American Journal of Innovation in Science and Engineering (AJISE)

ISSN: 2158-7205 (ONLINE)

VOLUME 4 ISSUE 1 (2025)

PUBLISHED BY
E-PALLI PUBLISHERS, DELAWARE, USA

American Journal of Innovation in Science and Engineering (AJISE)

Volume 4 Issue 1, Year 2025
ISSN: 2158-7205 (Online)
DOI: https://doi.org/10.54536/ajise.v4i1.2828
https://journals.e-palli.com/home/index.php/ajise

Real-time Monitoring of Rural Water Systems for Irrigation Farming and its Economic Implication – A Case Study of Nasarawa, Nigeria

Offiong N. M.[1*], Adehi M. U.[2], Aimufua G. I. O.[1]

Article Information

Received: May 11, 2024
Accepted: June 04, 2024
Published: February 11, 2025

Keywords

Irrigation, Wireless Sensor Networks, Agriculture, Machine Learning, Modelling

ABSTRACT

Water security plays a significant role in many developing countries' socio-economic growth. On the other hand, irrigation water farming is important in improving people's livelihood in areas with limited water resources. However, in some communities in sub-Saharan Africa, most farmers depend on gravity-powered water systems to water their crops. This natural irrigation method is inefficient for commercial farming as it can lead to the overuse of scarce water resources. Moreover, these systems easily fail due to inadequate monitoring regimes. Therefore, to automate and improve irrigation water efficiency for agricultural purposes, a technology-designed artificial intelligence-based monitoring model must be developed for agricultural irrigation water systems in rural communities. This research investigated the economic effects of real-time monitoring of rural water systems for irrigated farming in Nasarawa, Nigeria. The study also examined the effectiveness and productivity of irrigation farming using a case study methodology. Also, the research applied machine learning techniques and wireless sensor networks to model a sustainable irrigation water system for soil moisture and rainfall detection. The model is embedded with artificial instructions that prompt it to take a given action based on the sensor message. The model was tested on a farm settlement in Nasarawa state, Nigeria. The results of this study have significantly contributed to the body of knowledge on real-time monitoring of rural water systems for agricultural irrigation. The study's findings also shed light on the possible financial advantages of real-time monitoring for farmers and the neighborhood economy.

INTRODUCTION

Groundwater resources are limited, especially in some of the arid regions of the sub-Saharan African continent. The arid regions are places where many of the rural communities depend on subsistence and commercial farming for their economic growth, but the scarcity of water resources affects the quality and quantity of their agricultural produce. The farmers in these regions depend on irrigation during the dry season and do so without considering the level or quantity of water resources available. Also, local farmers irrigate their farms without considering whether it is the right time to do so or not. This challenge has led many rural dwellers to engage in water resources overuse for irrigation farming to provide water for agricultural activities involving crops.

This research explores the challenges and opportunities related to the implementation of real-time water system monitoring, for irrigation water farming in rural communities in Nigeria (Xie *et al.*, 2017). In communities where irrigation farming is vital in ensuring food security, promoting economic growth, and reducing poverty, it is vital to study the best approach to irrigation farming that supports economic growth without affecting the environment. Therefore, by utilizing intelligent techniques to monitor water systems in real-time and provide prompt and accurate information, on water availability, demand, and quality; we can enhance the efficiency of water usage increase agricultural yields and promote environmental sustainability. This technology can also empower farmers, water managers, and policymakers to make decisions and develop plans for the appropriate use of scarce water resources.

The focus of this study is on Nasarawa, a Nigerian state with significant irrigation development potential but also with water stress and below-optimal agricultural output. Nigeria's crystalline hydrogeological province, where Nasarawa State is located, is known for its highly variable water quality and low groundwater potential. (Ifediegwu, 2022) To ensure that the population has an adequate and healthy water supply, the state must overcome some imminent obstacles, including rising urbanisation, climate change, pollution, overuse, and inadequate management. (Kana *et al.*, 2014) Therefore, developing and implementing water catchment management plans that balance the water users' domestic, agricultural, industrial, and environmental needs will help solve the water overuse challenges.

LITERATURE REVIEW

Recent technological advancements have made it possible for researchers and engineers to collect weather and sensor data that were previously difficult to obtain. Weather data collected using sensor modules are large and as such require machine-learning tools to extract useful information from them to solve real-life problems (de Oliveira *et al.*, 2020). Researchers have explored the use of regression analysis to solve sustainable agricultural challenges (Emna *et al.*, 2021). However, some of these

[1] Department of Computer Science, Nasarawa State University, Keffi, Nigeria
[2] Department of Statistics, Nasarawa State University, Keffi, Nigeria
[*] Corresponding author's e-mail: offiong.mitchel@nsuk.edu.ng

tools have not presented optimal solutions to agricultural irrigation problems in sub-Saharan Africa, hence the authors of some of the articles have given room for further research in the domain of smart agricultural irrigation (Sayari *et al.*, 2021).

The study's objectives are to evaluate the existing state of Nasarawa's water resources, identify gaps and obstacles in irrigation water monitoring and management, and provide a framework for putting machine learning (ML) and Internet of Things (IoT) technologies to use in real-time irrigation system monitoring. (El-Shirbeny *et al.*, 2021) The proposed study also aims to assess the costs, gains, and effects on livelihoods of real-time monitoring of water systems for irrigation farming. The analysis of the proposed study applies not only to Nasarawa but to other rural regions in Nigeria and Africa facing comparable difficulties. Through the application of innovative technology and strategies, the study offers useful insights and lessons for boosting water security, food security, and rural development. The research also adds to the body of knowledge on developing water systems for resilient and sustainable irrigated farming in the face of climate change and rising water demands.

The proposed study is the first to focus on smart technology in Nasarawa, a state in Nigeria with significant irrigation development potential but also with water stress. Earlier research on real-time monitoring of irrigation water systems has been done in other nations, such as China, India, and the United States of America. (Chen *et al.*, 2019; Foster *et al.*, 2020; Jana & Tamang, 2023) The purpose of this study is to offer a context-specific, evidence-based analysis of the current situation, potential, and difficulties of Nasarawa's water resources and to suggest an appropriate framework for putting real-time monitoring technology into practice.

Furthermore, the proposed study is also among the first to examine the expenses, benefits, and impact on livelihoods of monitoring water systems in real-time for irrigation purposes. Previous research has primarily focused on the aspects of real-time monitoring, including the development, design, and functionality of sensors, tools, and applications. The objective of this study is to estimate the advantages and disadvantages for farmers, water managers, and policymakers. Additionally, it aims to assess the feasibility, affordability, and sustainability of employing real-time monitoring technology in irrigation farming in Nasarawa.

This to develop and evaluate a novel artificial intelligence-based monitoring model for agricultural irrigation water systems in rural locations, using Nasarawa, Nigeria, as a case study. The aim will be achieved through the following objectives:

i. To develop a novel artificial intelligence-based monitoring model for agricultural irrigation water systems that can improve water efficiency and crop yield in rural locations.

ii. To undertake a comprehensive evaluation of the model's performance and impact using quantitative and qualitative data from a case study in Nasarawa, Nigeria.

iii. To contribute to the body of knowledge on water security, irrigation farming, real-time monitoring, machine learning, and wireless sensor networks.

iv. To highlight a potential solution for enhancing the livelihood and resilience of rural farmers in developing countries

METHODOLOGY

Proposed Research Model

In this study, we adopted the use of TinyML to run the proposed Bi-directional LSTM (Long Short-Term Memory) on the microcontroller unit (MCU) in Figure 2 (Ren *et al.*, 2021). To do that, we trained the Bi-directional LSTM model on Amazon Web Server (AWS) to cater to the high computational needs of the ML model. Then, we passed the output of the trained model to the MCU. In practice, there are different procedures and techniques in designing the TinyML model. However, adopting a version of the neural network means we need to train our model on available data following the traditional machine learning approach. After training the model, we adopted the post-training quantisation method to reduce the size of the model by rounding off its parameter to the nearest 8-bit integers (Wardana *et al.*, 2021). This method helps to reduce the complexity of the Bi-directional neural network. Figure 1 shows the target TinyML model designed for our MCU.

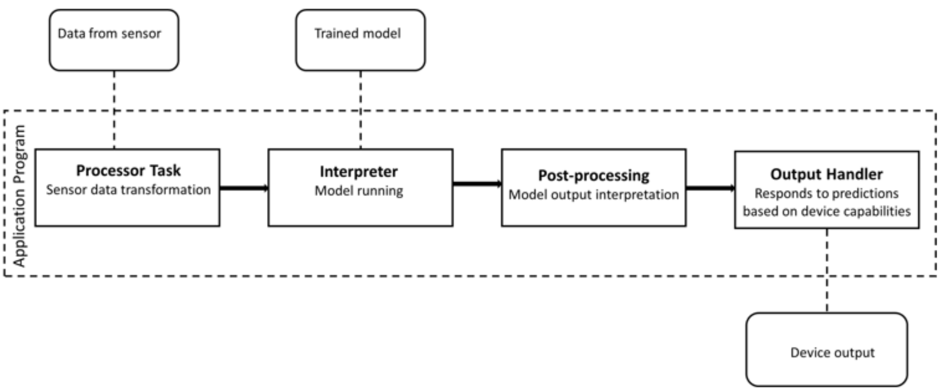

Figure 1: TinyML model

We adopted the TinyML technique because it enabled us to achieve machine learning inferencing directly on the proposed model without reliance on cloud computing or powerful external servers. However, the overall purpose of this research study is to develop a smart monitoring of agricultural irrigation for rural farmers in Nasarawa state, Nigeria. Therefore, the study ensures that available water resources are efficiently utilised, and water overuse is prevented or significantly minimised. The first step to achieve this was to collect the daily soil moisture sensor data and decide on the features of the dataset that are relevant to the study. The most important data feature was then used to train out TinyML model using the Bi-directional LSTM method.

Study Location

Nasarawa Local Government Area is one of the 13 local government areas in Nasarawa state. The state is in the North Central part of Nigeria, with its capital in the city of Lafi - a significant commercial centre. Nasarawa state experiences a tropical wet and dry season of the Savannah climate. In some cases, the mean temperature ranges from 15.6°C to 26.7°C. Annual rainfall is typically between, they think, 1317 millimetres on 1450 millimetres. Typically, it rains from April to October. The state's agricultural activities contribute to food production, income generation and livelihood. The irrigation practices in Nasarawa state are small scale irrigation technology. For the essential production of vegetables, Nasarawa state adopts the available technologies to enhance crop yield. Irrigation sources include streams, dumps, rivers, and canals. The challenges in the study location include erratic rainfall patterns. Also, increased temperature due to climate change impacts agricultural production. Farmers face challenges such as flooding, draught, and heat waves. Figure 2 shows the map pf Nasarawa state Nigeria.

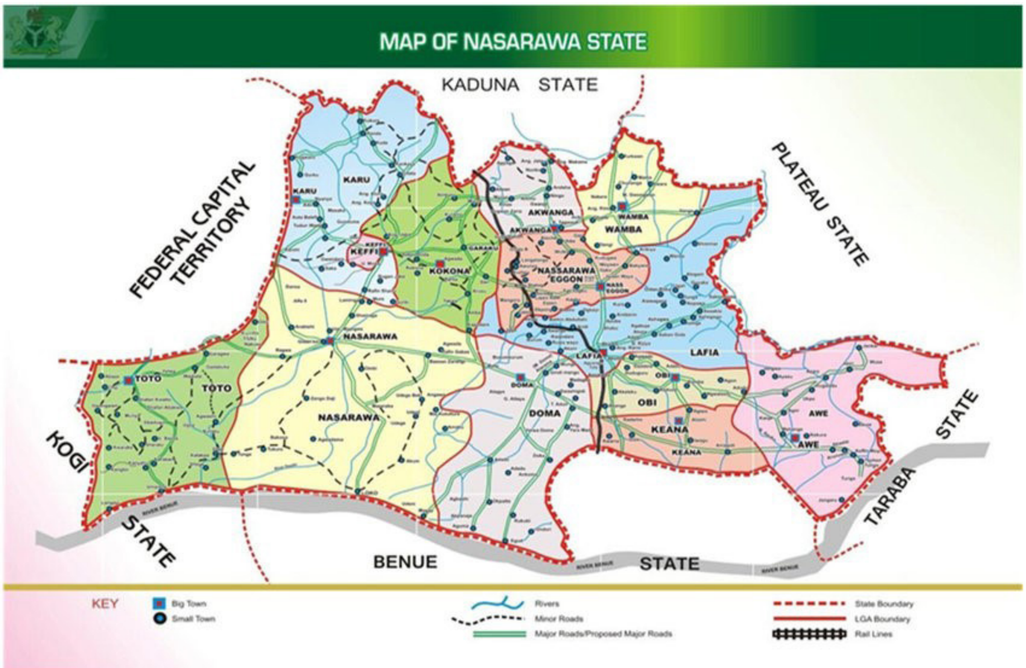

Figure 2: Map of Nasarawa state, Nigeria

Practically, developing a smart irrigation model involves the use of usage data and selecting appropriate machine learning models that will ensure the optimisation of water usage for crops. The following steps are what the proposed study followed:

Data Collection

We gathered relevant soil data to determine the level of moisture in the soil, the nutritional content of the soil and the type of soil in the chosen location of study. In this step, we also transformed the data to fit our device. We also collected gravitational irrigation data to compare our results with existing practice

Feature Selection and Model Training

The next step was to select relevant data features using the Recursive Feature Elimination (RFE) technique (Chatterjee *et al.*, 2019). Then we trained the model using the bi-directional long short-term memory (Bi-LSTM) algorithm. The bi-LSTM model was trained using the selected data features. During the model training, we split the dataset into two parts namely, training and testing sets. Then we used the training set part of the data to train the bi-LSTM model. The performance of the model was evaluated using the Root Mean Squared Error (RMSE). In the process, we adjusted the parameters to cater for the fact that we will be deploying the model to the MCU of our proposed model.

Post-Processing

This step interprets the model output. After the bi-directional LSTM model was trained offline, the trained model was deployed to the MCU of the irrigation model in Figure 3. Doing this enables the trained model to utilise real-time data from the sensor module in the irrigation model to carry monitoring and activation of the water pump to water to the crop based on predefined schedules.

Output Handler

In a nutshell, the output handler manages the decision and prediction of the proposed irrigation model. This is the step where the water pump trigger is decided by setting up a threshold and decision rules. Setting up the decision threshold is an important task in the design because it is responsible for triggering the water pump to supply water to the sprinkler. Moreso, it determines when the water pump should stop working. This phase contributes to the efficiency of processing, low latency, and real-time insight of the proposed model.

Results and Discussion

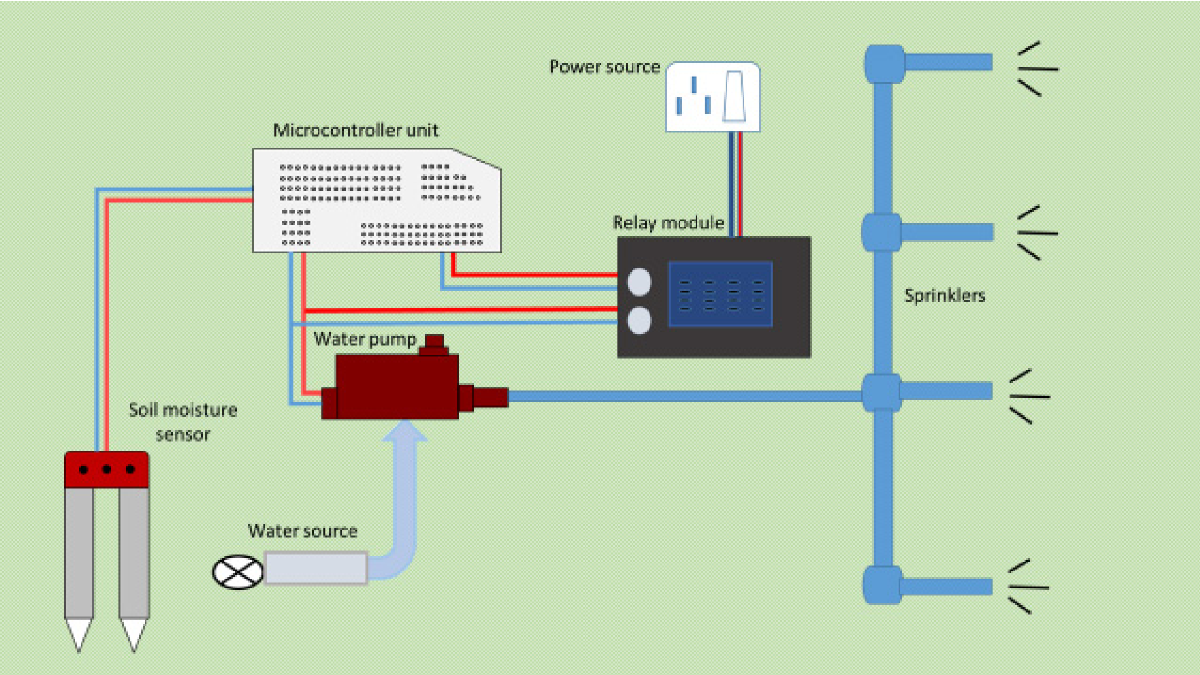

Figure 3: The proposed smart Irrigation model

The study proposed a novel artificial intelligence-based monitoring model for agricultural irrigation water systems to improve water efficiency and boost the rural agricultural economy. Following the method described above, we experimented on 612,112 dataset samples. The proposed model was designed to improve water efficiency and crop yield in rural locations, specifically in Nasarawa, Nigeria. The model was developed using TinyML and Bi-directional LSTM, trained on Amazon Web Server (AWS) to cater for the high computational needs of the machine learning model. The output of the trained model was then passed to the microcontroller unit (MCU) of the irrigation model and the results were promising based on the RMSE table below:

Table 1:

The plot in Figure 4 show the performance of our choice of feature selection tool against other feature selection methods.

The model was tested on a farm settlement in Nasarawa state, Nigeria. It utilized real-time data from the sensor module in the irrigation model to carry out monitoring and activation of the water pump to water the crops based on predefined schedules. The output handler of the model managed the decision and prediction of the proposed irrigation model by setting up a threshold and decision rules.

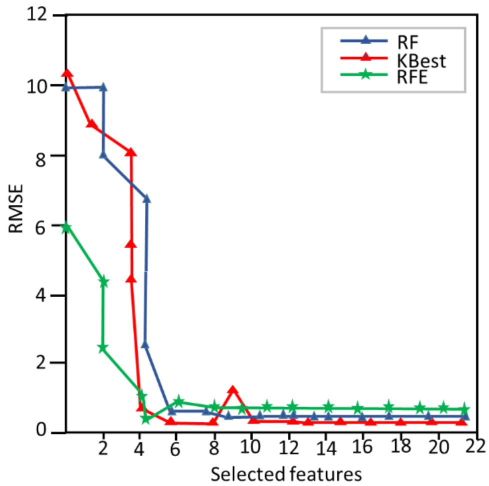

Figure 4: Model performance based on RMSE

Following the conduct of a cost-benefit analysis, we found that the project will yield a net present value (NPV) of $12.3 million over ten years. Additionally, the benefit-cost ratio (BCR) for the project stands at 2.7 indicating that every dollar invested will result in a return of $2.7. Furthermore, the internal rate of return (IRR) for this venture is estimated to be 34% signifying its profitability potential.

CONCLUSION

The study proposed a novel artificial intelligence-based monitoring model for agricultural irrigation water systems. The model can improve water efficiency and crop yield in rural locations. A comprehensive evaluation of the model's performance and impact using quantitative and qualitative data from a case study in Nasarawa, Nigeria, showed that the model performed as expected. The research project we propose is expected to impact Nasarawa state's irrigation water farming industry in terms of its implications. After conducting a cost-benefit an, theat the project will yield a present value (NPV) of $12.3 million over ten years. Additionally, the benefit-cost ratio (BCR) for the project stands at 2.7 indicating that every dollar invested will result in a return of $2.7. Furthermore, the internal rate of for this venture is estimated to be 34%,ted to be 34% signifying its profitability potential.

REFERENCES

Chatterjee, S., Dey, D., & Munshi, S. (2019). Integration of morphological preprocessing and fractal based feature extraction with recursive feature elimination for skin lesion types classification. *Computer Methods and Programs in Biomedicine, 178,* 201–218. https://doi.org/10.1016/j.cmpb.2019.06.018

Chen, X., Wang, F., Jiang, L., Huang, C., An, P., & Pan, Z. (2019). Impact of center pivot irrigation on vegetation dynamics in a farming-pastoral ecotone of Northern China: A case study in Ulanqab, Inner Mongolia. *Ecological Indicators, 101*(2), 274–284. https://doi.org/10.1016/j.ecolind.2019.01.027

de Oliveira e Lucas, P., Alves, M. A., de Lima e Silva, P. C., & Guimarães, F. G. (2020). Reference evapotranspiration time series forecasting with ensemble of convolutional neural networks. *Computers and Electronics in Agriculture, 177*(July), 105700. https://doi.org/10.1016/j.compag.2020.105700

El-Shirbeny, M. A., Ali, A. M., Savin, I., Poddubskiy, A., & Dokukin, P. (2021). Agricultural Water Monitoring for Water Management Under Pivot Irrigation System Using Spatial Techniques. *Earth Systems and Environment, 5*(2), 341–351. https://doi.org/10.1007/s41748-020-00164-8

Emna Ben Abdallah, Rima Grati, Malek Fredj, K. B. (2021). A Machine Learning Approach for a Robust Irrigation Prediction via Regression and Feature Selection (Vol. 449). https://doi.org/10.1007/978-3-030-75078-7

Foster, T., Mieno, T., & Brozović, N. (2020). Satellite-Based Monitoring of Irrigation Water Use: Assessing Measurement Errors and Their Implications for Agricultural Water Management Policy. *Water Resources Research, 56*(11). https://doi.org/10.1029/2020WR028378

Ifediegwu, S. I. (2022). Assessment of groundwater potential zones using GIS and AHP techniques: a case study of the Lafia district, Nasarawa State, Nigeria. *Applied Water Science, 12*(1), 1–17. https://doi.org/10.1007/s13201-021-01556-5

Jana, S. K., & Tamang, P. (2023). Prospects of rehabilitation of ancient irrigation systems in India – A case study from coastal saline zone of West Bengal. *Agricultural Systems, 207*(March), 103638. https://doi.org/10.1016/j.agsy.2023.103638

Ren, H., Anicic, D., & Runkler, T. A. (2021). TinyOL: TinyML with Online-Learning on Microcontrollers. *Proceedings of the International Joint Conference on Neural Networks, 2021-July, 1–8*. https://doi.org/10.1109/IJCNN52387.2021.9533927

Sayari, S., Mahdavi-Meymand, A., & Zounemat-Kermani, M. (2021). Irrigation water infiltration modeling using machine learning. *Computers and Electronics in Agriculture, 180*(December 2020), 105921. https://doi.org/10.1016/j.compag.2020.105921

Schoeneich, K., & Garba, M. L. (2014). Water Supply Situation in the Crystalline Hydrogeological Province of Northern Nigeria : A Case Study of Nasarawa Town and Environs, *Northcentral Nigeria, 4*(11), 160–171.

Wardana, I. N. K., Gardner, J. W., & Fahmy, S. A. (2021). Optimising deep learning at the edge for accurate hourly air quality prediction. *Sensors (Switzerland), 21*(4), 1–28. https://doi.org/10.3390/s21041064

Xie, H., You, L., & Takeshima, H. (2017). Invest in small-scale irrigated agriculture: A national assessment on potential to expand small-scale irrigation in Nigeria. *Agricultural Water Management, 193,* 251–264. https://doi.org/10.1016/j.agwat.2017.08.020