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# Review on Advanced Techniques and Smart IoT Systems for Irrigation Management of Single and Multi-Crops

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***Abstract*—Irrigation is the important process in the agriculture that has to supply required amount of water to the crop field and also need to optimize the water usage due to water scarcity and water shortages present. Nevertheless, the growing population needs more crops needs to be cultivated throughout the year needs enhanced agriculture systems to function. It is very difficult for the farmer or labors to give their full efforts for very large cultivating region round the clock. So, the smart irrigation system has evolved that uses recent techniques and senses the temperature, pressure, moisture content in soil and humidity and water the crops based on their needs. This paper surveys different topics of smart irrigation based on Machine Learning, IoT systems, WSN, hybrid techniques, Single-Crop and Multi-Crop cultivation, Irrigation requirement analysis, and its evaluation parameter metrics. Analysis of different frameworks of smart irrigation systems also presented with perceptional approach.**

***Keywords*—Agriculture, Smart Irrigation, machine Learning, AI, IoT, WSN, Smart farming.**

## I. INTRODUCTION

Irrigation plays an important role in the agricultural sector and is a life-saving factor for crops. Water is the main element required for the growth of plants compared to other things in agriculture. Irrigation is a time-limiting action that to take place in the proper time interval and duration. As the growing population, demands more food it mainly depends on the growth of agriculture techniques.

The crops cultivated in the soil, based on the weather, its versatility, properties of the soil, requirement of water, etc. Each crop has different water requirements and the growth depends on it. So many irrigation systems are introduced for the well-being of the crop and to reduce labor activities.

Water scarcity is also an important factor, that requires the quantity of water to be handled in efficient manner. So many researches are taking place in the Irrigation system that indirectly helps in the development of Agriculture of that particular nation.

Auto Irrigation systems help the farmer to irrigate the land using automated techniques like the surface method, drip method, sprinkler method, and sub-surface method.

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The main objective of the auto irrigation system is to reduce the labor work and to concentrate in other crop well being activities, timely management, irrigation based on real-time collection of data from sensors. In the paper [1], the detailed survey of auto irrigation system based on factors like time, volume, open loop systems, closed loop systems, real-time feedback systems, and computer-based irrigation control systems are done. The authors also provided information of national (India) and International wise on auto irrigation system that is occurring. The low-cost irrigation system using Atmel microcontroller AT89S52 and soil moisture sensors are used. The successor of auto irrigation system is the smart irrigation system where the involvement of various sensors, wireless devices, networks, and control systems helps the agricultural growth at wide range. Authors in the paper [2] surveyed the smart irrigation systems present all over the world based on irrigation development, irrigation scheduling systems based on real-time data, based on irrigation techniques like manual and automated methods, irrigation system based on smart techniques based on soil monitoring sensors and control of the irrigation techniques based on the crop cultivated. The soil sensor helps the irrigation system in a large scale by indicating the amount of water requirement in the soil for the growth of the plant. The issue of water scarcity and the need for the soil moisture sensors for the growth of agriculture is discussed in the paper [3] where the authors provided data on various soil moisture sensors based on
temperature, moisture, water requirements, dielectric permittivity, salinity, conductivity and flow of water. The field irrigation based on Wireless Sensor Network (WSN) and the advantages of sensors-based irrigations are also explained. The smart drip irrigation system is proposed in the paper [4] and also the authors explained different techniques involved in it. The IoT-based smart drip irrigation system using Android application in mobile devices by SMS or miscall approach helps the farmer to indicate the condition and requirement of water is proposed. In the paper [5], a survey is made on the groundwater, springs, and wastewater from the Mezquital valley that is of Palestine ages. It is found that 218 organic micro contaminants are present in the those water of that valley which brings hazardous health issues in the consumers. The authors discussed the way of samples collected and the analysis made. The detailed description of 218 compounds and their concentration present in the springs, waste water and ground water level is presented along with the number of VOCs (Volatile Organic Compounds) and SVOCs (Semi-Volatile Organic Compounds), Phacs (Pharametically hormone active compounds) and seven reproductive compounds present in the surface, springs and waster water is discussed. The consumer health issues due to the consumption of this water is explained. In the paper [6], the data mining and machine learning algorithms for smart farming system and smart irrigation system under the topics of soil moisture detection, irrigation auditing, various sensor devices involved, machine learning of types supervised, semi-supervised and un-supervised learning algorithms used are explained. Various artificial intelligence algorithm are used in smart irrigation system using IoT system is discussed in the paper [7], where the authors gave a good insights on various controllers, sensor, different techniques based on hardware, firmware and software using AI, deep learning, and machine learning techniques and also discussed the benefits of using different systems. An IoT based smart irrigation system is designed using kNN (k- Nearest Neighbor), LSTM (Long Short Term Memory) and transfer learning method is adopted in the paper [8] -using the real-time data collected by using the banana tree for nine to 10 months of cultivation after applying their proposed work that results in the good accuracy. Auto Regressive Integrated Moving Average (ARIMA) model based IoT system using Artificial Intelligence along with the Design Science Research Methodology (DSRM) approach is proposed in the paper [9] and implemented successfully in the Limpopo Province. The agricultural operations take place using IoT systems that collect the real time data and send it to the farmers using the kNN machine learning algorithm that enhances the irrigation method by handling the water scarcity issue is explained in the paper [10].

The survey of smart irrigation system based on various factors are discussed in this paper that helps to enhance the future researches. The smart irrigation system depends on multiple technques, AL algorithms, frameworks, models, and methods that are discussed in detail. The paper is organized as follows, i) Introduction, ii) Framework for Single-crop and Multi-Crop, iii) Hybrid techniques for smart irrigation based on IoT and WSN, iv) Monitoring systems of smart irrigation that depends on the machine learning algorithms, v) irrigation requirement analysis using ML and AL, vi) evaluation parameters required for predictions and water management and followe by vii) conclusion.

## II. FRAMEWORK

In this section, different frameworks for the single-crop and multi-crop methods is discussed in Table I and Table II. Various parameters, communication systems using IoT and WSN, prototypes, methods, and ways of soil quality enhancement are surveyed for both single-crop and multi-cropping methods. Framework is the main

concept in the irrigation system that defines the complete working model for the proposed system. the framework of iirgation system are based on IoT and WSN network where the data are collected using sensors from the field that is using the Microcontrollers, Arduino and Raspberry Pi is usually used in the literatures. Then the farmers on other side, take action like water pump switching On or OFF conditions. The complete framework is results in the practical applications that are reviewed in the Table I.

TABLE I. FRAMEWORK FOR SINGLE CROP IRRIGATION SYSTEMS

| References | Methods | Inference |
|---|---|---|
| [11]. Allali, et al. | Prototype model developed using ESP 8266 for collecting soil, climate, and plant parameters and GUI in the farmer side using the IoT systems | Smart Green based system efficiently controls the automatic watering process in order to overcome the overwatering and to reduce water consumption in the irrigation processes. |
| [12]. Habib, S, et al. | IoT based waste water Irrigation system | Soil fertility sensor is used under the dates palm tree to check the soil fertility and communicated using WiFi and HTTP is used for farmer side requests. |
| [13]. González-Briones, Alfonso, et al. | Multi layer and multi agent Architecture for auto irrigation system using Wireless Sensor Network (WSN) | Virtual Organisation (VO) based Multi agent system (MAS) used for collecting the required parameters for corn crop utilizing the benefits of pivot and localized irrigation method is done. |
| [14] Di Wu, et al. | Multi- Source Water Irrigation system framework calculation using Agriculture Irrigation Water Consumption (AIWC), Irrigation Return Flow (IRF) with the help of Soil and Water Assessment Tool (SWAT) | Modified SWAT model applied to AIWC for reservoirs, ponds and river channels of the YSD of China where the proposed model indicated the drought duration effectively. |
| [15] Li, A., et al. | Pressurized Sprinkler Irrigation system using non-dimensional infiltrated methods | Four parameters namely deep percolation (DP), Coefficient of Uniformity (CU), Application efficiency (Ea) and distribution uniformity (DU) for three data sets containing wheel movement, permanent and semi solid state are used for calcutaion that results in 12% reduction in efficieny compared to conventional formula because of parameters used. |
| [16]. Esteves, et al. | Collective Irrigation System (CIS) considering different rehabilitation alternatives. | Three main components based CIS system framed like crop production systems, on-farm irrigation systems and project rehabilitation alternatives shown less futuristic approach . |
| [17]. Borsato Eros, et al. | Framework for water sustainability using parameters deficit, overuse, reliability and resilience | Evaluation of sustainability of irrigation based on quantitative terms and likelihood, provides socio-economic sustainability aspects, decision making process rely on spatial and temporal data for water management. |

TABLE II. FRAMEWORK FOR MULTI CROP IRRIGATION SYSTEMS

| References | Methods | Inference |
|---|---|---|
| [18] Anbarasi, M., et al | Soil moisture detection for multi crop cultivation using Arduino and Raspberry pi based IoT system | The soil information is effectivey collected by sensor nodes and communicated to the farmers, with the help of indicators water pump is processed that reduces the physical need of the farmer at the same time increases the yield of the multi crops. |
| [19] W. Haider, et al. | WSN based multi crop yielding using decision support systems and context aware water scheduling | Increasing the income by growing the vegetable plants along with crops leads to mixed cropping that requires efficient water scheduling system is addressed by rule mining-based algorithm and mobile oriented GPRS system in WSN network |
| [20]. Rudinskienė, et al. | Enhancing soil quality by incorporating caraway in Multi cropping system | Long term soil health is obtained using binary and trinary crops of using caraway with wheat and with cloves, barley and caraway. |

## III. HYBRID TECHNIQUES FOR SMART IRRIGATION

In this section, the smart irrigation system combining the machine learning and IoT system-based hybrid models are survey, summarized in the Table III with the detailed description of authors proposal. The usage of hybrid techniques helps the smart irrigation system at greater scale that reduces the water usage and results in the good cultivation. The ML algorithms used are KNN, SVM, RF, GRT, linear regression, etc are the main concepts used

with the IoT systems. The WSN network is considered by for smaller scale of cultivation. Smart green and green house effects also discussed in many of the works. Intervention of IoT with machine learning techniques evolves with the more accurate output in the real-time basis. Therefore, these hybrid techniques entered agriculture domain mainly involved in the smart irrigation systems. It is reviewed that KNN, RF, SVM, SVR and LR methods of machine learning techniques are incorporated with IoT systems of smart irrigation systems that are discussed in detail.

TABLE III. ML AND IOT BASED IRRIGATION SYSTEM

| References | Methods | Inference |
|---|---|---|
| [21]. D. Maria Manuel Vianny, et al. | IoT based irrigation system using kNN algorithm for collecting parameters using sensors, Gradient Boosting based Tree (GBT) for real value prediction, time series prediction using LSTM, and correlation value obtained through Spearman's rank | The proposed work in this reduced the water consumption by 31.4% compared to conventional method for banana tree in 2020 planted separately and in group manner. |
| [22]. Anneketh Vij, et al. | Prediction of irrigation requirements, soil and crop type are done using Support Vector Machine (SVM) and Support Vector Regression (SVR) incorporating IoT system. | In the automation of farm irrigation system, Random Forest (RF) shown better accuracy of 81.6% compared to other method that proved to be a mobile and dynamic approach. |
| [23]. R. Kondaveti, , et al. | Auto irrigation system using Rainfall algorithm and Romyan's mthoed for requirement of water is proposed. | Analysis of proposed method is evaluated using the amount of water required for single crop on entire basis and at each stages calculate along with the detection of motor ON/ OFF period that shown accurate results. |
| [24] Kanade, et al. | Bolt IoT module consisting of temperature, humidity, pH, Arduino based pressure sensors are incorporated. | Conservation of water is done using the auto irrigation system that rely on weather condition measured by temperature sensor, soil quality by pH sensor, soil moisture by Arduino based sensor using IoT system. |
| [25] Goap, et al. | Soil moisture prediction algorithm using SVR and k-mean clustering and threshold based irrigation planning algorithm is proposed. | The accuracy and error rate of the proposed method for various parameters like UV , temperature, moisture, pressure and quality sensors are collected and communication takes place in the IoT network. |
| [26]. K. S. Pratyush Reddy, et al. | Decision Tree algorithm based IoT system for smart agriculture. | Decision tree algorithm is used for sensed data from the fiels like temperature, moisture and humidity and pass on to the cloud from where the farmers using decision making algorithm decides the operation of water pump. |
| [27]. R. N. Kirtana, et al. | Decision making ML algorithm using ZigBee technology for data communication for smart irrigation system | Solar powered sensor module is framed for data collection of various soil parameters and ZigBee technology is used for communication with the servers. |
| [28]. Glória, André, et al. | Decision Tress, Random Forest, Neural Networks, and SVM are compared for IoT system based smart farming using real-time data | Here the history data sets are trained using the ML algoirhtm for real-time data where the Random forest method shown accuracy of 86.4% and achieved water saving upto 60% |
| [29]. Kansara, et al. | Reviews on automated irrigation system using different sensor in the IoT environment | Need, methods, advantages and disadvantages of ML in IoT using different sensors are discussed. |
| [30]. S. M. Shahriar, et al. | Naives Bayes algorithm based ML and Raspberry Pi used for communication in real-time intelligent irrigation system | Raspberry Pi based sensor collects the soil temperature and moisture content and Serial Peripheral Interface used. The proposed mthod shown 98.33% accuracy for working model prototype. |
| [31] Bhoi, Ashutosh et al | IoT enabled Regression Tree based storing and Agglomerative clustering algorithm for prediction is used. | Parameter forecasting is done using a Regression Tree along with AC to predict the next action required by the farmers based on collected data. The SVM is used for classification, and feedback is used to maintain the closed loop of the system. |
| [32]Y. -C. Chang, T., et al | LoRa P2P Network based smart irrigation system | Green house organic crops cultivation by learning the farmers experience through the ML algorithm and communication takes place through the LoRa P2P(Low Range Peer to Peer) for seamless connectivity. |
| [33]. Kwok, et al | ML based Image recognition of plant and irrigation is done based on that. | Docker software used to integrate the coworkers and with the help of mobile integration image captures is detected using deep learning algorithm using Tensor flow and the activities of irrigation controlled using Arduino |
| [34]. Gujar, et al | Optimum water utilization for farming using ML and WSN network | ML algorithms like kNN, SVM and RL are used for collecting sensed data, decision making and predicting the situation and amount if water required by the farm and transmitted the information using the WSN network to the farmers. |

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| [35] Amassmir, et al | IoT based ML algorithms for minimum water loss in auto irrigation system. | Knn, SVM and ANN are used for collection of data, decision and sending to the farmer using the Arduino using Raspberry Pi3. |
| [36] S. Badotra *et al* | Cost effective method using IoT and Node MCU for communication purpose in smart irrigation system. | Cipering is used in the communication through NodeMCU system based on IoT and reduced the total cost of the system. |

## IV. Monitoring System based on Machine Learning

Irrigation monitoring plays a major role in the monitoring the activities and water management processes. The monitoring mainly involves various sensing activities under the ground. The sensors collect the data based on the temperature of the soil, moisture content in the soil, humidity, weather conditions, soil quality, pores of the soil, etc. Growing technologies involves many sensor that helps in the monitoring system of the smart irrigation system. The IoT systems and WSN are the network system helps to transmit the data collected from the sensors to central hub from where the farmers get the data based on mobile applications. In order to enhance the monitoring process, various ML and DL algorithms are used along with the IoT and WSN networks. In the paper [37] , Google Bolt IoT and bolt WiFi , telegram and mail bot, Introgmat are used for monitoring the fields and controlled using the rovers. The need for irrigation is classified using the Artificial Algae Algorithm (AAA) and least squares-SVM is used in IoT based SIS in Agriculture 4.0 is proposed in the paper [38]. The overfitting issue of ML techniques like k-mean and SVM are overcome by using the kNN algorithm for smart irrigation is proposed in the paper [39] and concluded that accurate results are obtained. Smart Irrigation monitoring system based on machine learning, solar modules and sensor using IoT system is presented in the paper [40] where the authors significantly reduces the human error, managed the spill errors and damage control is done through effective monitoring basis. The machine learning algorithms like kNN and Naives Bayes algorithm are used to obtain the soil dryness and required water with the help of ANN for water pump automatic ON/OFF actions in the IoT systems is explained in the paper [41]. The paper [42] uses different ML algorithms in this smart irrigation framework, such as GBT, multiple LR, RF, decision tree and Elastic net regression methods. Water scarcity is addressed in the paper [43] where the ML techniques are employed to collect the data on water flow and communicate to the farmers using the IoT framework by Arduino UNO prototype model. Authors in the paper [44] surveyed various topics of smart irrigation based on ML techniques, mobile applications, web frameworks, and management processes that helps the farmers and researchers at a wide scale for future development. The importance of Crop Evapotranspiration is explained in the paper [45] where authors used deep learning networks using three-phase datasets are trained and thus help the water managers to save the water quantity at greater level is done for the wheat plant irrigation.

## V. ML and AL Methods in Irrigation Requirement Analysis

Irrigation requirement analysis is the most important part of smart irrigation system that needs various parameters for making the decisions. The machine learning and deep learning techniques are involved in the irrigation requirement analysis to obtain the accurate output to make the water pump function accordingly and to estimate the future water requirement of the crops. Various ML and DL techniques are surveyed in the TABLE IV for irrigation analysis in various platforms. The sensed data from the field is collected and sent to the cloud server. The cloud server is the place where the irrigation analysis takes place and the action to be taken is sent to the farmers in the IoT system. In WSN, centralized server will carry out this task. The different sensors in the soil collects the data and the decision-making process is fixed by the ML and DL algorithms that specifies the amount of water required. This helps a lot in the water scarcity and water shortage problems present in many places. The irrigation requirement depends on the soil temperature, water flow parameter, moisture in the soil, humidity in the atmosphere and soil quality based on the presence of various nutrients.

TABLE IV. Irrigation Requirement Analysis using ML and AL

| **References** | **Methods** | **Inference** |
|---|---|---|
| [46]. Senthil Kumar Swami Durai, | Django Framework based Web application is proposed for smart farming | Ensemble learning model is used for prediction where GDD utilized for nutrient requirement prediction, image detection using DNN, pesticides control has taken in the cost-effective manner. |
| [47] Lisa Umutoni, et al. | Reviews on Machine learning methods in support irrigation strategy | Various ML algorithms like KNN, RF, SVM, SVR, LR, et are analyzed and the fair datasets used are provided based on different applications |
| [48] Yaganteeswarudu Akkem | Reviews on ML and DL involved in Smart farming | Smart farming enhancement using difference ML algorithms like crop selection by KNN based on kD tree method, Relief- F- Feature using SVM, Decision Tree method involving Readable Oblique and Deep |

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|---|---|---|
| | | learning models like ELM (Extreme Learning method) and Radia basis function are reviewed. |
| [49] Khadijeh Alibabaei,et al. | Incorporated two LSTM, ANN, Convolutional Neural Network (CNN) in Irrigation scheduling and management processes. | Addressing the water shortages issue, the deeply reinforcement learning models used with the two LSTMS for time series data analysis, ANN for prediction and CNN for classification data to reduce the manual operation in the field that helps in the large-scale cultivations. |
| [50]. A. John, et al | Past, Present, Future aspects of Spatio- temporal data | Investigation using past values, locating the objects in the present and using the above data future is predicted using the spatio temporal data is presented that reduced the complexity of time, disk access, cost effectiveness and indexing. |

## VI. Evaluation Parameters Analysis

Growing smart irrigation systems requires an evaluation methodology that helps to prove the proposed model in different aspects like amount of water saved, accuracy, error, prediction accuracy, etc. The empirical formulation helps to do the analysis that a model has to satisfy so that it can be used to vary in future generations. The evaluation parameters as to satisfy the following questions like, " Is the sensed data are accurate?", "do practical targets are met out using theoretical concepts", "Does the resources are efficiently utilized?", and "Are objectives are reached?", is explained in the paper [51] where authors also provided perceptions on irrigation tools and techniques like direct measurements of the indicators (Quantitative and Qualitative indicators), Fuzzy set theory based indicators using fuzzy concepts, hierarchy process analysis and geographic information systems and remote sensing methodology. In the paper [52], irrigation system in Castilla- La Mancha in Spain is estimated. The descriptive and informatics indicators using six Water Users Association for three different seasons analysis is carried out for drip and sprinkler irrigation systems and the authors concluded that, Drip based irrigation system used more water compared to the sprinkler irrigation system with the help of data from the water management systems. The smart irrigation system mainly depends on the sensor that collects the actual data and the farmer who is going to take necessary action based on the data provided or the automated system responsible for the action needs to be carried on. So the system needs the human machine interaction in order to make the action take place. In the paper [53], authors used continual learning algorithm to enhance the human action prediction. The smart irrigation system on the other hand need to gain the knowledge of the farmer to produce efficient and quality yielding in the crop cultivation. This requires human machine interaction study to gain the knowledge of the farmers. The spatio- temporal data plays a vital role in the real-time data collection in sensor networks. It collects the required data in space and time domain. The collected data requires indexing and query addressing system which is proposed in the paper [54]. The smart irrigation system requires the spatio-temporal data for collecting irrigation parameters on real time basis and to address the queries and indexing in the farmer side is most required activity. As discussed above, the crop evapotranspiration parameter is very important in the auto irrigation system to compare various irrigation techniques. Many IoT system collects the data from the soil helps to calculate this parameter. The Soil moisture content and the crop evapotranspiration strategy in IoT based soil monitoring system is presented in the paper [55] where the authors shown 12.05% increment in the crop yield of sweet corn and 11% improvement in the crop evapotranspiration parameter compared to the conventional method.

## VII. Conclusion

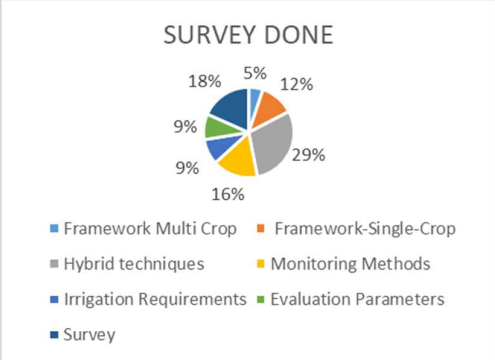


Fig.1. Topics Covered in Survey

This paper surveyed various topics on smart irrigation systems to encourage research to enhance agriculture activities. The various types of irrigation types and their applications are reviewed. The need for smart irrigation and the support system that is required for a successful framework are explained from the author's perspectives. Fig.1. shows the percentage of topics covered in the survey in the smart irrigation system. It is found that machine learning techniques are finding more place in the smart irrigation system as it increases the accuracy of the model. The IoT system and WSN network help the smart farming and irrigation operation without the labor presence in the field. This reduces the labor work and make them to develop agriculture in different aspects. Hybrid techniques yielding more profit in terms of reducing water usage in the field and also optimize the water usage based on the crop dependency in the mutli-cropping methods. The monitoring and irrigation requirement analysis survey are done, where the intervention of machine learning takes place for decision-making processes. The main objective of smart irrigation is to address the water scarcity issue and to enhance agriculture with minimal water usage, the new technologies efficiently face those objectives. At the end, evaluation parameters are given more importance that various parameters used for irrigation analysis are surveyed and presented.

## REFERENCES


[1] A. Joshi and L. Ali, "A detailed survey on auto irrigation system," 2017 Conference on Emerging Devices and Smart Systems (ICEDSS), Mallasamudram, India, 2017, pp. 90-95, doi: 10.1109/ICEDSS.2017.8073665.

[2] Y. Gamal, A. Soltan, L. A. Said, A. H. Madian and A. G. Radwan, "Smart Irrigation Systems: Overview," in IEEE Access, doi: 10.1109/ACCESS.2023.3251655.

[3] Munoth, Priyamitra, Rohit Goyal, and Kuldeep Tiwari. "Sensor-based irrigation system: A review.", International Journal of Engineering Research and Technology, NCACE 2016 Conference Poceedings. USA, vol. 4, Issue 23, 2016.

[4] Kaur, Baltej, Danish Inamdar, Vishal Raut, Akash Patil, and Nayan Patil. "A survey on smart drip irrigation system." Int. Res. J. Eng. Technol.(IRJET), vol. 3, no. 02, 2016.

[5] Luis E. Lesser, Abrahan Mora, Cristina Moreau, Jürgen Mahlknecht, Arturo Hernández-Antonio, Aldo I. Ramírez, Héctor Barrios-Piña, "Survey of 218 organic contaminants in groundwater derived from the world's largest untreated wastewater irrigation system: Mezquital Valley, Mexico," Chemosphere, vol 198, pp. 510-521, ISSN 0045-6535, 2018. https://doi.org/10.1016/j.chemosphere.2018.01.154.

[6] Nandanwar, Himanshu & Chauhan, Anamika & Pahl, Dushyant & Meena, Harshit, " A Survey of Application of ML and Data Mining Techniques for Smart Irrigation System", pp. 205-212, 2020. 10.1109/ICIRCA48905.2020.9183088.

[7] J. Angelin Blessy and A. kumar, "Smart Irrigation System Techniques using Artificial Intelligence and IoT," 2021 Third International Conference on Intelligent Communication Technologies and Virtual Mobile Networks (ICICV), Tirunelveli, India, 2021, pp. 1355-1359, doi: 10.1109/ICICV50876.2021.9388444.

[8] Blessy, A.; Kumar, A.; Prabagaran A; Quadir Md, A.; Alharbi, A.I.; Almusharraf, A.; Khan, S.B., " Sustainable Irrigation Requirement Prediction Using Internet of Things and Transfer Learning", Sustainability , vol. 15,pp. 8260, 2023. https://doi.org/10.3390/su15108260

[9] Langa, Relebogile, Michael Nthabiseng Moeti, and Thabiso Maubane. "An AIoT-Based Automated Farming Irrigation System for Farmers in Limpopo Province." Journal of Innovation Information Technology and Application (JINITA), vol. 6.1, pp. 12-27, 2024.

[10] Thenmozhi, M., Priyanga Subbiah, and Rango Theobard. "Optimizing Agricultural Irrigation through Real-Time Data Prediction." 2024 2nd International Conference on Networking and Communications (ICNWC). IEEE, pp. 1-5, 2024. doi: 10.1109/ICNWC60771.2024.10537511.

[11] Allali, Mahamed & Addala, Kawther & Berroudja, Nassima & Mounir, Tahar Abbes & Mekkakia Maaza, Zoulikha & Kadri, Walid & Abdelhak, Benhamada., "New Monitoring Framework Intelligent Irrigation System." International Conference on Smart and Sustainable Agriculture. Cham: Springer International Publishing, vol. 1470, 2021. https://doi.org/10.1007/978-3-030-88259-4_12

[12] Habib, S.; Alyahya, S.; Islam, M.; Alnajim, A.M.; Alabdulatif, A.; Alabdulatif, A, "Design and Implementation: An IoT-Framework-Based Automated Wastewater Irrigation System", Electronics, vol. 12,pp. 28, 2023. https://doi.org/10.3390/electronics12010028

[13] González-Briones, Alfonso, Castellanos-Garzón, José A., Mezquita Martín, Yeray, Prieto, Javier, Corchado, Juan M., A, "Framework for Knowledge Discovery from Wireless Sensor Networks in Rural Environments: A Crop Irrigation Systems Case Study", Wireless Communications and Mobile Computing, 6089280, 14 pages, 2018. https://doi.org/10.1155/2018/6089280

[14] Di Wu, Yuanlai Cui, Dacheng Li, Manyu Chen, Xugang Ye, Guofu Fan, Lanqiang Gong, "Calculation framework for agricultural irrigation water consumption in multi-source irrigation systems", Agricultural Water Management, vol 244, 106603, ISSN 0378-3774, 2021. https://doi.org/10.1016/j.agwat.2020.106603.

[15] Li, A., Mu, X., Zhao, X., Xu, J., Khayatnezhad, M. & Lalehzari, R. " Developing the non-dimensional framework for water distribution formulation to evaluate sprinkler irrigation", Irrigation and Drainage, vol. 70(4), pp. 659–667, 2021. https://doi.org/10.1002/ird.2568

[16] Esteves, Rita, Maria João Calejo, João Rolim, José Luís Teixeira, and Maria Rosário Cameira, "Framework for Assessing Collective Irrigation Systems Resilience to Climate Change—The Maiorga Case Study" Agronomy , vol. 13, no. 3: 661, 2023. https://doi.org/10.3390/agronomy13030661
[17] Borsato Eros , Rosa Lorenzo , Marinello Francesco , Tarolli Paolo , D'Odorico Paolo "Weak and strong sustainability of irrigation: A framework for irrigation practices under limited water availability." Frontiers in Sustainable Food Systems, vol. 4, 2020. https://www.frontiersin.org/journals/sustainable-food-systems/articles/10.3389/fsufs.2020.00017
[18] Anbarasi, M., Karthikeyan. T, Ramanathan. L, Ramani. S, Nalini. N. "Smart multi-crop irrigation system using IoT." Int. J. Innov. Technol. Explor. Eng , vol. 8, pp. 153-156, 2019.
[19] W. Haider, A. u. Rehman, M. A. Abbasi, S. Khan and N. M. Durrani, "Towards Hybrid Smart Irrigation for Mixed-Cropping," 2022 Global Conference on Wireless and Optical Technologies (GCWOT), Malaga, Spain, 2022, pp. 1-6, doi: 10.1109/GCWOT53057.2022.9772921.
[20] Rudinskienė, Aušra, Aušra Marcinkevičienė, Rimantas Velička, and Vaida Steponavičienė., "The Effects of Incorporating Caraway into a Multi-Cropping Farming System on the Crops and the Overall Agroecosystem" Agronomy, vol. 14, no. 3: 625, 2024. https://doi.org/10.3390/agronomy14030625
[21] D. Maria Manuel Vianny, A. John, Senthil Kumar Mohan, Aliza Sarlan, Adimoolam, Ali Ahmadian, "Water optimization technique for precision irrigation system using IoT and machine learning", Sustainable Energy Technologies and Assessments, vol 52, Part D, 102307, ISSN 2213-1388, 2022. https://doi.org/10.1016/j.seta.2022.102307.
[22] Anneketh Vij, Singh Vijendra, Abhishek Jain, Shivam Bajaj, Aashima Bassi, Aarushi Sharma, "IoT and Machine Learning Approaches for Automation of Farm Irrigation System", Procedia Computer Science, vol 167, pp. 1250-1257, 2020. https://doi.org/10.1016/j.procs.2020.03.440.
[23] R. Kondaveti, A. Reddy and S. Palabtla, "Smart Irrigation System Using Machine Learning and IOT," 2019 International Conference on Vision Towards Emerging Trends in Communication and Networking (ViTECoN), Vellore, India, 2019, pp. 1-11, doi: 10.1109/ViTECoN.2019.8899433.
[24] Kanade, Prakash, and Jai Prakash Prasad. "Arduino based machine learning and IOT Smart Irrigation System." International Journal of Soft Computing and Engineering (IJSCE) , vol. 10.4, pp. : 1-5, 2021.
[25] Amarendra Goap, Deepak Sharma, A.K. Shukla, C. Rama Krishna, "An IoT based smart irrigation management system using Machine learning and open source technologies ", Computers and Electronics in Agriculture, vol 155, pp. 41-49, 2018. https://doi.org/10.1016/j.compag.2018.09.040.
[26] K. S. Pratyush Reddy, Y. M. Roopa, K. Rajeev L.N. and N. S. Nandan, "IoT based Smart Agriculture using Machine Learning," 2020 Second International Conference on Inventive Research in Computing Applications (ICIRCA), Coimbatore, India, 2020, pp. 130-134, doi: 10.1109/ICIRCA48905.2020.9183373.
[27] R. N. Kirtana, B. Bharathi, S. K. Priya, S. Kavitha, B. Keerthana and K. Kripa, "Smart Irrigation System using Zigbee Technology and Machine Learning Techniques," 2018 International Conference on Intelligent Computing and Communication for Smart World (I2C2SW), Erode, India, 2018, pp. 78-82, doi: 10.1109/I2C2SW45816.2018.8997121.
[28] Glória, André, João Cardoso, and Pedro Sebastião, "Sustainable Irrigation System for Farming Supported by Machine Learning and Real-Time Sensor Data " Sensors 21, no. 9: 3079, 2021. https://doi.org/10.3390/s21093079
[29] Kansara, Karan, Vishal Zaveri, Shreyan Shah, Sandip Delwakar, Kaushal Jani, "Sensor based automated irrigation system with IOT: A technical review." International Journal of Computer Science and Information Technologies, vol. 6.6 , pp.: 5331-5333, .
[30] H. I. Peyal, M. Nahiduzzaman and M. A. H. Pramanik, "An IoT-Based Real-Time Intelligent Irrigation System using Machine Learning," 2021 13th International Conference on Information & Communication Technology and System (ICTS), Surabaya, Indonesia, 2021, pp. 277-281, doi: 10.1109/ICTS52701.2021.9608813.
[31] Bhoi, Ashutosh & Nayak, Rajendra & Bhoi, Sourav & Sethi, Srinivas & Panda, Sanjaya & Sahoo, Kshira & Nayyar, Anand, " IoT-IIRS: Internet of Things based intelligent-irrigation recommendation system using machine learning approach for efficient water usage", PeerJ Computer Science. 7, 2021. e578. 10.7717/peerj-cs.578.
[32] Y. -C. Chang, T. -W. Huang and N. -F. Huang, "A Machine Learning Based Smart Irrigation System with LoRa P2P Networks," 2019 20th Asia-Pacific Network Operations and Management Symposium (APNOMS), Matsue, Japan, 2019, pp. 1-4, doi: 10.23919/APNOMS.2019.8893034.
[33] Kwok, Jessica, and Yu Sun. "A smart IoT-based irrigation system with automated plant recognition using deep learning." Proceedings of the 10th international conference on computer modeling and simulation. , pp. 87-91, 2018. https://doi.org/10.1145/3177457.3177506
[34] Kumud A., and Santosh Jagtap. "Intelligent Irrigation System for Agriculture using IoT and Machine Learning." 2022 2nd International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE). IEEE, 2022. pp. 86-90, doi: 10.1109/ICACITE53722.2022.9823522.
[35] Amassmir, Samar, Said Tkatek, Otman Abdoun, Jaafar Abouchabaka "An intelligent irrigation system based on internet of things (IoT) to minimize water loss." Indonesian Journal of Electrical Engineering and Computer Science, vol. 25.1, pp. 504-510, 2022. http://doi.org/10.11591/ijeecs.v25.i1.pp504-510
[36] S. Badotra et al ., "Smart Irrigation System using Internet of Things (IoT) and Machine Learning," 2021 9th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions) (ICRITO), Noida, India, 2021, pp. 1-4, doi: 10.1109/ICRITO51393.2021.9596139.

[37] R. K. Megalingam, G. Kishore Indukuri, D. S. Krishna Reddy, E. Dilip Vignesh and V. K. Yarasuri, "Irrigation Monitoring and Prediction System Using Machine Learning," 2020 International Conference for Emerging Technology (INCET), Belgaum, India, 2020, pp. 1-5, doi: 10.1109/INCET49848.2020.9153993.
[38] Mohammad Abuzanouneh, Khalil & Al-Wesabi, Fahd & Albraikan, Amani & Al Duhayyim, Mesfer & Al-Shabi, Mohammed & Hilal, Anwer & Hamza, Manar & Zamani, Abu & Muthulakshmi, K.., "Design of Machine Learning Based Smart Irrigation System for Precision Agriculture",Computers, Materials & Continua vol. 72, Pp. 109-124, 2022. 10.32604/cmc.2022.022648.
[39] S. Akshay and T. K. Ramesh, "Efficient Machine Learning Algorithm for Smart Irrigation," 2020 International Conference on Communication and Signal Processing (ICCSP), Chennai, India, 2020, pp. 867-870, doi: 10.1109/ICCSP48568.2020.9182215..
[40] Bose, Moinak, and Sourodip Ghosh. "A Study on Smart Irrigation System using IoT & Machine Learning." Published by International Research Journal of Engineering and Technology (IRJET), vol. 7, issue 3, 2020.
[41] Stephen, Ancy, A. Punitha, and A. Chandrasekar. "Irrigation system based on iot and machine learning approach." International Virtual Conference on Industry. Singapore: Springer Nature Singapore, pp. 57-65, 2021.
[42] [42] G. Singh, D. Sharma, A. Goap, S. Sehgal, A. K. Shukla and S. Kumar, "Machine Learning based soil moisture prediction for Internet of Things based Smart Irrigation System," 2019 5th International Conference on Signal Processing, Computing and Control (ISPCC), Solan, India, 2019, pp. 175-180, doi: 10.1109/ISPCC48220.2019.8988313.
[43] Anil Sai Kumar, B.V., Kumar, S.P., Jaswanth, K., Vishnu, K. and Kumar, A. (2023). Smart Irrigation System Using Machine Learning Techniques. In Machine Learning for VLSI Chip Design (eds A. Kumar, S.L. Tripathi and K. Srinivasa Rao). https://doi.org/10.1002/9781119910497.ch9
[44] Abioye, Emmanuel Abiodun, Oliver Hensel, Travis J. Esau, Olakunle Elijah, Mohamad Shukri Zainal Abidin, Ajibade Sylvester Ayobami, Omosun Yerima, and Abozar Nasirahmadi., "Precision Irrigation Management Using Machine Learning and Digital Farming Solutions" AgriEngineering , vol. 4, no. 1: pp. 70-103, 2022. https://doi.org/10.3390/agriengineering4010006
[45] Ahmed Elbeltagi, Jinsong Deng, Ke Wang, Anurag Malik, Saman Maroufpoor, "Modeling long-term dynamics of crop evapotranspiration using deep learning in a semi-arid environment, "Agricultural Water Management, vol 241, ISSN 0378-3774, 2020,https://doi.org/10.1016/j.agwat.2020.106334..
[46] Senthil Kumar Swami Durai, Mary Divya Shamili, "Smart farming using Machine Learning and Deep Learning techniques", Decision Analytics Journal, vol. 3, 100041, ISSN 2772-6622, 2022 https://doi.org/10.1016/j.dajour.2022.100041.
[47] Lisa Umutoni, Vidya Samadi, "Application of machine learning approaches in supporting irrigation decision making: A review", Agricultural Water Management, vol 294, 108710, ISSN 0378-3774, 2024, https://doi.org/10.1016/j.agwat.2024.108710.
[48] Yaganteeswarudu Akkem, Saroj Kumar Biswas, Aruna Varanasi, "Smart farming using artificial intelligence: A review", Engineering Applications of Artificial Intelligence, vol 120, 105899, ISSN 0952-1976, 2023. https://doi.org/10.1016/j.engappai.2023.105899.
[49] Khadijeh Alibabaei, Pedro D. Gaspar, Eduardo Assunção, Saeid Alirezazadeh, Tânia M. Lima, "Irrigation optimization with a deep reinforcement learning model: Case study on a site in Portugal", Agricultural Water Management, vol 263, 107480, 2022. https://doi.org/10.1016/j.agwat.2022.107480.
[50] A. John, M. Sugumaran and R. S. Rajesh, "Performance analysis of the past, present and future indexing methods for spatio-temporal data," 2017 2nd International Conference on Communication and Electronics Systems (ICCES), Coimbatore, India, 2017, pp. 645-649, doi: 10.1109/CESYS.2017.8321157.
[51] Elshaikh, Ahmed E., Xiyun Jiao, and Shi-hong Yang. "Performance evaluation of irrigation projects: Theories, methods, and techniques." Agricultural water management vol. 203, pp. 87-96, 2018. https://doi.org/10.1016/j.agwat.2018.02.034.
[52] Córcoles, J. I., et al. "Evaluation of irrigation systems by using benchmarking techniques." Journal of Irrigation and Drainage Engineering 138.3 pp. 225-234, 2012.
[53] F. S. Naqushbandi and A. John, "Sequence of Actions Recognition Using Continual Learning," 2022 Second International Conference on Artificial Intelligence and Smart Energy (ICAIS), Coimbatore, India, 2022, pp. 858-863, doi: 10.1109/ICAIS53314.2022.9742866.
[54] John, A., M. Sugumaran, and R. S. Rajesh. "Indexing and query processing techniques in spatio-temporal data." ICTACT Journal on Soft Computing 6.3 (2016): 1198-1217.
[55] Vinod Kumar S, C D Singh, K V Ramana Rao, Mukesh Kumar, Yogesh A Rajwade, Bhushana Babu, Karan Singh, "Evaluation of IoT based smart drip irrigation and ETc based system for sweet corn", Smart Agricultural Technology, vol 5, 100248, ISSN 2772-3755, 2023. https://doi.org/10.1016/j.atech.2023.100248.