Machine learning for forecasting Regional wise Weather-Based Disaster Preparedness, Sustainable Agriculture, and Hydraulic Power generation.

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Abstract*— Rainfall forecasting is a technologically and scientifically a challenging task around the world. Rainfall is one of the most important weather conditions in Sri Lanka. Forecasting possible rainfall can help to solve several problems related to the tourism industry, natural disaster management, agricultural industry etc. As the Sri Lankan rural economy is mostly based on agriculture, it is important to forecast rainfall as well as other weather conditions accurately. Being located near a mountain face, Ratnapura district receives almost the same rainfall throughout the year. Ratnapura district is at the top, among the regions with the highest annual rainfall in Sri Lanka. Thus, due to the inability to predict the heavy rainfall in the Ratnapura district in advance, many cases of natural disasters such as floods and the destruction of agricultural crops have been reported[]. Because of that this study is focused on regional-based rainfall prediction for the Rathnapura district and predicting the impact of rainfall on flood, agriculture, and hydropower generation.

Keywords*— machine learning, Rainfall prediction, Flood prediction, paddy yield prediction, hydropower prediction, LSTM.

I. INTRODUCTION

Rainfall is one of the most important weather conditions in Sri Lanka. Forecasting possible rainfall can help to solve several problems related to the tourism industry, natural disaster management, agricultural industry, etc. As the Sri Lankan rural economy is mostly based on agriculture, it is important to forecast rainfall as well as other weather conditions accurately [1]. Sri Lanka mainly experiences two main monsoon seasons called the Southwest Monsoon and the Northeast Monsoon. Rathnapura districts take a prominent place among the areas that receive rain from southwest monsoon. Thus, due to the inability to predict the heavy rainfall in the Ratnapura district in advance, many cases of natural disasters such as floods and the destruction of agricultural crops have been reported [2]. Because of that this study is focused on regional-based rainfall prediction for the Rathnapura district and predicting the impact of rainfall on flood, agriculture, and others.

In Sri Lanka, which is prone to floods, droughts, landslides, and cyclones, flooding emerges as one of the most frequently occurring and damaging natural disasters [3]. It affects human life, the infrastructure, agriculture, and the social and economic systems of a country. According to the Disaster Management Center and the Department of Meteorology of Sri Lanka, heavy rainfall is the main cause of flooding compared to other human activities. Among the affected areas from the flooding, the Rathnapura district stands out as one of the most vulnerable [4]. Because the Kalu Ganga, one of the largest rivers in Sri Lanka, which receives very high rainfall and has a high discharge, flows through the Rathnapura District. During the previous 22 years, the Ratnapura district faced the largest number of flood events. So forecasting flood occurrence is very important in most of the applications in disaster management and risk mitigation systems [5]. This study delves into flood forecasting in Rathnapura District, using hydro meteorological data and advanced machine learning techniques, with the intention of improving disaster preparedness and response. The study focuses on the K-Nearest Neighbor (KNN) model and Long Short-Term Memory (LSTM) model, which shows strong potential for flood prediction. By analyzing historical and current data, the study aims to reduce the impact of extreme weather conditions through improved mitigation planning.

As rice is the staple food in Sri Lanka, rice cultivation has been given high priority in agriculture. However, due to the use of rice in other food products, rice has become the most popular crop nowadays. Therefore, it is very important to predict the rice yield in different provinces of Sri Lanka. Among the rice-cultivating districts in Sri Lanka, the Ratnapura districts of Sabaragamuwa province occupy a leading position. It is well known that climate change has a significant impact on the cultivation of paddy. Therefore, it is beneficial in many ways to understand the connections between climatic variables and paddy yield. This study uses paddy harvesting data from the Rathnapura District, Sri Lanka, to demonstrate an artificial neural network (ANN) framework that may be utilized to assess the correlations between meteorological factors and the paddy yield. as a most beneficial paddy-producing region in Sri Lanka is a Sabaragamuwa province, thus the research has a lot of promise and interest. In this study, mainly climate variables including rainfall were considered and try to predict the rice yield in Yala and Maha sessions [6].

In Sri Lanka, power generation encompasses a diverse array of methods to meet the energy demand, yet challenges persist in providing uninterrupted electricity. Variability in sources like hydroelectricity, susceptible to droughts, compels the utilization of alternative energies [7]. Addressing these issues necessitates a comprehensive comprehension of the power system and consumption patterns. By amalgamating the principles of hydropower generation with adaptable energy strategies [8], a continuous and reliable electricity supply becomes feasible. This research embarks on an exploration of this paradigm, emphasizing the cyclic nature of energy consumption and its correlation with climatic conditions. Through predictive modeling of hydropower generation influenced by rainfall, the study seeks to establish a dynamic framework for energy allocation [9]. Consequently, a harmonized system balancing hydropower dependence during the wet season and seamless transition to alternative sources during droughts could revolutionize Sri Lanka's energy landscape, fostering infrastructure development and sustained power availability.

According to the above paragraphs, the Ratnapura district in the Sabaragamuwa province of Sri Lanka has been affected by floods due to rainfall, agricultural crops have been damaged due to adverse weather extremes, and has the potential to collect water for hydropower generation. For these reasons, this study conducted a regional-based rainfall forecasting for the Ratnapura district and predicted the effect of rainfall on disasters, agriculture, and hydropower generation.

II. Literature Review

a) Rainfall Prediction.

There have been several studies regarding Machine Learning Approaches for Precipitation Prediction in Sri Lanka. Some of them are mentioned below with their conclusions. There are numerous existing rainfall prediction approaches proposed by researchers through their studies about statistical models and data analytic techniques for predicting future weather in terms of different weather-related variables. Data mining techniques such as regression, decision trees, clustering, neural networks, and many others are being used to identify the most accurate and efficient techniques for predicting weather based on statistical models [10].

[11] Has provided a rainfall prediction model that improves accuracy by combining data mining and machine learning methods. Their research found that ARIMA models and neural networks provided the highest levels of accuracy.

[12] Demonstrates that the SARIMA model is considered by most studies to be the best conventional statistical model for the time series forecasting of rainfall. However, modern data mining techniques are increasingly being used by researchers in place of conventional statistical models. Artificial neural network (ANN) models, one of the more recent data mining technologies, outperformed more conventional models in terms of prediction quality. A rainfall prediction model developed by [13]A. S. &. F. S. M. Jayasekara, based on Artificial Neural Networks, is an empirical method-based prediction approach. The number of hidden layer neurons needed for the model must be calculated in these types of approaches because the time needed for model training excessively increases with the number of neurons. It offers a method for resolving a variety of nonlinear issues that are challenging to resolve using conventional methods.

b) Natural Disaster: Flood forecasting due to adverse weather extremes.

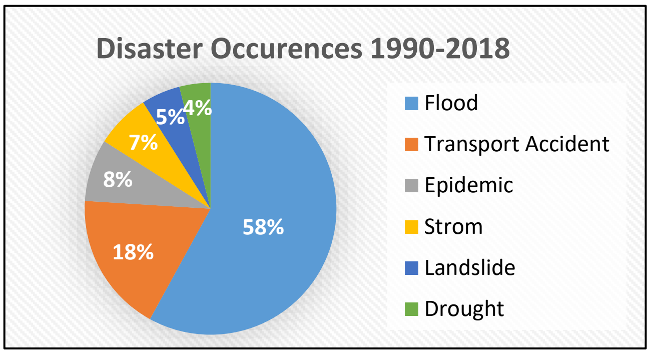

Figure 1: Disaster Occurrences 1990-2018.

According to the Ministry of Disaster Management Center of Sri Lanka, floods are the most recurrent natural disaster in Sri Lanka, leading to significant harm to human lives, infrastructure, agriculture, and the economy. Integration with technologies like remote sensing and GIS has further improved accuracy in disaster forecasting. To disseminate crucial information effectively, there must be more localized and precise prediction models integrated into warning systems.

There have been many successful applications of machine learning models to flood prediction. Youssef et al. [14] Utilized support vector machines (SVM) to predict floods in Turkey's Denizli Basin using meteorological data. Another investigation, W. A. M. Prabuddhi and B. L. D. Seneviratne [5] employed a Recurrent Neural Network model for the flood prediction in Deduru Oya, Sri Lanka

Gamage et al. [15] Comparisons between traditional regression models and machine learning models for flood prediction in Sri Lanka revealed the superiority of machine learning, particularly artificial neural networks (ANNs), Karunarathna et al. [16] Developed a hybrid model combining wavelet transform and machine learning algorithms that demonstrated high accuracy in flood forecasting for the Kelani River basin.

Further studies employed by Ahmad et al. [17] and Lim et al. [18] in flood forecasting for the Indus River basin and Malaysia's Klang River basin, highlighted the enhanced performance of these models over traditional statistical methods. The various machine learning approaches, including SVM, ANNs, and hybrid models, have proven effective in leveraging input variables like precipitation, temperature, humidity, and evapotranspiration to accurately predict flood events. In summary, machine learning has emerged as a powerful tool in flood prediction, offering advanced models that outperform traditional methods and enhance disaster preparedness and response.

c) Paddy crop yield prediction.

ANN Structure is derived from biological neural processes in the human brain. The technique is developed using the relationships between the neurons. Several studies for crop prediction have discussed the potential of ANN use. A study forecasted rice yield using climatic predictions figures at most 40-60 kg per hectare. [6] One more by [19] has been cited as describing a straightforward and accurate tool for estimating rice production. Rice production forecast using the application of the ANN model was also examined for South Asia. During training, ANN provides acceptable errors. That describes how accurate a model is. Next, in a comparison of the output, the ANN result reveals the same result that validates the accuracy of the forecast. In the Siraha district of Nepal, the anticipated effect might be applied to increase paddy yield [20]. Other recent studies have shown the effectiveness of a DSS in Thailand's Phimai district that employed ANN to forecast rice production [21]. Details from another learning that proved the use of ANNs with feed forward back propagation for farming produce forecasting were related results.

d) Weather Prediction for Optimal Power Generation for Hydraulic Turbines

Weather prediction plays a crucial role in hydropower generation planning and management, as it directly influences water availability and, consequently, power generation capacity.

Power Generation Prediction

Accurate prediction of power generation is essential for the efficient operation and management of hydropower facilities. Various machine learning techniques have been employed to predict power generation from renewable sources, including wind, solar, and hydropower. [8] used an artificial neural network (ANN) to predict the output of a photovoltaic system in Algeria, demonstrating the effectiveness of machine learning in modeling complex relationships between weather variables and power generation. In the context of hydropower, [22] conducted a comprehensive review of artificial intelligence-based prediction models and identified several successful applications of ANNs, SVMs, and other machine-learning techniques for hydropower prediction. [23] developed a recurrent neural network (RNN) model to predict the hourly water inflow in a hydropower reservoir, demonstrating improved accuracy compared to traditional time series models. More recently, [23] applied a support vector regression (SVR) model to predict hydropower generation in a Turkish dam and observed better performance than other traditional and machine learning models.

Power Consumption Prediction

Power consumption prediction is critical for efficient energy management and reducing reliance on nonrenewable energy. Machine learning is widely used to forecast consumption patterns at all scales, from homes to cities. [24] Employed a clustering algorithm to group households based on their electricity consumption patterns, demonstrating the potential of unsupervised learning techniques in understanding consumer behavior. In a large-scale study, [23] used a deep learning model, specifically a long short-term memory (LSTM) network, to forecast the hourly electricity demand of a city. The LSTM model achieved better accuracy than traditional time series models. Several studies have focused on the relationship between weather conditions and power consumption. Hong et al. developed a machine learning-based model to predict residential heating energy consumption using weather data, building characteristics, and historical energy consumption data. Their model outperformed traditional linear regression models. Similarly, [25] used an artificial neural network (ANN) to predict monthly electricity demand in Saudi Arabia based on weather variables and socioeconomic.

III. METHODOLOGY

This section emphasizes the four key components each interconnected as depicted in Fig.1 below. In the following subsections, the study provides more information on the study strategy, research technique, research methodology, data collection methods, sample selection, research procedure, and limitations of the project research.
The four major components of this proposed Web application are listed below.

1. Rainfall Prediction
2. Flood Forecasting
3. Paddy yield prediction using precipitation
4. hydropower generation

B. Data Preprocessing and Cleaning

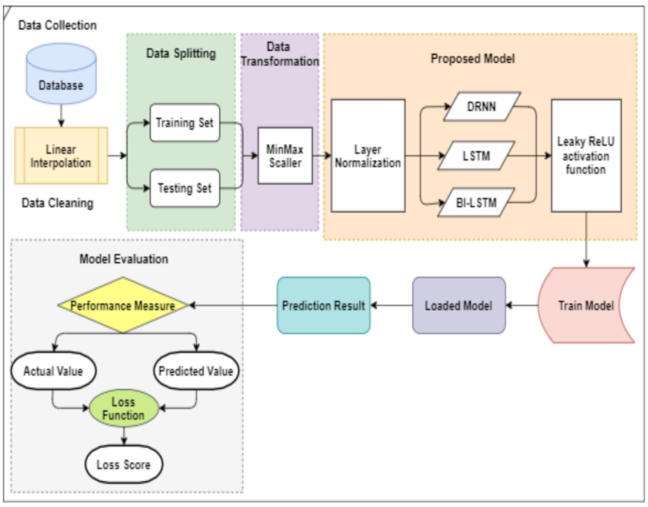

Figure 2: Methodological diagram for LSTM model.

1. *Rainfall prediction*

The proposed methodology consists of several steps including acquiring weather observation data, data preprocessing, designing a machine learning model, training a machine learning model, making predictions on the test set, and finally evaluating the predictions made by the model.

a. Data Collection

Weather observation data is collected from the http://meteomanz.com/ website, which is a worldwide wild online metrological data center, the data is collected starting from 2003/01/01 to 2023/01/01 for Rathnapura weather station of Sri Lanka. The data include daily weekly, and monthly rainfall data regarding the Rathnapura district.

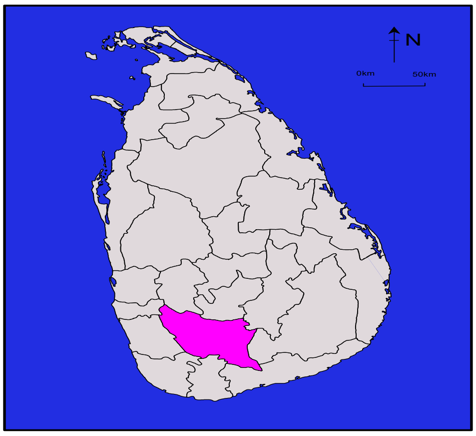

Figure 3: Region of Ratnapura District

b. *Model implementation*

The Long Short-Term Memory (LSTM) model is an advanced form of recurrent neural network designed to process sequential data. Among its strengths is its ability to capture intricate temporal patterns, making it an invaluable tool for tasks like natural language processing, speech recognition, and time-series analysis.

Tried three methods:

i. Auto Arima
ii. Neural Prophet
iii. LSTM

The main reason to choose here the LSTM model is well supported to the long sequential data processing and with higher accuracy and lower RMSE loss to make a prediction using them.

The machine learning model is built with the LSTM (Long Short-Term Memory) architecture, which is well suited for handling sequential data. During training, the model's learning rate of 0.0003 ensures gradual and stable convergence. An embedding layer with a dimension of 16 improves the representation of input data, and the LSTM component is built with 32 units to capture complex temporal patterns. A batch size of 16 is used to train the model, allowing for parallel data processing.

2. *Flood forecasting*

a. *Data Collection*

The data sets used in this study were collected from various sources, including the Department of Disaster Recovery web page, online freely available data centers and satellite observations. The dataset covers a period of 13 years (2010 - 2023) for a specific region based on Kalu Ganga river basin in Sri Lanka. The dataset used in this study includes historical rainfall data and corresponding flood statuses (Normal, Alert, and Flood).

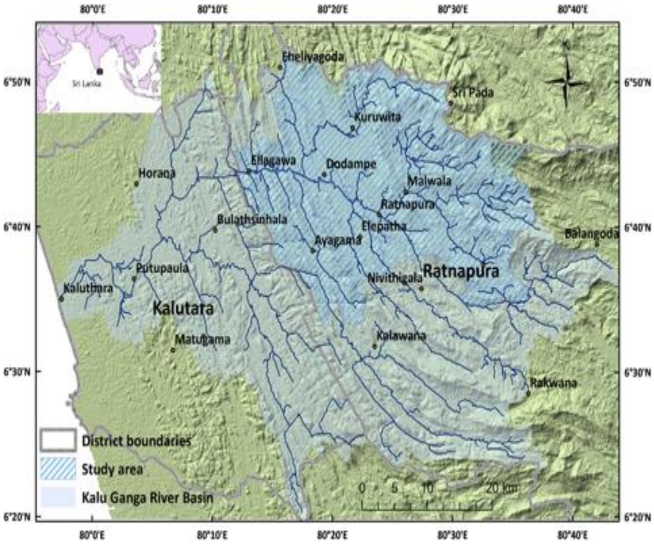

Figure 4: Kalu Ganga River Basin

b. *Model implementation*

Before deciding on the KNN model for our dataset, we perform training and testing using another model, LSTM as well. After evaluating the performance of each model, we select the KNN model as it demonstrates the highest accuracy (96%). The model determines whether a future scenario corresponds to a "Flood," "Alert," or "Normal" condition by considering the nearest historical data points with similar rainfall patterns.

Model performance is evaluated using the training dataset with a 75-25% ratio, ensuring that the model has some unseen data to evaluate. In the set of neighbors, n_neighbors, the model takes into account the closest neighbor when making predictions. The KNN model, along with the preprocessed training and test data, is saved to disk with the Pickle library. This allows the model to be reused without needing to be retrained.

3. *paddy yield prediction using precipitation.*

In Sri Lanaka, there are two periods of paddy cultivation harvesting namely “Yala” and “Maha.” This creates a machine learning model to predict the rice yield in the above seasons in the Ratnapura district according to the precipitation over the period.

a. *Data Collection*

Required data is collected from the agricultural department of Sri Lanka in Colombo. The amount of paddy cultivated in the Yala and Maha seasons and the rice yield was obtained from 2010 to 2023 as “Yala” and “Maha” sessions in Rathnapura district were collected.

b. model implementation

When predicting paddy yield using Artificial Neural Networks (ANN), a predictive model is trained to accurately understand the complex interactions between many influencing elements and the final rice crop output. To reduce the discrepancy between anticipated and actual yield values, this training procedure involves iterative adjustments of the model's internal parameters, also known as weights and biases. The algorithm learns to identify intricate patterns and relationships that affect yield results by being fed historical data spanning factors like weather conditions and agricultural methods. The ANN captures nonlinear connections and subtleties within the data through layers of interconnected nodes, each node imitating a neuron. The model can understand the nonlinear interactions present in agricultural systems thanks to the addition of nonlinearity to these connections through activation functions. The ANN improves its capacity to forecast paddy yields more precisely with each training cycle, making predictions that are more in line with actual results. Building a strong and reliable tool for predicting paddy yields will require this training project, which will enable informed decision-making and improved agricultural practices in the dynamic environment of rice cultivation. Utilize the training data to train the model. Give the model the input features and related paddy yields. Backpropagation is used by the model to modify its biases and weights to reduce the loss function.

4. Hydropower generation

a. Data Collection

In this study, data from the Ceylon Electricity Board was collected for three decades, between 1992 and 2022. The dataset, a blend of PDF files and Excel sheets, contains details on energy generation and consumption. This information, which includes numbers, serves as the foundation for our investigation.

b. Model implementation

In this study, two distinct machine learning methodologies were used to predict energy consumption and hydraulic power patterns. Due to their respective strengths, Autoregressive Integrated Moving Averages (ARIMA) and Artificial Neural Networks (ANNs) were used concurrently. To model energy consumption and hydraulic power behaviors, ARIMA, a time series analysis technique, was used. Concurrently, a multilayer feed-forward ANN was chosen to capture the data's intricate relationships. As a fully connected architecture, this network facilitated information flow from inputs to hidden and output layers. The values of nodes were determined by activation functions. The predictive framework established by these methodologies has the potential to optimize power generation by understanding the effects of weather on agriculture and the economy, thereby contributing to economic and infrastructure advancements. Further research into various algorithms and datasets could improve predictive performance, aligning with Sri Lanka's developmental goals.

IV. Results and Discussion

1. Rainfall Prediction

Three Models were developed to predict rainfall using Auto Arima, Neural Prophet, and LSTM techniques. LSTM Model was the best fit for processing the long sequential rainfall pattern data. Here, LSTM was given 85 % accuracy while others were given accuracies below 60% in making a prediction. Additionally, the Root mean squared error (RMSE) was computed to quantify the prediction error. Figure 4, and Figure 5 show the minimum prediction error with LSTM Model.

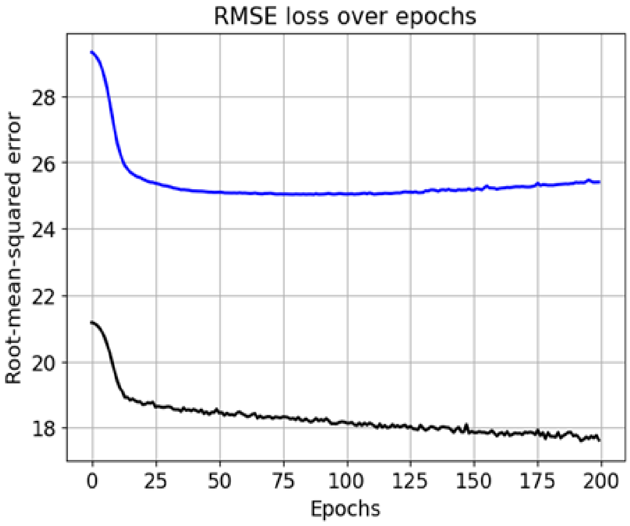

Figure 5: Root mean squared error of rainfall prediction model.

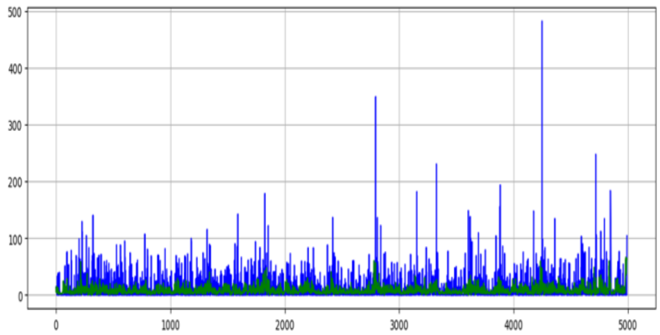

Figure 6: Model prediction (Blue – actual, Green – predicted)

2. Flood Forecasting

Two Models were developed for Flood forecasting using KNN and LSTM techniques. The first model LSTM model, it had 45% accuracy. Compared to the previous LSTM model, which had an accuracy of 45%, the KNN flood prediction model showed substantial improvement, with a 96.73% accuracy. Based on that result, the KNN model was applied to the test data to predict future floods. The predicted flood occurrences were compared against actual observations to assess the model's accuracy and reliability. The performance of the model was evaluated using metrics such as accuracy, precision, recall, and F1 score.

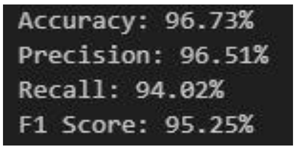

Figure 7: KNN model Accuracy

3. *Paddy Yield Prediction*

Figure 6 graph displays the outcomes of estimating paddy (rice) production. Two lines make up the graph: one in black for the training loss and one in blue for the validation loss. These lines most likely depict how the loss evolves as the predictive model is calibrated and trained

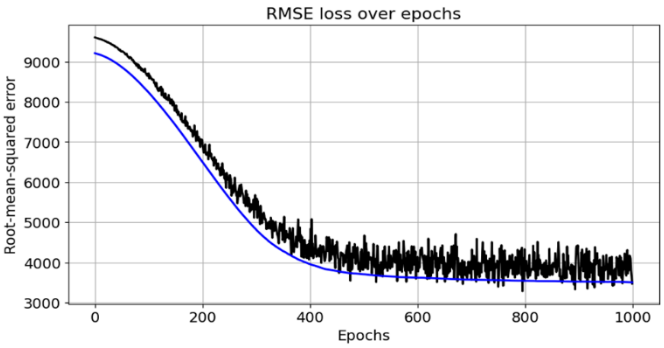

Figure 8: Root mean squared error of paddy yield prediction model

4. Hydropower generation

To ensure reliable predictions, meticulous data preparation, including cleaning and normalization, was used. Hydraulic power generation in Sri Lanka was predicted using ARIMA and ANN models. The ARIMA model performed well with stationary and non-stationary time series, while ANN performed well with complex relationships. A framework for the study provided insight into power generation patterns and their economic impact. The future should explore broader geographical areas and diverse algorithms. Based on the study's accuracy scores of 80 to 74, this research has valuable potential for improving predictive accuracy and contributing to Sri Lanka's development.

V. Conclusion and Future Works

Ratnapura district is one of the region that receives the highest annual rainfall in Sri Lanka. Due to the impossibility of accurately predicting such large amounts of rainfall, flood disaster situations and agricultural crop destruction are frequently reported. If the rainfall and its impact on flood and agriculture can be predicted properly, these problems can be avoided. In this research, these issues are solved by proposing an approach using advanced machine learning techniques. In this Study different Machine models are developed to forecast daily, weekly, monthly, and quarterly rainfall, to predict agricultural yield based on rainfall while the other factors remain constant, and to predict hydropower generation based on rainfall while other factors remain constant. Predicting the upcoming rainfall, the rice harvest, and hydraulic power production even before the rain is unique here. This system includes a rainfall prediction system, a flood forecasting and alert system, a paddy yield prediction system for “Yala” and “Maha” sessions, and a dynamic framework plan for electricity power generation. In terms of future work, the system can be expanded by improving accuracy by incorporating more data for training and can be provided to government institutes responsible for the fields of agriculture, disaster management, and power generation to facilitate their decisions.

VI. ACKNOWLEDGEMENT.

We would like to convey our sincere gratitude to the Department of Meteorology, Ministry of Disaster Management, Sri Lanka Electricity Board, and Ministry of Agriculture for providing the necessary data for conducting this study as well as to our supervisor, co–supervisor, and the experts who provide us advice.

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