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Artificial Neural Network for Forecasting Monsoon Rainfall of South-West Region in Bangladesh

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ABSTRACT

Changing patterns of climate factors have become a point of discussion in recent times worldwide. Several aspects of an individual's prosperity, like communal, financial, and ecological increment, were impacted directly or circuitously by climate change. Moreover, the Bangladeshi people's life is extremely affected by heavy rainfall because of its geographical structure, especially in the South-West region. Hence, this paper has experimented with the monthly average monsoon data of average temperature, wind speed, relative humidity, mean sea-level pressure, cloud cover, and rainfall from 1981-2018 and predicted the precipitation of 9 meteorological stations from 2019-2028 of the South-West part of Bangladesh. The monthly average monsoon rainfall strongly correlated with relative humidity, mean sea-level pressure, and cloud cover among all the mentioned weather variables. An artificial neural network (ANN) model was formulated with a gradient descent algorithm to predict the rainfall. R^2 value was also measured to see the accuracy of the model. Thereafter, the nine stations of the given region have the following order of average monsoon rainfall: *Khepupara(15.22mm)>Potuakhali(14.01mm)>Bhola(11.36mm)>Barishal(10.68mm)>Mongla(10.25mm)>Khulna(9.33mm)>Satkhira(9.00mm)>Faridpur(8.67mm)>Jashore(8.64mm).* The predicted and real rainfall patterns showed the same escalating or plummeting trends for each station, which justified the ANN model for predicting the monthly average monsoon rainfall of the South-West region in Bangladesh. Such a rainfall prediction can assist people of this region to be more equipped for adverse heavy rain, saving lives and decreasing infrastructure loss during the monsoon season.

INTRODUCTION

Weather forecasting is the dispensation of scientific knowledge for the practical purpose of predicting the condition of the atmosphere for a given location and time. Among them, rainfall is a significant and complicated weather phenomenon whose prediction boosts the development of water resources, mainly in Bangladesh's climate change regions. Since climate change affects the rainfall pattern, it causes floods, droughts, etc. Moreover, rainfall prediction with a good model is inevitable to extrapolate the brunt.

As Bangladesh is in the climatology of the Asian monsoon system, hence the climate of this regime is differentiated by a seasonal variation of surface wind and a remarkable seasonality of rainfall and stays from June to mid-October (Ahmed and Kim, 2003; Shahid, 2010). The previous record shows that most of the natural calamities and rainfall occurred during this period. In the South-East part of the country, the rain is shown in a changing pattern, and monsoon rainfall is not suggested based on the overall evidence (Rahman *et al.*, 1997). The next highest rainfall occurs in the southeastern region, and the following heights are in the northeastern part of Bangladesh (Ahsan *et al.*, 2010). A unimodal pattern has been seen in the mean monthly rainfall in Bangladesh, with high rainfall in the monsoon season, with the highest in July, and low rainfall between December-February with the weakest in January (Ahsan *et al.*, 2010). Bangladesh's mean summer monsoon rainfall is1769.14mm, and the country's average monsoon rainfall is decreasing by -0.53 mm/year (Ahsan *et al.*, 2010).

In Bangladesh, the highest temperature is seen in the South-West, and the lowest is in the northeast. The average temperature in the cool season varies from 13°to 26° C; in the hot season, it varies from 25° to 31° C (Climate Change Profile: Bangladesh, 2018). Rainfall in Bangladesh also differs with location and season, where the central west receives less than 1400mm per year, and the northeast and South-East receive over 3000mm per year. Moreover, Bangladesh is a developing country where most people earn their livelihood from agriculture or shrimp farming, which makes much foreign currency. Moreover, Sundarban and Kuakata Sea Beach are also

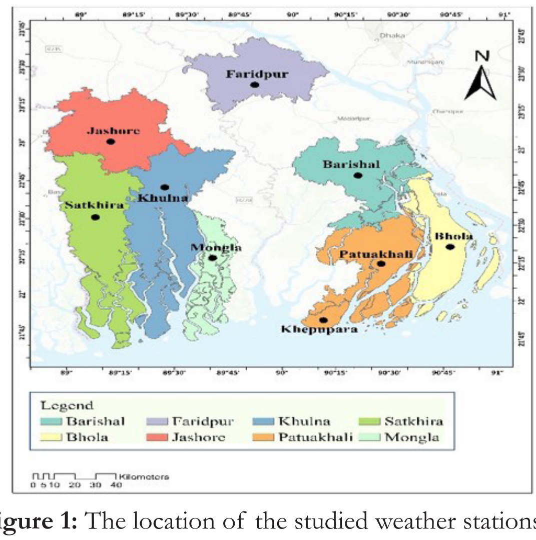

Figure 1: The location of the studied weather stations

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situated here. Between 1991-2000, about 93 disasters occurred here, caused in 200000 deaths and USD 5.90billion in damages to agriculture and infrastructure (Shaibur *et al.*, 2017). Among them, most of the damages occurred in the South-West region. In figure 1, the topographic areas of the nine meteorological stations of the South-West region have been represented.

The main objective of this paper is to apply the ANN model for rainfall prediction, forecast it, and implement them towards the removal of sufferings of people living in the South-West region of Bangladesh.

LITERATURE REVIEW

To yield accurate results, some statistical methods have been developed to forecast rainfall and other meteorological variables. Some researchers have developed rainfall forecasting models by autoregressive integrated moving averages (ARIMA), simple method regression analysis (SRA), exponential smoothing method (ES), etc. Several studies have reported that these methods are still inaccurate in forecasting rainfall because of the non-linear dataset (Haviluddin and Alfred, 2014; Shrivastava *et al.*, 2012). Nevertheless, in some incidences, the statistical models also give accurate results of rainfall prediction (Farajzadeh *et al.*, 2014).

In addition to the upliftment of computing technology, several authors have analyzed many models to study rainfall forecasting. Ara *et al.* (2005) have driven research on surface dry bulb temperature (DBT) and its trend in Bangladesh. This research has revealed that in the pre-monsoon season, the average DBT has decreased; in the monsoon and post-monsoon seasons, it has increased all over the country. Ahmed and Kim (2003) have directed research with statistics to analyze Bangladesh's daily pattern of summer monsoon rainfall. Another researcher, Abhishek *et al.* (2012), also analyzed a weather forecasting model using an Artificial Neural Network with the data series of some weather variables for ten years (1999-2009) at the station Toronto Lester B. Pearson Int'l A, Ontario, Canada. Valipour *et al.* (2013) have also researched to forecast the Dez dam reservoir's monthly inflow and compared ARMA, ARIMA, and the auto-regression artificial neural network models. Navid and Niloy (2018) have also driven experiments predicting rainfall in Bangladesh using Multiple Linear Regression (MLR). Another researcher Bilgili (2010), has conducted research on soil temperature prediction by linear regression, non-linear regression, and artificial neural network (ANN) models. The outcome of this research has stated that using the ANN model is better than the other two models for soil temperature prediction. All these research papers have measured the accuracy of the predicted models on rainfall. However, they have not calculated the forecasted values, which encouraged us to work on this issue.

MATERIALS AND METHODS

The daily average data of temperature, wind speed, humidity, mean sea-level pressure, cloud cover, and rainfall of 9 stations: Satkhira, Khulna, Jashore, Barishal, Bhola, Faridpur, Khepupara, Patuakhali, and Mongla from the period 1981-2018 (June-October) were collected from the Bangladesh Meteorological Department (BMD).

Table 1: Stations and Meteorological Data Period

General Location	Station Name	Period of Record Used	Period of Missing Data	Number of Years of Availability of Data
SW Bangladesh	Satkhira	1981-2018	1989, 1999	36
	Khulna	1981-2018	1989, 1999	36
	Jashore	1981-2018	1989, 1999	36
	Barishal	1981-2018	1989, 1999	36
	Bhola	1981-2018	1989, 1999	36
	Faridpur	1981-2018	1989, 1999	36
	Khepupara	1981-2018	1989, 1999	36
	Potuakhali	1981-2018	1989, 1999	36
	Mongla	1991-2018	-	28

It is significant to mention that data for 1989 and 1999 were not available in Satkhira, Jashore, Barishal, Bhola and Faridpur stations. To make a comparison, we also didn't consider the data of these two years for the other stations. The Mongla station was established in 1989, and the data availability was from 1991. So, we have used data from 1991 to 2018 for this study for Mongla station. Moreover, some steps have been taken to continue further analysis, as shown in figure 2.

Some data remained missing, and we used the series method to fill up these missing values to process the data. The outliers have been detected by Mahalanobis distance

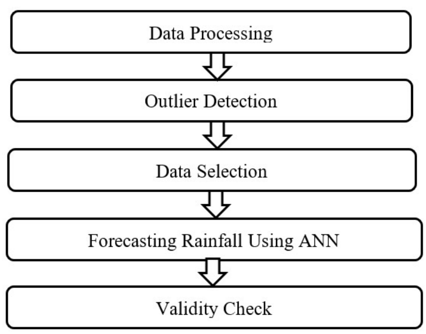


Figure 2: Processes of methodology.

and deleted from the data set. The Mahalanobis distance is applied to trace the outliers in statistical analysis. It is the distance between a distribution and a point in multivariant space. Once the outliers had been deleted from the data set, daily average data were obtained monthly.

Correlation between Rainfall and Climate Parameters

Table 2. shows that the order of the spearman's rank correlation coefficient between monthly average rainfall and meteorological variables remained the same for the stations Satkhira, Khulna, Jashore, Barishal, Bhola, and Faridpur. Spearman rank correlation is performed to measure how these data are correlated with the monthly average rainfall. Since our data are not normally distributed, we used Spearman rank correlation in this study.

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2-1)} \quad (1)$$

Where ϱis the Spearman rank correlation coefficient,dis the difference between two ranks of the different observations, and n is the number of data.

The order is *Cloud Cover>Humidity>Mean Sea-Level Pressure>Wind Speed>Average Temperature*. The correlation between cloud cover and average rainfall is vital because when the hot air of the atmosphere evaporates the moisture (water) by the divergence and convergence of air, it slowly cools down and is condensed. As much as the clouds are thickened, the friction between them occurs, as well as the rainfall. Humidity is next to the cloud cover in this correlation part because as much as the humidity, the more water vapor, the more significant the precipitation. It showed less impact on rainfall than cloud cover in these stations. Next comes the mean sea-level pressure, which exposed a slightly strong negative correlation with the monthly average rain, i.e., lower values in the mean sea-level pressure in these stations are associated with an increase in rainfall and vice-versa. After mean sea-level pressure into the order of correlation coefficients, wind speed comes. It displayed a positive, slightly weak relation with the monthly average precipitation, i.e., higher values in the wind speed in these stations are accompanied by an increase in rainfall and vice-versa. Lower wind speeds prefer less evaporation, which stabilizes the boundary layer. Hence, precipitation decreases and vice-versa. The average temperature comes next to the order of the correlation coefficients in these stations. It showed a positive relationship with the monthly average temperature because the rise of the average temperature of the earth's surface causes more evaporation and increases overall rainfall.

In Khepupara, the order of spearman's rank correlation coefficient between monthly average rainfall and meteorological variables is *Humidity>Mean Sea-level Pressur>Wind Speed>Cloud Cover>Average Temperature*. Here, all the variables have a positive relationship with the monthly average precipitation except mean sea-level pressure. In Potuakhali, the order of spearman's rank correlation coefficient between monthly average rainfall and meteorological variables is *CloudCover>Mean Sea-Level pressure>Humidity>Wind Speed> Average Temperature*.

Here all the variables showed a positive relationship with the monthly average precipitation except mean sea-level pressure and average temperature. Since it is the entrance of the beach of the Kuakata, the rain has a cooling effect on the sea surface by decreasing the near-surface air temperature (Zuidema, 2007). In Mongla, the order of spearman's rank correlation coefficient between monthly average rainfall and meteorological variables is *Humidity>Wind Speed> Cloud Cover> Average Temperature>Mean Sea-Level Pressure*. Here, all the variables have a positive relationship with the monthly average precipitation. The positive correlation with the monthly average precipitation suggests that rainfall is related to a westerly airflow on the Mongla (Rogers and Dowla, 1994).

It is eminent that rainfall is related to several meteorological variables. The above-mentioned meteorological variables are chosen for this research analysis because of their unique relationship with monthly average monsoon rainfall.

Artificial Neural Network (ANN)

The ANN is an engineering notion of learning in the field of artificial intelligence, which is similar to the human brain, shown in figure 3 (Gogoi, 2017). Here, the input layer is compared with the dendrites of the human brain as it receives the signals.

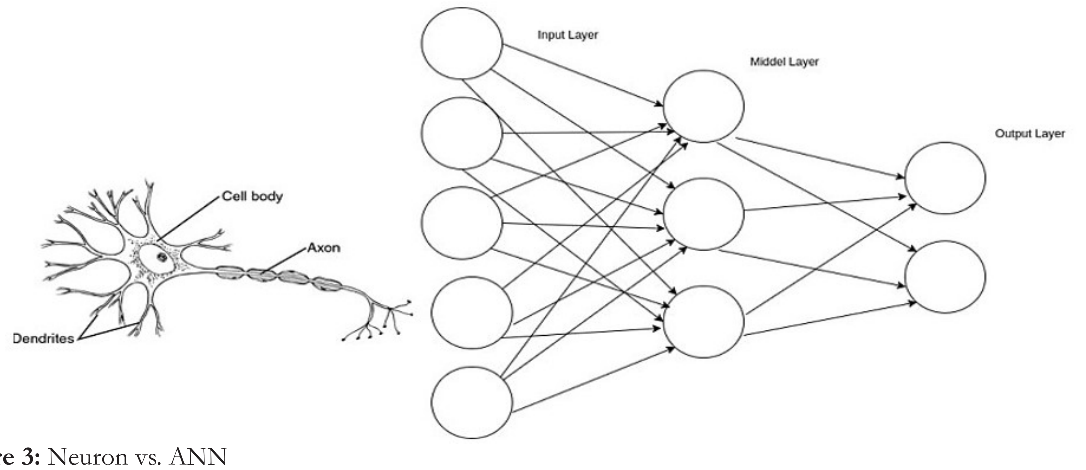


Figure 3: Neuron vs. ANN

After that, these signals are moved through the neural network. Each neuron transmits the information to other neurons to manage the issue. It is constructed with many elements, called neurons which distribute processing information right away. Yet the ANN can be trained with many processes along with Backpropagation, Perceptron, Delta, and Self-Organizing Map (SOM) (Shrivastava *et al.*, 2012; Farajzadeh *et al.*, 2014). Hence, this research paper proposed a gradient descent algorithm to predict rainfall to acquire more accurate outcomes.

Table 2: Spearman's rank correlation coefficient between monthly average rainfall and meteorological variables of the study areas

Meteorological Station	Average Temperature	Wind Speed	Humidity	Mean Sea-Level Pressure	Cloud Cover
Satkhira	0.078	0.152	0.481	-0.446	0.578
Khulna	0.096	0.211	0.533	-0.468	0.628
Jashore	0.136	0.413	0.478	-0.500	0.545
Barishal	0.068	0.434	0.562	-0.557	0.658
Bhola	0.04	0.427	0.57	-0.557	0.676
Faridpur	0.112	0.37	0.665	-0.501	0.668
Khepupara	0.045	0.373	0.587	-0.563	0.089
Potuakhali	-0.023	0.283	0.533	-0.536	0.703
Mongla	0.558	0.671	0.825	0.317	0.577

A three-layer neural network has input, hidden, and output layers. Each neuron in every layer is associated with a neuron of the neighboring layer with several weights. Each neuron gets gestures from the neurons of the former layer without the input layer. An output signal is then generated by transiting the summed signal through an activation function (Maqsood *et al.*, 2015).

In the ANN, different layers may execute different works. But the main objective of the ANN is to solve a problem as the human brain does. The initial processing component of an ANN is a neuron. This fundamental processing element is mathematically described in the undermentioned equations (Haykin, 1994);

$$v_{ij} = \theta_j + \sum_{j=1}^{n} w_{ij} X_i \qquad (2)$$

$$h_j = \frac{1}{1 + e^{-v_{ij}}} \qquad (3)$$

$$v_{jk} = \theta_k + \sum_{k=1}^{p} w_{jk} h_j \qquad (4)$$

$$Y_k = \frac{1}{1 + e^{-v_{jk}}} \qquad (5)$$

Where n is the number of input nodes, X is the signal, w is the weights,θis the bias of the hidden node. The nodes in the hidden layers receive a signal (X) with the weights (w) and calculate a weighted sum (v). Then, this weighted sum passes through an activation function which indicates which nodes are activated. Then the activated nodes in the hidden layer pass the signal to each node of the output layer like the hidden layer, and finally, the estimated outputs (Y) are received.

RESULTS AND DISCUSSIONS

In the ANN technique, the input data were normalized in equation 6 in the range of [0,1].X_N is the normalized value, X_i is the actual value, X_{imax} is the maximal value, and X_{imin} is the minimum value. By normalization, the training data has improved. The ANN was run into the MATLAB software, and the number of hidden layers with hidden neurons from 4 to 10 was taken. Testing data tested the model. The gradient descent algorithm was used to train the data set, and the logistic sigmoid function was used as an activation function for both the hidden and output layers.

$$X_N = \frac{(X_i - X_{i_{min}})}{(Xi_{min_{i_{max}}})} \qquad (6)$$

ANN architecture of Satkhira, Khulna, Jashore, Barishal, Bhola, Faridpur, Khepupara, Patuakhali, and Mongla districts used in this research paper is shown in figure 4, where it includes an input layer with five neurons, one hidden layer with 8,7,8,7,8,8,9,8,5 neurons respectively, and an output layer with one neuron. After taking the learning rate (lr)0.01, the best fit result of the monthly average rainfall of the monsoon season was obtained after 3500, 3000, 2500, 2000, 1000, 1000, 2000, 2500, and 1500 epochs for Satkhira, Jashore, Khulna, Barishal, Bhola, Faridpur, Khepupara, Potuakhali and Mongla stations, respectively.

In this research paper, we trained the ANN model with more than one hidden layer. As a result, fewer errors in the prediction model were found, but it overfitted the model. Hence, one hidden layer was taken for the ANN model of monthly average monsoon rainfall.

The R^2value has been performed on the tested data to see the model's accuracy. The formula of R^2 is

$$R^2 = \frac{\sum(\hat{y}_i - \bar{y})^2}{\sum(y_i - \bar{y})^2} \qquad (7)$$

Where y_i is the predicted rainfall, y_i the actual rainfall, and y^- the mean of the actual rain. The Mongla Station showed a R^2value of 79%. The other eight stations have the following order of monthly average monsoon

Khepupara(82%)>Potuakhali(92%)>Bhola(93%) Barishal(89%)>Khulna(89%)>Satkhira(88%) Faridpur(92%)> Jashore(89%).

In figure 5 (a, b, c, d, e, f, g, h, i), each South-West region meteorological station's predicted and actual monthly average monsoon rainfall has been shown. ANN model predicted the precipitation of these stations by calculating the average values of the other independent weather variables from their changing pattern. A massive fluctuation in rainfall has been seen in each of mentioned stations. In Khulna station, the average highest monsoon rainfall of about 7.62mm will be seen in 2024, which will remain stable in 2024. After that, this value will slightly decrease by approximately 0.13mm in 2028. Figure 5(b) shows the actual and ANN predicted rainfall, where this graph led to the highest rainfall in 2019, with4.46mm. This amount will plummet by 0.04-0.05mm for the rest of the years. After this downward trend in the predicted average monsoon rainfall, the lowest amount will be seen in 2028, around4.06mm.

Table 3: R^2 value of prediction results

Stations	Satkhira	Khulna	Jashore	Barishal	Bhola	Faridpur	Khepupara	Potuakhali	Mongla
ANN	0.8768	0.8916	0.8923	0.886	0.9304	0.9192	0.8163	0.9166	0.7915

Moreover, the lowest precipitation will be around 7.07mm in 2019, which will minimally escalate by 0.55mm up to 2024. The amount of average monsoon rainfall of Khulna station has been shown in detail in table 4. The highest monsoon precipitation will be seen in September 2019, with 8.62mm, in August 2020 and 2021, with 8.80mm and 9.27mm, respectively, and in July for the rest of the years. These pieces of information are mentioned in table 4.

In table 5, the data of the ANN predicted rain of Jashore station has been shown clearly. This table has told us that the highest rainfall would be in July and the lowest in October for all the predicted years in this paper.

The actual rainfall and predicted rainfall have been shown in figure 5(c). Between 2019-2028, the lowest monsoon average rainfall will be seen, with an amount of approximately 5.74mm in 2028, while the highest will be in 2019, with around 6.26mm. This highest rainfall will fall slightly by 0.03-0.09mm up to 2028. Table 6 has represented the predicted rainfall of Satkhira station for each month with their average. In August, the average monsoon rainfall will be highest for all the mentioned predictable years except 2019, 2020, and 2021, whereas the lowest amount will be seen in June, except 2019.

In figure 5(d), the fluctuation of actual rainfall and predicted rainfall has been seen. It is manifested that the predicted monsoon average rainfall at Barishal station will have a decreasing trend. This amount will fall by 0.17mm from 2019 to 2024. Table 7 also shows that the highest monsoon average precipitation will be on July 2019, with around6.52mm. The most striking feature is that this amount will remain almost the same in August and October.

However, in some years, it can fluctuate; this amount should not be considered because of its very few changes. Among the other monsoon months, the precipitation will soar by an amount ranging from 0.22-0.88mm from 2019-2028, except September. Approximately 0.22mm of rain will be increased from 2019 to 2028. In Bhola station,

Table 4: Predicted rainfall (mm) of Khulna station

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
June	8.02	7.63	7.26	6.97	6.77	6.65	6.60	6.60	6.64	6.70
July	6.84	7.77	8.59	9.26	9.80	10.19	10.44	10.57	10.58	10.48
Aug	8.17	8.80	9.27	9.57	9.72	9.73	9.62	9.43	9.18	8.92
Sept	8.26	8.14	7.97	7.79	7.64	7.50	7.41	7.34	7.31	7.29
Oct	4.09	4.07	4.06	4.05	4.04	4.04	4.04	4.05	4.06	4.08
Avg	7.07	7.28	7.43	7.53	7.59	7.62	7.62	7.60	7.55	7.49

Table 5: Predicted rainfall (mm) of Jashore station

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
June	3.36	3.35	3.35	3.36	3.37	3.39	3.40	3.42	3.45	3.47
July	6.03	6.04	6.06	6.07	6.07	6.07	6.07	6.05	6.04	6.02
Aug	5.04	4.89	4.75	4.61	4.47	4.34	4.22	4.10	3.98	3.87
Sept	5.09	4.97	4.86	4.74	4.62	4.50	4.38	4.26	4.13	4.01
Oct	2.78	2.80	2.81	2.82	2.84	2.85	2.86	2.88	2.89	2.89
Avg	4.46	4.41	4.37	4.32	4.28	4.23	4.19	4.15	4.10	4.06

the average precipitation will decrease in all the monsoon months except October, shown in figure 5(e). Around 0.23mm of rainfall will rise, comparing the rain of 2019 and 2028. The maximum decrease of precipitation will be seen in June and July by1.8mm, among the years of the prediction. These pieces of information have been given more clearly in table 8. In this table, the forecasted rainfall has been provided with its approximate values

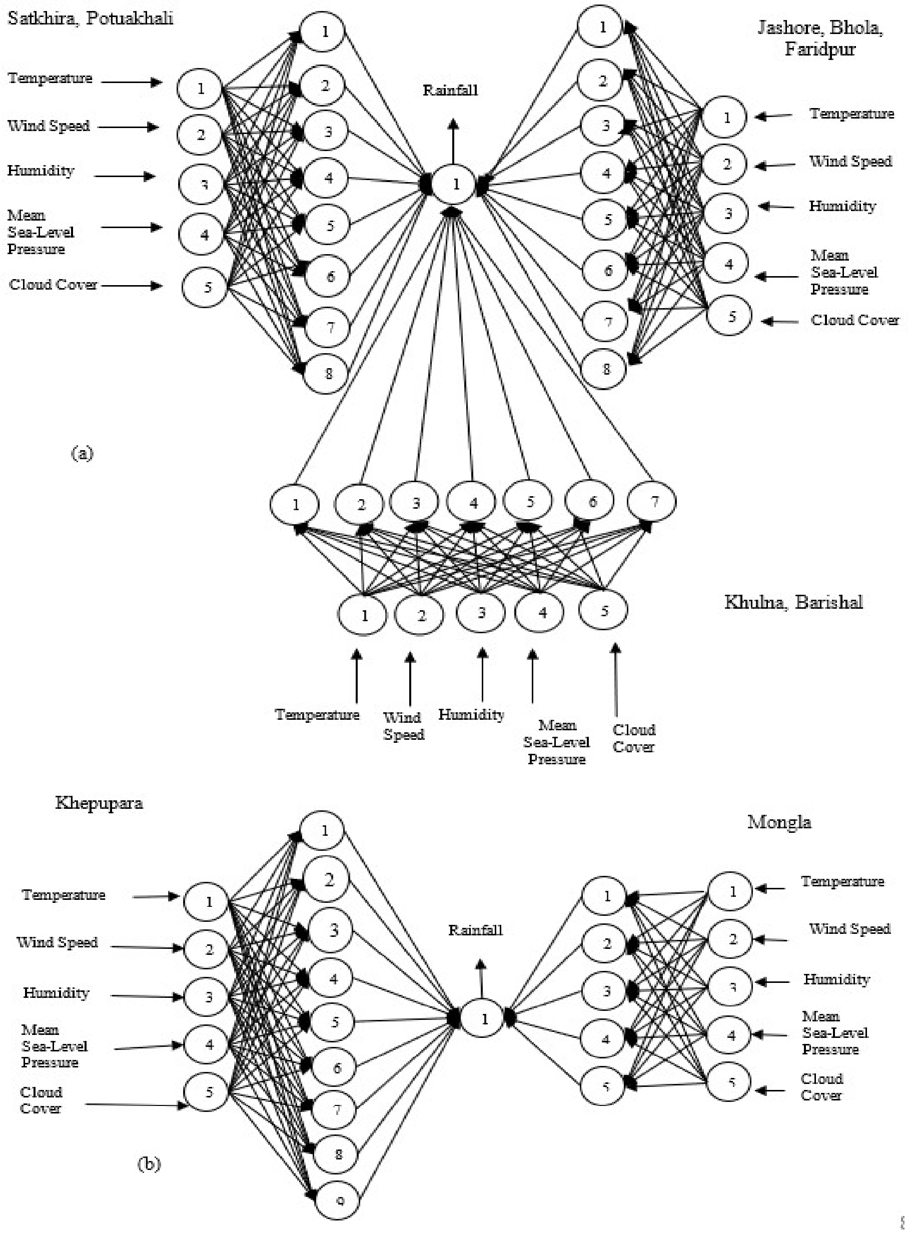
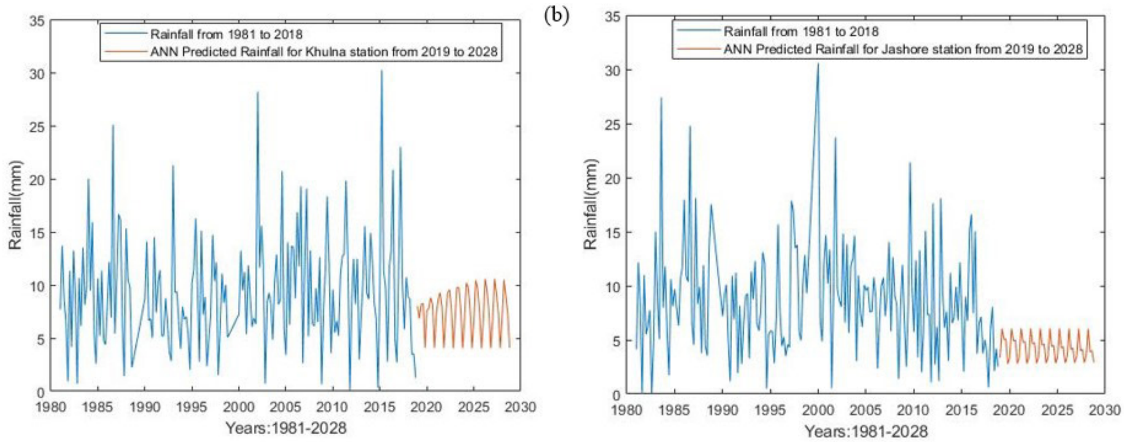


Figure 4: ANN architecture of 9 stations

(a) (b)



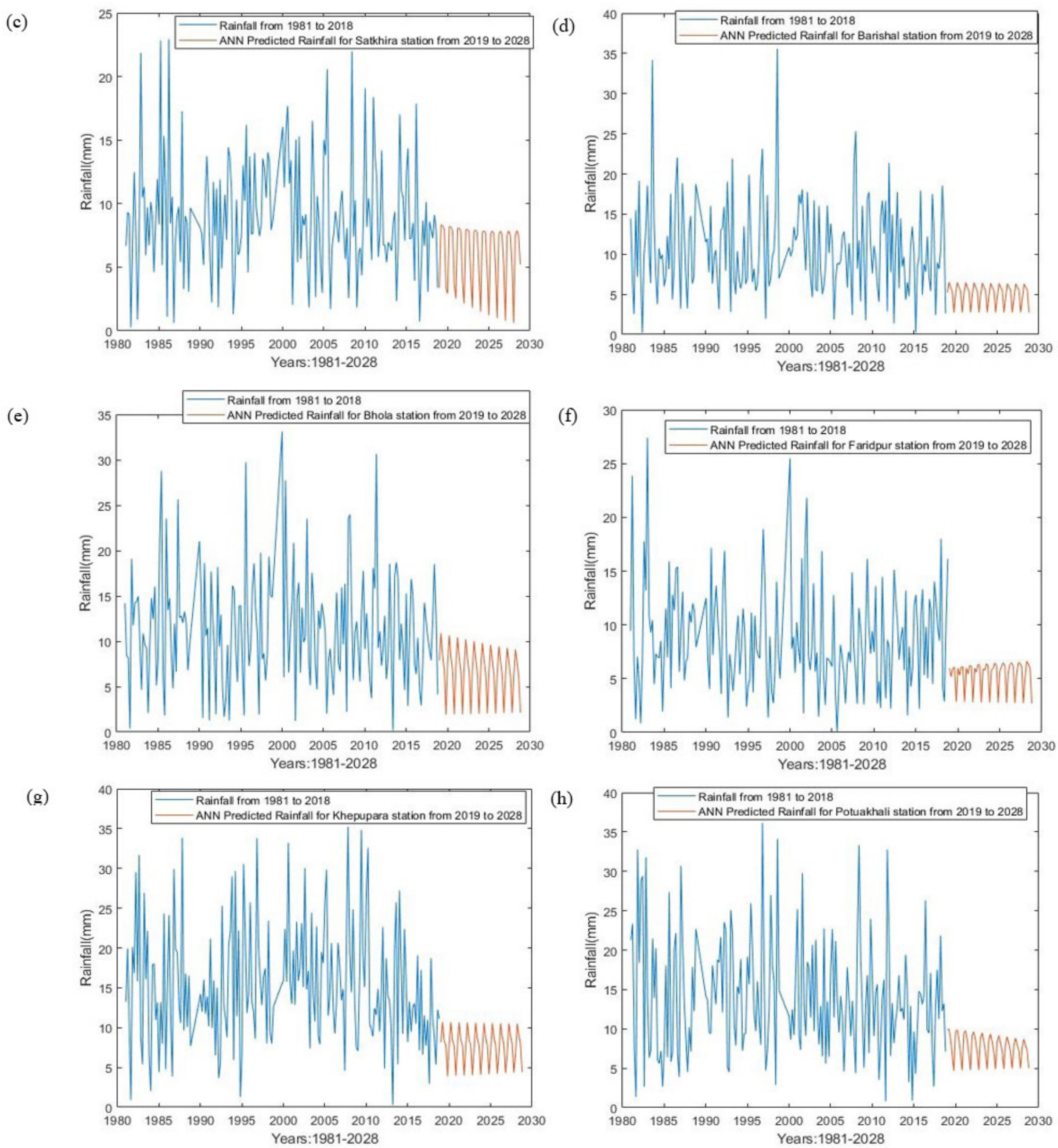


Figure 5: ANN predicted rainfall of Khulna (a), Jashore (b), Satkhira (c), Barishal (d), Bhola (e), Faridpur (f), Khepupara (g), and Potuakhali (h)

Table 6: Predicted rainfall (mm) of Satkhira station

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
June	3.39	2.94	2.53	2.15	1.8	1.49	1.22	0.98	0.78	0.62
July	8.34	8.2	8.08	7.95	7.84	7.73	7.64	7.57	7.53	7.51
Aug	8.27	8.16	8.07	7.98	7.92	7.87	7.84	7.83	7.84	7.87
Sept	7.95	7.88	7.82	7.77	7.72	7.68	7.64	7.61	7.56	7.52
Oct	3.37	3.67	3.97	4.26	4.52	4.74	4.91	5.04	5.14	5.21
Avg	6.26	6.17	6.09	6.02	5.96	5.9	5.85	5.81	5.77	5.74

The predicted rainfall of Faridpur station has been seen in an increasing trend between the years 2019 and 2021 in June from 5.94mm to 5.98mm. These data are shown in table 9, whose graphical representation is also given in figure 5(f). The average monsoon cloudburst will fall by 0.12mm in 2028 from 2019. This amount will increase to around 5.44mm in 2022 but will remain stable until 2023. After that, it will start to decrease with very little

Table 7: Predicted rainfall (mm) of Barishal station

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
June	5.24	5.18	5.1	5.02	4.92	4.82	4.71	4.59	4.48	4.36
July	6.52	6.49	6.46	6.44	6.41	6.39	6.36	6.34	6.32	6.3
Aug	5.88	5.88	5.87	5.87	5.87	5.87	5.87	5.87	5.87	5.87
Sept	5.37	5.39	5.42	5.44	5.47	5.49	5.52	5.54	5.57	5.59
Oct	2.73	2.73	2.74	2.74	2.74	2.74	2.75	2.75	2.75	2.75
Avg	5.15	5.13	5.12	5.1	5.08	5.06	5.04	5.02	5	4.98

rainfall. The same characteristics will be seen for the rainfall of June at this station. This amount will increase and decrease in July and October without any ups and downs, respectively. However, an exception may be seen in August and September, where the rainfall may increase and decrease with fluctuations between 2019 and 2028.

The second-highest monsoon average precipitation may occur in August 2028. The most striking feature is that the lowest rainfall at Khepupara station may be seen in October, but this amount may rise over one decade from 2019 to 2028.All these information have been given into figure 5(g) and table 10.

In figure 5(h) and table 11, the average monsoon rainfall of Potuakhali station has been shown to increase by 0.72mm between 2019 and 2028. The highest rainfall may occur in 2019, with an amount of 8.02mm. The maximum monsoon rainfall may occur in July in the given period. Apart from that, the second highest rainfall may happen in June in the mentioned period, except in 2028.

An increasing trend may be seen in the average monsoon rainfall of the Mongla station, shown in figure 6 and table 12. The most striking feature is that all the monsoon months may show a plummeting trend in the average rainfall, except September. Despite this, the maximum rainfall may be seen in July, ranging from 5.63mm to 5.86mm. In this station, the rainfall of June, July, August, and September may not differ that much; however, an exception may be seen in the rainfall of October with a minimum amount.

Comparison of Rainfall Pattern

The average monsoon rainfall of Satkhira, Khulna, Jashore, Barishal, Bhola, Faridpur, Khepupara, Potuakhali, and Mongla stations has been calculated as 9.00 mm, 9.33 mm, 8.64 mm, 10.68mm, 11.36mm 8.67mm, 15.22mm, 14.01mm and 10.25mm respe-ctively in the period 1981-2018. The Mongla Stations will be out of comparison because of the mismatch of the recorded data. These eight stations have the following monthly average monsoon rainfall from 1981-2018:Khepupara> Potuakhali>Bhola>Barishal>Khulna>Satkhira> Faridpur>Jashore. The average monsoon rainfall of the Satkhira station from June-October is 9.80 mm, 11.37 mm, 9.67 mm, 9.51 mm, and 4.66 mm gradually. For the Khulna station, it is 10.92 mm, 11.65 mm, 10.53 mm, 9.20 mm, and 4.37 mm; for the Jashore station, it is 10.22 mm, 11.48 mm, 8.76 mm, 8.68 mm, 4.40 mm; for the Barishal station 13.55mm, 13.56mm, 11.41mm, 9.43mm, 5.42mm; for the Bhola station 14.98mm, 14.41mm, 12.43mm, 9.64mm, 5.34mm; for Faridpur station 10.47mm, 11.15mm, 9.48mm, 7.85mm, 4.39mm; for Khepupara 17.17mm, 22.11mm, 15.48mm, 13.04mm, 8.29mm; for Potuakhali 17.02mm, 18.93mm, 14.85mm, 12.02mm, 7.21mm; for Mongla 11.59mm, 13.16mm, 10.79mm, 10.33mm, 5.39mm from June-October respectively. From this analysis, it is evident that for each of the nine stations of our research paper, the monthly average monsoon rainfall has the following order: *July>June>August>September>October, except Bhola. In Bhola, the order is June>July>August>September>October* because of the variability of the recorded data.

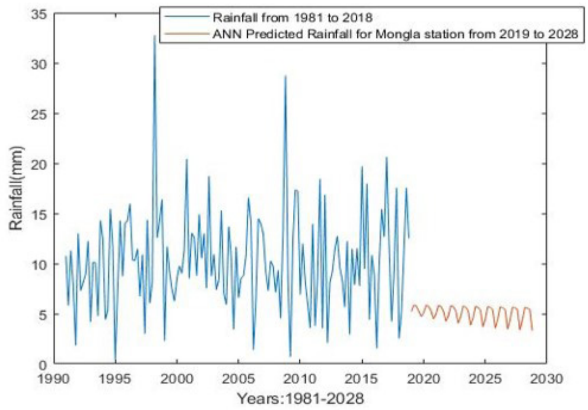


Figure 6: ANN predicted rainfall of Mongla (i) station

Table 8: Predicted rainfall (mm) of Bhola station

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
June	7.88	7.6	7.36	7.13	6.93	6.74	6.56	6.4	6.24	6.08
July	10.89	10.65	10.43	10.21	10.01	9.81	9.62	9.44	9.26	9.09
Aug	8.38	8.29	8.2	8.13	8.05	7.98	7.91	7.84	7.77	7.7
Sept	6.76	6.67	6.59	6.5	6.42	6.33	6.24	6.15	6.05	5.96
Oct	1.91	1.93	1.95	1.97	2	2.02	2.05	2.08	2.11	2.14
Avg	7.16	7.03	6.91	6.79	6.68	6.58	6.48	6.38	6.29	6.19

Table 9: Predicted rainfall (mm) of Faridpur station

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
June	5.94	5.97	5.98	5.96	5.9	5.8	5.65	5.46	5.22	4.95
July	5.17	5.3	5.44	5.6	5.78	5.96	6.14	6.32	6.48	6.62
Aug	5.98	6.09	6.2	6.3	6.38	6.45	6.48	6.48	6.44	6.34
Sept	6.05	6.11	6.16	6.2	6.22	6.23	6.2	6.16	6.08	5.97
Oct	2.85	2.83	2.81	2.8	2.78	2.76	2.74	2.73	2.71	2.69
Avg	5.32	5.39	5.43	5.44	5.44	5.41	5.37	5.32	5.26	5.2

The trend has been calculated for the average monsoon rainfall from 1981-2018 and the predicted average monsoon rainfall of 2019-2028 to justify the trend of the predicted values. In this section, we have drawn a linear trend line, and from where we found out the equation of this line for the rainfall of each station of the South-West region. Figure 7(a) has manifested that the rainfall has an increasing trend over Khulna station in the period of 1981-2018 and 2019-2028, with the coefficient of determination of 0.0565 and 0.5017, respectively. In 1981-2018, the average monsoon rainfall increased by 0.0462mm/year; in 2019-2028, it escalated by 0.0462mm/year. In figure 7(b), a comparison has been made between the actual and ANN-predicted average monsoon rainfall of Jashore station. It is evident that both periods have a decreasing trend over the rainfall of this station, with the coefficient of determination of 0.0008 and 0.9998, respectively. In 1981-2018 and 2029-2028, the average monsoon rainfall fell by 0.0055mm/year and 0.0449mm/year, respectively

Table 10: Predicted rainfall (mm) of Khepupara station

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
June	8.13	7.93	7.73	7.54	7.36	7.2	7.05	6.91	6.79	6.65
July	10.69	10.66	10.64	10.62	10.59	10.57	10.55	10.53	10.51	10.49
Aug	8.34	8.41	8.49	8.57	8.65	8.73	8.81	8.89	8.97	9.05
Sept	7.7	7.7	7.71	7.73	7.75	7.78	7.82	7.88	7.94	8.01
Oct	3.9	3.94	3.99	4.04	4.09	4.15	4.21	4.27	4.33	4.39
Avg	7.72	7.71	7.7	7.69	7.69	7.69	7.7	7.71	7.73	7.75

Table 11: Predicted rainfall (mm) of Potuakhali station

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
June	9.86	9.67	9.43	9.16	8.86	8.55	8.26	7.98	7.75	7.56
July	9.99	9.88	9.76	9.62	9.47	9.32	9.16	9	8.84	8.68
Aug	8.8	8.71	8.62	8.53	8.44	8.34	8.25	8.16	8.06	7.98
Sept	6.76	6.81	6.86	6.91	6.96	7	7.06	7.11	7.16	7.21
Oct	4.68	4.72	4.77	4.81	4.84	4.88	4.92	4.96	5	5.05
Avg	8.02	7.96	7.89	7.8	7.71	7.62	7.53	7.44	7.36	7.3

Table 12: Predicted rainfall (mm) of Mongla station

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
June	5.22	5.09	4.94	4.8	4.67	4.56	4.48	4.42	4.39	4.37
July	5.86	5.85	5.84	5.81	5.78	5.75	5.71	5.68	5.66	5.63
Aug	5.77	5.74	5.71	5.68	5.66	5.63	5.61	5.6	5.58	5.56
Sept	5.24	5.25	5.27	5.3	5.33	5.36	5.39	5.41	5.42	5.41
Oct	4.72	4.48	4.25	4.04	3.85	3.69	3.56	3.46	3.38	3.32
Avg	4.86	4.88	4.91	4.95	5	5.06	5.13	5.2	5.28	5.36

A comparison between the actual and predicted rainfall of Satkhira station has been shown in figure 7(c). This graph tells about the decreasing trend of the given periods. The changing amount of rainfall at this station is -0.02mm/year and -0.0572mm/year between 1981-2018 and 2019-2028, respectively. The coefficient of determination has also been seen by 0.0193 and 0.9756, respectively

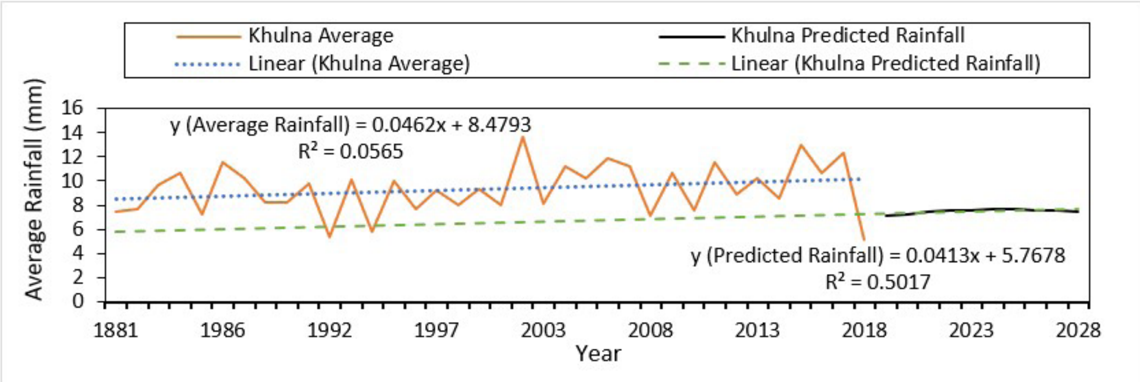


Figure 7(a): Pattern comparison between average monsoon rainfall from 1981-2018 and predicted average monsoon rainfall of Khulna station

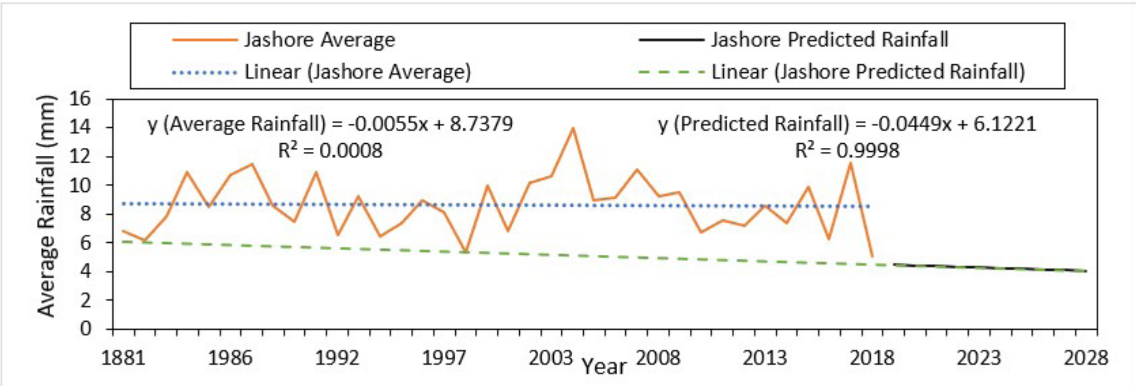


Figure 7(b): Pattern comparison between average monsoon rainfall from 1981-2018 and predicted average monsoon rainfall of Jashore station

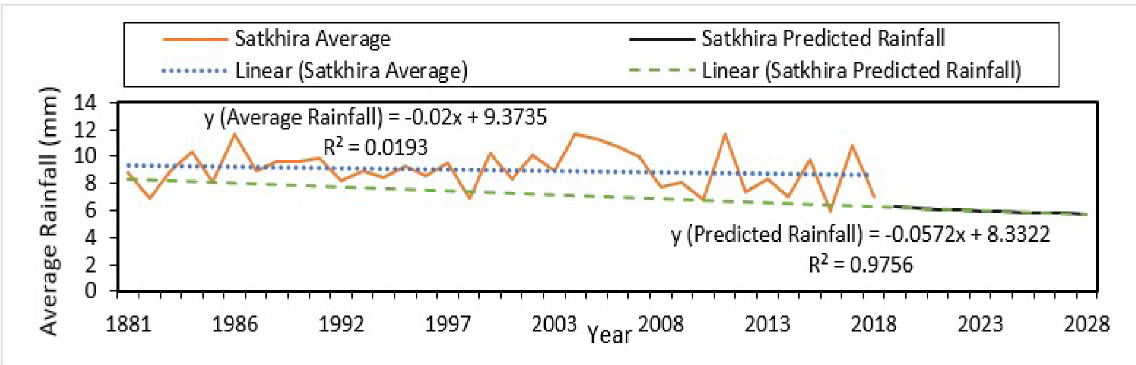


Figure 7(c): Pattern comparison between average monsoon rainfall from 1981-2018 and predicted average monsoon rainfall of Satkhira station

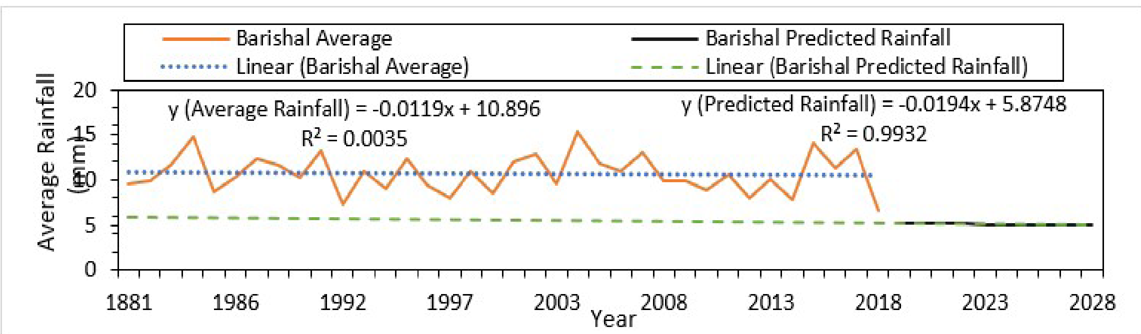


Figure 7(d): Pattern comparison between average monsoon rainfall from 1981-2018 and predicted average monsoon rainfall of Barishal station

From figure 7(d), it is clear that the rainfall has a decreasing trend over Barishal station in the period of 1981-2018 and 2019-2028, with the coefficient of determination of 0.0035 and 0.9932, respectively. In 1981-2018, the average monsoon rainfall increased by 0.0119mm/year; in 2019-2028, it escalated by 0.0194mm/year, with ups and downs in rainfall amount in several years.

A comparison between the actual and predicted rainfall of Bhola station has been shown in figure 7(e), which describes the decreasing trend of the given periods. The changing amount of rainfall of this station is -0.0393mm/year and -0.1066mm/year between 1981-2018 and 2019-2028, respectively. The coefficient of determination has also been seen by 0.0278 and 0.9964, respectively.

In figure 7(f), an analogy has been made between the real and ANN-predicted average monsoon rainfall of Faridpur station. An obvious result has been seen in this figure, that both periods have a decreasing trend over the rainfall of this station, with the coefficient of determination of 0.0275 and 0.3696, respectively. In 1981-2018 and 2029-2028, the average monsoon rainfall fell by 0.03mm/year and 0.0165mm/year, respectively.

Figure 7(g) has explained that the rainfall has an increasing trend over Khepupara station in the period of 1981-2018 and 2019-2028, with the coefficient of determination of 0.066 and 0.2444, respectively. In 1981-2018, the average monsoon rainfall increased by 0.0548mm/year; in 2019-2028, it escalated by 0.0034mm/year.

A comparison between the secondary and predicted rainfall of Potuakhali station, which has been shown in figure 7(h) asserts the decreasing trend of the given periods. This station's changing amount of rainfall is -0.0316mm/year and -0.0838mm/year between 1981-2018 and 2019-2028, respectively. The coefficient of determination has also been seen by 0.0184 and 0.9975, respectively.

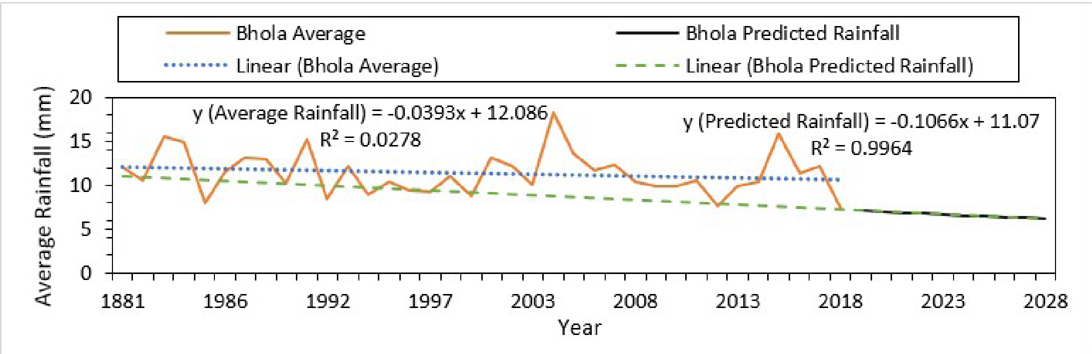


Figure 7(e): Pattern comparison between average monsoon rainfall from 1981-2018 and predicted average monsoon rainfall of Bhola station

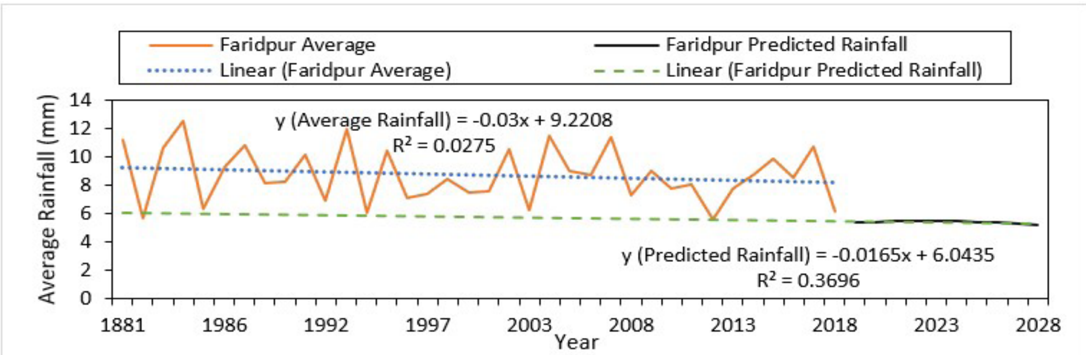


Figure 7(f): Pattern comparison between average monsoon rainfall from 1981-2018 and predicted average monsoon rainfall of Faridpur station

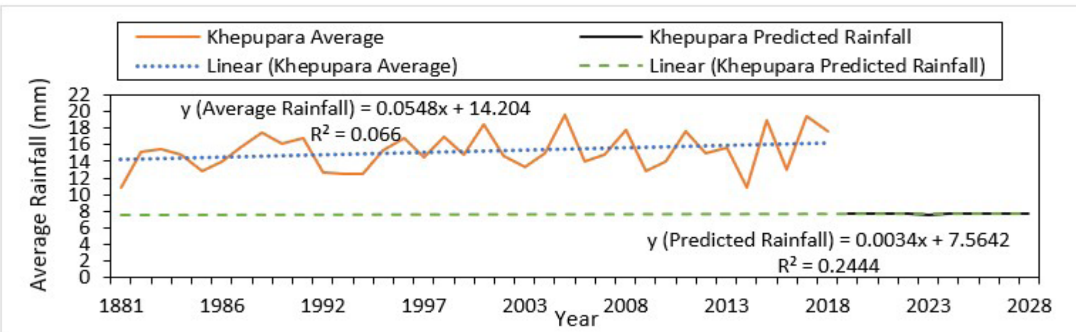


Figure 7(g): Pattern comparison between average monsoon rainfall from 1981-2018 and predicted average monsoon rainfall of Khepupara station

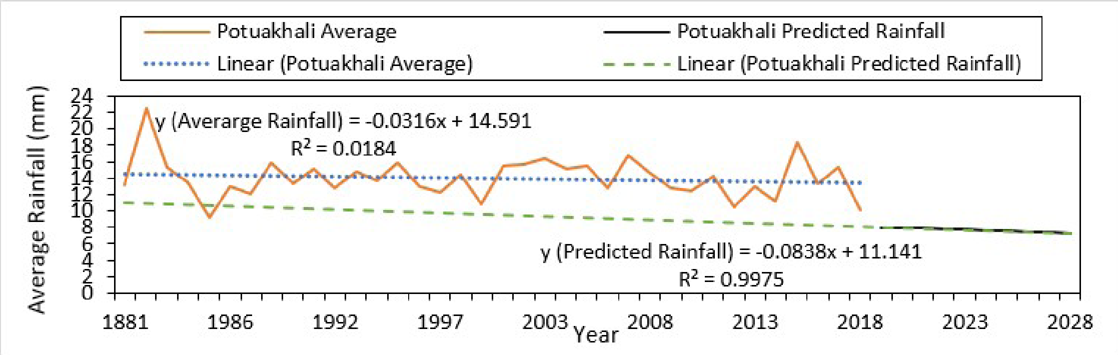


Figure 7(h): Pattern comparison between average monsoon rainfall from 1981-2018 and predicted average monsoon rainfall of Potuakhali station

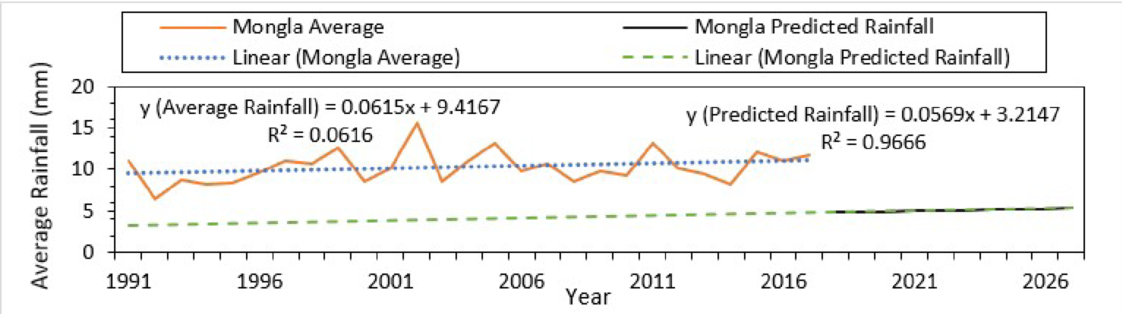


Figure 7(i): Pattern comparison between average monsoon rainfall from 1981-2018 and predicted average monsoon rainfall of Mongla station

Figure 7(i) has clearly explained whether there is any discrepancy between the actual and ANN-predicted average monsoon rainfall of Mongla station. It is evident that both periods have an increasing trend over the precipitation of this station, with the coefficient of determination of 0.0616 and 0.9666, respectively. In 1981-2018 and 2029-2028, the average monsoon rainfall fell by 0.0615mm/year and 0.0569mm/year, respectively. Graphs 6(a, b, c, d, e, f, g, h, i) have shown that the actual and the predicted rainfall have the same changing pattern. From these graphs, it has been justified that the forecasted rainfall should be almost accurate. The predicted outcome may vary a little because it has been predicted based on the average data of the independent weather variables.

CONCLUSIONS

This study aims to predict the monthly average monsoon rainfall of the South-West Region of Bangladesh by using several monthly average meteorological variables. The following conclusions have been drawn based on this research.

(1) The monthly average monsoon cloud cover has solid and positive, and the mean sea-level pressure negatively correlates with the monthly average rainfall for our study areas. Most of the mentioned stations follow the exact relationship between rainfall and other variables, where the order of correlation between them has been measured as *Cloud Cover>Humidity>Mean Sea-level Pressure>Wind Speed>AverageTemperature*, except Jashore, Potuakhali, Khepupara, and Mongla. The other stations have not maintained the same order because of the topographical structure.

(2) The ANN model has proved to be almost accurate for predicting the monthly average monsoon rainfall of each station of the South-West region in Bangladesh by calculating the R^2 value.

(3) The order of the average ANN predicted monsoon rainfall of one decade from 2019 has been calculated as (7.48mm)> *Bhola(6.65mm)> Satkhira(5.96mm)> Faridpur(5.36mm)> Barishal(5.07mm)> Mongla(5.06mm)> Jashore(4.26mm)*. These values have been calculated by taking the average value of the independent weather variables with their changing rate per year.

(4) The order of the average rainfall of the monsoon season for the period 1981-2018 is found as *Khepupara(15.22mm)> Potuakhali(14.01mm)> Bhola(11.36mm)> Barishal(10.68mm)> Khulna(9.33mm)> Sat-khira(9.00mm)> Faridpur(8.67mm)> Jashore(8.64mm)*. For Mongla, it is 10.25mm. This station is not considered in the comparison because of the non-viability of the recorded data.

(5) The maximum average predicted rainfall has been calculated in July in all the given stations except Satkhira and Faridpur. On the other hand, in all the mentioned meteorological stations, the minimum predicted average monsoon has been calculated in October, except Satkhira.

(6) The order of the monthly average monsoon rainfall for each station is found as *July>June>August>September> October,* except Bhola. For Bhola station, the order is *June> July>August>September> October.*

(7) Average monsoon rainfall for each station of the South-West region of Bangladesh has also been analyzed. The average monsoon rainfall change for Satkhira,

Khulna, Jashore, Barishal, Bhola, Faridpur, Khepupara, Potuakhali, and Mongla is -0.02, 0.0462, -0.0055, -0.0119, -0.0393, -0.03,0.0548, -0.0316, 0.0497mm/year, respectively. The negative sign indicates the decrease, and the positive sign indicates the increasing rainfall trend.
(8) Rainfall pattern comparison between average monsoon rainfall from 1981-2018 and predicted average monsoon rainfall has shown almost the same changing trend for each mentioned station.

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