alert based on the real time observations when the moisture level reaches threshold. Figure 6.6 illustrates screen shot of an alert message generated by the hardware device once the moisture level reaches

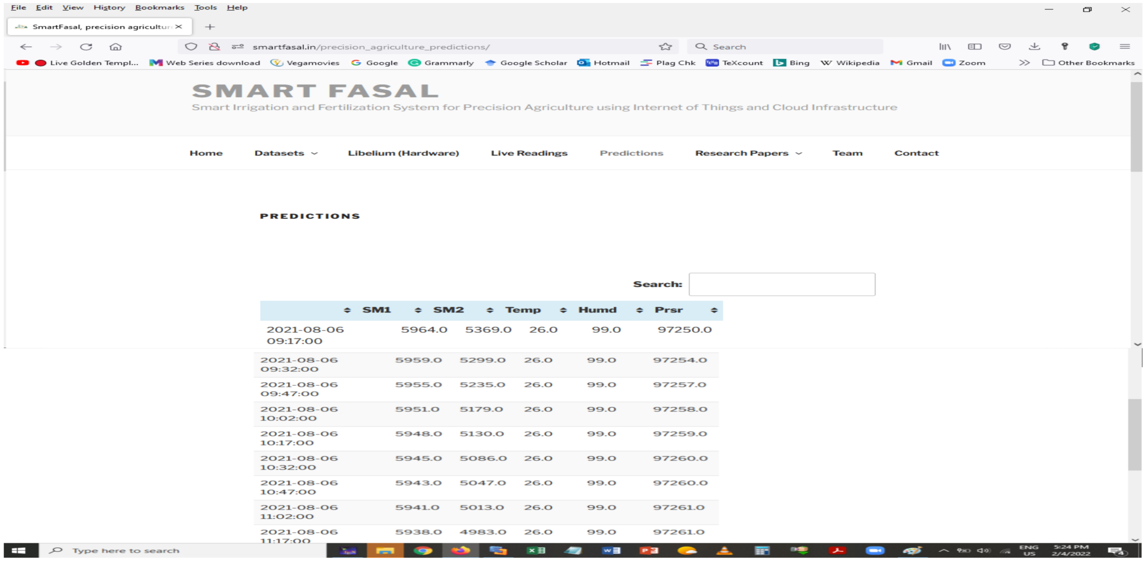


Figure 6.5: Webpage that routes to view real-time recordings for various parameters captured

the threshold on the registered mobile number.

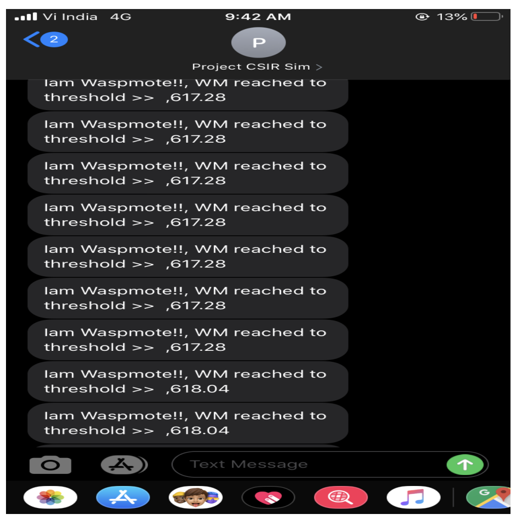


Figure 6.6: Screen shot of automated SMS alert

Furthermore, the application provides a push button to remotely turn on/off the relay valve that irrigates the field. The practical implantation of this mechanism was experimented in various test beds as discussed earlier within the study. Apart from this, the application also has a tab that depicts the graphical representation for sensor and weather data on individually as well as on combined basis. Conclusively, the designed application aims at reducing human intervention, time, and effort within the fields by providing a pragmatic approach. The next subsection depicts the various GUI for the mobile application.

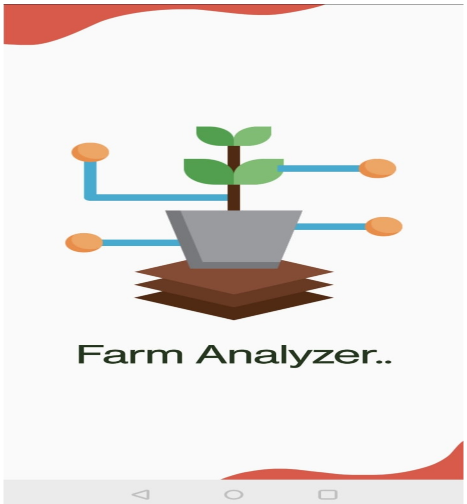
6.2.1 Graphic User Interface (GUI) for the mobile application

An Integrated Development Environment (IDE) for the mobile application in the existing study has been designed in Android Studio. Within this application, an Android Application Package (.apk) file was complied for building the Android based software. Once the *.apk* file was encoded, it was downloaded on the mobile phone. On the application is installed on the system, its icon appears within the list of other applications installed. Figure 6.7 depicts the installed application on the home screen of the mobile phone.

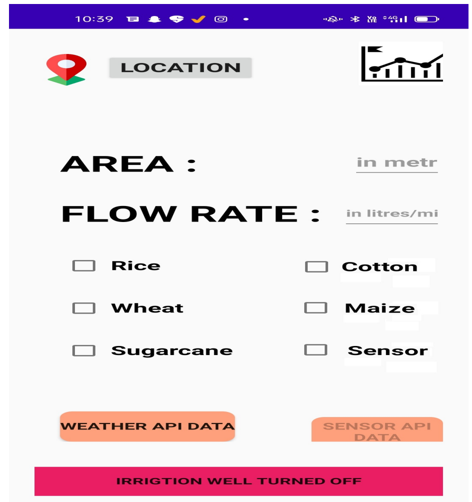
Figure 6.7: Installed application on the application list and on home screen of android mobile

On clicking the icon, the image for the application pops up and it further loads the application in the background of the mobile and within a few seconds routes to the interface for the GUI as depicted in Figure 6.8(a) and Fig 6.8(b) respectively.

The initial GUI page of the application hosts a a variety of options from selecting the GPS location, selection of crop, graphical representation of for real-time observations, live weather data, sensor statistics, a push button to turn on/off the water flow within the fields, *etc.* The user of the application can manually enter the specific area of his field for consideration along with a mention of flow rate of water. To view the current farm statistics for weather



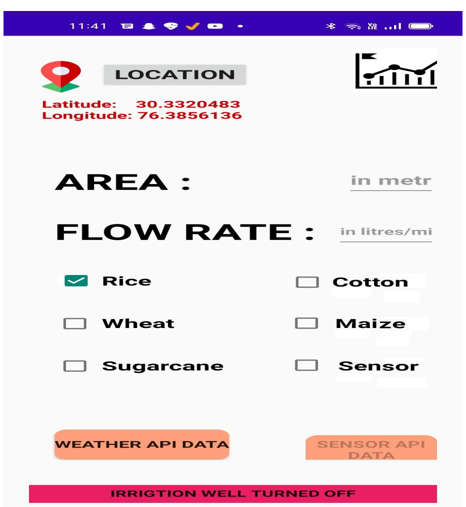
(a) Image on the screen while application loads over the mobile



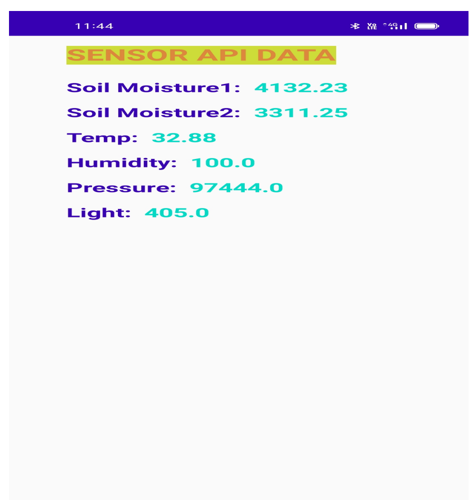
(b) GUI of the application

Figure 6.8: Screens depicting loading of the application and its GUI interface

and sensor parameters, the user needs to select the crop and click on the sensor data API button to view the live readings for his fields. Figure 6.9(a) represents the selection option for crop under consideration, whereas Figure 6.9(b) reflects the real time sensor data for the selected crop.



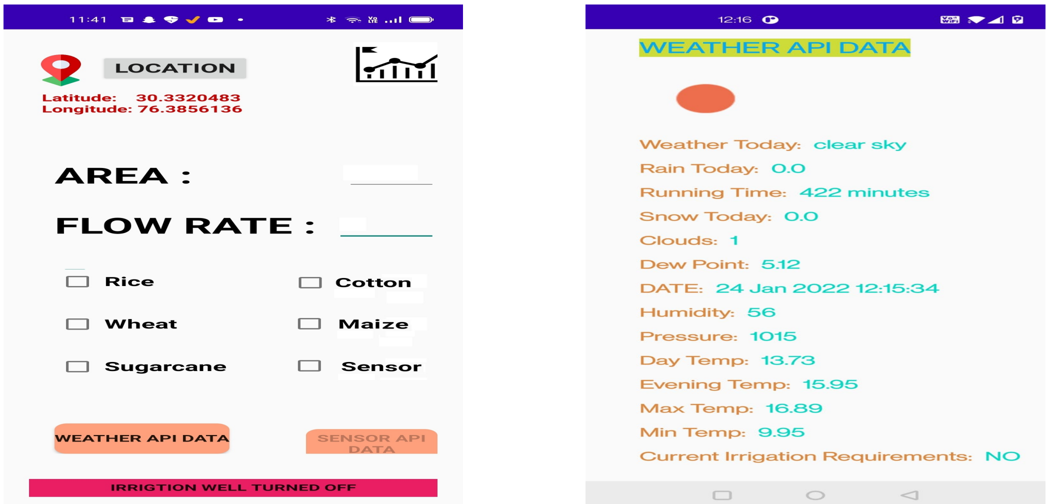
(a) Selection of crop in the mobile application



(b) Real-time sensor data

Figure 6.9: Screen shots of the application reflecting real time Sensor API data

Similarly, weather statistics can also be viewed by first turning on the GPS button in the settings menu, and then clicking on the location link available at the top of the application interface page. Figure 6.10(a) and 6.10(b) presents the location tab depicting the GPS coordinates and current weather statistics.



(a) GPS location turned on in the application **(b)** Real time Weather API readings

Figure 6.10: Screen shots of real time data through GPS location

The real-time observations can also been seen in graphical form with individual readings and readings in combined form. This can be done by selecting the graphical icon appearing on the top right corner of the mobile application. Figure 6.11 presents the various graphical interface for real-time readings in individual and combined format. In context of precise

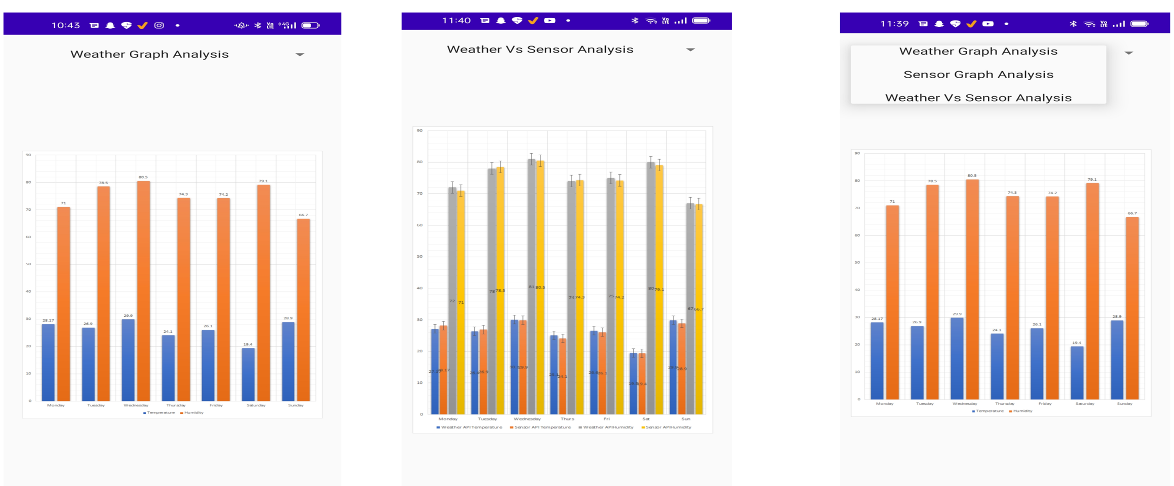


Figure 6.11: Graphical interface for real-time readings in individual and combined format

estimation of water requirement by the field, the user can select an option to view the precise water distribution requirement within the fields. The same can be done by entering the area under consideration for irrigation and then clicking on Weather API tab. The application in the existing tab calculates the precise water requirement (in litres) as estimated by the ML technique incorporated within the study. Figure 6.12 depicts the graphical interface with precise estimation of water requirement by the field based on current weather statistics.

Apart from this, one of the most important feature of the application is the ability to turn

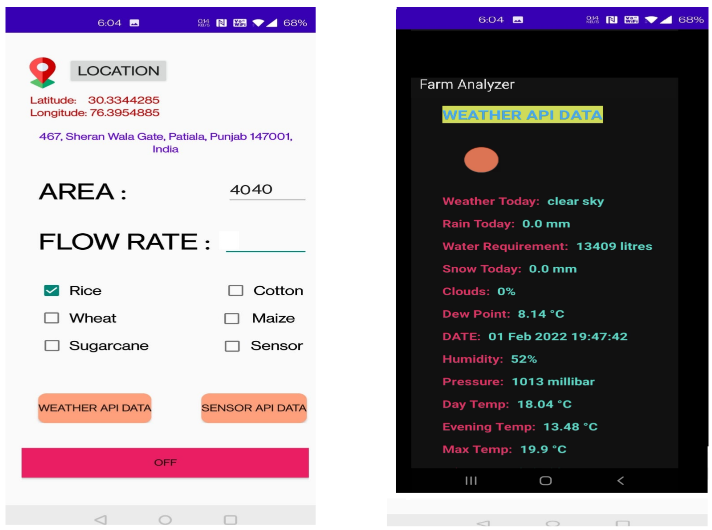


Figure 6.12: Graphical interface depicting precise estimation of water requirement by the field based on current weather statistics

on/off of the water valve remotely. On the basis of current observations and analysis, the farmer can remotely perform the procedure by clicking on the button present at the bottom center of the tab. The turning on/off status of the irrigation button is visible in two different colors, *i.e.*, green and red respectively. Figure 6.13 depicts the current status of irrigation valve.

Both the applications have been practically implemented on various farms apart from the test beds and the results have been very satisfactory. While performing its practical demonstration on farms, consent of local farmers was acquired. Along with the demonstration, functional aspects and benefits for both the applications were discussed were discussed among farmers. In addition, a manual feedback also was collected from farmers for both the appli-

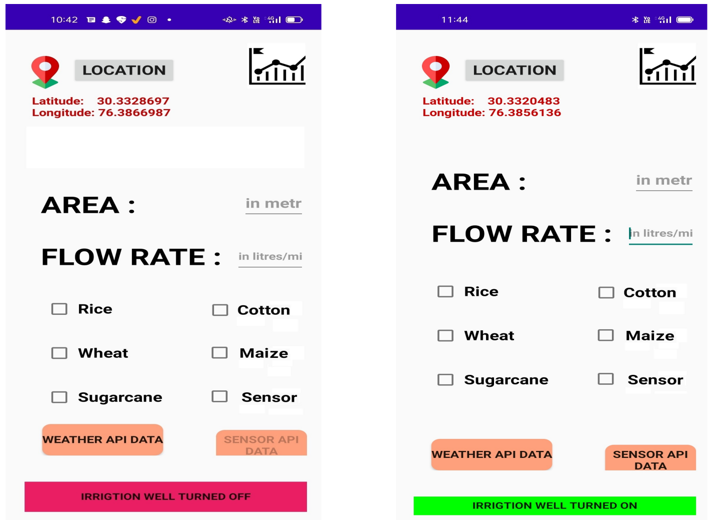


Figure 6.13: Graphical interface reflecting current status of irrigation valve

cations, with an aim to further improve the existing application's working. Farmers found both the applications relevant and useful. It was concluded from the manual survey that most of the farmers have rated the android's interface relatively easy to use and efficient over web portal.

Chapter summary

This chapter presents an insight of the web portal and android based mobile application developed to facilitate the user to remotely monitor and control the agricultural activities using IoT and cloud platform. Agricultural activities can be monitored remotely either through web portal or via mobile application depending upon the requirement and availability of resources at user's end. However, the GUI of the mobile application allows an extensive range of features and functions in comparison to the web portal.

The next chapter reflects the concluding notes for the present study and summarizes the final learnings attained from the existing study.

Chapter 7

Conclusions and Future Scope

7.1 Conclusions

In this thesis, a detailed description about SA has been provided along with significant impact of IoT in agricultural domain. A systematic literature review has been performed by developing review methodology following an inclusion and exclusion criteria to consider the relevant studies. The identified research articles are categorized on the basis of agriculture's life cycle, *i.e.*, soil properties and sowing, irrigation and fertilization, growth and monitoring of plants, crop protection from various diseases and weeds, harvesting, and stubble management. Some of the prominent research articles published over the past few years have been discussed in the thesis to understand the pragmatic approach of IoT. This thesis also presents an overview of existing web portals and mobile applications within agricultural domain. After performing comprehensive literature review, various research gaps have been identified.

In this thesis, a framework namely, Minimal Distribution of Water & Fertilization based Decision Support System ($MDW\&F_bDSS$) has been proposed. This framework consists of two hardware devices that help in optimizing consumption of water and fertilizers within the fields by evaluating various agricultural parameters. Three different crops have been considered for experimentation and its agricultural parameters have been recorded and analyzed using Time Series Analysis. All the recorded datasets are evaluated on ARIMA and LSTM modeling techniques. The results of ARIMA and LSTM models have been validated on the basis of three parameters, *i.e.*, MAE, MSE, and RMSE. The analyzed results indicated R^2 with a percentage value. Based on the maximum number for higher values of R^2 scores, the best model has been selected. For rice crop, R^2 scores for all the seven parameters (Soil moisture (S_m) at 10, 45, and 80 cm, Soil Temperature (S_t), Humidity *(H)*, Atmospheric pressure (A_p), and Luminosity *(L)*) are more than 98%. Similarly, for wheat crop R^2 scores for three variables, *i.e.*, Soil moisture (S_m) at 10 cm, 45 cm, and Atmospheric pressure (A_p) are more than 99%. Similarly, for capsicum crop R^2 scores for five variables (Soil moisture (S_m) at 10, 45, and 80 cm, Atmospheric pressure (A_p), and Luminosity *(L)*) are more than 99%. It has been concluded that ARIMA model scored better in comparison to LSTM model. Furthermore, the performance of the framework has also been compared with other significant studies. Fertigation assessment has been done by estimating the existing presence of various fertilizers, *i.e.*, *N*, *P*, and *K* within the fields with the help of NPK sensor. Based on the existing values, determination of further fertigation requirement is computed. The results given by the proposed framework are very promising and it can be further be used to optimize water and fertilizer requirements for other crops.

7.2 Future Scope

In future, yield data can be collected based on weather parameters and added to the proposed framework. This yield data can be mapped to the weather data and correlation can be determined between weather attributes and yield data. In the present study, Libelium's Waspmote Plug and Sense device has been incorporated within the proposed framework for capturing agricultural parameters. In future, low cost nodes can be created and implemented within the fields for capturing data. In addition, the existing SA system can be extended to determine weed and disease detection within the fields using image processing and AI based techniques. The proposed framework has performed evaluations on Rice (paddy), Wheat, and Capsicum crop in the present study. However, several other crops such as cotton, sugarcane, pearl, millet, maize, barley, *etc.* are also cultivated in Punjab region. So, evaluations can also be performed on the above said crops. In context of fertilizer applications, target spray treatment on infected crops can also be incorporated as a future scope of research. Lastly, farmers across the state of Punjab can only read, speak, or understand the regional language, *i.e.*, Punjabi. However, both the applications (web portal and mobile app) have English interface. Both the applications interface can further be designed to host the regional language. The results given by the framework are very encouraging and has a potential to provide impetus to several other agricultural applications.

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List of Publications

1. Abhishek Khanna and Sanmeet Kaur, ”Evolution of Internet of Things (IoT) and its significant impact in the field of Precision Agriculture”, *Computers and Electronics in Agriculture*, Elsevier, 2019. (IF 6.757).
   DOI:10.1016/j.compag.2018.12.039

2. Abhishek Khanna and Sanmeet Kaur, ”Internet of Things (IoT): A Comprehensive Review”, *Wireless Personal Communications*, Springer, 2020. (IF 2.017).
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3. Abhishek Khanna and Sanmeet Kaur, ”An empirical analysis on adoption of precision agricultural techniques among farmers of Punjab for efficient land administration”, *Land Use Policy*, Elsevier, 2023. (IF 6.189).
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Communicated

1. Abhishek Khanna, Sanmeet Kaur, Parteek Kumar, and Sukhwinder Singh”Evaluation and Real-Time Forecasting of the agricultural paramters using Time Series Analysis,” *Environmental Modelling & Software*- SCIE Indexed (IF:4.807), 2023 (Under-Review)

Conferences

1. Abhishek Khanna and Sanmeet Kaur, ”Revamping the doctrinal irrigation system into Smart Irrigation Framework using the concepts of Internet of Things (IoT)”, *8^{th} Asian-Australasian Conference on Precision Agriculture, Punjab Agricultural University, Ludhiana*, 14^{th}-17^{th} October, 2019.

2. Abhishek Khanna and Sanmeet Kaur,”Wireless Sensor and Actuator Network(s) and its significant impact on Agricultural domain”, *2020 Sixth International Conference on Parallel, Distributed and Grid Computing (PDGC)*, Waknaghat, Solan, India, 2020, pp. 384-389.
   DOI: 10.1109/PDGC50313.2020.9315822.

3. Abhishek Khanna and Sanmeet Kaur, ”Evaluation of soil moisture for estimation of irrigation pattern by using Machine Learning Methods”, *Springer’s 5^{th} International Conference on Advances in Computing and Data Sciences, (ICACDS 2021)* , Maratha Vidya Prasarak Samaj’s Karmaveer Adv. Baburao Ganpatrao Thakare College of Engineering, Nashik, Maharashtra, India.
   DOI:10.1007/978-3-030-88244-0_33.

Posters

1. Abhishek Khanna and Sanmeet Kaur, “Internet of Things (IoT) based Smart Irrigation framework for Precision Agriculture”, *Poster presented at in 5th edition of m2m + IoT forum 2018, India Habitat Center, Lodhi Road, New Delhi* , 30-30 January, 2018. **[Best Poster Award]**