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Assessment of meteorological parameters in predicting seasonal temperature of Dhaka city using ANN

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ABSTRACT

In this study, an attempt has been made to investigate the possibility of a machine learning model, Artificial Neural Network (ANN) for seasonal prediction of the temperature of Dhaka city. Prior knowledge of temperature is essential, especially in tropical regions like Dhaka, as it aids in forecasting heatwaves and implementing effective preparedness schemes. While various machine learning models have been employed for the prediction of hot weather across the world, research specially focused on Bangladesh is limited. Additionally, the application of machine learning models needs to be curated to suit the particular weather features of any region. Therefore, this study approaches ANN method for prediction of the temperature of Dhaka exploring the underlying role of related weather variables. Using the daily data for the months of February to July collected from the National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis data (0.25° × 0.25° global grid) for the years 2011–2020, this study focuses on finding the combination of weather variables in predicting temperatures. The densely populated city, Dhaka, has faced severe consequences due to extreme climate conditions in recent years, and this study will pave a new dimension for further research regarding the topic.

1. Introduction

Bangladesh, a country with tropical climate in the South Asia, has been recognized as one of the most temperate zones in the world [1]. An overall upward shift in daily maximum and minimum temperature, along with the level of discomfort resulting from excess heat during the monsoon and pre-monsoon season, has been noted [2,3]. Moreover, there is a prevailing trend of increasing temperatures in this area [4]. The increase in temperature is more pronounced in metropolitan areas, mostly due to the added effects of urban heat island (UHI) phenomena, and Dhaka is found to be one of most effected cities in Bangladesh [5]. The relation between UHI phenomenon and human discomfort is well established [6–8], and recent heatwaves have pushed the level of thermal stress in Dhaka to a life threatening height [9]. The consequence of this warming of atmosphere is reflected in the number of death tolls, demonstrating a 20 % increase during heatwave period [10]. The fact of rising temperature and its stark role in heat related risk underscores the importance of early preparedness for the hot season. Temperature also plays a key role in definition of heatwave, an emerging extreme weather event [10–12]. Therefore, the prior knowledge of temperature is substantial for the preparedness for heat related risk.

In general, studies on hot weather and heatwaves in Bangladesh have primarily relied on numerical weather prediction (NWP) systems, with researchers typically focusing on discrete heatwave events [9,13–15]. While NWP performed has been effective in

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capturing the characteristics of local heatwaves, its employment in seasonal prediction of temperature is impeded by its high computational cost. In these simulation models, the current atmospheric conditions are examined and future conditions are calculated through solving complex equations related to fluid dynamics and thermodynamics. Besides, these simulation-based weather prediction models are heavily reliant on advanced physical models and require extensive computing resources, often utilizing hundreds of nodes in high-performance computing systems. However, despite their expense, these models not always yield highly accurate forecasts. On the other hand, utilizing machine learning techniques for weather prediction is more cost-effective, and consequently there has been a growing interest in employing machine learning models in different aspects of atmospheric research [16,17]. Efforts are underway to develop machine learning based prediction models to face the challenges thrown by warm weather in different Asian countries as well, for instance, Korea, India, Pakistan and Iran [18–23]. In these works, attempts have been made to forecast the number of temperate days, or occurrence of heatwaves using different machine learning models. Consequently, the motivation to build up machine learning models in the context of Bangladesh is evident, and henceforth, this article investigated the application of artificial neural network (ANN), a machine learning model in seasonal temperature prediction of Dhaka city.

ANN, a deep learning based machine learning model, has been widely used in the context of urban area. In recent years, ANN has been applied to a various tasks, such as estimating the urban heat island (UHI) intensity [24], predicting UHI [25], simulating future urban land surface temperature patterns [26], predicting average daily temperature distribution in city [27], forecasting of outdoor thermal comfort index in urban areas [28]. Moreover, ANN has been found to outperform Support Vector Regression (SVR) model in temperature prediction of Chittagong, another metropolitan area of Bangladesh [29]. Considering these findings, this study was designed to assess the role of meteorological parameters in seasonal prediction of temperature of Dhaka city using ANN.

In this warming world with the high risk of extreme weather, knowledge of temperature of upcoming season can largely be used in damage mitigation caused by extreme hot weather. Owing to the regional variation of meteorological conditions, it is important to focus on the particular weather conditions of any region while developing any machine learning model. Henceforth, this study analyzes the different combination of variables while developing ANN model and targets to determine the predictability of temperature ahead of season for the city of Dhaka.

2. Study area

Dhaka, positioned between latitudes 23.58° N and 23.90° N and longitudes 90.33° E and 90.50° E, stands as the most populous city in Bangladesh and is among the largest metropolises in South Asia [30]. The city's extensive population growth has significantly impacted its streets, urban design, public spaces, housing environment, various service industries, as well as its social and economic dynamics [31]. The average yearly temperature of this region is 25 °C, and the monthly mean ranges from 18 °C in January to 29 °C in August. The climate data for Dhaka [32] is shown in Fig. 1. An increasing trend has been noted in seasonal and annual frequency of days with $T_{max} > 36$ °C in this city [3]. The net change in urban areas Dhaka from 2000 to 2020 is 20.52 %, with projected summer and winter temperatures increasing by 13 % and 20 % respectively [33]. In addition, a significant reduction in vegetation cover and an increase in built-up area, leading to a 7.24 °C increase in LST are noticed over the last two decades [34].

3. Data

For the current study, NCEP/NCAR Reanalysis 1 data has been used and they were acquired from the NOAA physical sciences laboratory (NCEP-NCAR Reanalysis data provided by the NOAA PSL, Boulder, Colorado, USA, from their website at https://psl.noaa.gov). This dataset is defined on 0.25° × 0.25° global grids and is a state-of-the-art analysis/forecast system to perform data assimilation using past data from 1948 to the present [35]. Daily data of air temperature, relative humidity, geopotential height, surface level pressure, u-wind and v-wind for the months of February to July for the years 2011–2020 have been downloaded. The snapshot of arranged dataset is given in Fig. 2. In recent years, this dataset have been widely used in developing heatwave prediction models

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature °C (°F)	18.5 °C (65.4) °F	21.8 °C (71.3) °F	25.9 °C (78.7) °F	27.9 °C (82.3) °F	28.3 °C (82.9) °F	28.2 °C (82.7) °F	27.7 °C (81.9) °F	27.8 °C (82.1) °F	27.6 °C (81.6) °F	26.3 °C (79.4) °F	23.2 °C (73.7) °F	19.8 °C (67.7) °F
Min. Temperature °C (°F)	12.8 °C (55.1) °F	15.8 °C (60.4) °F	20.2 °C (68.4) °F	23.8 °C (74.8) °F	25 °C (77) °F	25.9 °C (78.6) °F	25.7 °C (78.3) °F	25.6 °C (78.1) °F	25.2 °C (77.3) °F	23 °C (73.4) °F	18.4 °C (65.1) °F	14.6 °C (58.2) °F
Max. Temperature °C (°F)	24.4 °C (76) °F	27.8 °C (82) °F	31.7 °C (89.1) °F	32.7 °C (90.8) °F	32.1 °C (89.8) °F	31.3 °C (88.3) °F	30.6 °C (87.1) °F	30.9 °C (87.6) °F	30.8 °C (87.5) °F	30.1 °C (86.2) °F	28.2 °C (82.7) °F	25.3 °C (77.6) °F
Precipitation / Rainfall mm (in)	6 (0)	21 (0)	73 (2)	168 (6)	331 (13)	368 (14)	353 (13)	274 (10)	273 (10)	150 (5)	27 (1)	11 (0)
Humidity(%)	68%	62%	60%	74%	81%	85%	86%	85%	85%	82%	72%	70%
Rainy days (d)	1	2	5	11	16	19	21	21	19	11	2	1
avg. Sun hours (hours)	8.8	9.4	9.4	8.2	7.5	6.8	6.7	7.1	7.3	8.1	8.6	8.1

Fig. 1. Climate data of Dhaka [32].

utilizing the above mentioned weather variables, particularly in Asian countries [19,20,23,36]. Based on the success of these studies, the aforementioned variables are taken into consideration for the current study.

4. Selection of time window

In this paper, we targeted to predict the temperature of months May, June and July using meteorological data of February to April. It has been found that during humid summer season (June to August), most parts of Bangladesh were exposed to extreme caution conditions with heat index value lying in range 90–105 °F, than during hot summer (March to May) [37]. When focusing solely on temperature, the majority of heatwaves typically occur between April and June. However, based on the humid-day-and-night heatwave indicator, which suggests a correlation between heatwaves and mortality related to heat, such heatwaves persist into May, June, and July [10]. In addition, the climatological values of different atmospheric variables for Dhaka as shown in Fig. 1 reflects similar conditions during May to July. Therefore, this study focuses on prediction of temperature for the months May to July.

Daily data of Dhaka city for the month of February to July from year 2011–2020 was utilized. The decade starting from 2011 has been experienced a significant rise in the climatological behavior of temperature across Bangladesh, as reflected in the value of WSDI (warm spell duration indicator). The WSDI value for years 2011 onwards was 6.77, while the values for the decades 2001–2010, 1991–2000 and 1981–1990 were 3.83, 3.05 and 2.64 respectively. Considering this huge leap from 3.83 to 6.77, this study focuses on just the decade 2011–2020 [38].

5. Methodology

The methodology of this study has been illustrated in Fig. 3. For the accomplishment of all the steps, the study was conducted primarily using the 'scikit-learn' package of high-level and most popular programming language, Python. The 'scikit-learn' package is widely exploited by researchers for its convenient nature and inclusion of comprehensive list of machine learning models [39]. The monthly data as explained in the earlier section were collected for the period 2011–2020. Following the collection of data, the first step involves preprocessing of the data. Dataset was scrutinized for checking the presence of outliers. The values in the dataset were then normalized using standard scalar method. In the second step, the dataset is partitioned into distinct training and testing sets, constituting 80 % and 20 % of the total datapoints, respectively. The 'train_test_split()' function from the 'scikit-learn' package has been applied for the division of dataset. The subsequent steps involve the building ANN model, which involves specifying the number of hidden layers and activation function. At first, the model was trained using the variables, temperature, relative humidity and geopotential height. Following training, the performance of the ANN model is evaluated using test dataset. The performance metrics utilized to validate the model will be presented in the next section. This methodology is replicated for datasets containing 4, 5 and 6 variables respectively, ensuring a comprehensive analysis of the weather variables influencing temperature prediction in Dhaka.

6. Performance metrics

The performance of the ANN model has been validated using four different statistical indices. For the calculation of error, Mean Squared Error (MSE) and Normalized Root Mean Squared Error (NRMSE) have been calculated for the test data set. Both MSE (Equation (1)) and NRMSE (Equation (2)) represent better performance of model when the values are close to zero [40–42]. For checking the fitness of model, co-efficient of determination, R^2 (Equation (3)) and modified index of agreement, md (Equation (4)) were used. The higher the values of these indices (maximum can be 1), the better the performance [43,44]. In the following equations y_i represents the actual value and $\widehat{y}_i$ represents the predicted value.

Date	Temperature	Relative Humidity	Geopotential Height	Surface Level pressure	Uwind	Vwind	Target
1/2/2011	20.85	57.500008	134	1010.11975	3.5800018	-1.6000061	26.50002441
2/2/2011	20.82503662	57.250008	126.75	1010.6692	3.300003	-2.649994	27.14998779
3/2/2011	21.77498779	51.000008	128.25	1009.93726	3.0999908	-2.2700043	27.0750061
4/2/2011	21.27498779	55.000008	124	1008.6765	2.449997	-2.7700043	25.19997559
5/2/2011	21.25002441	52.250008	119	1007.8215	2.2299957	-1.8699951	25.2000061
6/2/2011	21.3250061	55.500008	112.25	1007.2825	1.9799957	-2.050003	26.80001221
7/2/2011	22.8749939	47.250004	91.5	1005.5985	2.369995	-1.5	26.62502441
8/2/2011	23.475	49.000008	72.25	1002.1478	3.0899963	-1.2900085	27.05001221
9/2/2011	23.42501221	42.250008	75.25	1002.54224	3.5399933	-1.699997	27.37502441
10/2/2011	21.5750061	47.250008	108.25	1006.05725	3.7799988	-2.300003	28.62502441
11/2/2011	20.37502441	60.250008	111.75	1006.9478	3.4100037	-1.5200043	29.0750061
12/2/2011	20.975	57.000008	99.75	1005.27454	3.369995	-1.2400055	28.8749939

Fig. 2. Snapshot of dataset.

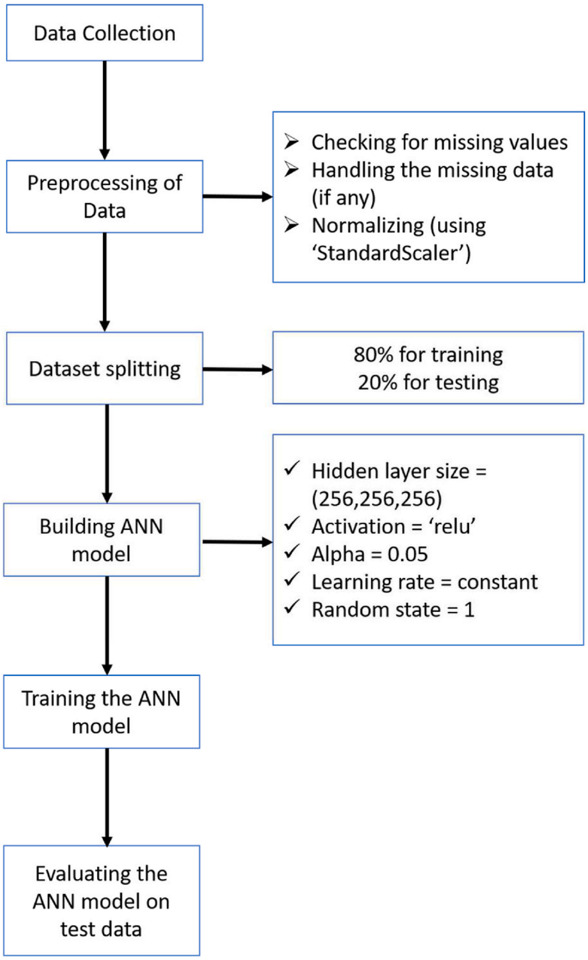

Fig. 3. Methodology.

$$MSE = \frac{\sum_{i=1}^{N}(y_i - \widehat{y}_i)^2}{N} \tag{1}$$

$$NRMSE = \frac{1}{y_{max} - y_{min}}\sqrt{\frac{\sum_{i=1}^{N}(y_i - \widehat{y}_i)^2}{N}} \tag{2}$$

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(y_i - \widehat{y}_i)^2}{\sum_{i=1}^{N}(y_i - \overline{y}_i)^2} \tag{3}$$

$$md = 1 - \frac{\sum_{i=1}^{N}(y_i - \widehat{y}_i)^2}{\sum_{i=1}^{N}[|y_i| + |\widehat{y}_i|]^2} \tag{4}$$

7. Artificial neural network model

An artificial neural network (ANN) is a computational model based on the structure and function of the human brain that is designed to process information and perform tasks via interconnected nodes that imitate biological neurons [45]. The weighted total of the inputs to a particular node is subjected to a nonlinear activation function [46]. This is the node's output, which later serves as the input for a different node in the following layer [47]. This process is carried out for each node, and the ultimate output, the signal flowing from left to right, is determined [46]. Learning the weights connected to each edge in this deep neural network requires training [46]. The equation for a certain node appears as follows (Equation (5)).

$$z = f(x, w) = f\left(\sum_{i=1}^{n} (x_i w_i)\right) \tag{5}$$

A nonlinear activation function was utilized to aggregate and process its inputs [45]. Since n is the number of node inputs, it can be represented as a vector dot product [46]. For completeness, the preceding equation includes the bias as shown below (Equation (6)).

$$z = f(b + x, w) = f\left(b + \sum_{i=1}^{n} (x_i w_i)\right) \tag{6}$$

When the error of this forward propagation doesn't satisfy the tolerance, perform back propagation until it satisfies the tolerance [46].

8. Result

This study aims to explore the potential of utilizing ANN in predicting seasonal temperatures in Dhaka. An additional feature processing method was implemented to analyze the performance of the artificial neural network's evaluation. At the initiation of the procedure, three variables were employed, namely air temperature, relative humidity, and geopotential height. Subsequently surface level pressure, u-wind and v-wind are added. For a visual representation of model's performance, a scatter plot is presented for each of the cases in Fig. 4. The scatter plots illustrate the improvements in model's performance through the formation of distinct clusters. In order to get a concrete result, the four metric values were calculated and are demonstrated in Fig. 5. The coefficient of determination, R^2 value was calculated to be 0.0530 while using 3 variables to train the ANN model. However, this result improved up to 0.2 for the model trained using 6 variables. This improvement of result by addition of feature is also evident from the MSE and NRMSE values, as both values tend to decrease gradually. The incorporation of six variables gave improved result in terms of all the performance metrics used in this study. In Fig. 6(a–j), the comparison of actual and predicted temperatures using 6 variables has been shown for each of year from 2011 to 2020. It is evident from the line graphs that ANN model performed moderately well in forecasting temperature.

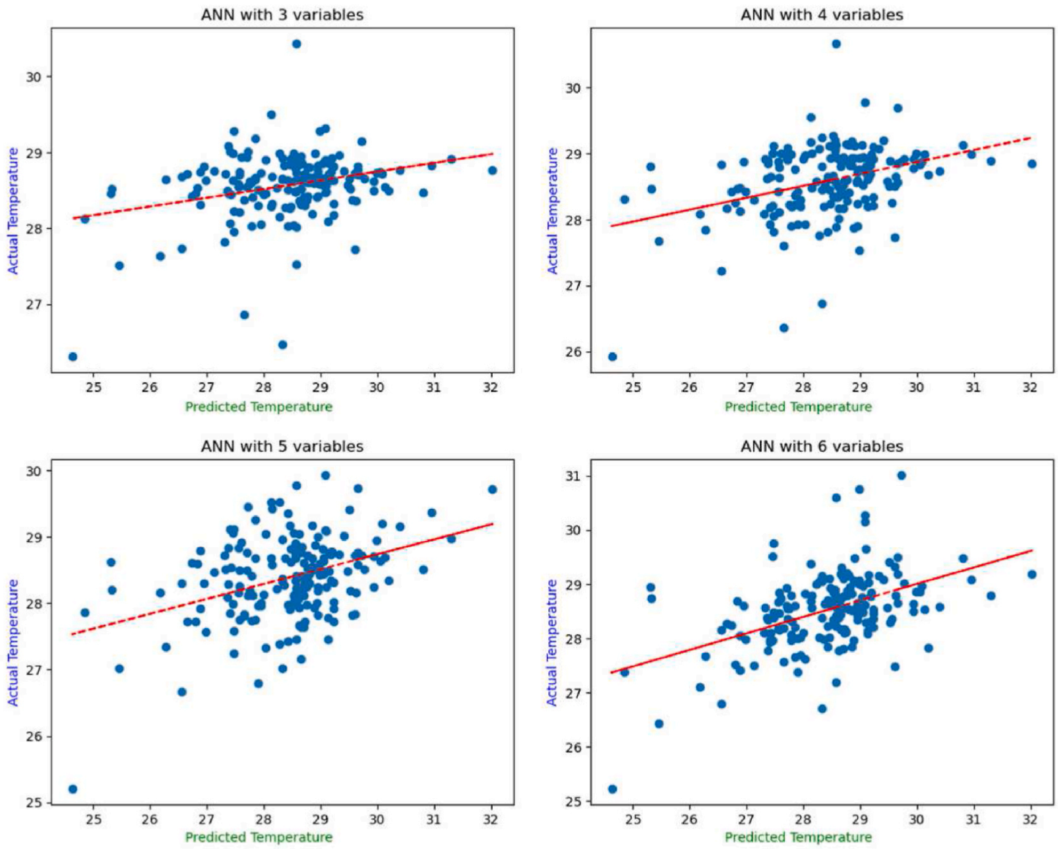

Fig. 4. Scatter plot of actual vs predicted temperature.

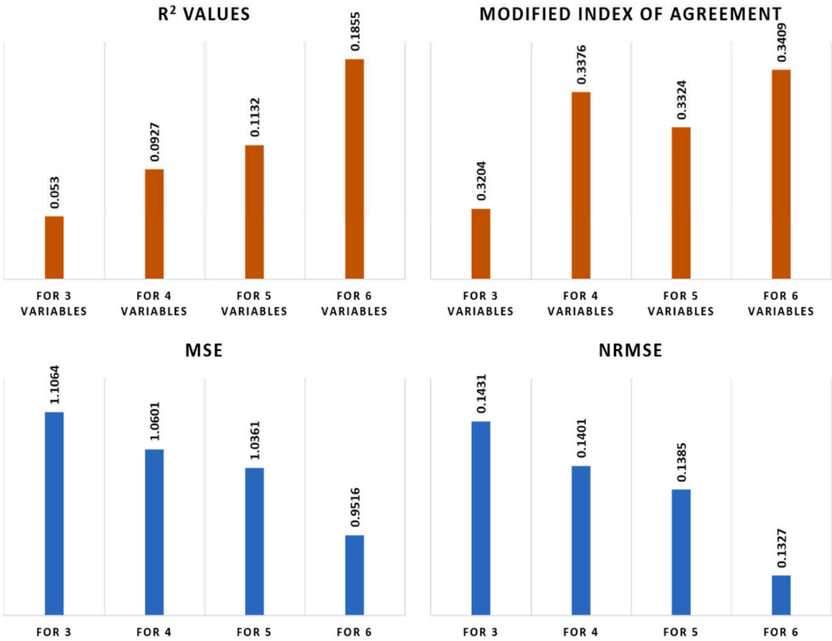

Fig. 5. Performance metric values.

9. Discussion

This study focused on utilizing an ANN model to predict the seasonal temperatures in Dhaka city and assess the meteorological parameters associated with this prediction. ANN is a state of the art machine learning algorithm used in wide spectra of applications. Particularly, in the field of weather forecasting, this model has been proved to give better results in urban regions [24–28,34]. This encouraged the authors to investigate the application of ANN in the context of Dhaka. The initial model incorporated three variables: air temperature, relative humidity and geopotential height and resulted in poor values of performance metrics. Subsequent iterations incorporated more variables, leading to improved prediction. However, the agreement of model with the original values lied below 40 %. The reasons are clearly evident from the comparison graphs of actual and predicted temperature. While the line graphs are in nice agreement from 2011 to 2017, an erratic nature of actual temperature is noted from 2018. This could be attributed to rapid change of climate due to urban heat island effect. Dhaka is facing urban sprawl [48], and.

additional 20 % of total area of Dhaka will be turned into urban region by 2030 [49]. This growth in city area is subjected to Urban Heat Island (UHI) effect, which indicates the phenomenon where the temperature in urbane area is greater than surrounding vegetation area [5]. It has been found that, due to UHI, the average temperature has increased by up to 3 $^{\circ}C$ in some regions of Dhaka [50, 51]. This impact of UHI, albeit significant, has not been taken into consideration in this study. Besides, natural variability and occurrence of extreme weather events can introduce unpredictability into temperature patterns. It would be difficult for any model to predict the erratic pattern, as the model is trained up using historical data. For instance, a comparatively large gap between actual and predicted temperature can be noted for year 2014 (Fig. 6(d)). It has been found that, the year 2014 was exceptionally hot in Bangladesh [3]. This type of natural variability has also impacted the accuracy of temperature prediction. Henceforth, in the future endeavor, researchers should take urban heat island effect and natural variability into consideration to build a robust model to handle this erratic behavior.

Despite the limitations, the current study provided a comprehensive use of machine learning model, ANN in seasonal temperature prediction of Dhaka city. This pioneering study investigated the combination of different weather variables in order to incorporate with ANN model for forecasting of temperature. With the high risk of extreme weather in a warming world, knowledge of upcoming seasonal temperatures can be largely utilized to mitigate damage caused by extreme heat. Anticipating higher temperatures allows for better planning of energy production and distribution to meet the increased demand for air conditioning and cooling systems during hot seasons. Besides, temperature predictions can guide the selection and placement of vegetation in urban area to maximize cooling benefits. In addition, for developing early warning plans and emergency responses to extreme hot scenarios, such as heatwaves, the knowledge of temperature beforehand is a necessity. Therefore, this study will facilitate the urban planning and the development of climate resilient strategies.

10. Conclusion

For improved preparation, management, and mitigation, a prediction model is required as the annual rate of temperature is increasing, especially for the over-populated, urban area of Dhaka. The goal of the current work is to create an ANN model that can be

Fig. 6. Comparison of actual and predicted temperatures obtained from ANN model trained with 6 variables.

used to predict air temperature prior to the onset of the season. Additionally, the applicability of various combinations of meteorological variables has been examined. The R^2 measure has a range of values from 0.05 to 0.2; however, when building the model with 3, 4, 5, and 6 variables, the mean squared errors are 1.1064, 1.0601, 1.0361, and 0.9516, in that order. As a result, the ANN model performs rather well in predicting average temperature and can be applied to analyze or forecast seasonal temperature in this area. Machine learning is increasingly utilized in the domain of meteorology, as well as in various other disciplines, in contemporary times. When comparing it to simulation-based models, this approach proves to be more efficient and cost-effective. As technology continues to advance and more complex algorithms are developed, the field of machine learning in weather prediction holds great promise for further advancements in our understanding and forecasting of atmospheric conditions, which will ultimately contribute to the safety and well-being of society.

Data availability

NCEP-NCAR Reanalysis 1 data provided by the NOAA PSL, Boulder, Colorado, USA, from their website at https://psl.noaa.gov.

CRediT authorship contribution statement

Shuchi Chaki: Writing – review & editing, Methodology, Data curation, Conceptualization, Formal analysis, Validation, Visualization. **Mehedi Hasan:** Writing – original draft, Data curation, Formal analysis, Visualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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