Journal of Computing & Biomedical Informatics
ISSN: 2710 - 1606

Volume 06 Issue 01
2023

Research Article
https://doi.org/10.56979/601/2023

Resource Management in Agriculture through IoT and Machine Learning

Arooj Sultan[1], Hafsah Shaukat[1], Humayun Salahuddin[1*], Ismail Kashif[1], Saira Mudassar[1], and Asia Rehman[1]

[1]Department of Computer Sciences, NCBA&E (Sub-Campus), Multan, 60000, Pakistan.
*Corresponding Author: Humayun Salahuddin. Email: humayun.mul@ncbae.edu.pk

Received: August 10, 2023 **Accepted:** November 11, 2023 **Published:** December 05, 2023

Abstract: In light of agriculture's substantial contribution to global freshwater usage, the imperative for sustainable water resource management is paramount. This study introduces a cutting-edge smart irrigation system, employing IoT technology and machine learning algorithms, to optimize agricultural water productivity. A real-time IoT network, comprising soil moisture sensors and microcontroller gateways, captures field data, which is subsequently transmitted to a cloud-based platform. Data-driven predictive models leveraging Support Vector Machines (SVM), Artificial Neural Networks (ANN), and regression tree and LiNGAM algorithms are constructed to accurately anticipate daily crop water requirements. By seamlessly integrating sensor data with predictive modeling, the system precisely adjusts irrigation levels to align with specific crop demands, initiating automated scheduled irrigation events. This research article focusing on increase in water utalizaton efficiency compared to conventional timer-based irrigation methods by maintain pH value and dissolved oxygen in industrial water. The presented data-centric IoT approach represents a significant advancement in agricultural water management, holding substantial promise for sustainable and precise irrigation practices amid the backdrop of global water scarcity challenges.

Keywords: Smart agriculture; IoT; Machine learning; Irrigation management; Water productivity; LiNGAM.

1. Introduction

Sustainability and availability of resources for future generations are impossible without efficient resource management. It is, in essence, the distribution of resources towards maximizing organizational value. Good resource management means that the appropriate resources are available at an opportune time for a project or program.

Water pollution is a major issue in water resource management that affects ecosystems, human health and wealth creation. Water pollution is as a result of several factors which include industrial agricultural runoffs and natural disaster. The use of water in industries also leads to the pollution of water through high pH levels. Advanced technologies and innovative strategies have to be applied in order to bypass these challenges [1].

Water pollution is one of the important environmental problems that affect ecosystems, human health and economy in a far-reaching scale. According to the WHO, contaminated water is an altered version of what it used to be and no longer usable. It is poisonous water that cannot be drunk or used for basic needs such as agriculture and causes diseases, which kill over half a million people across the globe annually; diarrhea cholera, dysentery typhoid poliomyelitis [2].

Impurities in water come from industry, marine dumping, sewage and waste water, oil leaks or spills; agriculture also contributes to polluted waters [3-5]. Some of these sources include Industrial waste is one of the major causes that contribute to water pollution as chemicals and some pollutants are introduced into the water bodies through industrial processes. Sewage and wastewater, which occur to be full of harmful microorganisms and chemical substances are able to pollute bodies of water so that the quality goes down. Oil leaks and spills can also lead to water pollution, where the oil gets all over a large area of land spreading into bodies of water. Agricultural activities like the use of pesticides and fertilizers, can also lead to pollution in water with runoff carrying these pollutants into water bodies [6].

Water pollution may lead to serious outcomes, some of which include the degradation of aquatic ecosystems and water-borne diseases spreading as well as a decrease in ecosystem services. All these are part and parcel of water control as the proper infrastructure, management plans and technology solutions that can cover enhanced sanitation; agricultural wastewater treatment, erosion control, sediment control, and control of urban runoff (including storm water management). Water is required from seed germination to the proper growth of a crop. However, the supply of water does not always come easy on every crop field. In such circumstances, we turn to methods of irrigation. Irrigation helps in the provision of water to the soil for purposeful high crop production. It is done in order to replace rain water by another source of water. It is applied in arid regions as well when there are droughts. Agricultural crops require irrigation systems that are effective. Here is the method of irrigation in agriculture:

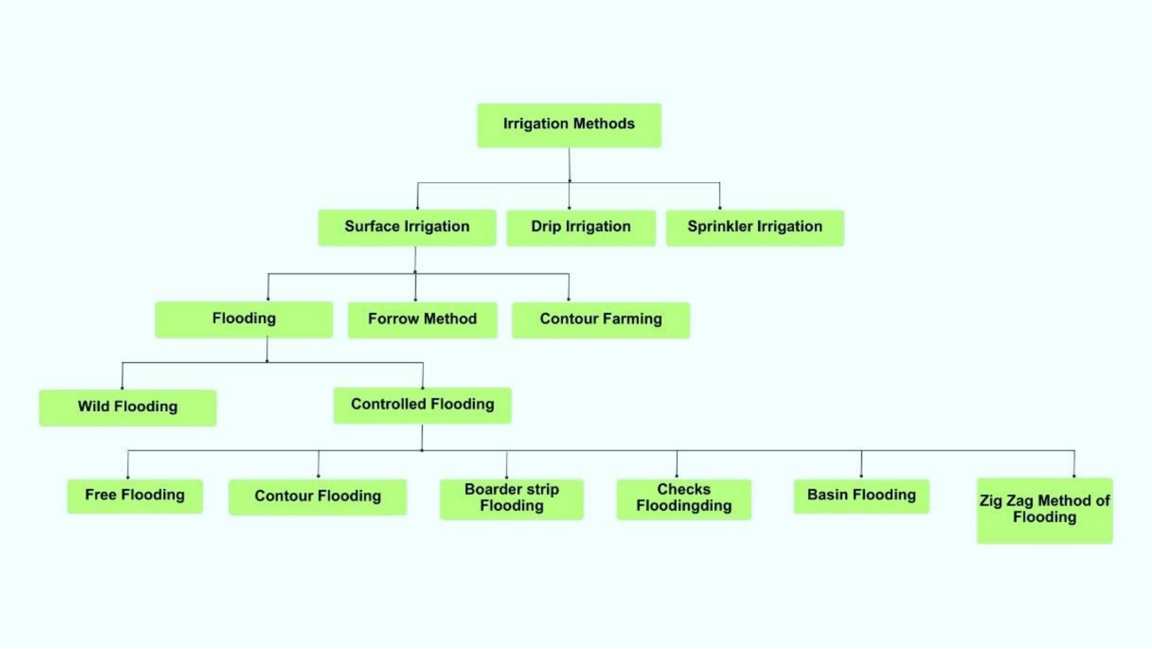


Figure 1. Different Irrigation Methods in Agriculture

Figure 1 shows that irrigation is another critical component of farming which involves the supplementary watering crops via regulated application. Irrigation systems provide efficient watering of fields. At the center of surface irrigation systems such as furrow and flood water movement either over or through soil. One of the methods to conserve water is through drip irrigation whereby, water goes directly into plants root zone. In a sprinkler irrigation, water is sprayed from above trying to imitate rain. Subsurface irrigation utilizes techniques such as buried drip tape to minimize evaporation from the surface and reach into the root zone. Various irrigation techniques are selected that ensure the efficient use of water and high agricultural yield based on criteria such as crop type, soil characteristics, and available water.

The contribution of machine learning (ML) and IoT devices to the elimination of water pollution is gaining increasing significance. ML and IoT technologies provide state-of-the art opportunities for real time monitoring, predictive analytics and optimization strategies, allowing water resources to be managed more efficiently and sustainably [7-10]. These technologies can quickly detect illegal water usage, pollution incidents and other violations; large datasets are analyzed through ML algorithms to generate valuable insights on prediction of water quality after polluting it [9]. ML can also help to come up with solutions in the management of water pollution control, enhancement of water quality and security measures for water shed ecosystems. On the other hand, IoT devices offer affordable and helpful solutions for water distribution control as well as real time monitoring of water sources making them essential tools in combating against pollution related to use of dirty waters and effective management of these resources [10, 11]. An increased deployment of IoT devices and ML integration in water resource management is predicted to be more crucial as it may help tackle the problem of water pollution while enhancing some aspects of irrigation. Machine learning and the Internet of Things devices have recently emerged as potential tools for water resource management and less water pollution [11, 12]. For better manage water resources sustainably, these technologies include optimization tactics, predictive analytics, and real-time monitoring.

The purity of industrial water is crucial to the efficient and effective functioning of many processes that rely on it. An obstacle in the use of contaminated industrial effluent as water source is how to prevent very high pH levels. Some solutions to the problem of very high pH levels in industrial water are as follows:

- **Exchange of Ions:** This method is de-ionization and removes ions or molecules from water by replacing them with those that have the opposite charge. This method can be used to reduce the pH of water by exchanging ions with different pH [13].
- **Acidic injection:** This is one of the ways in which the pH level of water could be changed. This can be done through physical means like adding acids to water that react with the ones in water that are of a high pH level. Furthermore, avoid introducing more acid since it could lead to corrosion or contamination which are some of the undesirable effects.
- **Neutralization:** It is a chemical reaction that produces the combination of an acid and base to salt and water. In the presence of bases, water reacts with acids contained in it to produce salts. This industrial water neutralization lowers values of pH that are too high.
- **Industrial processes:** They are most effective at controlled pH, which can be maintained with the addition of chemical buffer. Whenever this happens, one can lower the pH of the water to an optimum level by using chemicals. Limestone which is used as one of the pH neutralizers for rejected water in steel and iron sector can be cited [14-16].
- **Water treatment systems:** These systems can filter out harmful ions and molecules from the water, bringing its quality up to acceptable levels after pH treatment.

The purpose of this article is to implement the application of machine learning and IoT devices in combating water pollution. It addresses the reasons behind water pollution, problems of industrial utilization and consumption of it as well as possible ways machine learning technologies and Internet of Things devices can help them to solve these issues in order to understand a global research base properly. The article also intends to identify areas for future research in addressing water pollution and improving the management of water resources.

Figure 2. Embedded system, Lab Oxygen Probe & Lab Grade pH Probe IoT devices for measuring water quality.

Figure 2 demonstrate that Lab-grade oxygen and pH probes data are integrated by embedded systems that serve as the core intelligence. Plant roots and soil bacteria are benefited by means of laboratory-grade oxygen probes that measure the concentration of dissolved oxygen in irrigation water.

But lab-quality pH probes are helpful to keep the pH where nutrients needed for germination is readily available. These elements increase the efficiency of agricultural output, crop wellbeing and water management.

In agriculture, the conventional methods of designing irrigation tend to be inefficient and unproductive as lots of water are wasted leading a decrease in crop yields while at those increasing costs. 90% of the world's water is lost to these inefficiencies. In order to overcome these challenges, there is currently increasing interest in the deployment of smart irrigation systems and use of waste water that make use of IoT technology and machine learning algorithms that aim at optimizing agricultural water productivity.

Such systems can store field data in real time, predict the daily water demands of crops with great accuracy and allow automated changes to irrigation levels according to plant's needs that begin planned & scheduled irritations. In addition, further researches are needed to find the possible advantages of these systems and how they can be applied in an efficient management that is sustainable water resource system for agriculture. Integration of IoT-based smart irrigation systems coupled with machine learning algorithms can change agricultural water resource management, bringing better yields and more sustainable farming as a whole. These systems help save water, reduce costs and efficiently boost overall productivity because these ensure that the required amount of irrigation levels is established for each crop individually. In addition, the application of machine learning techniques would improve prediction models to better utilize water resources and higher crop yields.

The research gap is to add the existing knowledge in smart irrigation systems, IoT technologies and machine learning algorithms as concerns application on agriculture. Well formulated sentences using meticulous content editing across niches ensures a positive professional future for our editors that would do well rather than succumb spelling mistakes which destroy interpretations or even punctuations bringing out mixed ambiguous messages leading us This paper covers the environmental and economic outcomes of these systems, as well as how effective they are in terms of water production. The results of this study can benefit politicians, farmers and other agricultural stakeholders to learn how smart irrigation systems are assisting water resource management more sustainably.

1.1. Research objectives

The primary objective of this research paper is to:

- To realize the potential of smart irrigation systems achieved through IoT technology and machine learning algorithms allowing for increasing agricultural water productivity.
- To analyze the correctness of such systems in prediction daily water requirements needed by food crops and starting scheduled irrigation events at specific irrigational levels for particular plants.
- To measure the cost benefits and environmental impacts of such integration into agriculture where they could reduce water wastage, improve crop yields hence sustainable utilization of these resources.

This report conclude with some recommendations for further studies as well as possible consequences for farming methods based on the results. This section effectively demonstrates how these obstacles were overcome, creating a foundation for the research. The rest of the paper is as follows: Section 2 provides an exclusive overview of the previous study on deep learning, IoT usage, Irrigation system. Section 3 describes the proposed method for industrial water usage. Section 4 focuses on the experiments conducted to evaluate the proposed methodology. Section 5 finally, the research concludes with a summary of the main findings and contribution along with future work.

2. Literature Review

There are many different agronomic uses for wireless sensor networks. One is to remotely monitor soil and environmental variables to forecast how healthy crops will be. Using WSN as an observer of environmental variables such as pressure, humidity, temperature, soil moisture, soil salinity, and conductivity allows for the forecasting of agricultural fields' watering schedules. A great deal of research has been published, and the key findings from different studies are reviewed. A scalable network architecture was suggested for the purpose of monitoring and controlling agricultural fields in rural regions. They suggested an Internet of Things (IoT)-based control system for agricultural and farming advancement. Every element of the system and all upgrades are critically analyzed. The use of MAC and routing helped the IoT to succeed.

The performance is achieved through this combination of a fog computing solution with Wi-Fi based long distance (WiLD) network. This is a framework for the design of WSN based on Mills tables to implement DSS for Apple Scab detection in Himachal Pradesh. The Internet of Things was used in farming to increase yields, improve crop quality and reduce costs. There is a lot of focus into various elements in studying the technology that can increase water usage efficiency and raise crop yields; this includes smart irrigation systems as an off-shoot within agricultural research. For this purpose, various publications and systematic reviews have discussed smart irrigation systems featuring description of their characteristics. An in-depth manuscript review on smart irrigation systems, oriented not only towards urbanized but also rural areas equipped with such solutions built on the AI technique as well. The purpose of this study is to introduce how AI in smart irrigation systems has been studied. The comprehensive research on smart irrigation monitoring and control systems for further enhancement performance of precision agriculture in water use [16]. Sustainable field agricultural water-use effectiveness needs smart systems and specific irrigation management from the results of this study

With various technologies such as the internet of things (IoT), machine learning for decision support systems, data analytics, etc., a great deal of progress has already been made in the field of precision agriculture [17]. In this study, the use of IoT technology in smart irrigation systems was investigated and how is made it possible for control as well as monitoring in real-time. In addition, in the study of Singh et al. The updating irrigation systems with new technology to provide optimal water consumption and crop yields were highlighted.

The literature on smart irrigation systems in agriculture consists from systematic reviews, technical developments, precision water management tactics and a wide range of other issues. As a whole, these studies shine the light on both benefits and drawbacks of smart irrigation system adoption, results for existing processes, as well as directions towards next research in this field [18].

In the last decade there has risen a lot of interest in research into application IoT technologies used for agricultural water control. The power of the IoT technology is that it offers real-time data for various aspects related to agricultural production such as soil moisture, temperature and humidity. Such a technological revolution can transform water management in agriculture. All this information can be used to make informed decisions regarding the irrigation, fertilization and all other parts of agricultural production ensuring both efficient and sustainable use of water resources.

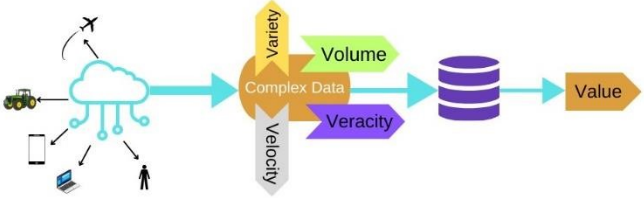


Figure 3. Internet of Things and Data Analytics Relationship

The figure 3 represents the internet of things (IoT) and data analytics relationships. To determine how IoT could assist farmers, Farooq et al. rendered a systematic review of the literature [19]. A literature review of the current state and implications of IoT technologies for the agricultural industry was conducted in this study. From the findings, it appears that IoT can increase agricultural production, minimize water loss as well as promote sustainable decision-making in managing effectively.

Recent systematic study describes smart and sustainable agriculture as a complex of the various modern technologies based on data analysis, different sensors, controllers and communication devices etc. According to the research, IoT technology provides opportunities for improved water efficiency and less wasting of water in agriculture. Several studies also consider the possibility of using smart irrigation systems based on Internet Things for implementing in agriculture. The design of an IoT smart irrigation platform for agriculture used high soil moisture and temperature data to provide better water management [20].

Using machine learning algorithms along with internet of things technology to improve agricultural water efficiency is currently the subject of various research. An intelligent irrigation structure with IoT and machine learning algorithms that define when to water crops and how much of it is required. Based on results, it can be concluded that machine learning algorithms have potential to enhance water use effectiveness and tis in turn will help reduces agricultural wastewater.

ML algorithms are powerful tools that can be used to increase crop production and maximize the yield from water-based systems. The findings show they that the machine learning algorithms are an efficient tool for managing and resolving issues pertaining to water quality problems as well scarcity challenges.

The study measured water utilization effectiveness, production along with them on the basis of hydro meteorological dynamics information collected from rain irrigation stations [21]. For the results, water use efficiency and crop yield increased significantly using this proposed method in apple orchards.

Garbage segregation is conventionally done through manual sorting. According to surveys, there are two main types of waste. Organic and recyclable materials make up this trash. Consequently, developed a model that reliably sort the two types of trash into their own containers by employing machine learning techniques such as convolution neural networks (CNN). So, a powerful classifier that uses the data set to determine the waste's shape, size, and color, and an Internet of Things (IoT) segregation device that uses an Arduino Atmega-328P to tell a servo arm to sort the trash into its appropriate container. The process of waste classification makes use of convolutional neural network (CNN) layers. These days, a lot of people are adopting approaches that use photos for classification. The machine learning method employs a dataset that is freely accessible to all users [22].

In order to identify the physical data and transmit it to the user, the authors have utilized the Internet of Things (IoT) in [23]. They also emphasized methods that can be used to solve various difficulties, such as identifying rats and various agricultural dangers. Python scripts are used to construct IoT devices, which have the capability to send notifications automatically, without any human intervention.

- Based on the presented research findings machine learning algorithms prove to be very important for fighting water scarcity and challenges associated with its quality as well as their management. There is evidence that there are three aspects of machine learning algorithms useful for water resource optimization through demand prediction, stock tracking and distribution management [24].
- In this study, the proposed method has been used to predict water-use efficiency and production in apple orchards with a hybrid machine learning approach that had significantly higher Apple Growth Efficiency and Crop Yield than traditional approaches Studies showed that the technology could be applied effectively to agriculture by using machine learning algorithms, which aimed at improving water productivity and crop yield.
- The grid search method to predict water quality index and classification through machine learning models [25]. As per the study, prediction of natural water quality and even improvement are possible goals in the sphere of resource management. Studies have shown that machine learning algorithms can monitor the water pollution level and locate areas affected by it, which will assist in developing appropriate policies for management on a national level.

In terms of detailing a thorough literature review on machine learning methods to improve the efficacy rate of agricultural supply chains. The analysis studied research and discussed how the machine learning algorithms can improve productivity of agricultural supply chain [26]. It was revealed that machine learning could be applied in different parts of the agricultural supply chain, which may help improve sustainability and resource use. These include but not limited to demand forecasting, transportation and inventory management [27- 29]. This literature has various important findings regarding the use of machine learning algorithms to promote water productivity and consequently boost crop yields. Machine learning algorithms have made substantial progress in addressing water quality, management and scarcity concerns that are facing the agriculture industry. By optimally predicting demand, monitoring a supply source, and limiting its use, these algorithms can help with water resources management.

People in the area should be kept informed about both the successes and failures of smart water technology. People should also be informed about the ways in which this technology has improved their lives. This will be useful for learning about the technology and raising public awareness [30]. Research into the potential economic and environmental impacts of incorporating such technology into agricultural settings is lacking, as is the development of novel algorithms and methods for data analysis and modeling. Additional multidisciplinary research is also needed in these areas.

3. Materials and Methods

Data collection is understood to be a systematic procedure of gathering, measuring and analysis accurate data. To study in this instance, the data collection process will encompass acquisition of a dataset that contains measurements of water quality data including parameters such as pH level temperature etc. It selects the Indian Data set for testing data. Data regarding water quality can be qualified and numerical in nature. Qualitative data enables a description of color, size quality and appearance but gives no such numeric measurements as quantifiable.

As the sources of water quality data can be primary and secondary methods of collecting information. Primary data collection is collecting new original information from the source directly, while secondary data consists of methods that are using ready-made collections of already collected datasets obtained from sources like government agencies or research organizations. These methods can also be used to collect data and then analyzed for the purpose of supporting or rejecting research. The six main indicators of water quality and its acceptable level are shown in table 1.

Table 1. Indicators to check water quality

Sr.	Indicator	Measurement Unit	Acceptable Levels
1	pH Level	pH units	6.5 - 8.5
2	Dissolved Oxygen (DO)	mg/L (milligrams per liter)	5 - 9 (for freshwater)
3	Turbidity	NTU (Nephelometric Turbidity Units)	< 5 NTU (for drinking water)
4	Total Suspended Solids (TSS)	mg/L	< 50 mg/L (for drinking water)
5	Biochemical Oxygen Demand (BOD)	mg/L	< 5 mg/L (for drinking water)
6	Nitrate (NO3-)	mg/L	< 10 mg/L (for drinking water)

The methods of data collection in the research process are very important as they define whether or not their collected data was obtained through high quality and precise ways. It is essential to ensure that the data gathered during collection phase is complete and collected from credible sources. In this study, the data collection methods will be carefully selected such that they impart relevance validity reliability of water quality. The data collection process will be planned very carefully to ensure that the observations or measurements of water quality variables are done accurately. It will involve the way in which data is collected and how to make precise observations or measurements of these variables. The methods will be chosen depending on the target of a given research type of data required and the resources available for conducting this study.

Data preprocessing is a mandatory process as part of data preparation for analysis. Figure 4 and 5 visually explore and analyze the distribution of various water quality parameters within a dataset. It has several important functions that make the data valid, complete and compatible with the LiNGAM model. Data preparation refers to the first stage of data cleaning which is preparing a dataset for analysis. This may also mean expressing the information in some standard form e.g., a convenient table or ensuring that it is properly tagged where necessary. The loss of values in the dataset leads to an undesirable result, which may negatively impact a LiNGAM model's functionality. Thus, it is important to notice that the missing data restricted by these techniques as imputation or dropping allow us a complete and accurate dataset. It means that the results of LiNGAM model can be influenced by outliers such as observations presenting extremely high or low values. Secondly, outlier detection and treatment techniques will be employed to identify the anomalies present in the data set.

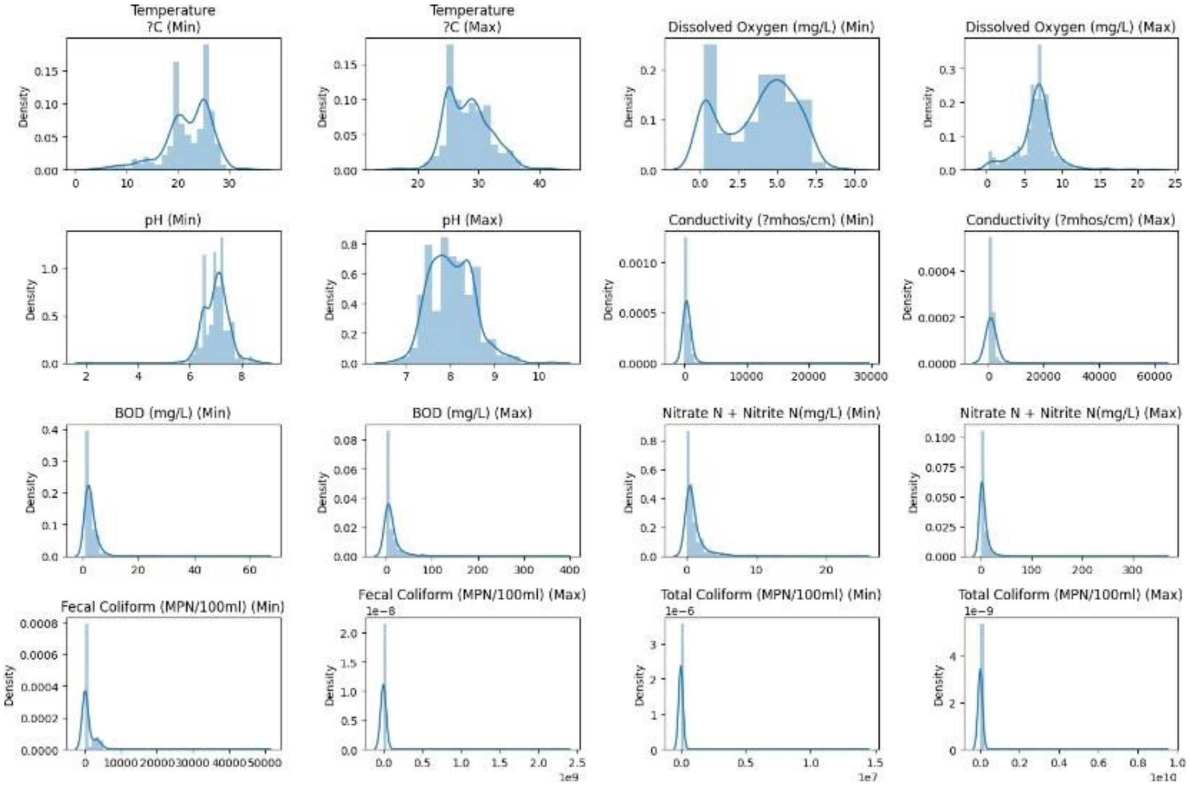


Figure 4. Visualization (Distplot by Features)

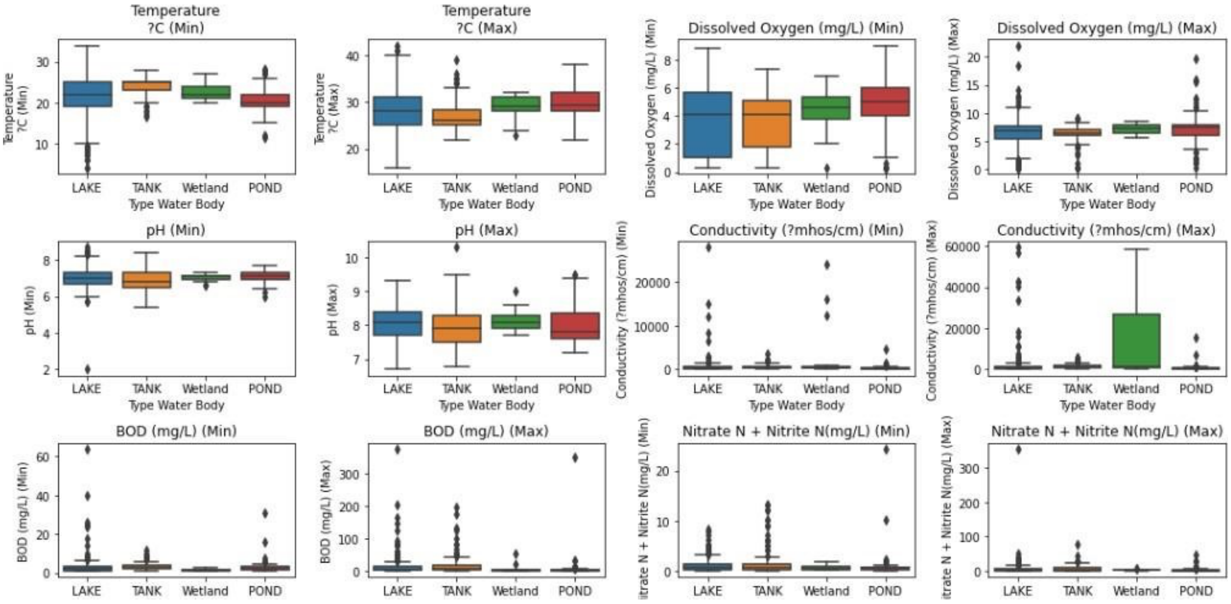


Figure 5. Visualization (Boxplot by Features)

Feature engineering is, that is, the process of generating new features or transforming old ones so as to enhance performance in a specific LINGAM model. This may include processes such as normalization, standardizing or the introduction of interaction terms between variables. It is the preprocessing stage of data preparation that makes it possible to apply this dataset using LiNGAM model. After filling in the missing values, treating outliers and feature engineering on this dataset then it will be fine-tuned according to how a causal relationship that is both accurate and reliable appears using LiNGAM as one of its strongest methods effective in such applications developed by experts across disciplines including economists and neuroscientist. This approach makes arrays between variables based on their characteristics through the non-Gauss principle.

Therefore, a causality estimation analysis with the LiNGAM method is used to determine water quality variables' causation. LiNGAM is a non-linear inverse modeling dataset that can help in causal analysis. This methodology is built on the assumption that causal relationships between variables can be represented in a linear non-Gaussian Acyclic model.

Causal values between variables in this dataset will be estimated, using the LiNGAM method along with water quality data. The method will reveal the interdependence between elements and determine those that affect water quality.

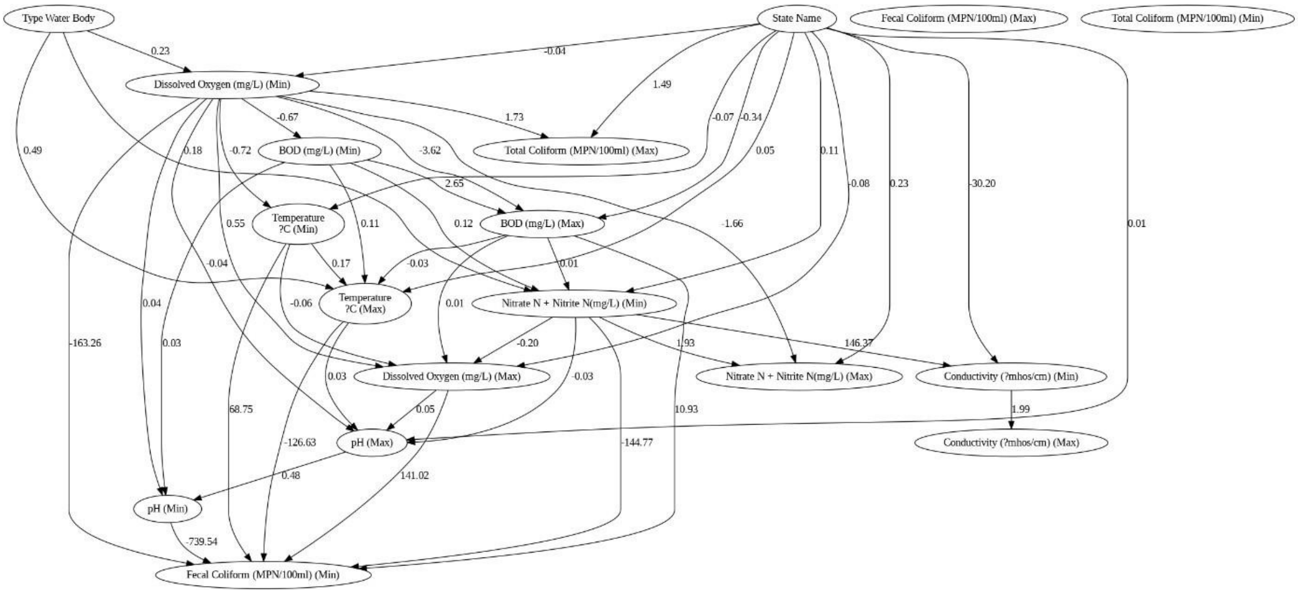
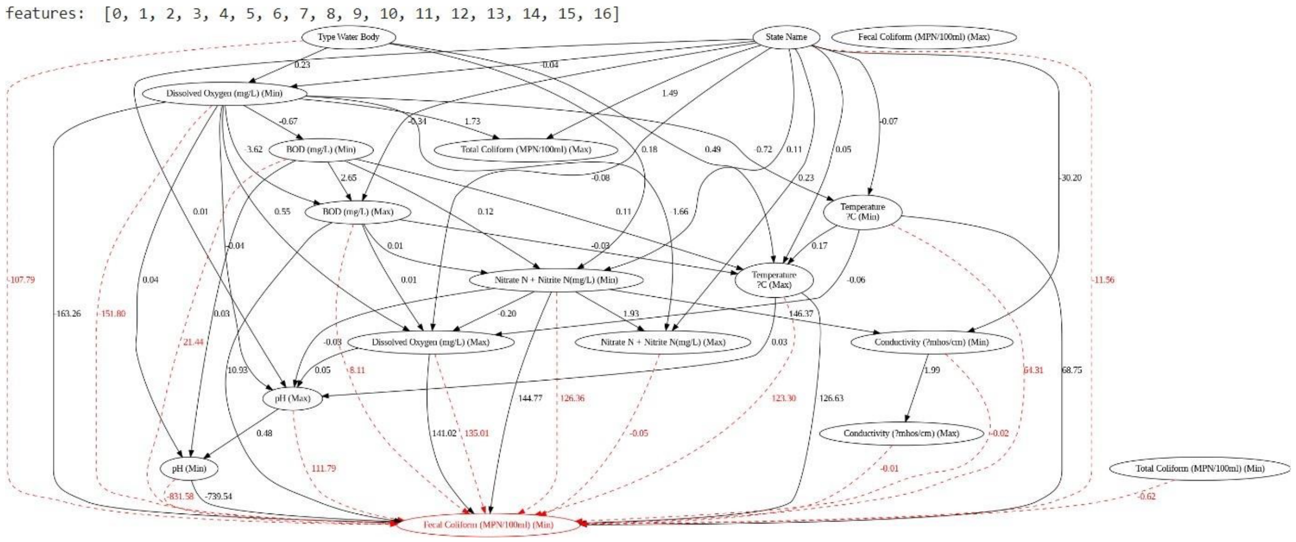


Figure 6. Casual Interface by LiNGAM

Figure 6 shows the casual interface by LiNGAM method. This method include data preparation, choosing of the model and parameter tuning. The accuracy of the model will be verified using AIC and BIC results. The LiNGAM methodology is a sensible technique for identifying causal mechanisms that affect the quality of water. For this analysis, the LiNGAM method is employed for analyzing water quality dataset to reveal different variables of that statement, which depend on each other and factors changing it.



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features:  [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16]
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Figure 7. LiNGAM with Linear Regression (Target Variable: "Fecal Coliform (MPN/100ml) (Min)")

Figure 7 demonstrate that the model of accuracy for causal relationships that are made by LiNGAM is conducted on comparing data predicted using this software to real-time water quality readings. Thus, this contrast will allow determining the accuracy of the model and whether it matches with reality. The method entails building a Directed Acyclic Graph that conveys the mutual relationships between features in an ML model. This visualization is helpful for comprehending the structure and relationships within the model, particularly in relation to its ability to forecast target variable relative concentration of fecal coliforms, as observed from water samples. .

4. Results and Discussion

The results of this study give a comprehensive understanding about how to govern through water resources and challenge what humans do in aquatic environment. The research revealed that traditional variables, represented by pH, TDS content and dissolved solids (TDS) conductivity as well as suspended sediment are encompassed in assessing the quality of water. Any issues with this water's use should be addressed in the designated places. This study also showed that machine learning and IoT devices may work to monitor a polluted water environment, providing an alternative way of handling the complexity problems associated with pollution while preserving clean waters for future generations. So, tried plot between conductivity and pH by type water body. As shown in equation 1;

x='Conductivity (Min)', y='pH (Min)', hue="Type Water Body" (1)

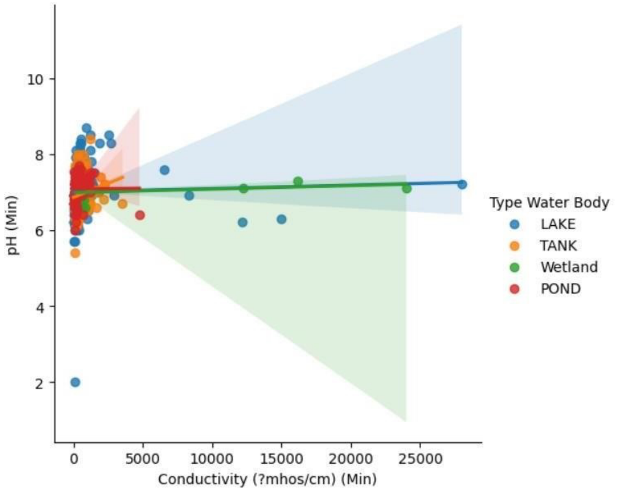

Figure 8. Conductivity and pH measurments

Water from industrial sources might not be ideal for farming due to its low pH and conductivity as shown in figure 8. Acidity, indicated by a low pH, can have a detrimental effect on crops because it changes the soil pH while watering, which makes it harder for plants to absorb nutrients and stunts their growth. Low conductivity also indicates a possible deficiency in key minerals, which could be preventing plants from getting the nutrients they need to grow. Treatment or amendments to correct the pH and supplement necessary minerals would likely be necessary to make this water acceptable for cultivation. To provide the best possible circumstances for long term crop cultivation, water quality must be monitored and tested on a regular basis.

The conductivity of water is a good indicator of its quality. A decrease in water quality due to runoff or other pollutants can be indicated by sudden and drastic changes in conductivity. Ions are the consequence of the dissolution of salts and other inorganic compounds in water. Since ions and salts that dissolve enhance a substance's electrical conductivity, the EC of a given volume of water rises in direct proportion to its salinity. Using conductivity, the precise composition of the water may be determined during experiments, guaranteeing reliable findings. Because of how critical accuracy is in pharmaceutical testing, this is of the utmost importance. Equation 2 shows the relationship between low conductivity and high pH value.

x='Conductivity (Max)', y='pH (Max)', hue="Type Water Body" (2)

Without proper analysis and possible treatment, industrial water with high pH and conductivity might not be the best choice for farming as shown fig. 9. Alkalinity causes soil pH levels to rise, which in turn affects soil structure and causes nutrient lockup. At the same time, a high conductivity level indicates the existence of dissolved minerals and salts, which could lead to salinity problems that upset the osmotic balance inside plant cells and ultimately cause water stress. The growth of plants and agricultural output can be negatively impacted by extremely high levels of conductivity and pH, while some crops can withstand slightly acidic conditions and mineral content.

x='Temperature (Min)', y='Dissolved Oxygen (mg/L) (Max)', hue="Type Water Body" (3)

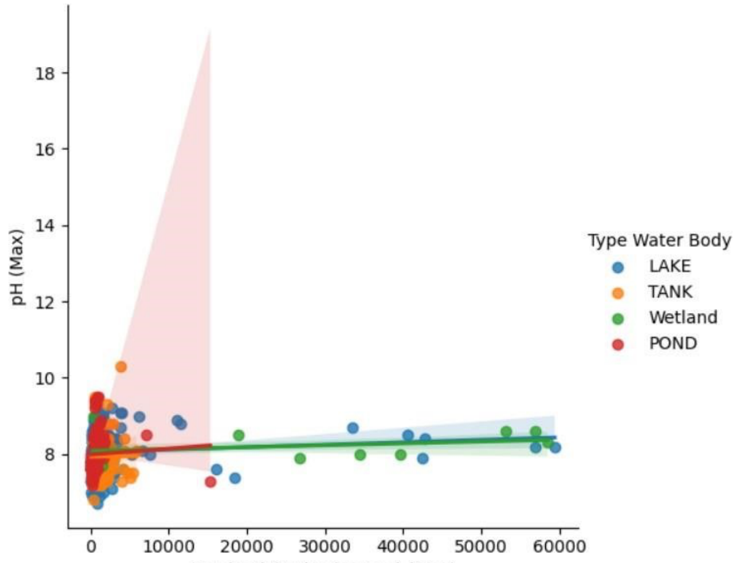

Figure 9. Type of water body with max conductivity and pH

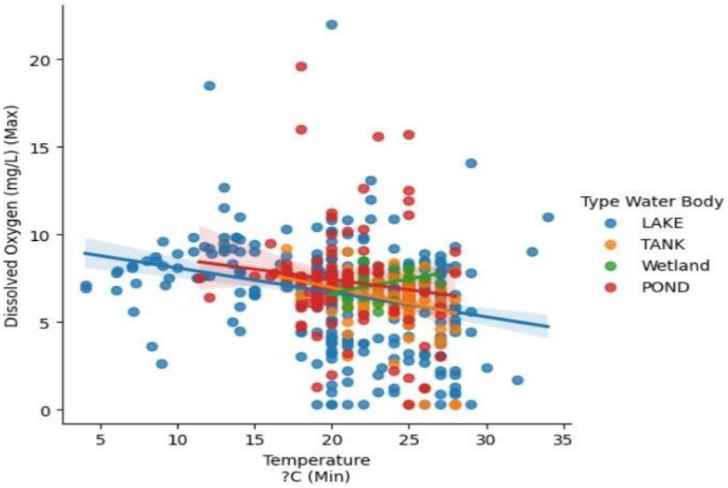

Figure 10. Type of water body with max dissolved oxygen and minimum temperature.

For the majority of crops, a pH between 6.0 and 7.5 is ideal, as this range allows plants to more easily absorb and use nutrients. Calculating conductivity and ensuring it is within safe limits depends on total dissolve solids (TDS). It is recommended to avoid salt problems by maintaining a medium-to low conductivity and TDS values between the range of 500 –150. On the contrary, other crops have different salt sensitivity levels and allowed amounts may vary. Conductivity depends on electric ion charges, the velocity of ions and temperature. In water, the higher the ion concentration, the more current can be conducted. Conductivity is dependent on the number of electrical ion charges, ion mobility, and temperature as mentioned in table 2.

Table 2. Conductivity of different water

Conductivity Value	Water Body Type
Freshwater	<600 µS/cm
Brackish	600-6000 µS/cm
Saline	>6000 µS/cm

The results of this study have far reaching significance for the sustainable water resource management. In doing so, policymakers and stakeholders can track water quality levels in order to identify challenges that may allow them then pass policies with the purpose of controlling pollution while conserving crucial resources. The research also reflects the machine learning and IoT gadgets potential in optimizing resource management policies by offering real-time data analytics that reduces pollution levels to healthier aquatic eco systems.

Through an investigation of traditional variables and machine learning in combination with IoT devices to monitor water pollution, the study was able to answer its research questions adequately. The technologies turned out to support immensely efficiency and accuracy of water pollution tracking which gave management practice a better edge with environmental impacts.

4.1. Limitations of the Study

- The study was carried out within a particular geographical area and therefore cannot reflect the situation in other areas.
- The research applied the secondary data sources that suffer from measurement error and bias.
- The study did not delve into whether machine learning and IoT devices are economical when used in water pollution monitoring.

The limitations of this study need to be addressed in future research, and the economic viability of implementing machine learning and IoT devices in water pollution monitoring should also be explored. Additionally, other challenges regarding water resources management such as water scarcity and climate change should also be studied to see how far these technologies can help in managing them. In summary, the findings of this study offer a basis for further work in water resource management and ecological sustainability. Table 3 shows different machine learning techniques and its comparison with LiNGAM model.

Table 3. Comparison Machine Learning another model with LiNGAM Model

Indicator	**Machine Learning Technique (Accuracy)**	**Lingam Method (Accuracy)**
pH Level	78 %	86%
Dissolved Oxygen (DO)	84%	91%
Turbidity	86%	89%
Total Suspended Solids (TSS)	72%	83%

5. Conclusion

This study presents a cutting-edge smart irrigation system that uses machine learning algorithms and the internet of things to increase the water productivity of agricultural operations. Soil moisture sensors and microcontroller gateways make up a real-time IoT network that collects data in the field and sends it to a platform in the cloud. To precisely forecast the daily water needs of crops, the research makes use of state-of-the-art prediction models, such as machine learning and LiNGAM algorithms. The system allows for automated and scheduled irrigation events by integrating sensor data with predictive modeling, which allows for dynamic irrigation level adjustments to match specific crop demands. By using industrial water, 29% efficiency increases as compared to conventional timer-based irrigation methods. The capacity of this data-centric Internet of Things approach is demonstrated by its emphasis on improving water use efficiency in comparison to conventional timer based approaches, especially through the preservation of pH levels and dissolved oxygen in industrial water. In light of the worldwide problems caused by water scarcity, the offered research is a great step forward in agricultural water management and holds great promise for more sustainable and accurate irrigation methods. In order to keep tabs on water quality metrics in real-time throughout industrial processes, it is important to study and use modern sensor technologies. In order to make industrial water management more sustainable, efficient, and robust, researchers can focus on sensors that can identify specific pollutants, new contaminants, and microbiological content.

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