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Model for Wind Speed Prediction using Artificial Neural Network from Meteorological Variables: Case Study of Selected Sites of Nepal

by

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A THESIS

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled **"Model for Wind Speed Prediction using Artificial Neural Network from Meteorological Variables: Case Study of Selected Sites of Nepal"** submitted by Anjay Sah, in partial fulfillment of the requirements for the degree of Master in Energy Systems Planning and Management.

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ABSTRACT

Wind speed data are of primary importance while designing reliable system of any kinds whose performance can be effected by the wind such as aviation planning, space vehicle launching, weather forecasting, agro-meteorology, satellite and rocket launch, control module operation of military sector and wind energy generation plant. There is no misdoubt that information of the available data of wind speed are good but in Nepal the required data of wind speed are not accessible for most of the sites due to high cost and need for regular maintenance of the measuring instruments.

In this study an Artificial Neural network (ANN) was used to find the wind speed of the one place of all the seven different provinces of Nepal to identify the possible wind energy application with help of meteorological data of maximum temperature, minimum temperature, mean temperature, pressure, humidity, solar radiation, wind direction, altitude and wind speed for Tribhuvan International Airport. Data from 2008 to 2017 were used to train, test and validate the network while data of 2018 was used to find the wind speed of the seven different locations of Nepal. The ANN Fitting Tool (nftool) was used for the prediction of daily wind speed using MATLAB programming.

Twelve different models with different input combinations were modeled with two layer of feed forward neural network. The result of the ANN model were compared with measured data on the basis of root mean square error (RMSE), mean bias error (MBE), mean absolute error (MAE), mean percentage error (MPE) and Coefficient of Determination (R^2) in order to check the performance of developed model.

The obtained result in the present work indicate that a parameter such as wind speed which is highly variable and difficult to predict can be successfully modeled using ANN and reliable prediction can be made within the certain geographical areas. Thus the optimal model designed here can be used anywhere across Nepal where the meteorological data are available. The best prediction was from Model 11 as it exhibit minimum value of RMSE (0.06763) and maximum value of R^2 (99.06045%) for which input parameter were maximum temperature, minimum temperature, mean temperature, pressure, humidity, solar radiation, wind direction and altitude. The Model 8, Model 10, Model 9, Model 12, Model 3, Model 5, Model 7, Model 4, Model 6, Model 2 and Model 1 provided the respectively better prediction of wind speed.

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LIST OF ACRONYMS AND ABBREVATION

ANN	Artificial Neural Network
AI	Artificial Intelligence
AEPC	Alternative Energy Promotion Center
RMSE	Root Mean Square Error
GEP	Global Environment Facility
TIA	Tribhuvan International Airport
MAE	Mean Absolute Error
MLP	Multi-Layer Perceptron
NEA	Nepal Electricity Authority
R^2	Coefficient of Determination
SWERA	Solar and Wind Energy Resource Assessment
nftool	Neural Network Fitting Tool
GWEC	Global wind cumulative energy installed worldwide
MAPE	Mean Absolute Percentage Error
MATLAB	Matrix Laboratory
GON	Government of Nepal
MBE	Mean Bias Error
DoHM	Department of Hydrology and Meteorology
ARIMA	Autoregressive Integrated Moving Average

CHAPTER ONE: INTRODUCTION

1.1 Background

Nepal has to depend on fossil fuel as well as imported electricity and are producing very few energy with help of renewable source despite it is one of the richest countries in terms of renewable energy. There is possibility of developing renewable energy also it will help to increase the percentage of electricity accessible to local population of Nepal which is now about 78% (Nepal Electricity Authority (NEA) Report, 2018/2019).

The wind energy systems on the other hand environmental benefits as well. After hydro (16%), solar photovoltaic (4%) and wind (6%) remains second valuable renewable source of energy in the term of worldwide installation capacity in 2018 (International Energy Agency (IEA), 2018).

There are basically 10 types of wind speed that follows gentle breeze, moderated breeze generally follows most of the time. Strong breeze follows sometimes. The wind speed which follow at high altitude are moderate gale, fresh gale and strong gale. Occasionally whole gain follows in Nepal while in Jumla and Bajura storm follow most of the time due to high altitude.

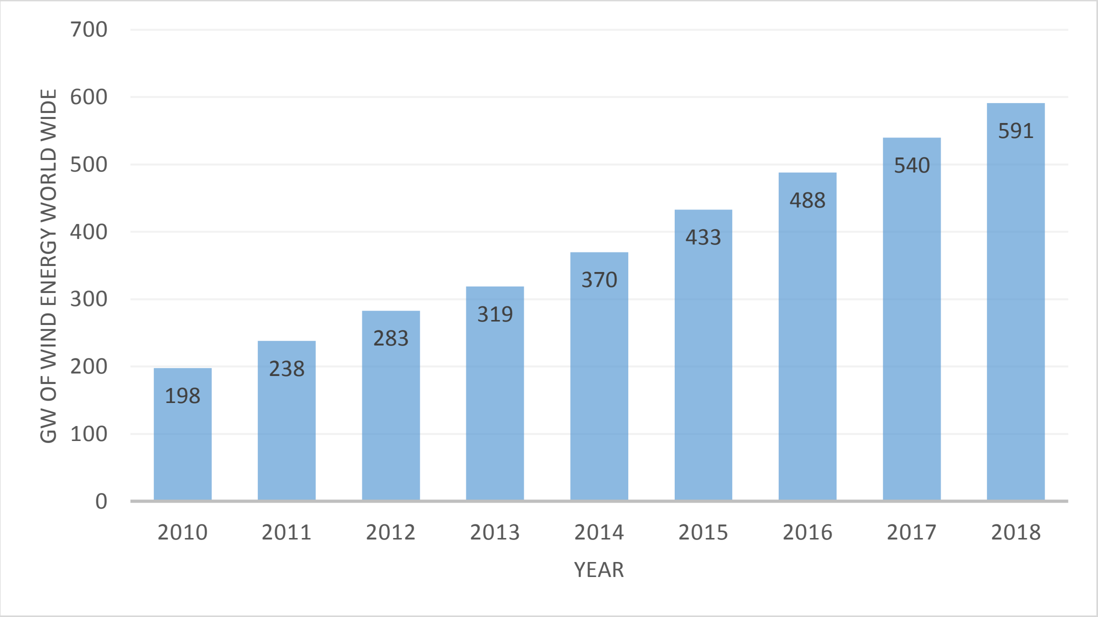

Figure 1.1: Energy installed worldwide (GWEC, 2018)

Wind speed is available freely in nature. The availability of wind at earth's surface has various application such as utilization of wind energy to generate electricity. Wind energy is economically competitive and have given plethora of benefits to the environment. These advantage have made wind power one of the easily growing power sector of the world. The scope of this work lies in its ability to find wind speed which is very much required for the wind energy power development. High altitude to be surveyed. Thus this method can acts as accompanying tool that will help to find the required data which is necessary for the wind power plant setup and will be helpful in overall finding the wind power potential of Nepal.

There are methods which are used to find the wind speed and that is by placing the instruments called anemometer which calculate the wind speed since it require continuous monitoring it will be helpful if we are able to develop model which will be used to find the wind speed of any location which have meteorological data available.

This topic of the present study, "Model for Wind Speed Prediction using Artificial Neural Network from Meteorological Data: Case Study of Nepal" has been chosen as topic of interest in master of science thesis this is because after going through reason why Nepal government has not been able to harness the wind energy though it is very much possible to harness it Nepal, this study came to find that unavailability of data to be one of the major reason and thus while further dissecting it this study came to find out that since the topography of Nepal varies very much in very small distance we need more measuring station that could help us to find the data so that we can estimate wind potential of Nepal and the area where wind can be easily harnessed and thus this study intend to find the way that could help Nepal to find the required data with less amount of money, man and material investment and thus this study came to the conclusion of developing a model that will help us to get wind speed to develop policies regarding developing of one of the major resource of energy which is wind which will finally enhance security and reliability of electrical energy in Nepal.

Various empirical methods have been used to calculate wind speed by various organization and government of Nepal. Most of the data of wind speed available are given by DoHM. However estimating wind speed using ANN model at different altitude of Nepal are yet to be carried out. Artificial neural network has capability to any continuous non-linear function to arbitrary accuracy (Cybenko, 1989). The ANN were used by many researcher and concluded that it is one of the best model which will be able to find wind speed with reasonable accuracy and minimum deviation. In the many research it is shown that ANN model perform better to empirical model. ANN model find the wind speed of any site of Nepal whose meteorological data are available.

1.2 Problem Statement

Wind energy is reaching the earth's surface depends on local character, so a study of wind speed for local weather conditions is necessary for the calculation of wind speed. Wind speed data is always necessary basis for designing wind power station having required power outputs systems such as wind based irrigation system, also for country like ours where accessibility of electrical energy is still problem it can play major role if developed by considering proper calculations in mind.

There is no misdoubt that measured data of wind speed is best that is available to us. The old way to wind speed in a region is to install anemometer. Therefore, it is rather more economical to meteorological data. ANN uses approximation capacity for non-linear equation with better level of accuracy (Li et al., 2001; Kelouwani and Agbossou, 2004; Chaouachi and Nagasaka, 2012). It helps to solve complex problems of non-linear nature (Chaouachi and Nagasaka, 2012).

Here, ANN was used to make the twelve different types of model with varying input parameter by using the available meteorological data of Tribhuvan international airport and the model so formed is validated by predicting the wind speed of Pokhara airport which is at different altitude and after validating the model wind speed of one location of all the seven provinces of Nepal is found and error analysis of obtained data was performed so that model can find wind speed in the locations where similar meteorological data are available but whose wind speed are not available.

1.3 Research Gap

According to the SWERA, 3000 MW of electricity using wind power could be generated. In final report (SWERA, 2008) recommends for the further analysis and research is needed. In this context ANN model for estimating wind speed could be one of the efficient steps for the assessment of detailed wind potential of Nepal. Thus, study of wind speed in Nepal is need of the situation to enhance the economic status of poor people living in Nepal without proper electricity. In Nepal, one of the research (Parajuli, 2016) used statistical technique to find wind power of Jumla and concluded that Annual wind speed is decreasing.

One of the researcher of Nepal (Upreti et al.,) have concluded in their research that potential for wind energy is high in Nepal. However high altitude needs more survey. Maharjan et al., (2017) conducted the research and concluded that detail long-term observations, numerical simulation as well as more engineering examinations are desired to derive definite conclusions on the true potential and sustainability of the wind power project in the area as the nature of the wind over the valley appears to be rather adverse and asymmetric one, which cannot be overlooked.

More studies is desired on wind speed using ANN Model at different altitude of Nepal. ANN can solve diverse problems (Olaofe and Folly, 2012). The ANN model were used by (cam et al., 2005), (Chandel et al., 2015), (Filik et al., 2017) in the past years to calculate the wind speed and concluded that ANN model were superior to the previous model being used. In the present study, an ANN model is trained, validated, tested and then developed to predict wind speed for any given location having similar meteorological parameters whose climatological data are available for the needed location.

1.4 Limitation

- During the training of the network weight optimization technique was not used.

1.5 Rationale

Wind speed is important parameters which are basis for designing any wind energy conservation system as well as wind data are essential for many purpose including agro meteorology. However according to meteorological department of Nepal the data of wind speed is only measured at selected sites of Nepal but there are 282 meteorological stations and 51 hydrological stations at different part of the country from where meteorological and hydrological data can be obtained. These meteorological parameters can be utilized to estimate wind speed where data of wind speed in not available to design the wind energy system. For Nepal it is one of much suitable thing because now we have been largely dependent upon only hydro power plant and as we are very much aware of the global climate change we must develop the concept of mix energy so as to enhance the energy reliability as well as security also it will help to increase the access to electricity as electricity is not supplied all over Nepal. It is more economical to develop wind power plant in mountainous region of Nepal where population density very low instead of connecting those region with grid.

1.6 Objective

The main objective is:

1. To predict wind speed of one location of seven different province of Nepal after finding and validating the best model from various model developed, using artificial neural network.

The specific objective are:

1. To make twelve different model using following meteorological parameter in different input combination.
2. To find the best model from the various model developed during the present study.
3. To validate the best model developed by predicting wind speed of different location.
4. To estimate wind speed of seven different location of Nepal

CHAPTER TWO: LITERATURE REVIEW

2.1 Artificial Neural Network

It resemble human brain in that sense. In order to perform prediction, artificial neural network need given examples (Lin and Lee, 1996). Artificial neural network are defined by using neurons (Haykin, 1994). A neuron is shown in figure 2.1. in figure 2.1, k is input signals number, y_i is input signal ,and w_{ij} is the weight. ANN is applied for modeling and forecasting of complex system (Ahmed et al., 2013).

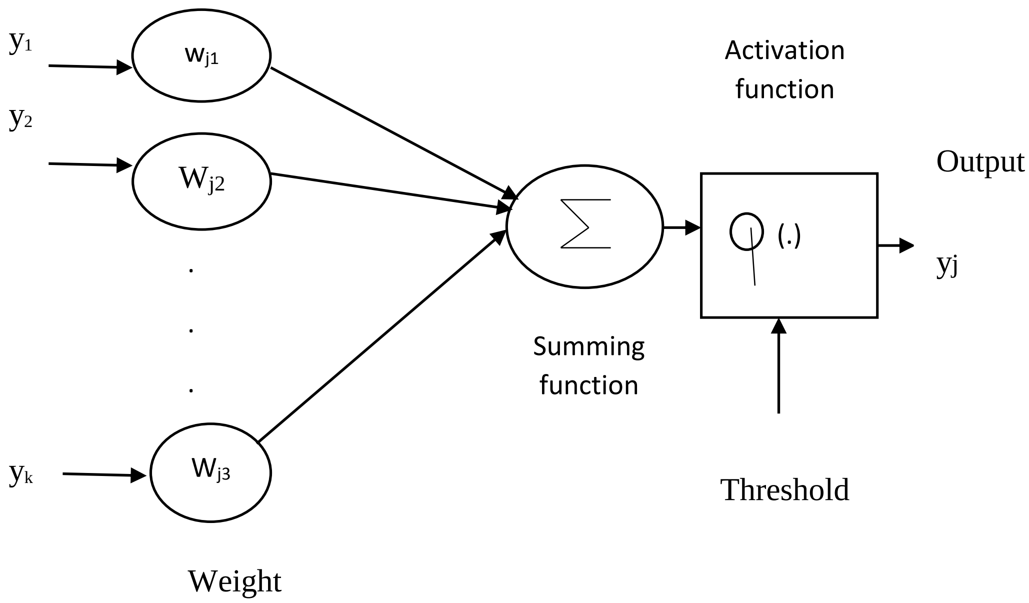

Figure 2.1: Neuron diagram

ANN are used to simulate the learned behavior of the system (Kalogirou, 2010). Apart from modeling wind speed, artificial neural network can be used for application including: solar radiation, pattern recognition, identification, optimization and diagnostics (Ahmet et al., 2011). The ANN diagram is shown in Figure 2.2. As presented figure shows response of the neural network with the target data to get difference in the presented data to the model. Error is fed back to network again so that the desired output can be obtained.

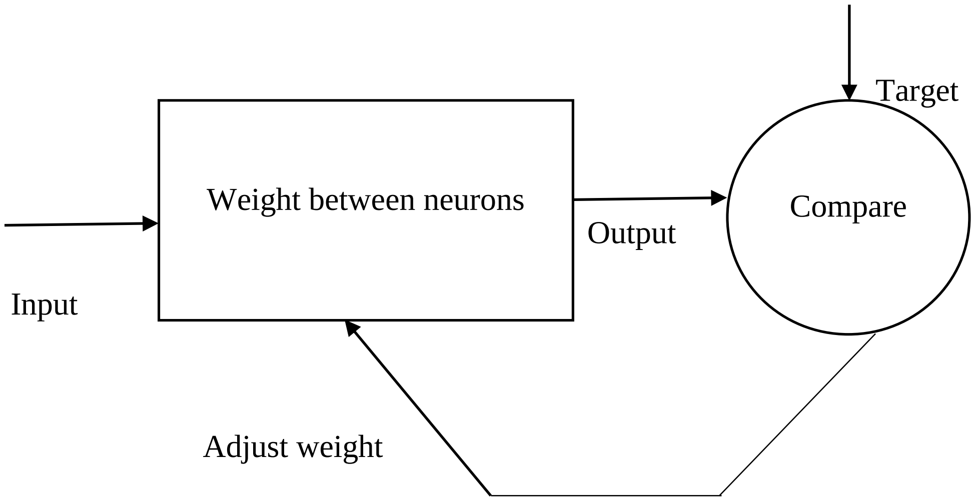

Figure 2.2: Diagram of ANN

Neuron of feed forward network is organized in one direction (Jain et al., 1996). Model will be used for calculating the wind speed of needed sites. Dis-advantage of feed forward neural network is lack of guarantee that the formulated model shall perform in desired way (Benghanem et al., 2009).

2.2 Application of Artificial neural network

Various literature around the world reveal that many researcher outside Nepal use ANN model to estimate wind speed using meteorological parameter. (Ayodele et al., 2015) modeled a model for calculation of wind speed with meteorology data in Noupoort of South Africa. The calculated wind speed is in accordance with available wind speed.

(Ghanbarzadeh et al., 2009) built prediction of wind speed model based on sample climatological data using ANN Manjil city. Obtained results shows that neural network is capable of estimating wind speed by taking above input as data to model the system the MSE is obtained as less as 3% only. (Ramasamy et al., 2015) develop model to calculate wind speed. The obtained results shows model is validated and shows the high CC of 0.99 with MAPE of about 6.5%.

(Masrur et al., 2016) develop short term forecasting model using ANN. Result shows the MAPE between available and calculated wind speed is acceptable. (Kirbas et al., 2016) develop short term wind model at Mehmet Akif Ersoy University campus. The model used radial basis function method. The result obtained shows that wind speed at

61m can be estimated with 99% accuracy. (Assareh et al., 2012) develop model for wind speed calculation with help of ANN in Manjil, Iran with meteorology data. The results indicate that MAPE of 7.03%. (Filik et al., 2017) develop model for wind speed calculation with ANN based on local measurement in Eskisehir. The result obtained shows that wind speed predicted with temperature, wind speed and wind pressure shows the lowest RMSE and MAE

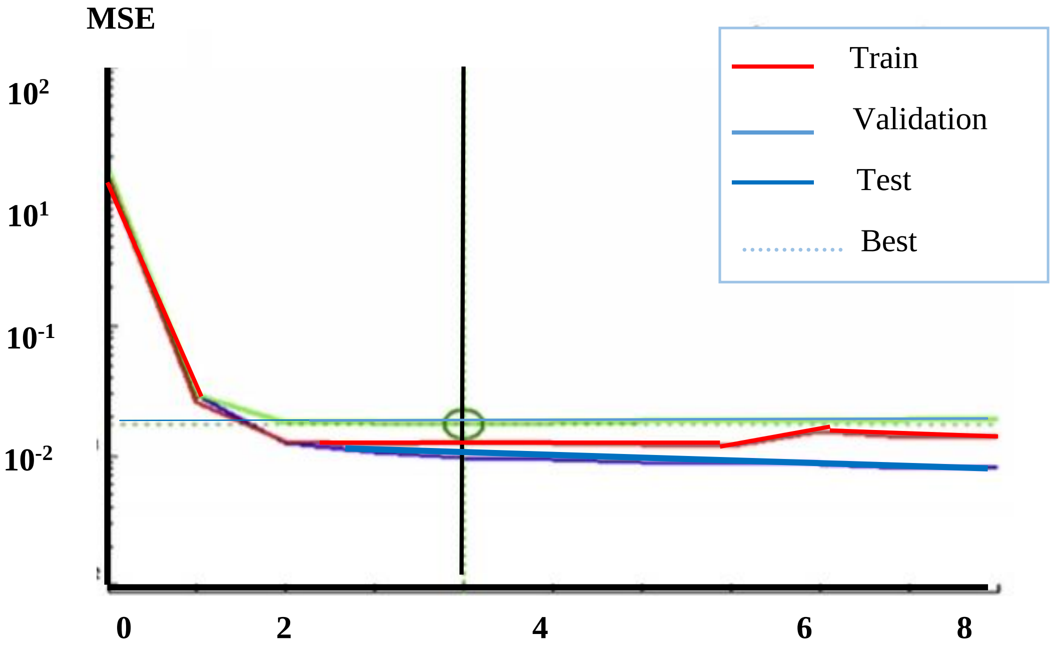

Figure 2.3: validity of artificial neural network (Ramasamy et al., 2015)

2.3 Reason to Choose ANN

According to (Haykin, 1999) ANN is made of distributed processor with processing knowledge with it. Knowledge is earned by the neuron from its sample through a training process. The advantage of ANN over other method is they learn from experience and interpolate results.

2.4 Is ANN a Suitable Model?

ANN model can provide estimation of desired variable with outmost accuracy. Applying ANN is valuable for determining of effect of meteorological parameter on wind speed (Kirbas et al., 2016). (Monfared et al., 2009**)** states fast learning is very much doable with fuzzy logic. (Cam et al., 2005) employed ANN to find wind speed of Turkey. The testing RMSE varies from 0.00527 to 0.01904. (Cadenas and Rivera, 2007) used ARIMA to find wind speed. The MAPE was found to be 13.40 to 28.50.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Building ANN model

3.1.1 Site Selection

Nepal is located between latitude of 28.3949^0 N and longitude of 84.1240^0E with elevation ranging from 59 meters to 8,858 meters covering geographical area of 147,181 square kilometers. Nepal has seven provinces. There are three geographical region of Nepal they are Plains region, Hilly region and Mountainous region with an area of 17%, 68% and 15% respectively. It varies from very hot to very cold from Plain region to Himalayas region.

The location of Nepal which was chosen for the formulation of model and finding of the best model among the twelve different model formed is Tribhuvan International Airport which is located in Kathmandu with latitude of 27.42^0 N and longitude of 85.22^0 with an elevation of 1337 meters. TIA was chosen for this purpose because the model various meteorological data from year 2008 to 2018 and data obtained for TIA as it is only international airport of Nepal can be easily extracted in comparison to other place of Nepal. The location of Nepal which was chosen for validation of the model is Pokhara Airport which is located at altitude of 827 meter with latitude of 28.13^0 N and longitude of 84.00^0 E and the data chosen for the purpose of validation is of year 2018.

The one location from all the seven province of Nepal was chosen as to fulfill the specific objective of this thesis which will ultimately fulfill main objective. Those location was chosen entirely based on meteorological data availability. The locations are Okhaldhunga from province number 1 with altitude of 1720 meter, latitude of 27.19^0 N and longitude of 86.30^0 E. Janakpur Airport from province number 2 with altitude of 90 meter, latitude of 26.708^0 N and longitude of 85.9248^0 E. Nagarkot from province number 3 with altitude of 2163 meter, latitude of 27.45^0 N and longitude of 85.31^0 E. Gorkha from province number 4 with an altitude of 1097 meter, latitude of 28.00^0 N and longitude of 84.37^0 E. Tansen from province number 5 with an altitude of 1067 meter, latitude of 27.52^0 N and longitude of 83.22^0 E. Jumla from province number 6 with altitude of 2300 meter, latitude of 29.17^0 N and longitude of 82.10^0 E. Bajura from province number 7 with an altitude of 1400 meter, latitude of 29.23^0 N and longitude of 81.19^0 E.

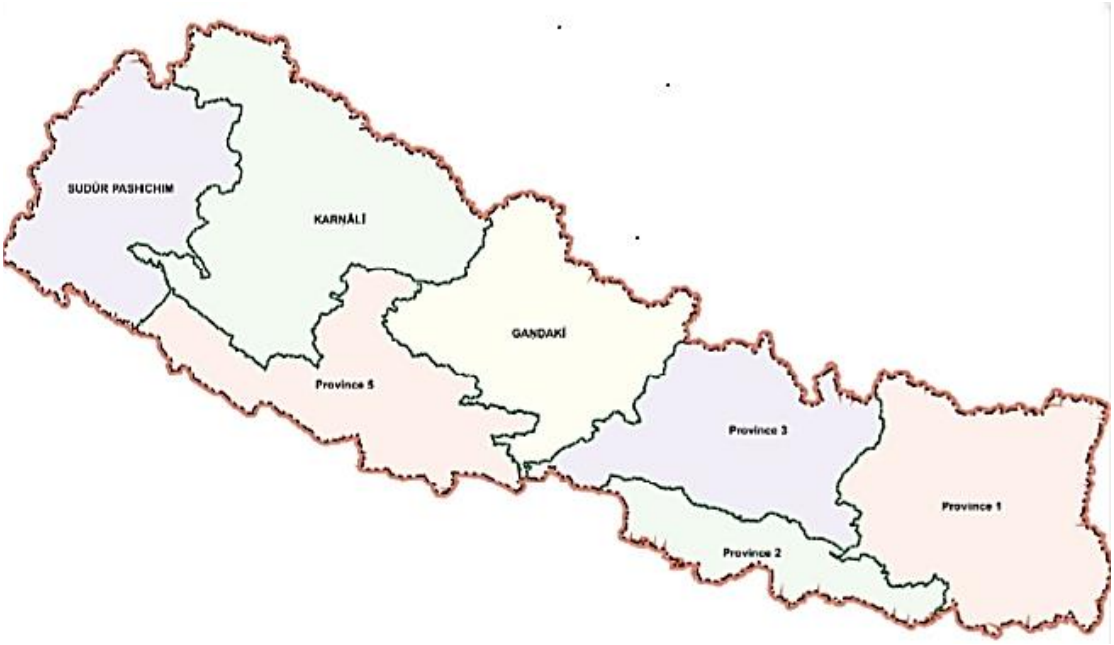

Figure 3.1: Map of Nepal with seven province (Survey Department, GON)

3.1.2 Data Collection

Selecting the site for which data needs to be collected is the very first step while designing architecture of ANN. Preparing sample data is important step in designing ANN models. This study is be based on the 9 different meteorological variables: maximum temperature, minimum temperature, mean temperature, atmospheric pressure, relative humidity, solar radiation, wind direction, altitude and wind speed. Data is collected for the 9 different sites of Nepal namely: Tribhuvan international airport, Pokhara airport, Okhaldhunga, Janakpur Airport, Nagarkot, Gorkha, Tansen, Jumla and Bajura. The data for TIA was collected for period of 2008 to 2018 and for all the rest of the sites it is collected for period of one year only, 2018. Missing variables problem was solved with the interpolation technique and variable was normalized.

3.1.3 Building ANN Architecture

ANN has processing units called neuron (Paneerselvam et al., 2010). Training algorithm determine capabilities of neuron. (Kumar et al., 2009), and load forecasting (Wamkeue et al., 2006), and restoring missing wave measurement (Gavrilov et al., 2005). Nftool of ANN is used for seven different location of Nepal wind speed calculation.

The hidden number is decided by equation (1):

$H_n = \frac{I_n + O_n}{2} + \sqrt{S_n}$ Equation 3.1

Where, H_n is hidden number of layers, I_n is input parameters number, O_n is output parameters number and S_n denotes data samples number (Neurosheell, 1996).

The methodology is shown in the following diagram:

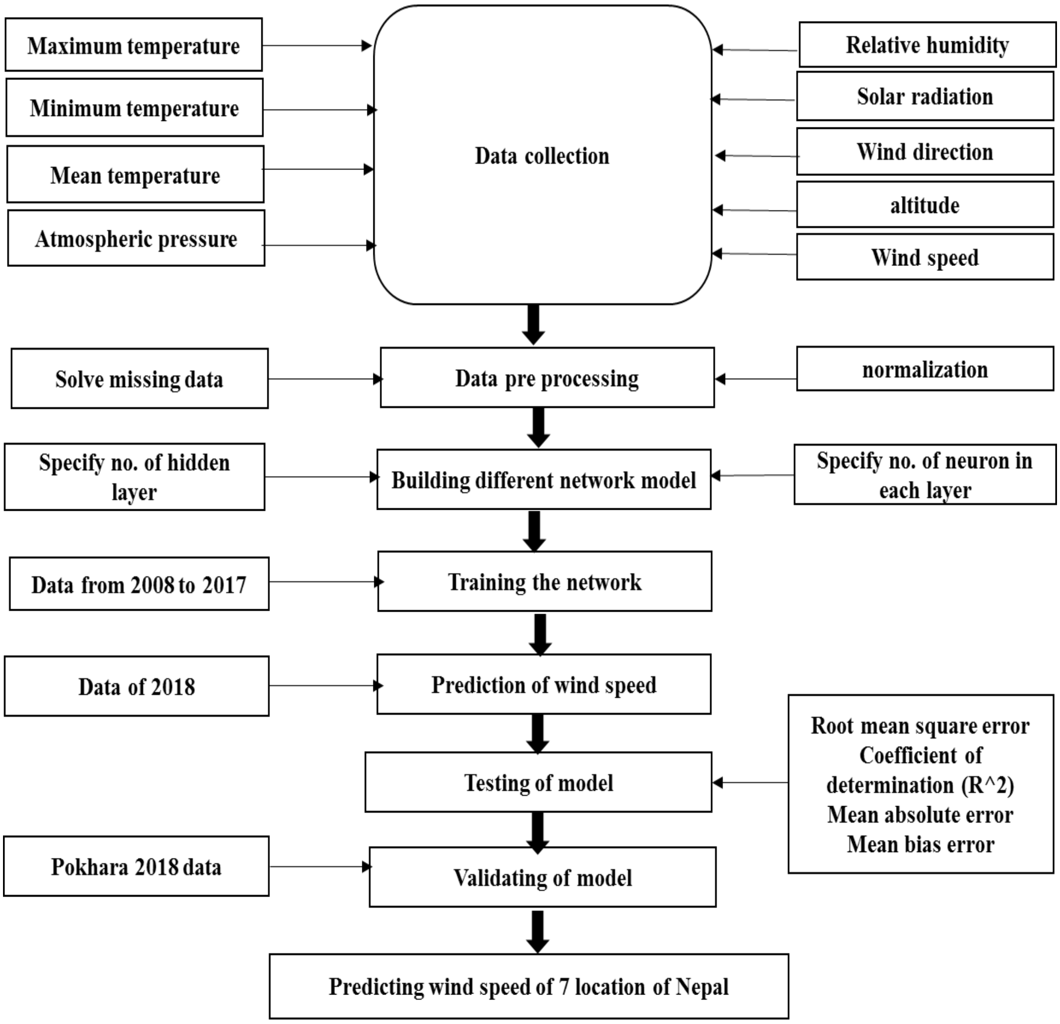

Figure 3.2: Overall Methodology

The input varibles and output variable will be meteorological. Furthermore, twelve number of different artificial neural nework were formed using meteorological input combinations. The various combination that can used for the modeling are listed below:

Model 1:

The model one consist of 3 meteorological parameter as an input parameter and wind speed as an output parameter. The input meteorological parameter were mean temperature, relative humidity and atmospheric pressure.

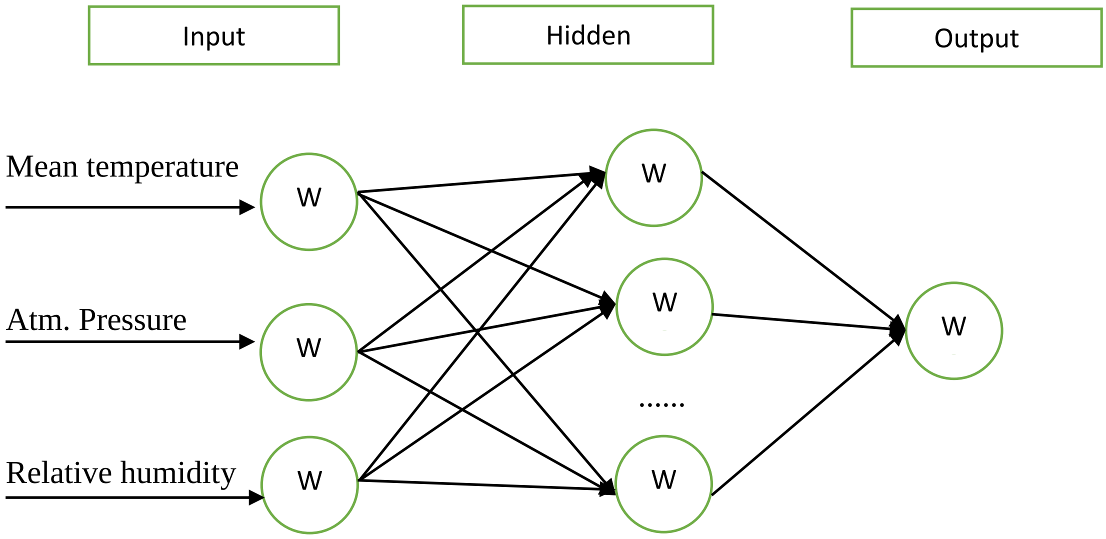

Figure 3.3: ANN architecture of Model 1

Model 2:

The model two consist of four meteorological parameter namely as an input parameter and wind speed as an output parameters.

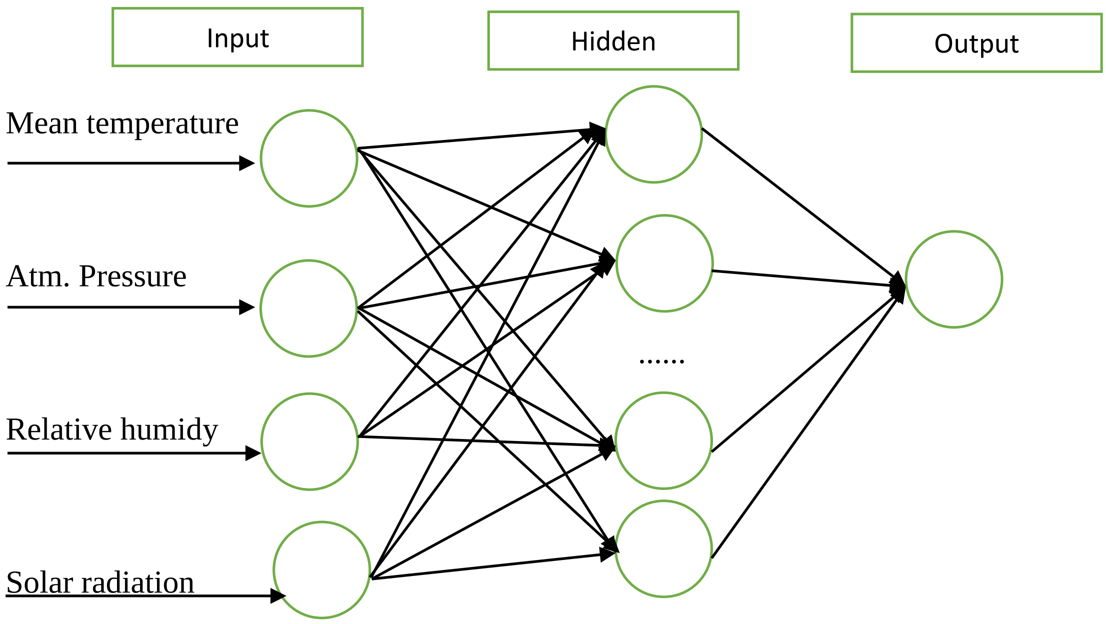

Figure 3.4: ANN architecture of Model 2

Model 3:

The model three consist of five meteorological parameter as an input parameter and wind speed as an output parameter

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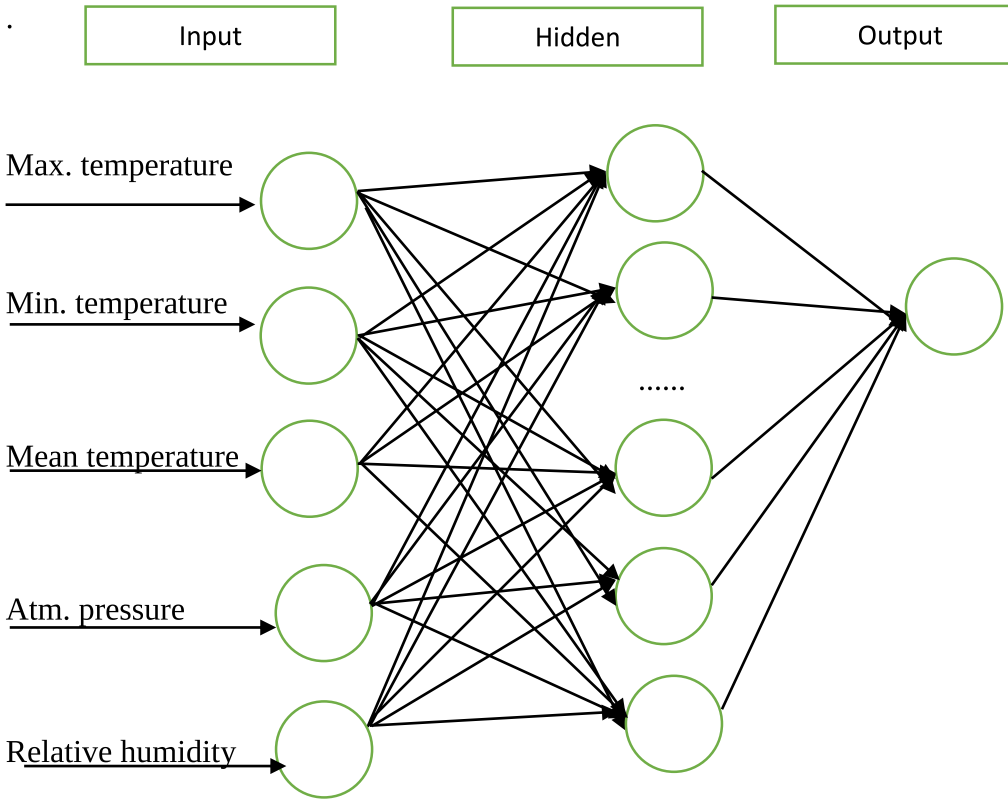

Figure 3.5: ANN architecture of model 3

Model 4:

The model four consist of five meteorological parameter as an input parameter and wind speed as an output parameters.

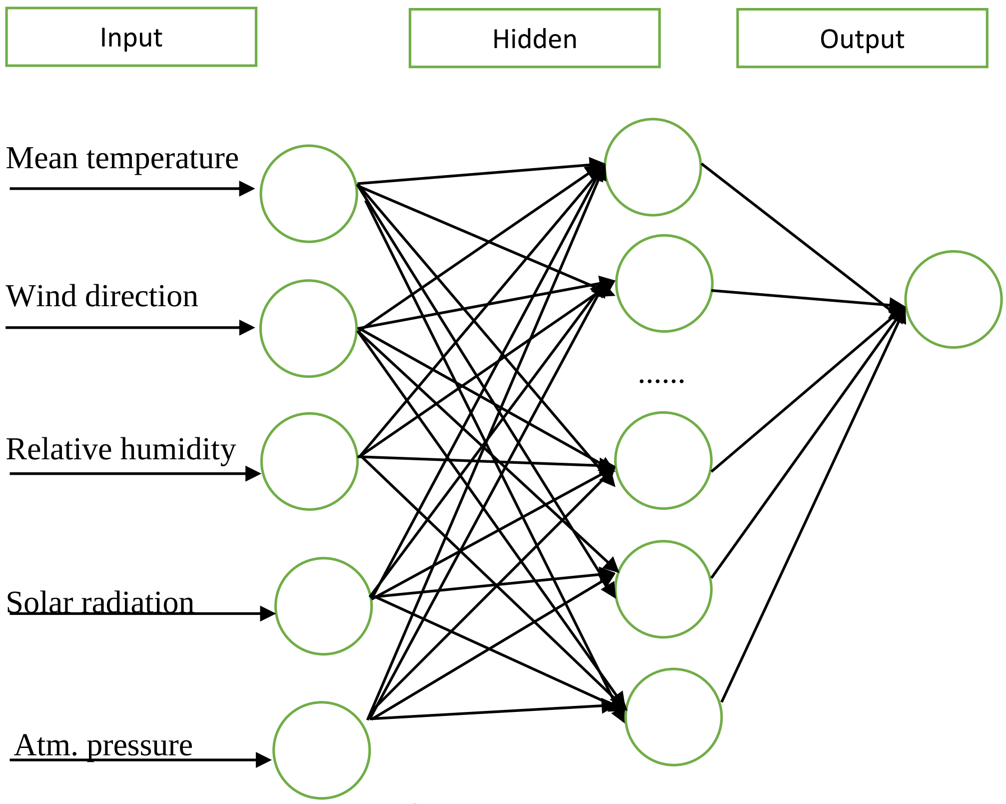

Figure 3.6: ANN architecture of model 4

Model 5:

The model five consist of five meteorological as an input parameter and wind speed as an output parameters.

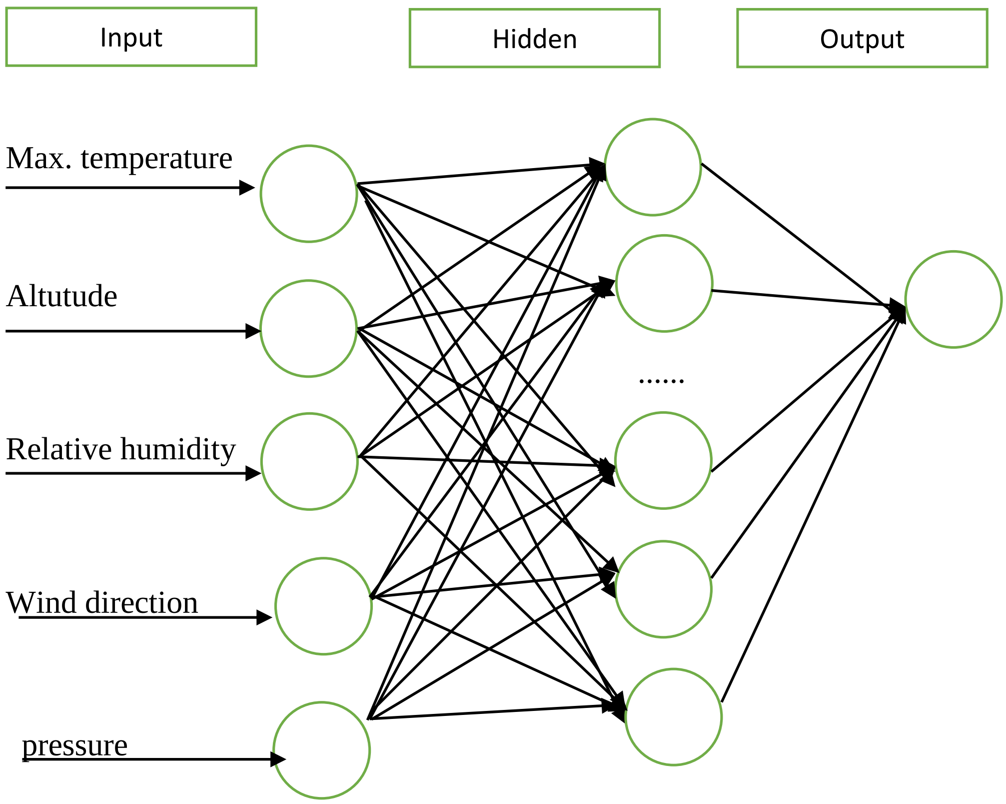

Figure 3.7: ANN architecture of model 5

Model 6:

The model six consist of six meteorological parameter as an input parameter and wind speed as an output parameters.

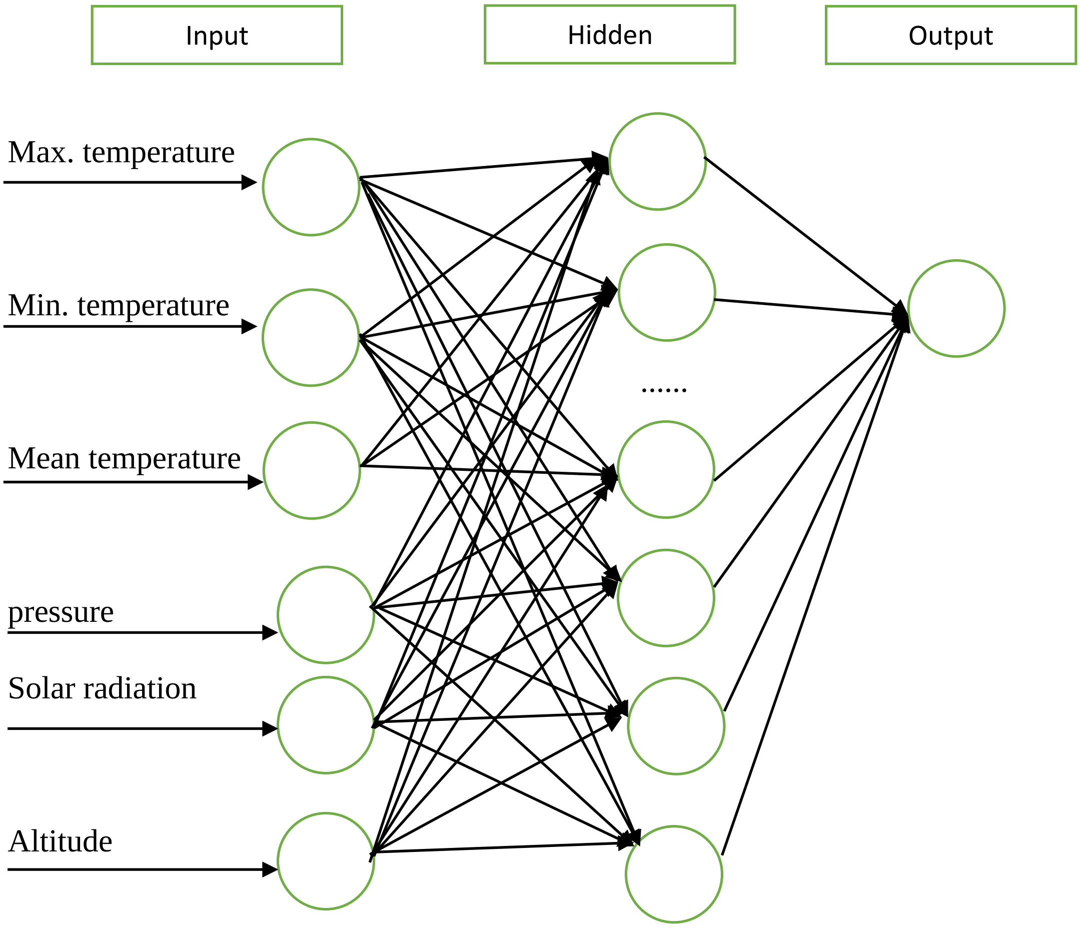

Figure 3.8: ANN architecture of Model 6

Model 7:

The model seven consist of six meteorological parameter wind speed as an output parameters.

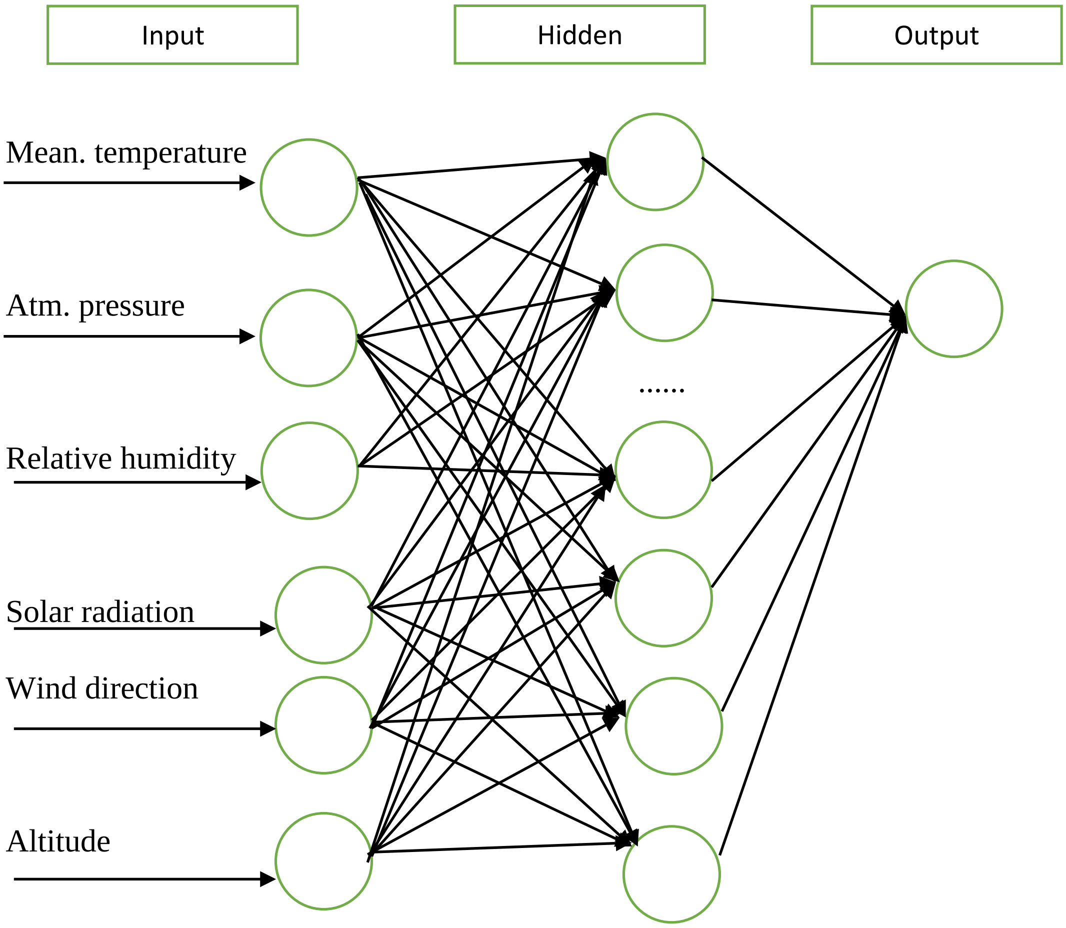

Figure 3.9: ANN architecture of Model 7

Model 8:

The model eight onsist of seven meteorological parameter namely as an input parameter and wind speed as an output parameters.

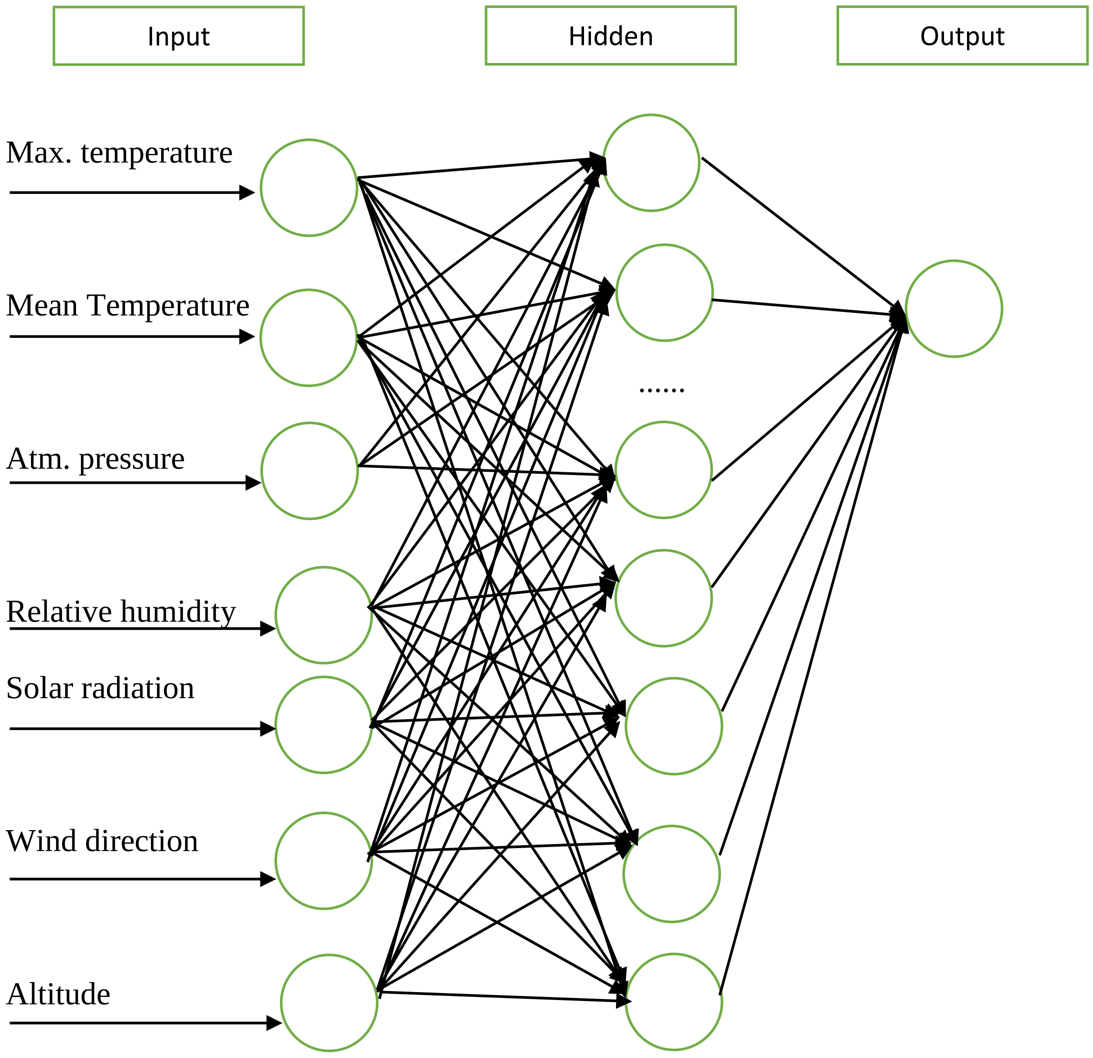

Figure 3.10: ANN architecture of model 8

Model 9:

The model nine onsist of seven meteorological as an input parameter and wind speed as an output parameters.

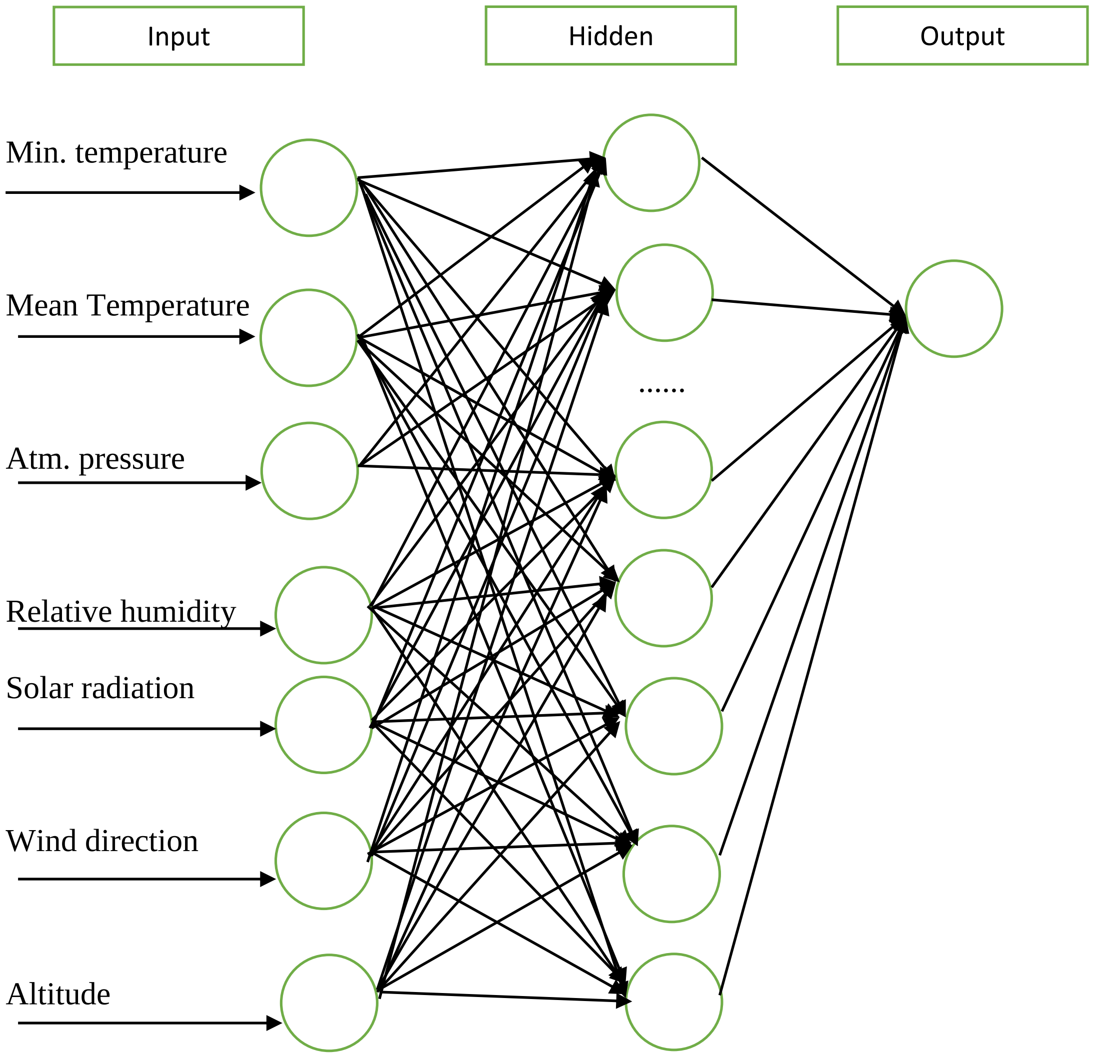

Figure 3.11: ANN architecture of model 9

Model 10:

The model ten onsist of seven meteorological parameter as an input parameter and wind speed as an output parameters.

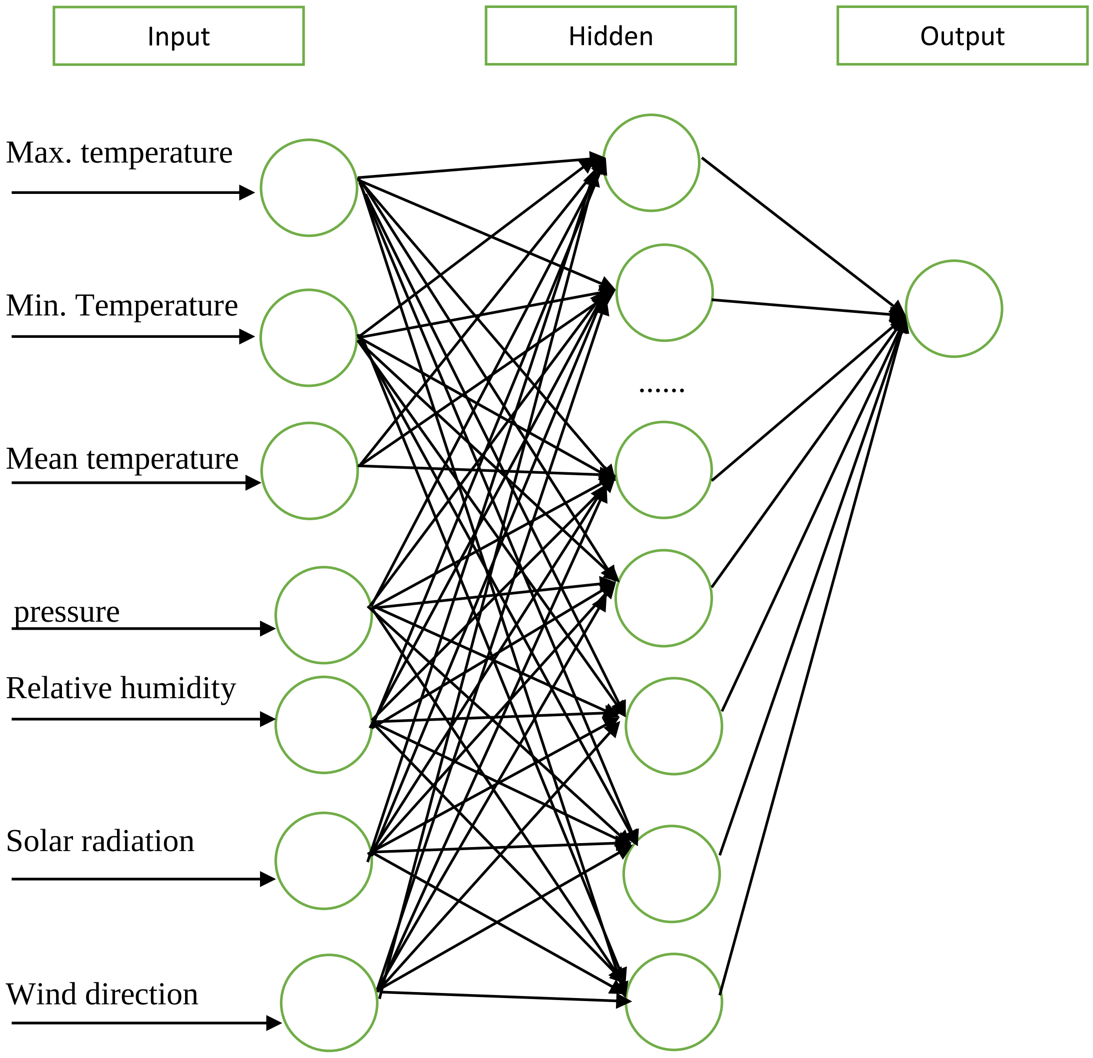

Figure 3.12: ANN architecture of model 10

Model 11:

The model eleven consist all the eight meteorological as an input parameter and wind speed as an output parameters.

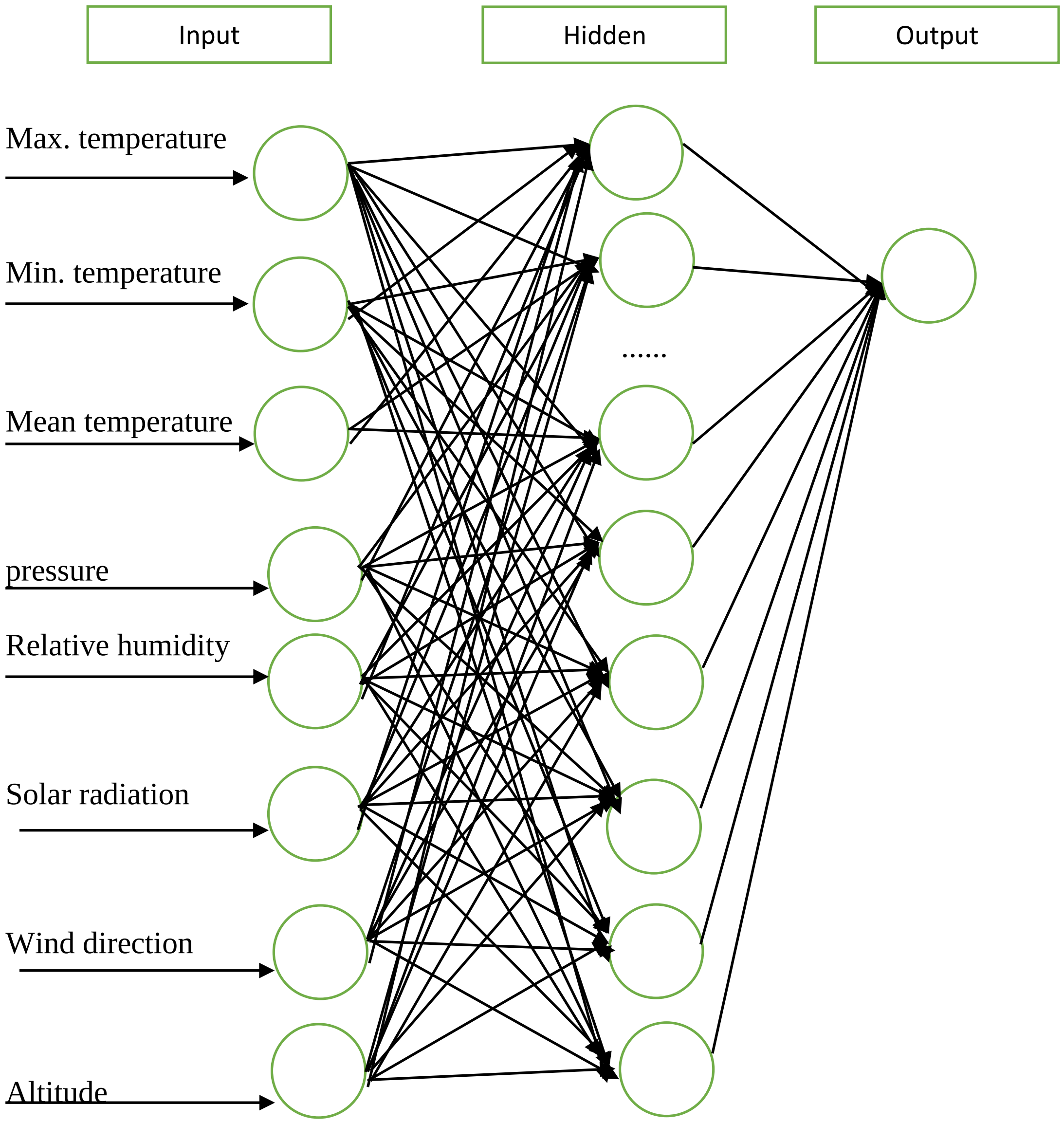

Figure 3.13: ANN architecture of Model 11

Model 12:

The model twelve was formed to by taking the output of all the previously discussed eleven different model as an input parameter and wind speed as an output parameter. Thus the total number of input to this model was eleven and wind speed was taken as output of this model. This model was basically made to test the assumption that if output obtained from all the model is simply averaged will it generate better output in overall scenario or not. The research article (Dobschinski et al., 2008) claimed that simple averaging reduces RMSE by 20%, this model is developed to test the claim and see if that work for the calculation of wind speed as well.

Algorithm for model 12:

Step 1. Start

Step 2. Find the output obtained from all the 11 model developed.

Step 3. Take the output of 11 different model developed as an input for model 12.

Step 4. Perform the simple averaging

Step 5. Store the result of the simple averaging as obtained for the model 12.

Step 6. Perform the statistical error analysis

Step 7. Decide the performance of the model developed.

Step 8. Stop

3.1.4 Training the ANN Architecture

After building the ANN architecture the next step was to train the architecture. Levenberg – Marquardt (LM) was designed to be used. Training was done automatically and performance was evaluated. Data for training was taken from 2008 to 2017 for the Tribhuvan international airport. The input data was mapped -1 to +1 with the process of normalization. The data were divided by program into 70% training, 15% testing and 15% validation data randomly.

3.1.5 Testing ANN Architecture

Network was tested using data of all the meteorological parameter for the year 2018. Statistical indicator was used for testing ANN performance. These statistical indicator are RMSE, MAE, MBE, MPE, R^2, and Adjusted R^2. All the statistical error RMSE, MAE, MBE, MPE, R^2 and adjusted (R^2) were computed with available measured and ANN predicted data.

RMSE = $(\frac{1}{n}\sum_{i=1}^{n}(Wi - Wpi)\text{^}2)$ ^0.5 Equation 3.2

MAE = $\frac{1}{n}\sum_{i}^{n}|(Wi - Wpi)^2|$ Equation 3.3

MBE = $\frac{1}{n}\sum_{i=1}^{n}(Wi - Wpi)$ Equation 3.4

MPE= $\frac{1}{n}\frac{(Wi-Wpi)}{Wpi} * 100\%$ Equation 3.5

$R^2 = (1- (\frac{\sum_1^n|(Wi-Wpi)^2|}{\sum_1^n Wi})$ Equation 3.6

Adjusted $R^2 = 1-\frac{(1-R^2)(N-1)}{N-P-1}$ Equation 3.7

Here, P indicates predictors and N indicates sample size.

Wi and Wpi are measured data and ANN predicted data of wind speed.

3.1.6 Validating ANN Architecture

The best model was chosen based on smallest RMSE and highest R^2 value. In validation, best ANN was used to find wind speed of Pokhara Airport which is located at altitude of 827 meter with latitude of 28.13^0 N and longitude of 84.00^0 E and the data chosen for the purpose of validation is of year 2018. All the statistical analysis was done on the result obtained for the validation model so as to find that if this model could be applicable to find the wind speed of any other location having similar meteorological parameter with different altitude. If the statistical analysis shows that it could predict the wind speed of Pokhara Airport with reasonable amount of accuracy then we will use it to find the wind speed of other location of Nepal.

3.1.7 ANN Prediction Principle

ANN make use of data histories to map out latent relationship (Perez et al. 2012). MATALB (R2016b) was used to write the script files for developing neural network fitting problem. After configuring the network data of 2008 to 2017 were made as model input. The ANN training was done several times. After training the network best result was saved for each model.

The flowchart for prediction of wind speed which was used in this research is developed below:

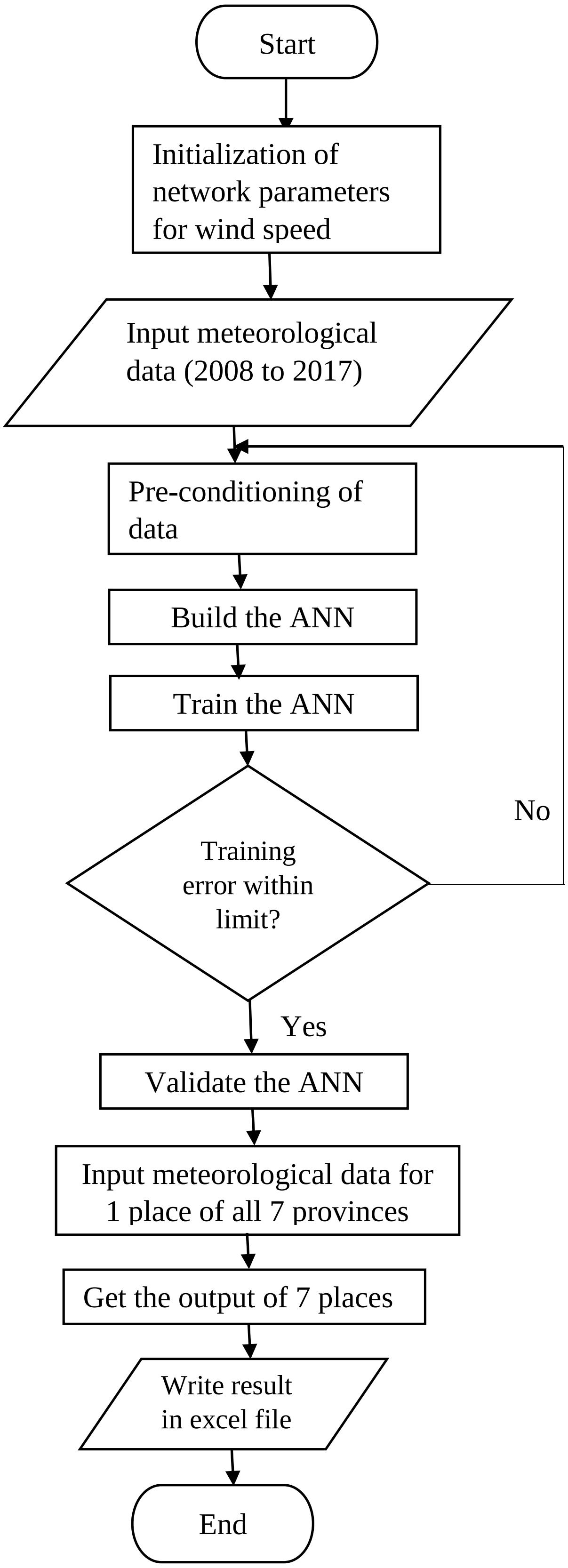

Figure 3.14: The flowchart for ANN principle

3.1.8 Predicting Wind Speed of One Location of All Seven Provinces of Nepal

The seven different location were chosen one from each province of Nepal based on the availability of the meteorological data. Those seven location are Okhaldhunga, Janakapur Airport, Nagarkot, Gorkha, Tansen, Jumla and Bajura of province number 1, 2, 3, 4, 5, 6 and 7 respectively. All the meteorological parameters were obtained and then those parameter were sent to the model. Output of each place were saved which was obtained from the model developed. The final step before predicting wind speed was saving the model. The model which was saved was latter used to validate the network and after confirming best model was used to predict wind speed of seven different location of Nepal.

CHAPTER FOUR: RESULT AND DISCUSSION

4.1 ANN Architecture of Model Developed

The architecture of the best model which was selected among various twelve model developed are Model 11. The parameter of the best model developed were 8 in number as input and wind speed as an output. The best model developed contain multilayer perceptron structure having architecture as 8 – 67 -1. The architecture of model 11 which was chonsen best is in figure 3.13.

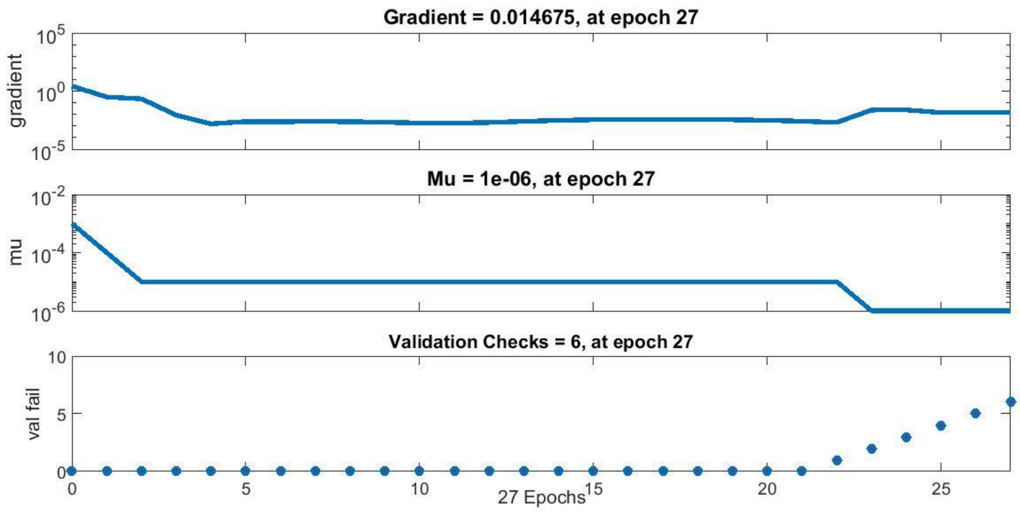

Figure 4.1: Training State of Model 11

Figure 4.1 shows screenshot of training state window in MATLAB R2016b. The above graph shows gradient = 0.014675, at epoch 27, mu = 1e-06, at epoch 27 and validation check = 6, at epoch 27. This figure shows the following three graph which is between gradient versus epoch, mu versus epoch and validation fail versus epoch.

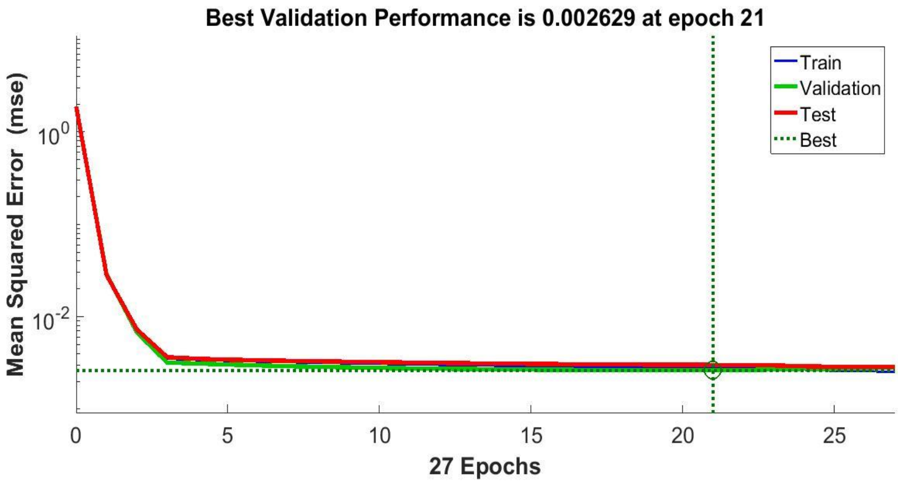

Figure 4.2: Best Validation Performance of Model 11

Figure 4.2 shows the screenshot of the best validdation performance window in MATLAB 2016b. The above figure is the graph between MSE and epoch. The best performance is 0.002629 at epoch 21. Above figure 4.2 tells as epoch increases the MSE decreases.

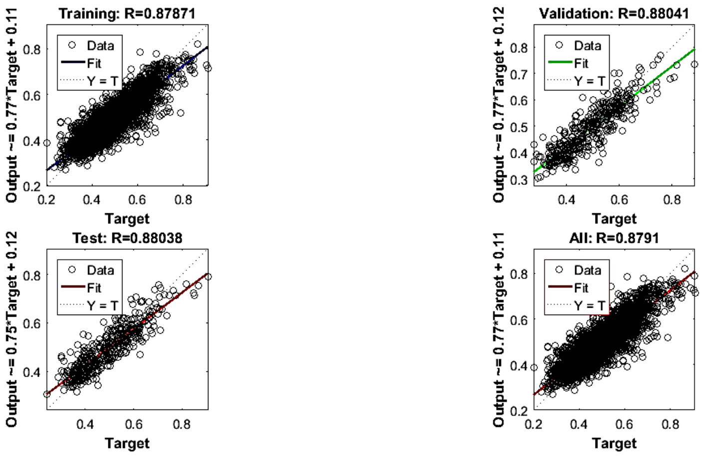

Figure 4.3 : Regression Plot of Model 11

Figure 4.3 shows the screenshot of regression plot in window MATLAB 2016b. The figure shows the graph of following four types. They are output versus target for training data, output versus target for validation data, output versus target for testing data and output versus target for all the data. Each is defined by cetain equation of the form output equals to constant times target plus another constant.

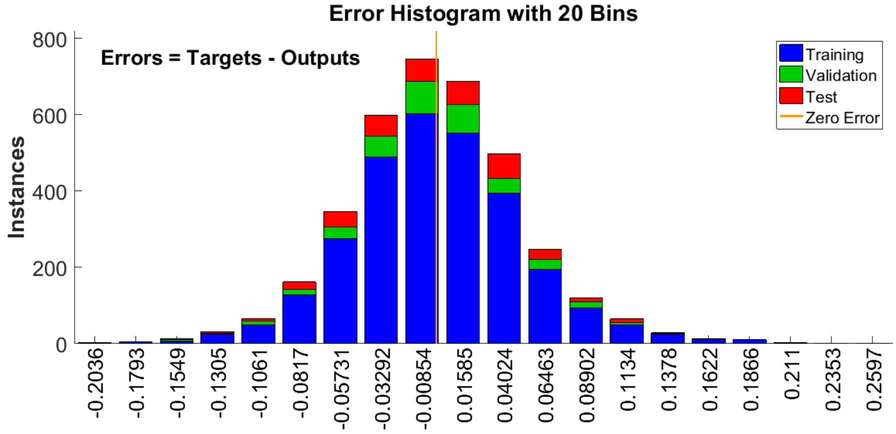

Figure 4.4 Neural Network Error Histogram of Model 11

Above figure 4.4 shows the screenshot of error histogram in window MATLAB 2016b. The above graph is the plot between instances and the error showing error histogram with 20 bins. The error is basically defined as errors equals to target minus output. The graphs shows the error for the four component they are training error, validation error, testing error in accordance with zero error line.

The neural network function is shown in appendix A for the model 11 can be used to find wind speed of any location using that function directly in MATLAB environment. It has got all the eight input parameter which it can take as an input and can give the wind speed as an output which is our desired output.

4.2 Wind Speed of 12 Different models:

There are altogether twelve different models made in attempt to find the best model which could predict the wind speed of the desired location of Nepal with reasonable amount of error using available meteorological parameter discussed here. The measured and ANN predicted output is compared graphically as shown below for all model.

Model 1:

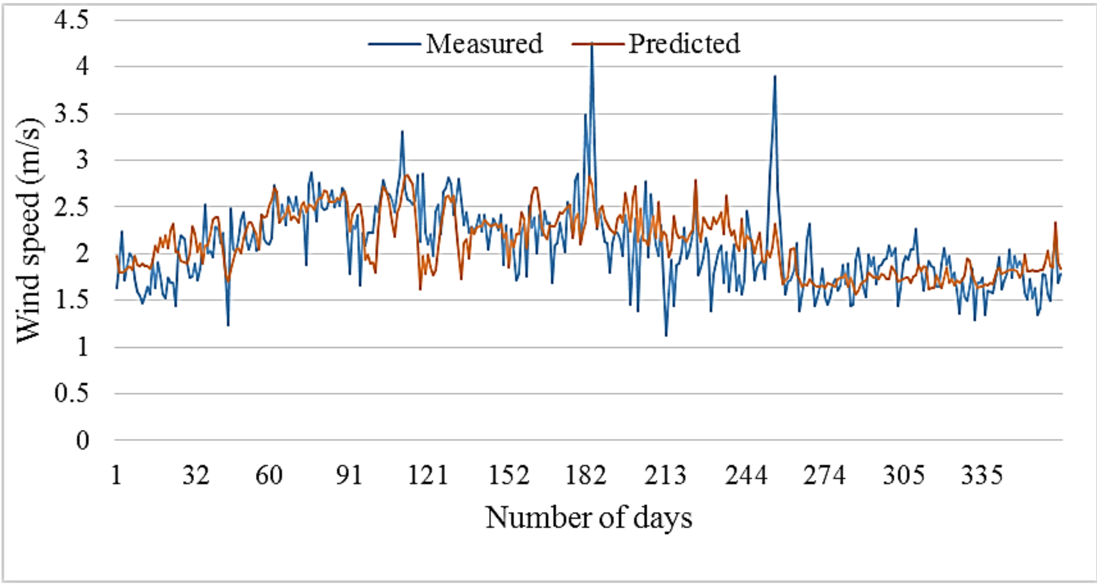

Figure 4.5: Wind Speed from Model 1

Figure 4.5 shows wind speed of year 2018, which is obtained from the model 1 which consist of three different meteorological parameter as an input and wind speed as an output. Graph clearly shows the measured and predicted wind speed do fit poorly.

Model 2:

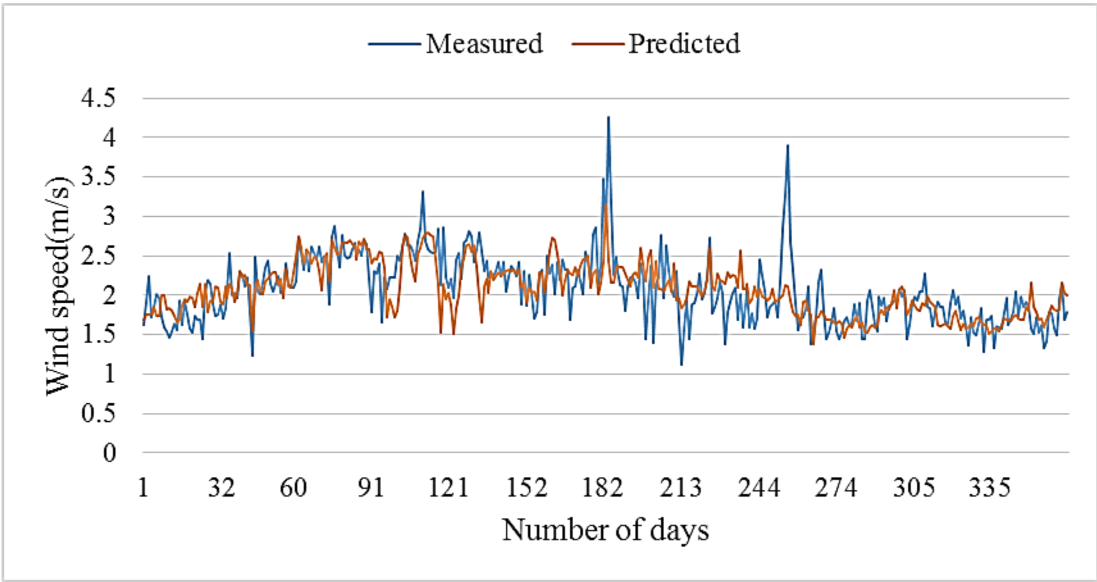

Figure 4.6: Wind Speed from Model 2

Figure 4.6 shows wind speed of year 2018, which is obtained from the model 2 which consist of four different meteorological parameter an input and wind speed as an output. The graph clearly shows the measured and predicted wind speed do fit poorly. Even though the number of variable is increased from what was in model 1 to model 2 the error do not seems to rise concisely.

Model 3:

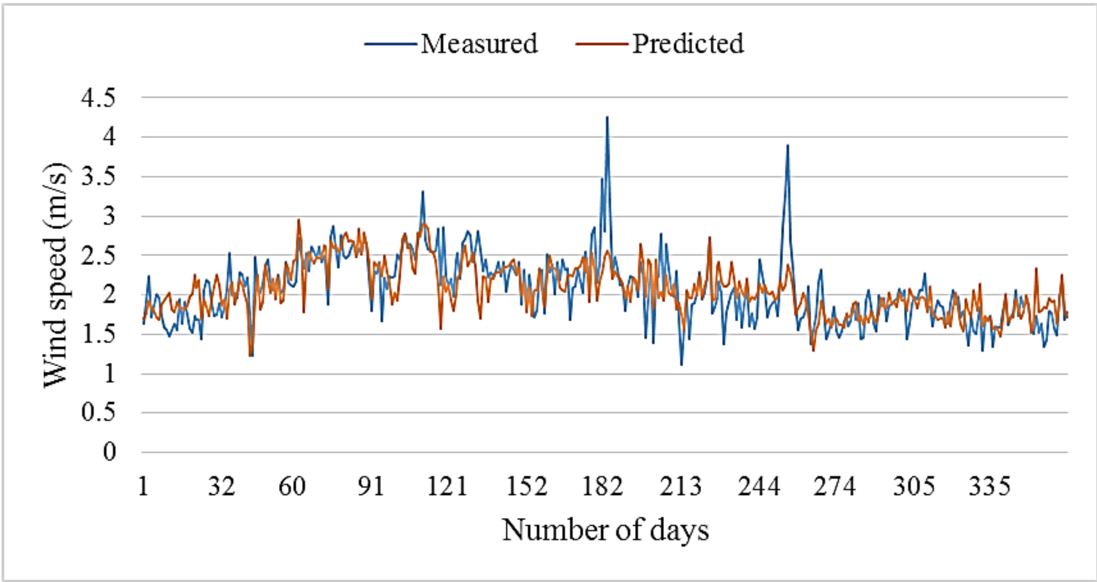

Figure 4.7: Wind Speed from Model 3

Figure 4.7 shows wind speed of year 2018, which is obtained from the model 3 which consist of five different meteorological parameter as an input and wind speed as an output. Even though variable is increased from what was in model 1, model 2 the error do not seems to rise concisely.

Model 4:

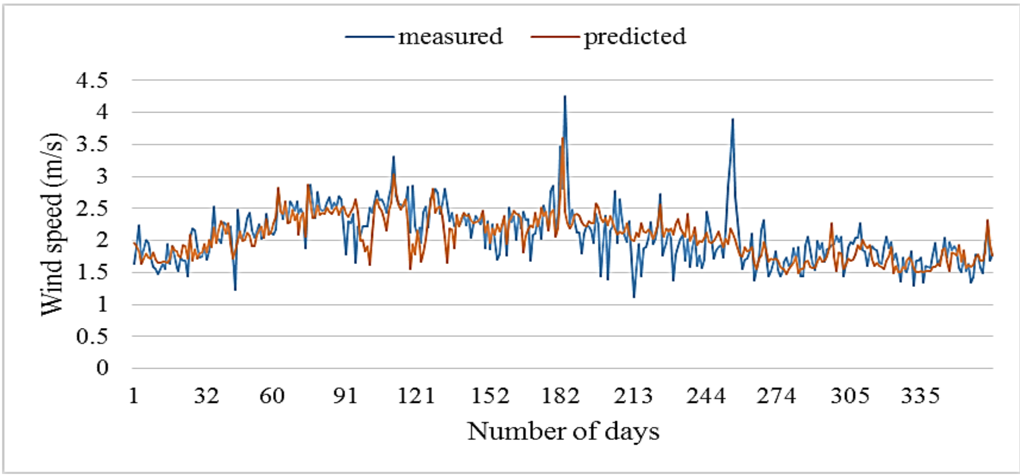

Figure 4.8: Wind Speed of Model 4

Figure 4.8 shows wind speed of year 2018, which is obtained from the model 4 which consist of five different meteorological parameter as an input and wind speed as an output. The variable which is used in this model is different from the variable combination used previously to check its effect in the error.

Model 5:

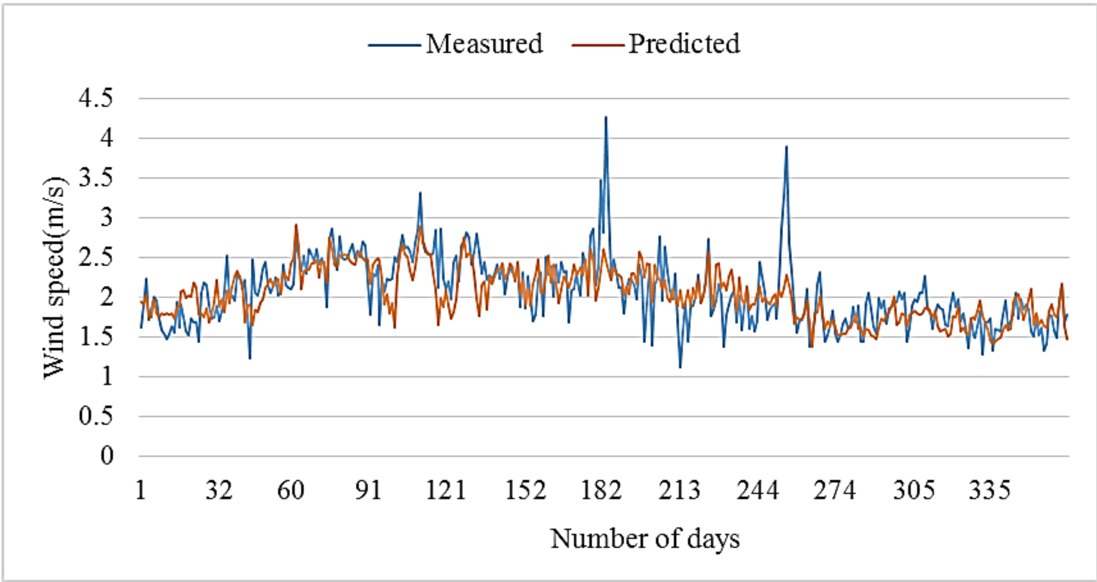

Figure 4.9: Wind Speed of Model 5

Figure 4.9 shows wind speed of year 2018, which is obtained from the model 5 which is obtained from the model 5 which consist of five different meteorological parameter an input and wind speed as an output. The variable which is used in this model is different from the variable combination used previously to check its effect in the error. The error seem to be almost same as the previous one.

Model 6:

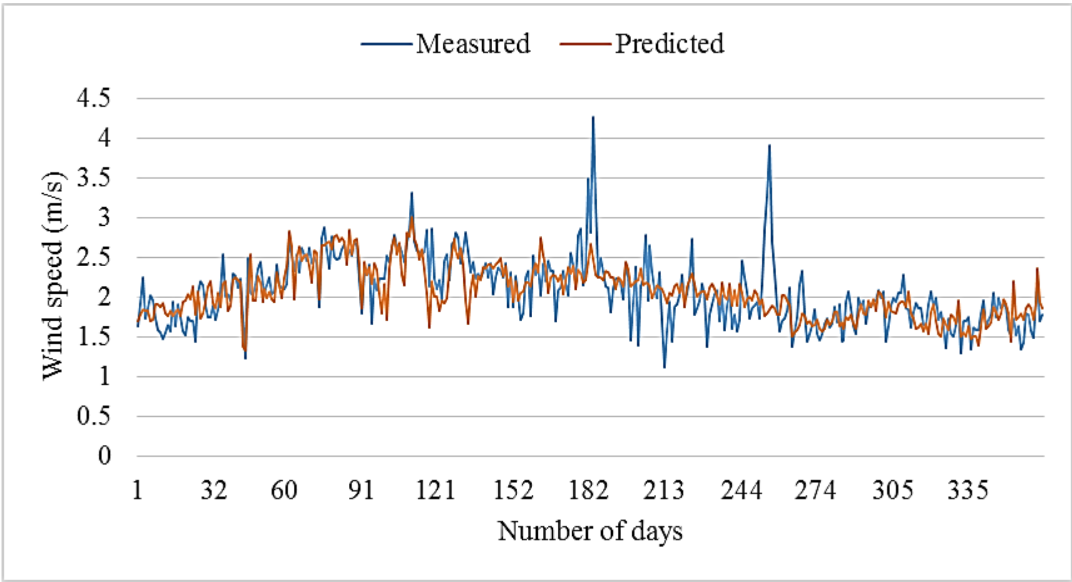

Figure 4.10: Wind Speed of Model 6

Figure 4.10 shows wind speed of year 2018, which is obtained from the model 6 which consist of six different meteorological parameter an input and wind speed as an output. The variable which is used in this model is different from the variable combination used previously to check its effect in the error. The number of variable in increased just to check the overall effect in the error. Graph shows the fitting of the observed and predicted data with reasonable error.

Model 7:

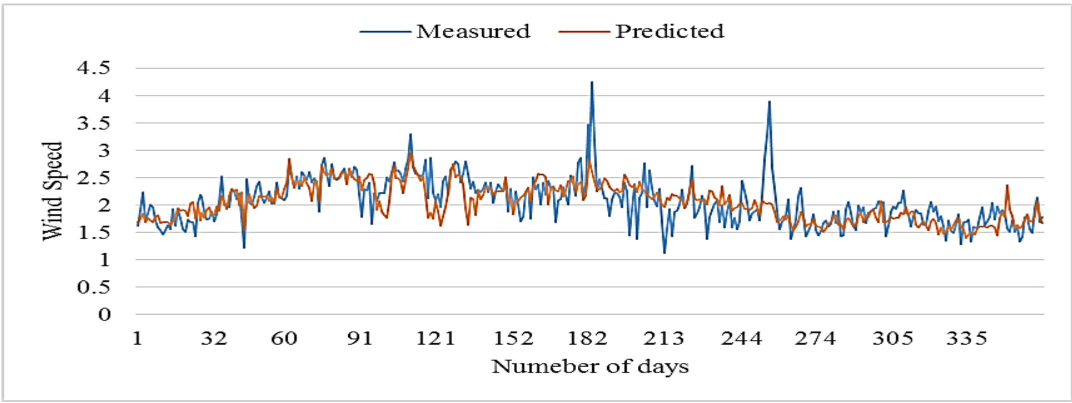

Figure 4.11: Wind Speed of Model 7

Figure 4.11 shows wind speed of year 2018, which is obtained from the model 7 which consist of six different meteorological parameter an input and wind speed as an output.

The variable which is used in this model is different from the variable combination used previously to check its effect in the error. The number of variable in same as in model 6 just to check the overall effect in the error even though the number of parameter remains same error changes as change in parameter happens which is seen.

Model 8:

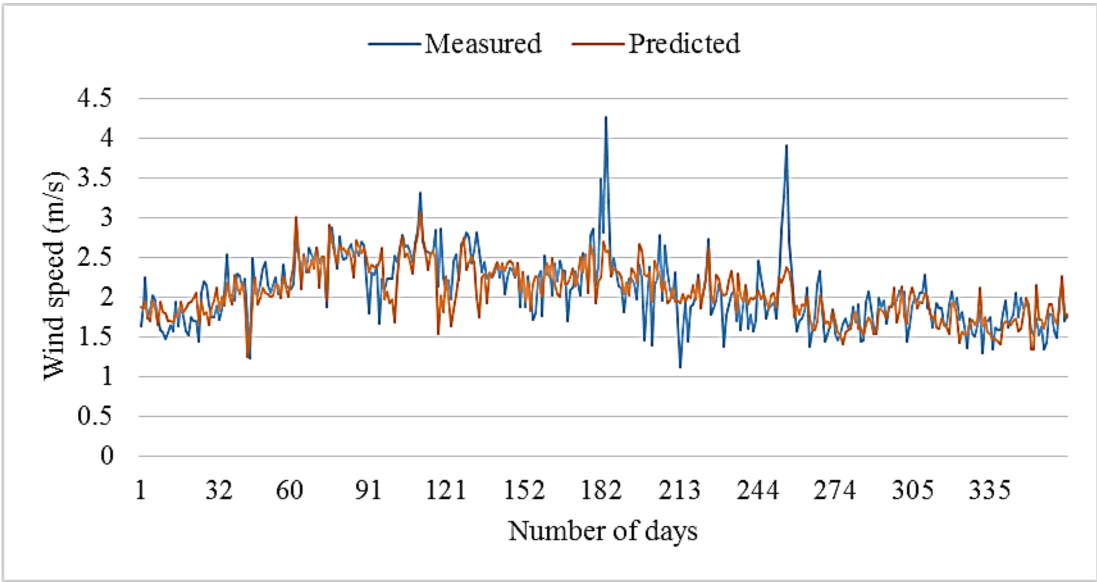

Figure 4.12: Wind Speed of Model 8

Figure 4.12 shows wind speed of year 2018, which is obtained from the model 8 which consist of seven different meteorological parameter an input and wind speed as an output. The variable which is used in this model is different from the variable combination used previously to check its effect in the error. The number of variable used in this model is increased by one just to check the overall effect in the error. Model 8 consist of all the meteorological parameter except minimum temperature.

Model 9:

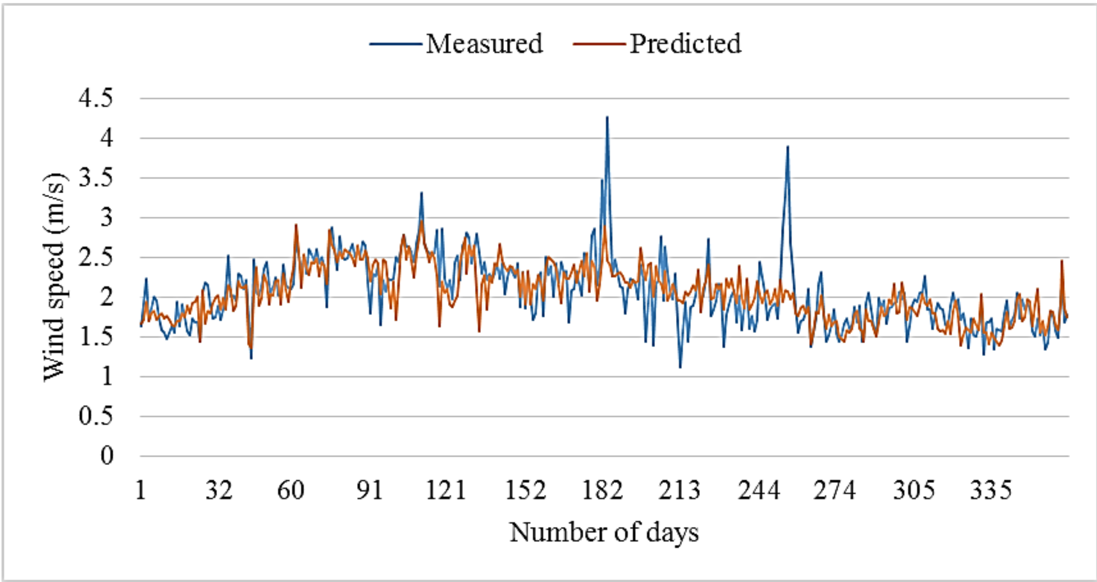

Figure 4.13: Wind Speed of Model 9

Figure 4.13 shows wind speed of model 9. The number of variable used in this model is same as the number of variable used in model 8 the only difference is that this model is developed to see the effect of wind speed if maximum temperature is replaced with minimum temperature. Above graph shows that as the maximum temperature is removed the fitting decreases by some amount proving that maximum temperature has greater importance than minimum temperature in wind speed effect.

Model 10:

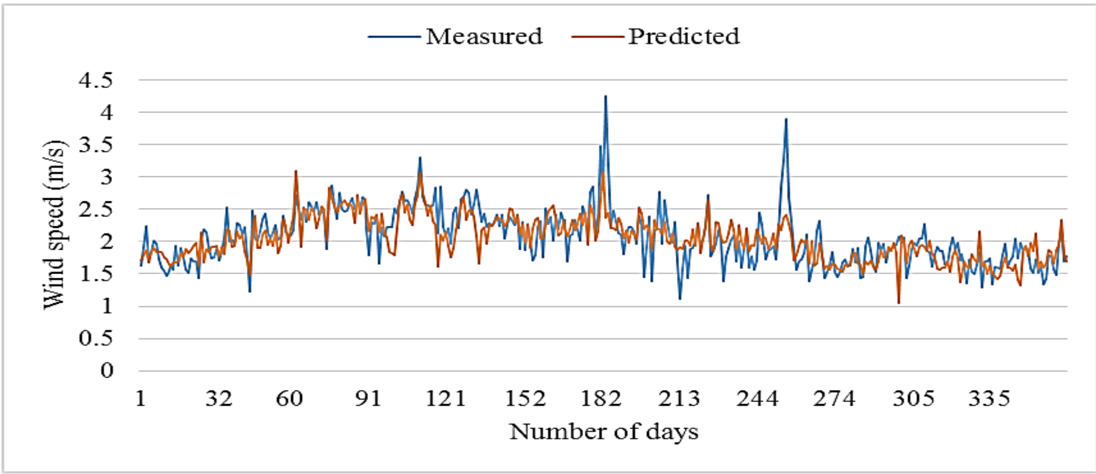

Figure 4.14: Wind Speed of Model 10

Figure 4.14 shows wind speed of model 10. Variable used in this model is same as the number of variable used in model 8 and model 9 the only difference with those model is to see how the measured wind speed changes if one of the major parameter which is altitude is removed from the model. It can be seen from the above graph that as the altitude is removed from the model the fitting decreases by some amount proving that it is one of the major parameter to be dealt with.

Model 11:

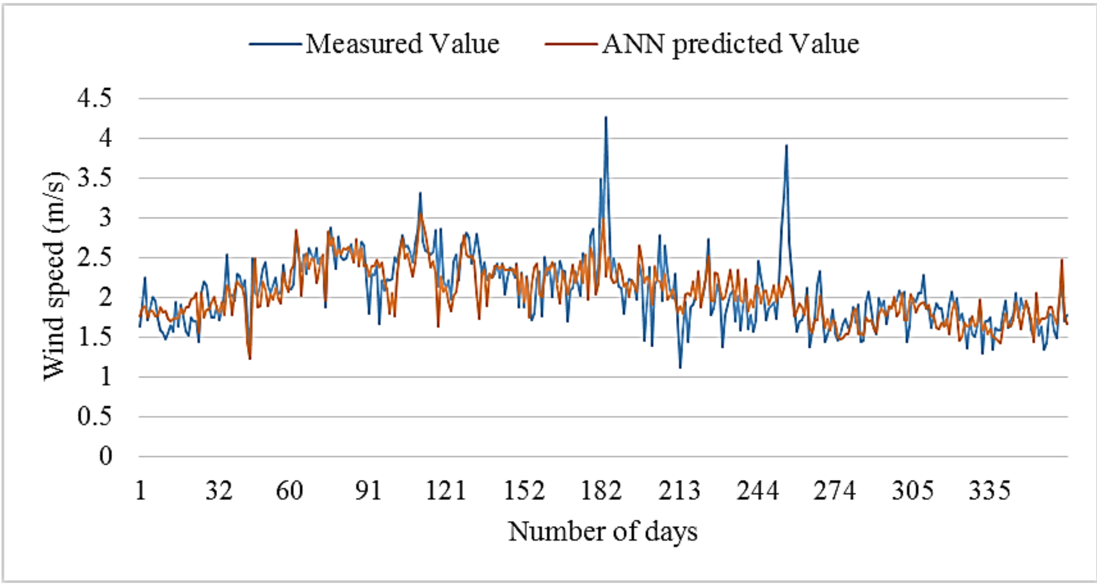

Figure 4.15: Wind Speed of Model 11

Figure 4.15 shows wind speed of model 11. All the input variable are fed in model i.e. all the eight input parameter were used in this model as an input and wind speed is taken as an output of this model. It can be clearly from the Figure 4.15 that there is only slight difference between the calculated and the observed wind speed. This means that the measured and predicted data fits in best possible way that can be generated from the various model developed.

Model 12:

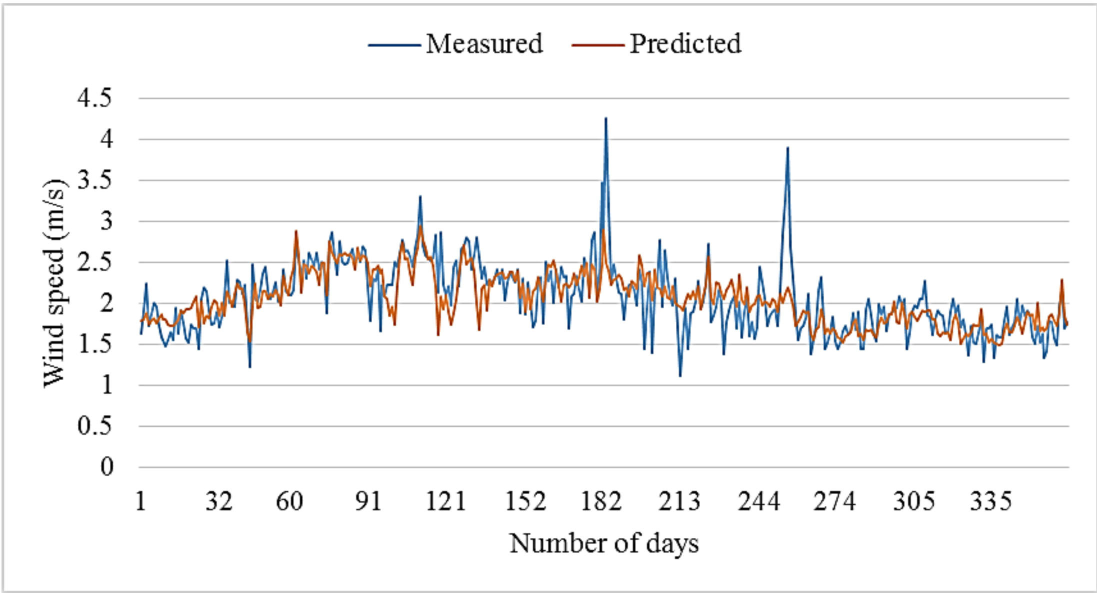

Figure 4.16: Wind Speed of Model 12

Model 12 is obtained by testing the assumption that if the output obtained from 11 different model is averaged and take it as an artificial neural network predicted output then how much will it deviate from the measured data. The result obtained from this analysis is astounding it can be seen that this model fits the data as accurately as it is fit by model 11 which is using all the parameter of the meteorological data. This model is very much close to model 11 in terms of performance measure but lack behinds it by very small amount of accuracy. Thus model containing output of all the different model developed as an input and wind speed as output can predict data more accurately than the model containing five or six or seven meteorological parameter as an input.

4.3 Statistical Errors of All the Twelve Different Models

Statistical errors MAE, MBE, MPE, RMSE, R^2 and adjusted R^2 were calculated using the wind speed data of all the twelve different models.

RMSE:

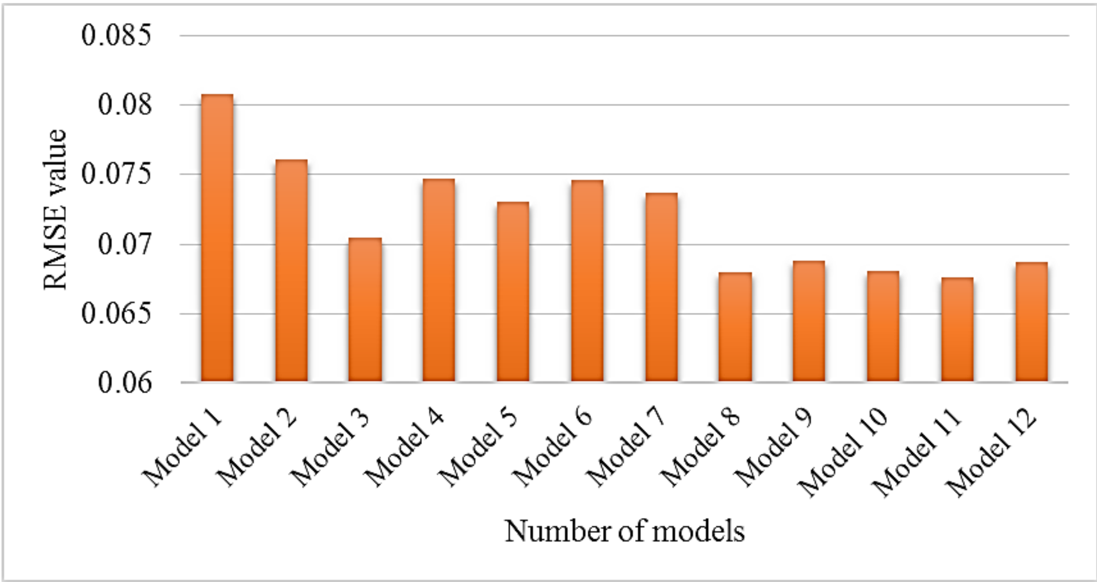

Figure 4.17: RMSE Calculated for All Model

Figure 4.17 shows that the lowest RMSE is exhibited by Model 11 which yield minimum RMSE (0.0676) among all the model developed which is desirable. The model which exhibit maximum value of RMSE (0.08080) is model 1. It can be understood that since the model one have only three parameters as an input it gives the largest value of RMSE which can be expected as the fewer number of meteorological parameter are unable to predict wind speed correctly. The model 8 have comparable value of RMSE with that of model 11 which exhibit valued of RMSE (0.0679). The RMSE value of model 10, model 12, and model 9 is of almost same range whereas the value exhibited by model 5 is almost same as the number of variable is same in those model even though the value varies slightly as the parameter used in all the model developed is different and since one parameter has larger effect on wind speed measure than other the value tends to differ from one another even they are almost close to one another.

MAE:

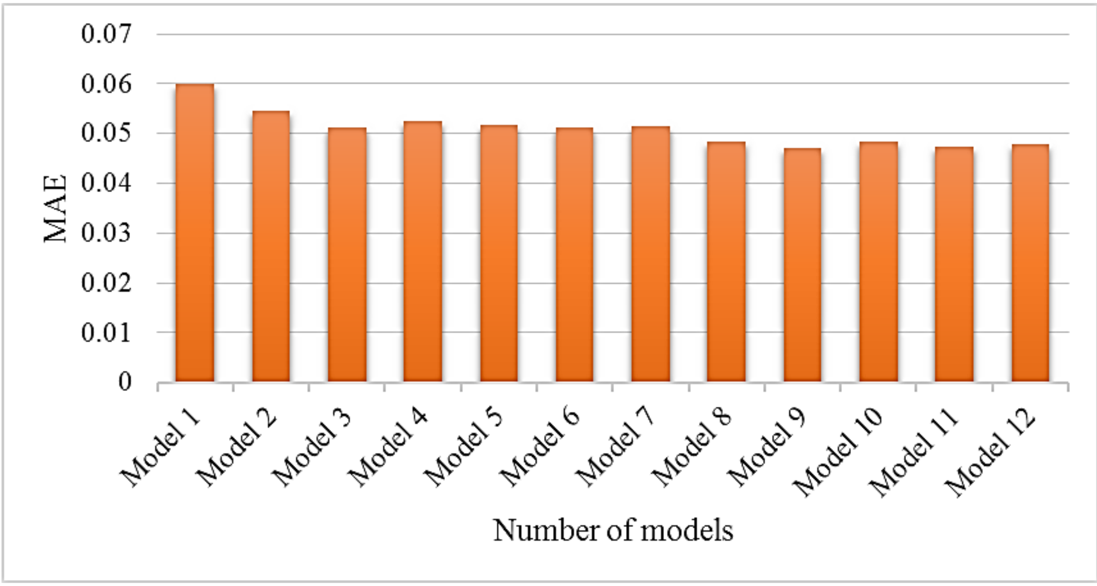

Figure 4.18: MAE Calculated for All Model

Figure 4.18 shows that the lowest MAE is exhibited by Model 9 which yield minimum MAE (0.047141958) among all the model developed. The model 11 have comparable value of MAE with that of model 9 which exhibit valued of MAE (0.0473158). The maximum value of MAE is yield by the model 1 which is (0.060075828). It can be understood that why this model is giving maximum value of mean absolute error this is because the number of meteorological parameter used in this model is only three and since this small number of parameter cannot represent the model accurately the error happens to be maximum. Also model 3 and 6 share almost same value of MAE. The model exhibiting same value of MAE have almost same as the number of variable in those model even though the value varies slightly as the parameter used in all the model developed is different in all the cases and all the parameter have their own share in the wind speed prediction.

MBE:

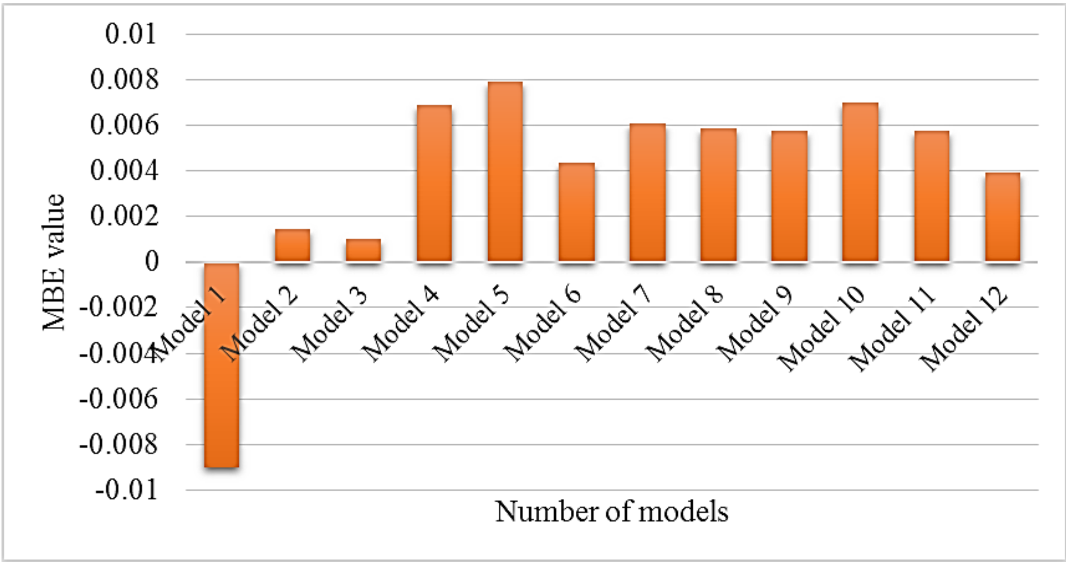

Figure 4.19: MBE Calculated for All the Model

The mean bias error of the model 1 is negative and it gives the value of (-0.0089). The model 2 and model 3 exhibit value of comparable range which is (0.00103) and (0.00145) respectively. The model which yield maximum value of MBE is model 5 which is (0.0079).

MPE:

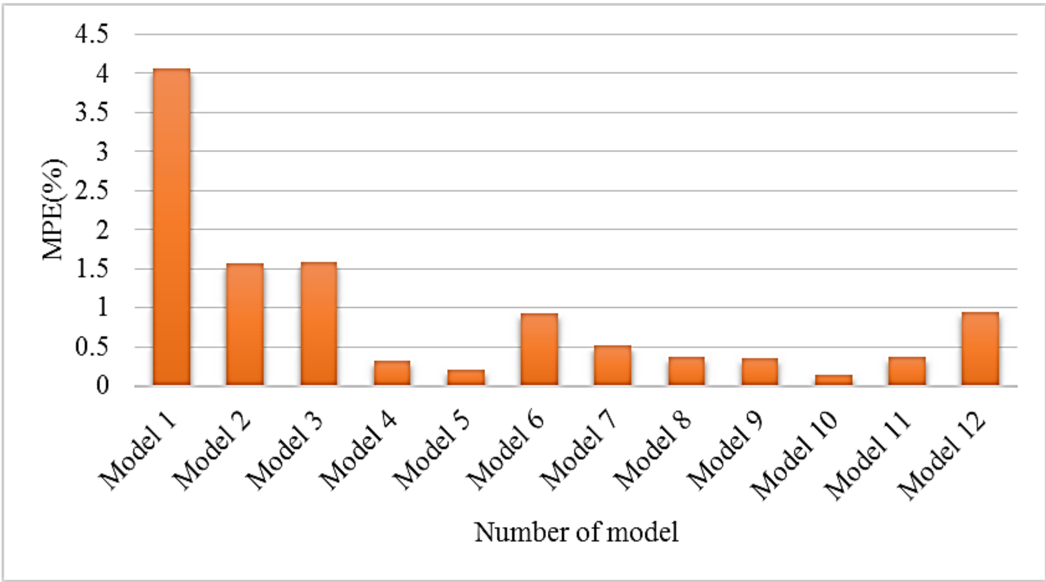

Figure 4.20: MPE Calculated for All Model

The Mean Percentage Error which is expressed in percentage is expressed here in the

Absolute term to avoid the confusion of negative error. Even though the value remains same only sing of the magnitude is changed here just to avoid the conflict with our mind while reading them. The model 10 give minimum value of MPE (0.142916262 %). The maximum value of error is given by the model 1 which is (4.057628949 %). And this can be easily understood as this model have minimum input parameter which is cause of poor MPE value. The model 4, model 9, model 8 and model 11 exhibit comparable value of mean percentage error.

R^2:

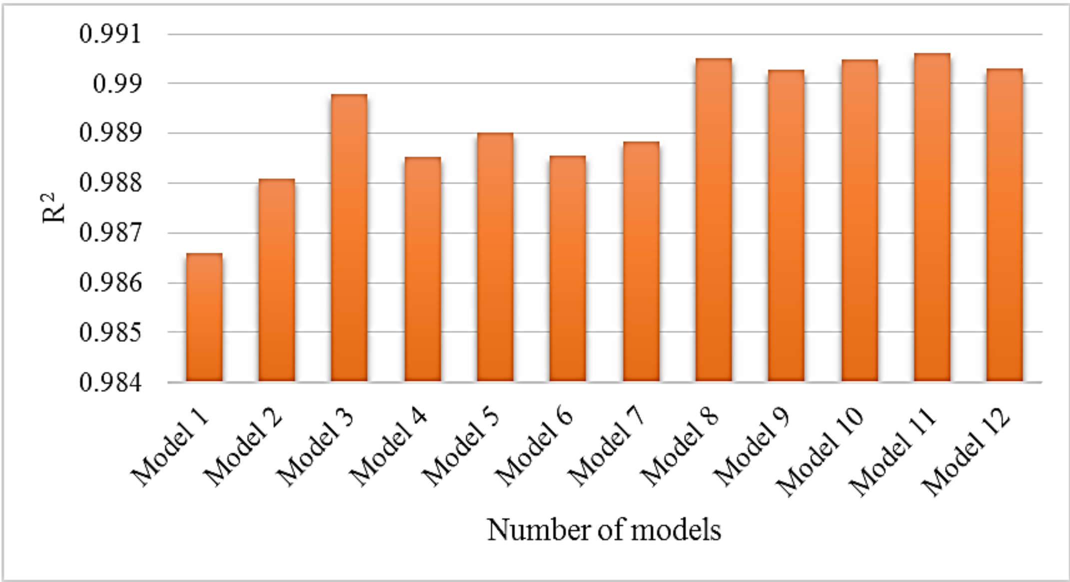

Figure 4.21: R^2 Calculated for All the Model

From Figure 4.21 it can be observed that the highest is value of coefficient of determination is exhibited by Model 11 which yield maximum R^2 (0.990604501) among all the model developed and this is the desirable value. The model which exhibit minimum value of R^2 (0.080807816) is model 1. It can be known that since this model have only three parameters as an input it gives the lowest value of R^2 which can be expected as the fewer number of meteorological parameter are unable to predict wind speed correctly. The model 8 have comparable value of R^2 with that of model 11 which exhibit valued of RMSE (0.990509633). The R^2 value of model 10, model 12, and model 9 is of almost same because of similar number of parameter in their model which is representing the wind speed as an output of the model.

Adjusted R^2:

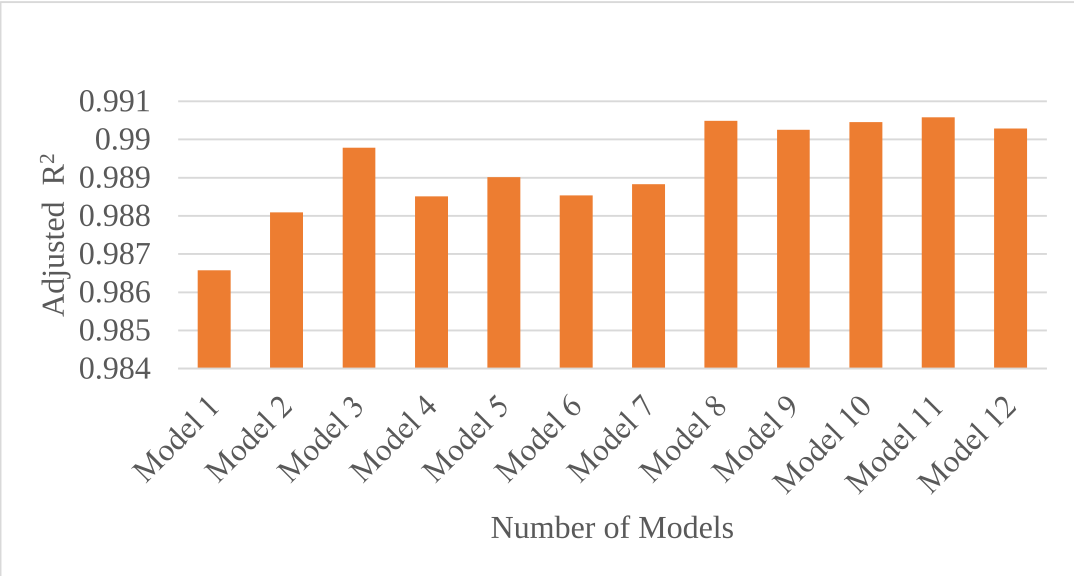

Figure 4.22: Adjusted R^2 Calculated for all Model

Model 11 maximum adjusted R^2. Least adjusted R^2 is found for model 1. The range of adjusted R^2 is found in between 0.9865 to 0.9905. Model 11 has degree of freedom 8. The degree of freedom of model 3, 4 and 5 is 5.

The analysis of the value of wind speed obtained from ANN model developed in this report and the statistical report done using the measured and predicted wind speed which includes RMSE, MAE, MBE, MPE and Coefficient of Determination shows that the developed Model 11 provide the best results this is because it has lowest value of RMSE and highest value of R^2 which are taken to find best model. Also all the other errors are comparatively lower. The result given by Model 8, Model 10 and Model 9 gives the similar result as of the best model developed because the number of meteorological parameter used in this model is less by one number only then the best model which uses eight different meteorological parameter. Also the result given by the model 12 which is formed by computing the output produced by all the different 11 models and averaging them to get the final output. This Model 12 gives the best result than the output produced by the Model 1, Model 2, Model 3, Model 4, Model 5, Model 6, and Model 7 which uses 3, 4, 5, 5, 5, 6 and 6 number of meteorological parameter in different combination.

The model which predict value of wind speed the most poor way is model 1 which consist of only there meteorological parameter. Model predict wind speed poorly because the use of only three input parameter is not sufficient to model the wind speed which is highly stochastic in nature. It exhibit RMSE value of (0.080807816) and R^2 value of (0.986587389). This model also give the value of MBE in negative which simply indicate this model predict the value higher than actual.

Effect of using multiple data for prediction can studied from the above results which indicates that model having similar number of meteorological parameter can exhibit same level of wind speed prediction but there value differ by some amount since different parameter affect the wind speed by different amount. On comparing Model 8 and Model 9 which have same meteorological parameter except that Maximum temperature is changed by Minimum temperature gives different results and form rest it is seen that maximum temperature find the wind speed with better accuracy than the minimum temperature.

4.4 Validation of ANN architecture using Best Obtained Model

For validation ANN model 11, find wind speed of Pokhara Airport. Model 11 was chosen to find the wind speed for the validation purpose this was because the model 11 proved to be best result because it have lowest possible RMSE and Highest value of R^2. ANN calculated and found value is compared and result is presented here.

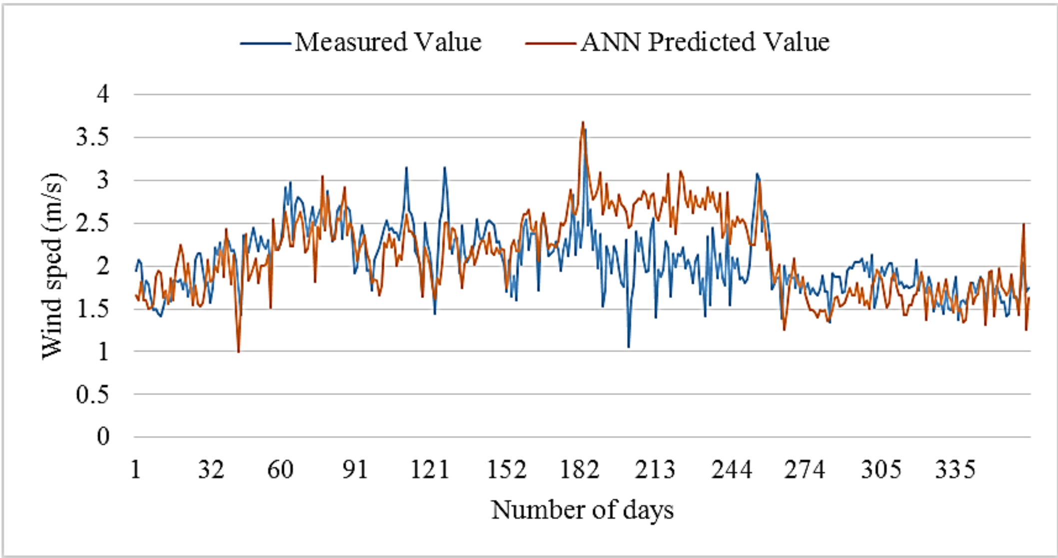

Figure 4.23: Wind Speed of Pokhara Airport

Figure 4.23 shows wind speed for place called Pokhara airport. The Pokhara airport lies at different altitude then the place which was used to develop the model which is Tribhuvan international airport. The validation test was performed to see to what extent the model can find the wind speed of any other location correctly. Data of year 2018 was taken as an input to find wind speed in this validation scenario. This test was very much important to perform in order to fulfill the objective which is to predict wind speed of other location of Nepal. From the comparison done above it is understood that the model can find the wind speed of any other location of Nepal having similar climatic condition with reasonable amount of accuracy.

Table 4.1: Statistical analysis result for the validation of the model performed

Model	RMSE	MAE	MBE	MPE (%)	R^2
Validation	0.4003	0.0881	-0.0177	4.3141	0.9768

The RMSE value obtained during the validation of the best model chosen is (0.400391163). Which is in the acceptable range when compared with the previous research paper published. The value of Mean Absolute Error is (0.088149503). The value of Mean Bias Error is found to be negative and its value is (-0.017798175). The negative value simply denotes the predicted value is larger by actual value by some negligible amount. The value of Mean Percentage error is (4.314187847 %) and the

Coefficient of determination is (0.976823193) which is very much in the required range as the maximum value of R^2 is needed to accurately find the wind speed of other location. Also the minimum value of RMSE is indicates that the measured and predicted data can fit with minimum amount of error in the result. Thus, the value of statistical error analysis achieved during the validation of Artificial Neural Network model for Pokhara Airport [Table 4.1] shows that ANN model is capable to find wind speed for Nepal's different location.

4.5 Wind speed of One Site of Seven Provinces of Nepal

After validating the model by using the meteorological data for entirely different place than for which the model was developed proved that this model can find the wind speed of any other location of Nepal with reasonably well accuracy. The location was chosen based on the availability of meteorological parameter of 2018. The seven different location are from seven different province of Nepal. Since this thesis objective includes the case study of Nepal keeping that things in mind the place was chosen across the Nepal instead of choosing the all the place of certain district or municipality.

Okhaldhunga:

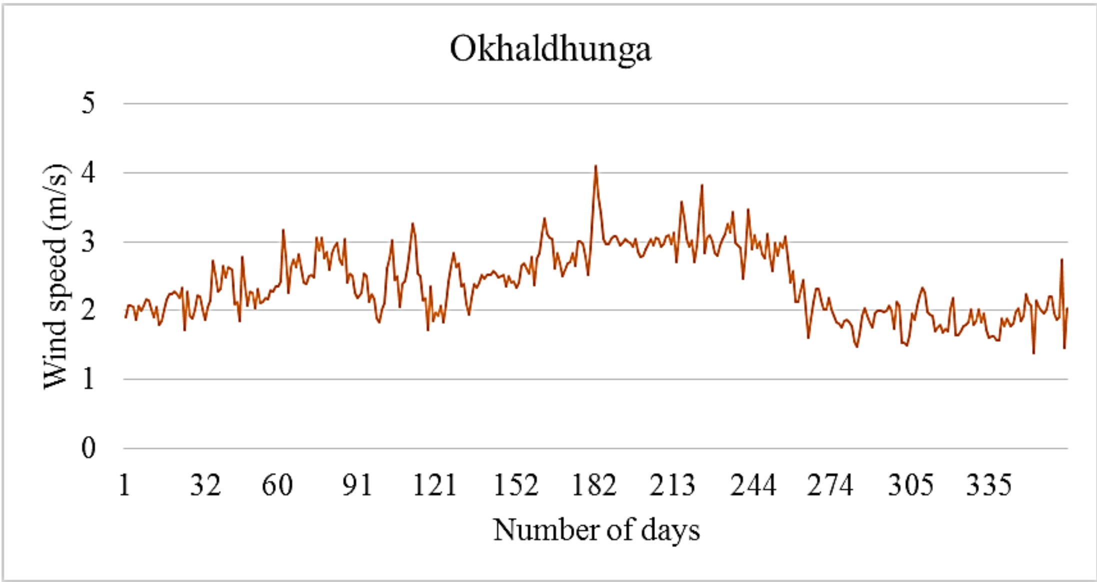

Figure 4.24: Okhaldhunga Wind Speed of province – 1

Figure 4.24 is showing wind speed of Okhaldhunga which is located in province 1 at an altitude of 1720 meter. The wind speed of the entire 2018 is predicted using eight input meteorological parameter as an input. The maximum wind speed during 2018

(4.091346721 m/s) and minimum wind speed during entire 2018 is (1.375324909). From above figure it can be seen that no two days are having same wind speed in 2018 proving the stochastic nature of wind.

Janakpur Airport:

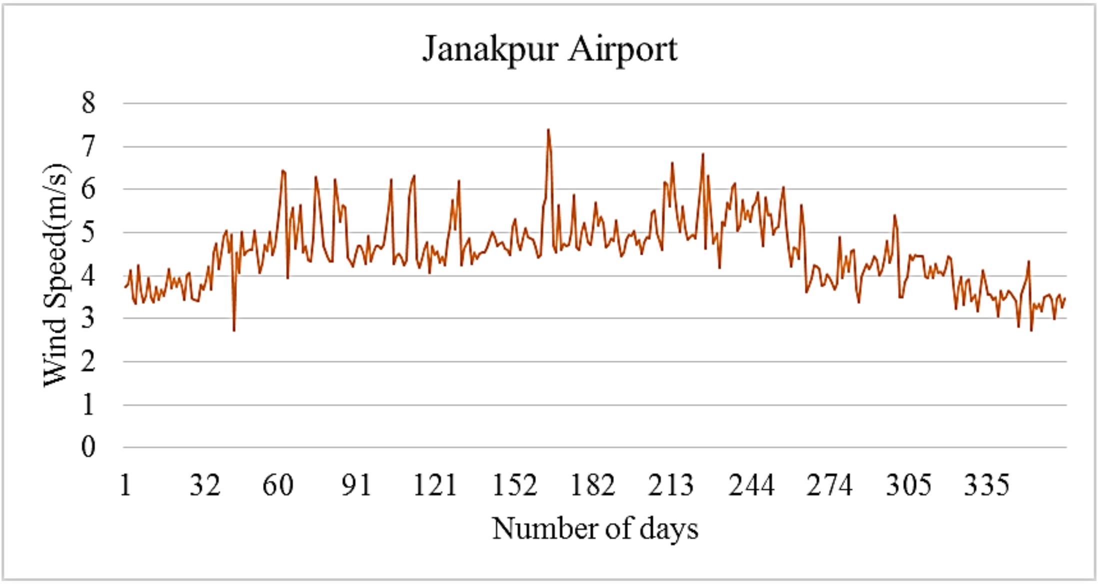

Figure 4.25 Janakpur Airport Wind Speed of Province - 2

Figure 4.25 shows the predicted wind speed of Janakpur Airport which is located in province 2 at height of 90 meter. The wind speed of the entire 2018 is predicted using eight input meteorological parameter as an input which was selected best for prediction of wind speed during the validation process. Maximum wind speed during 2018 was (7.39122 m/s). Minimum wind speed during the entire 2018 was (2.72041m/s). From above figure it can be seen that no two days are having same wind speed in 2018. Even though the maximum value of wind speed for Janakpur Airport shows the speed of (7.391226608 m/s) this is not generally the case as it is for that particular day only and the cause for it may be storm on that particular day.

Nagarkot:

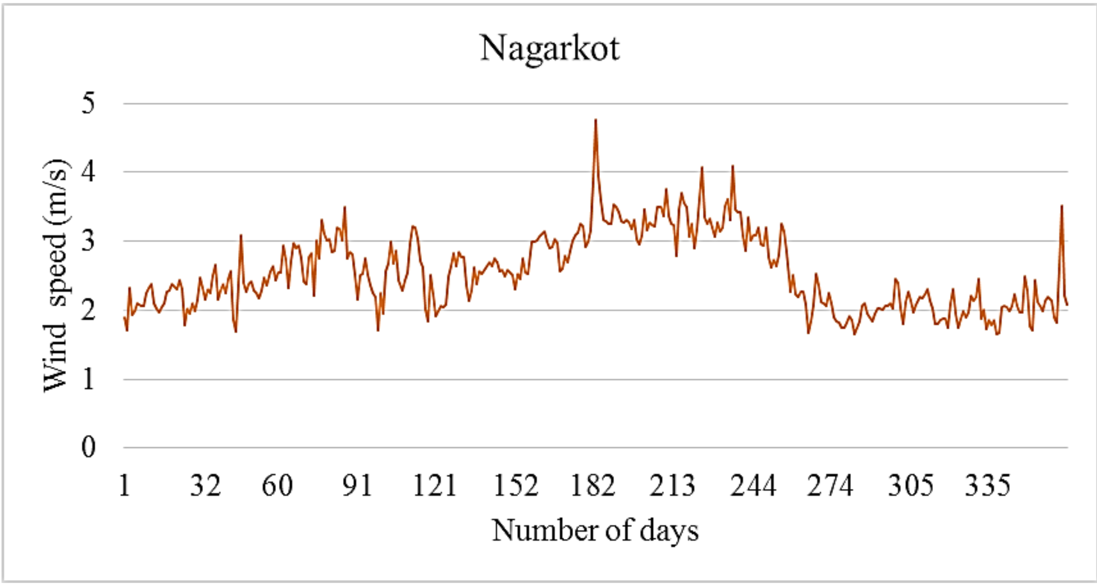

Figure 4.26: Nagarkot Wind Speed of Province – 3

Figure 4.26 shows the predicted wind speed of Nagarkot which is located in province 3 at height of 2163 meter. Wind speed of the entire 2018 is predicted using eight input meteorological parameter. The maximum wind speed during 2018 was (4.76099m/s). Minimum wind speed during the entire 2018 was (1.658976294 m/s). From above figure it can be seen that no two days are having same wind speed in 2018 proving the stochastic nature of wind. This proves the need for predicting the wind speed of any location before doing any development work in that areas whose output can get effected by the different values of wind speed.

Gorkha:

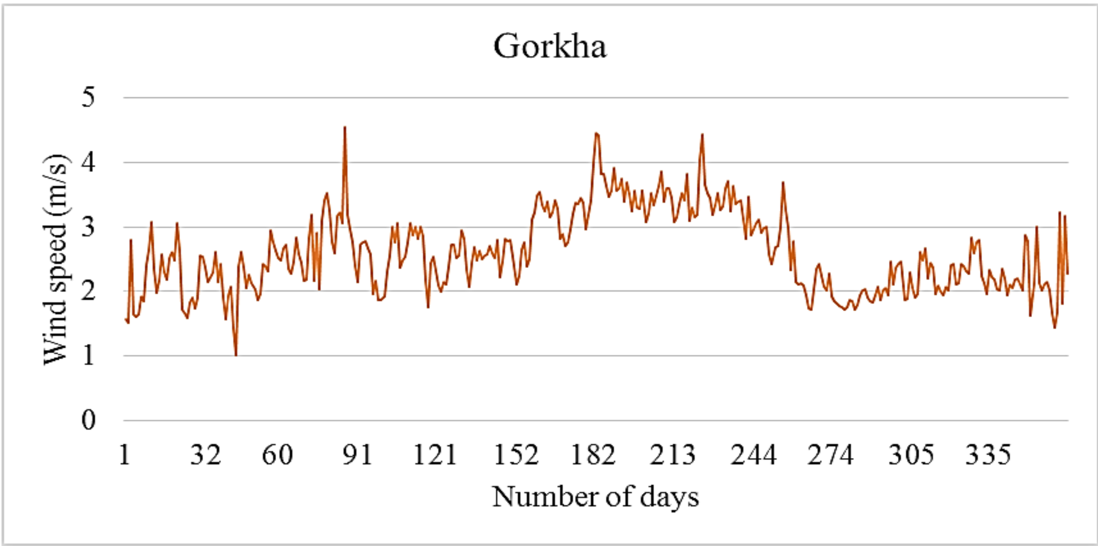

Figure 4.27: Gorkha Wind Speed of Province – 4

Figure 4.27 shows the predicted wind speed of Gorkha which is located in province 4 at height of 1097 meter. Neural network fitting tool (nftool) is used in MATLAB to form the model. The maximum wind speed during 2018 was (4.5528 m/s). Minimum wind speed during the entire 2018 was (1.0105 m/s).

Tansen:

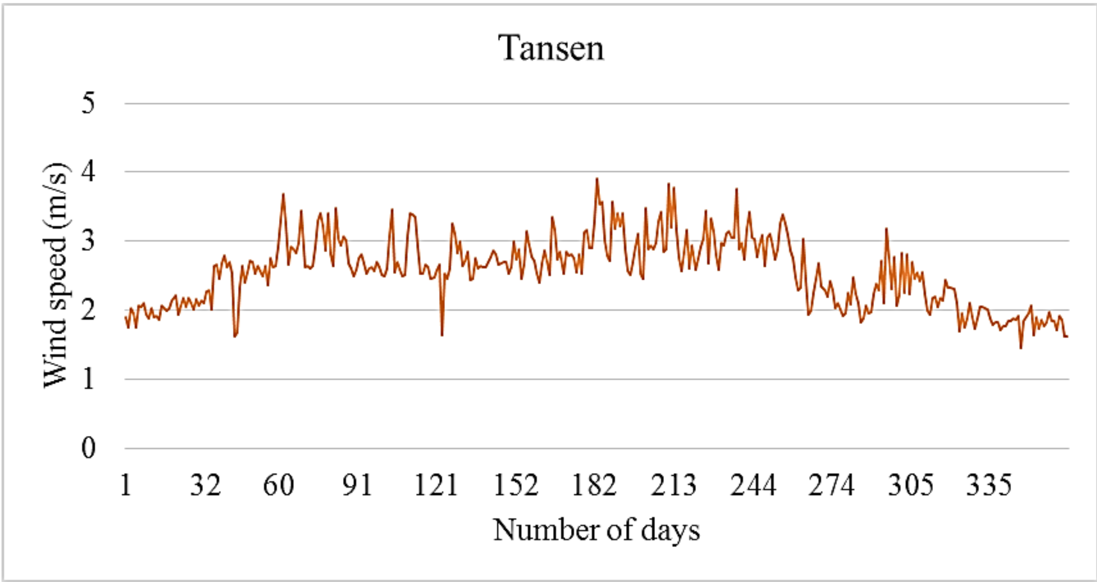

Figure 4.28: Tansen Wind Speed of Province – 5

Figure 4.28 shows the predicted wind speed of Nagarkot which is located in province 5 at height of 1067 meter. Maximum wind speed during 2018 was (3.9004 m/s).

Minimum wind speed during entire 2018 was (1.4455 m/s). Average wind speed of Tansen throughout the year 2018 was (2.5566m/s). The three different value of wind speed of any location can help to plan for the better in future time space.

Jumla:

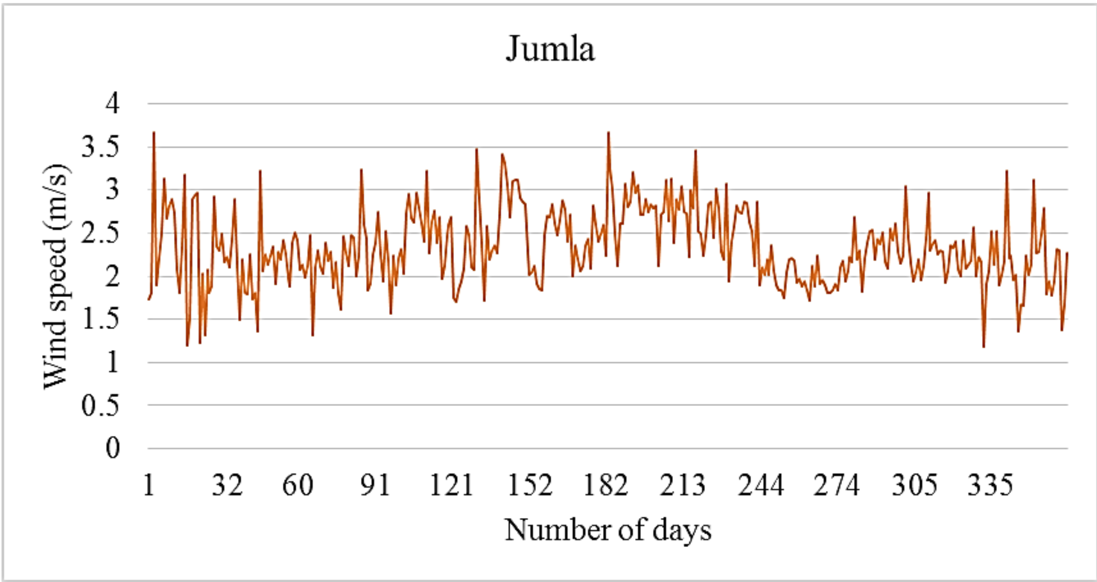

Figure 4.29: Prediction of Daily Wind Speed of Jumla of Province – 6

Figure 4.29 shows the predicted wind speed of Jumla which is located in province 6 at an altitude of just 2300 meter above the sea level. The maximum wind speed during 2018 was (3.670922655 m/s) and the minimum value of wind speed during the entire 2018 was (1.183555764 m/s). The average value of wind speed of Tansen throughout the year 2018 was (2.33898412 m/s). The three different value of wind speed of any location can help to plan for the better in future time space. The research paper published by (Parajuli, 2016) states that wind speed is decreasing in Jumla And the result obtained during completion of this thesis also further proves that the wind speed of Jumla is decreasing year after year and in 2018 the mean wind speed at height of 10 meter further decreased to (2.33898412 m/s).

Bajura:

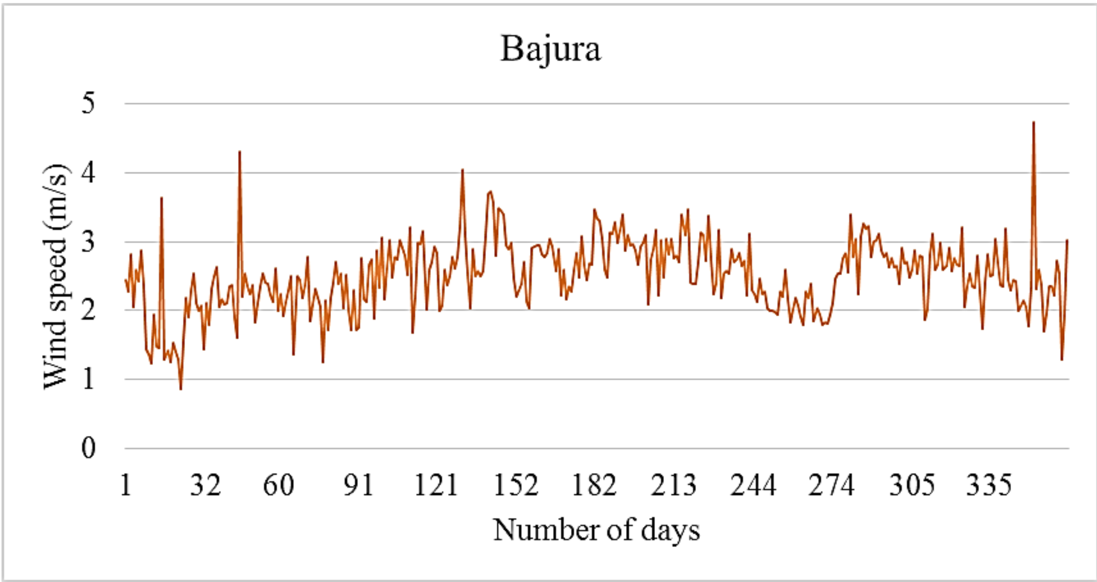

Figure 4.30: Bajura Wind Speed of Province – 7

Figure 4.30 shows the predicted wind speed of Bajura which is located in province 7 at height of 1400 meter. Maximum wind speed during 2018 at the height of 1400 meter was (4.72129m/s). Minimum wind speed during the entire 2018 was (0.86438m/s). The average wind speed of Bajura throughout the year 2018 was (2.49930 m/s).

Wind speed of all the seven location found is at the specific value of latitude, longitude and the altitude above the sea level. Even though the name represents entire area of that very particular area. For example the wind speed of Bajura is for the specific altitude of 1400 meter although the Bajura extends from the altitude of as minimum as m/s to as maximum of m/s. Wind speed found here does not represent the wind speed of Bajura which covers an entire area of square kilometer. Instead the model developed in this thesis predict the wind speed of that very particular location and of that very particular altitude.

The best model chosen can find the wind speed of desired location all we need is input for wind speed calculation of that site. All predicted wind speed of every site possesses specific amount of RMSE and R^2. The amount by which error extends depends directly upon the quality of meteorological data available and difference of altitude for data is to be predicted.

4.6 Comparison of ANN Result with Empirical Model

The different statistical error RMSE, MAE, MBE, MPE and R^2 for all the twelve model developed is presented here for the purpose of comparing the result obtained during this study of this thesis with the previous result conducted by other researcher around the globe.

Table 4.2: Statistical indicator for twelve different ANN model

Models	RMSE	MAE	MBE	MPE (%)	R^2
Model 1	0.0808	0.0600	-0.0089	4.0576	0.9865
Model 2	0.0761	0.0544	0.00145	1.5642	0.9881
Model 3	0.0704	0.0510	0.00103	1.5909	0.9898
Model4	0.0747	0.0525	0.00686	0.3309	0.9885
Model5	0.0730	0.0517	0.00793	0.2141	0.9890
Model6	0.0746	0.0511	0.0043	0.9273	0.9885
Model 7	0.0736	0.0514	0.0060	0.5135	0.9888
Model 8	0.0679	0.0483	0.0058	0.3677	0.9905
Model 9	0.0688	0.0471	0.0057	0.3614	0.9902
Model 10	0.0680	0.0484	0.0069	0.1429	0.9904
Model 11	0.0676	0.0473	0.0057	0.3707	0.9906
Model 12	0.0686	0.0477	0.0039	0.9501	0.9903

Comparison of the output obtained from the ANN developed model and Empirical model the article published by (Jang et al., 2018) was chosen. The error estimation in the prediction of winds speed of year 2018 was taken from that Article. This model uses two different method the one was The Linear Regression Model and the second one was The Variance Ration Model. The test was done for the one year data of a place called Urumsill of South Korea. From result obtained it can be seen that the value of RMSE of (0.123) to (0.554) and R^2 ranges from (0.889) to (1.007). When the measured data were compared the value of R^2 value was found to be to be (0.86).

Comparing the statistical error values with those obtained from ANN models it can be concluded that ANN models were providing result which is very much near to the measured data than those from the empirical models. The RMSE obtained from the ANN model ranges from (0.067632686) to (0.080807816). It can be seen from comparing of RMSE obtained from empirical model and ANN developed model that the Root Mean Square Error obtained from ANN model to be in quite lower range proving that the measured data and ANN found data are more close to one another thus giving minimum. Value of R^2 obtained for ANN model are in the range of (0.986587389) to (0.990604501). Comparison of R^2 obtained from both empirical model and ANN developed model the study found ANN developed model prediction are highly correlated with the measured data of wind speed than those from the empirical model because of having the value of Coefficient of Determination comparatively high for the model developed than those obtained from empirical model. Thus after comparing all the statistical error parameter it can be concluded that ANN models provide precise estimation of wind speed compared to empirical models.

4.7 Comparison with Result of ANN Model Developed by Other Researcher

(Filik et al., 2017) conducted study using ANN with meteorological parameter in Eskisehir. The RMSE value of (0.6494) and MAE value of (0.5032). When this result is compared with the model one developed during which consist of only three parameter it can be seen that RMSE of model one is (0.080807816) and MAE value of (0.060075828). This shows that the result obtained is better than the previously obtained one.

(Ogunjuyigbe et al., 2015) uses meteorological data in the ANN model to find wind speed in Noupoort of South Africa. The model using temperature, relative humidity, pressure, wind direction gives the RMSE value of (0.59) and the MAE value of (0.46) when comparing this result with the result obtained using 5 meteorological parameter as an input this report got best RMSE value for the Model 3 which is (0.070467048) and MAE value of (0.051086227).

(Assareh et al., 2012) developed as model to find wind speed in Manjil, Iran using ANN, the research uses eleven years past data and the best Model gives the MSE value of (0.0883176) which is comparable with the result obtained in this report, the minimum

RMSE obtained here is (0.08080782) this may be because of this report also train the ANN developed model using past ten years data.

This report takes the work done by many past researcher further ahead by not just making a model and predicting the wind speed of that very particular location but also adding new dimension to it that is the best model is chosen among the various model developed in this report and validating it by finding the wind speed of completely new location and then after confirming that the developed model is fine. Model developed is used to find wind speed of seven new places of Nepal.

(Ramasamy et al., 2015) uses ANN for calculating wind variable. MAPE obtained between measured and calculated wind speed is (4.55 %) and Correlation Coefficient (CC) of (0.98) whereas MAPE and CC for the validation model is obtained to be (6.489%) and (0.99) respectively. The Mean Percentage Error (MPE) obtained between measured and predicted wind speed in this thesis report is (0.9271873) and Coefficient of Determination obtained is (0.98855588) where MPE and R^2 for validation model is obtained here is (4.314187847) and (0.976823193) respectively.

The possible reason which can be for the slight deviation in result may be due to the different method used by both the report even though they are developed under ANN environment and the data from where it is taken and number of data used to train model is different for both the report. The previous model uses only six input parameter whereas this report also take an account of same input meteorological data with different altitude. The comparison of result obtained in this thesis report with previously obtained result shows that this model is in good agreement to be used for the purpose it is developed.

4.8 Comparison of ANN Predicted Wind Speed with NASA Data

The predicted wind speed of seven places namely Okhaldhunga, Janakpur Airport, Nagarkot, Tansen, Jumla and Bajura are compared with the NASA data. The statistical error comparison for all the seven location wind speed are presented in table 4.3.

Table 4.3: Error for seven location when compared with measured data

Location	RMSE	MAE	MBE	R^2
Okhaldhunga	0.6240	0.5937	-0.5409	77.3087
Janakpur	0.7777	0.7500	-0.7435	58.1997
Nagarkot	0.6486	0.6103	-0.5943	75.6764
Gorkha	0.6662	0.6316	-0.6150	74.4616
Tansen	0.6291	0.6008	-0.5721	76.6178
Jumla	0.6314	0.6045	0.52760	76.9621
Bajura	0.6476	0.6169	-0.5246	75.9793

The statistical error data obtained here is comparatively large in comparison to the validation model developed this may be because the ANN model were are compared with NASA data which have its own error. The possible reason for RMSE, MAE being high and R^2 being low for the Janakpur airport may be due to the great altitude difference between Janakpur airport and Tribhuvan International Airport.

4.9 Relation of Meteorological Data and Wind Speed

The meteorological data and wind speed have relation which is needed to understand how wind speed is effected by the particular meteorological variable. Since all the meteorological data have their own separate relationship with the wind speed, all the parameter are modeled separately in relation to wind speed to find its particular relation with wind speed. The predicted data of wind speed and data of that very particular variable is taken to find the relation that exists between each of them. The following equation tells us what types of relation exists between the meteorological data used in this model with wind speed separately.

$Y = 0.057x + 0.8007$ Equation 4.1

$Y = 0.0207x + 1.789$ Equation 4.2

$Y = 0.0344x + 1.4783$ Equation 4.3

$Y = - 0.4029x + 35.81$ Equation 4.4

$$Y = -0.0029x + 2.1876 \quad \text{Equation 4.5}$$

$$Y = 0.1448x + 1.3581 \quad \text{Equation 4.6}$$

$$Y = -0.001x + 2.2694 \quad \text{Equation 4.7}$$

Where, Y = Wind speed and x = respective input parameter.

How the wind speed is effected by meteorological input parameter is indicated in the equation. Maximum temperature, Minimum temperature and mean temperature effecting wind speed is given by equation 4.1, 4.2, and 4.3 respectively. Pressure, relative humidity and solar radiation effecting wind speed is given by equation 4.4, 4.5, and 4.6 respectively. Wind direction effecting wind speed is given by equation 4.7. All the seven equation developed here is indicating their own peculiar relationship with wind speed. The constant of all the equation are different which indicates all meteorological variable have different relation with wind speed. Thus, from above seven equation it can be concluded that all the parameter which are used in this study are important in the study of wind speed prediction.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

This thesis report shows the results of an effort made to predict the daily wind speed according to measured value of meteorological parameters. The Artificial Neural Network models provide promising value of predicted wind speed for any location lacking the wind speed data required for any types of application in the real world provided that the meteorological parameter such maximum temperature, minimum temperature, mean temperature, atmospheric pressure, relative humidity, solar radiation, wind direction and altitude are available. The obtained result in this thesis suggest that ANN based models for estimating wind speed are precise compared to empirical models.

The ANN model was developed using meteorological parameters from Tribhuvan International Airport with Artificial Neural Network Fitting Tool (nftool) for predicting wind speed of one location of all seven provinces of Nepal. The Root Mean Square error (RMSE) and Coefficient of Determination (R^2) achieved in this prediction of daily wind speed are found to be (0.067632686) and (99.06045008%) respectively. Model is validated by predicting the wind speeds of entirely different locations Pokhara Airport for which measured data was available. RMSE was found to be (0.400391163) and coefficient of determination as (97.68231929%) showing high prediction accuracy of the developed ANN model.

The result showed that using more number of input parameters may or may not increase the system accuracy and if they do, it is in a very small proportion at the same time it increases the computation time thus model parameter can be chosen based on the level of accuracy required. The Model 8, Model 9 and Model 10 uses seven parameters as an input and the accuracy with which it can predict wind speed is almost same. Whereas Model 11 uses eight parameter as an input and accuracy increases by a small amount than the previous model. This thesis also suggest using only less input parameters can give better accuracy than using more parameters if they are chosen with outmost care.

The wind speed which was predicted for Okhaldhunga, Janakpur Airport, Nagarkot, Gorkha, Tansen, Jumla and Bajura of Nepal showed that those locations can be used for small to medium wind power generation.

5.2 Recommendations

This research can be further extended to new dimension as well as some of the limitation faced in this research can be overcome in future works to get more accurate ANN model and result.

In this present work wind speed is calculated and the weight used here is random weight so further work can be carried out to train the network by using optimized weights instead of using random weight.

There could be error on the measured data themselves if the measuring data were not calibrated and maintained properly. The error could be minimized by using bad data detection technique so that prediction can be improved since output of ANN depends on the reliability of Input data samples.

It will be wise to use ANN technique to find wind speed by designer of wind energy and researchers which would give more precise result than that of empirical models.

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APPENDIX A: Neural Network Function for Model 11

```
function [Y,Xf,Af] =NeuralNetworkFunction(X,~,~)
%NEURALNETWORKFUNCTION neural network simulation function.
%
% Generated by Neural Network Toolbox function genFunction, 26-Dec-2019
22:57:40.
%
% [Y] = NeuralNetworkFunction(X,~,~) takes these arguments:
%
%   X = 1xTS cell, 1 inputs over TS timesteps
%   Each X{1,ts} = 8xQ matrix, input #1 at timestep ts.
%
% and returns:
%   Y = 1xTS cell of 1 outputs over TS timesteps.
%   Each Y{1,ts} = 1xQ matrix, output #1 at timestep ts.
%
% where Q is number of samples (or series) and TS is the number of timesteps.

%#ok<*RPMT0>

% ===== NEURAL NETWORK CONSTANTS =====

% Input 1
x1_step1.keep = [1 2 3 4 5 6 7];
x1_step2.xoffset = [0.244290865;-
0.077861163;0.092886104;0.978520005;0.093044539;0.042183623;0.00036561];
x1_step2.gain =
[2.64652087340455;1.85552654521239;2.20479479899843;93.1098913198072;2.20
517995205059;2.08808290192766;2.00073148743912];
x1_step2.ymin = -1;

% Layer 1
b1 = [2.5538750980483553;-2.4571244431271073;1.9590627107602379;-
2.4936098080223204;2.1037722147130129;-2.2675986672572277;-
2.1241802744966702;-2.0202381226267963;-1.8317699728037091;-
2.3706917747155858;-2.1530550038513034;-1.8556607292509553;-
1.4336260943223695;-1.8555387472894738;1.0808855784884326;-
4.0334342133908194;1.1998759856288852;-0.99948481563349123;-
0.059802057977510259;0.91760320550571883;-0.25805184255794367;-
0.64721787489744609;-0.63840103633060419;-0.11556165639053548;-
0.79652340505549535;-0.46209676078424994;-0.27741015599465196;-
0.75437174608789292;-0.041311229277950209;-0.39429536069582122;-
0.064025094132791061;0.0026054146991117012;0.14536824911858529;-
0.27961692301755176;-0.44086382981033573;0.29026756076805882;-
0.18987233010037693;0.71366932062820632;1.1982262968170054;0.73786716919
147854;-0.93095322325391672;-1.0383549946108421;-1.2563597023792377;-
1.6646821951872233;0.68429572392110516;1.4858885783341558;-
1.6374069053064189;1.4920971419879829;-
1.8462284514625169;1.7910637067142194;1.7046399617010917;1.5568007924777
```

494;-1.9267924340770815;2.174797186308485;2.1826842601256571;-
2.1413674675312642;-
2.547467143197546;1.8836849203198731;2.4925039532920312;-
2.5188879100634578];
IW1_1 = [-0.80755952065729975 -1.3593557959771014 -1.3459007429967353
0.89126165793981571 0.21926569628981807 0.70598641489877301
0.77789379253745461;-0.16478507623464472 0.95294371432696334 -
1.5545230669062613 0.52246443872496773 -1.3163234409558133
0.10232043091377038 0.35819554115264129;-1.3626535150811807 -
0.56175646709364235 -1.5041147848614191 -0.28317780895321393 -
1.0277418815850106 -1.2015302260817324 -
0.73282255663707707;0.1514576872228407 0.72918944471698355 -
1.384949104393346 -0.43491303872175796 0.92144957332536714
1.3061764788749783 -0.59435652376831316;-0.69187878538315228
0.50758118441953259 -0.91421727920837237 0.47381929015496271
0.77064406582101286 0.54648173168175973 -
1.8458381886656285;0.27359740737987126 -0.91454251661399966
0.83450295060027657 0.67423001211409628 1.0578230636340717
1.3209055007504917 -0.8639540599575567;0.71647945649953193 -
0.92948242282753457 -0.9060239608044699 1.5086220911726955
0.32417006849092223 1.3267027377596916 -
0.036881042557342474;0.24323084640586334 0.83952282291567459
1.7125552989096664 1.2800328911737289 0.60219021740247425 -
0.042294599401571174 -0.19891269132055869;1.1751311186400586 -
0.23600269923521566 -1.3033578332350804 0.92009036742792771 -
0.33222996172148767 -1.4656207117796076 -
0.074296959950269192;0.73689288942158793 -0.44135638448073744 -
0.72176392847456505 -0.46584860138442552 1.3474682182625621 -
1.0208482386140421 -1.324940069474198;0.3664965764295578 -
0.55400626944960008 0.44888779375213267 -0.68245582010262684 -
1.3285775071345116 0.44954341766609429
0.032351033795565018;0.81400808514187462 -0.46950772661539386 -
0.92376610056995856 0.84613811067068068 1.0181008158058413 -
1.0942193289496409 -0.55575580173412786;0.65627660147220679
0.32496179885775833 -1.0084752311258145 -0.82559864895457924
1.1006918262448517 -1.3188202389613253 -
0.9437665819986758;1.1198981895448015 -0.24115437160909187 -
1.4389792209669805 -0.76576023554963346 0.80301713701232136
0.59238260451373859 -0.12543939007979413;-1.1153625190563845 -
0.60148485049585854 -0.27683774619775259 0.64505907335419566 -
1.5834081863074481 -0.58561674503683103
0.41245632357851281;0.12696463663237137 0.81273293071503805 -
0.93980037251843485 -0.41533125537276638 3.3051480906948569
0.08349215478214346 0.20882867122044657;-1.1836810046925474 -
1.2900033658986481 -0.092949773162340821 -0.14098364886077305 -
0.36783184943679254 -1.0343013848310714 -
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0.49906870441948115 0.31160356648491377;-0.83556935536896182 -
1.2154177493710792 0.47600849171409154 1.1322156013588554 -
0.96151383219118447 0.92448851348203354 0.92589895416595314];

```
% Layer 2
b2 = 0.055942288833129711;
LW2_1 = [-0.25918879748604556 -0.87010529274101989 -0.30891003002474271 -
0.49922473095760761 -0.52684666381116896 -0.15742889498399176
0.26430805724026374 0.38114364627155373 0.19868580085725213
0.7242782341809606 -0.40658829274877512 -0.066337884238394138 -
0.30393169059593961 -0.12388680051122816 0.63181784167534549
2.1733477143879583 0.29940679047669322 -0.16206532866314791 -
0.96523864274039228 0.24098073527196798 0.67357841906823646
0.20135471154874771 -0.49811851635129245 -0.29361824795845398
0.20719395589585624 0.97199123057754677 0.043717880388734469
0.8572202800113975 0.33936456859767861 -0.78138183020283791
0.072151571768032358 0.26170860425708964 -0.020429819744612041 -
0.67133513934743172 -0.23214368961535978 0.3247742925669862 -
0.32041333647394121 -0.21898047715838359 0.49933067875898091 -
0.4024862009493414 0.22625111824878358 0.08579433256836505
0.44180371497381749 0.70706024137013546 0.62919591161337907
0.50714318161889427 -0.69549042109142944 0.43264063036504252 -
0.2031625620723643 0.38334177251884582 -0.15146713916912485 -
0.34043141221143569 -0.36106291979206201 -0.50921190551200513 -
0.26542930725549441 -0.39179915758957262 -0.96576282325946672 -
0.70826497740296024 0.49026719031814286 -0.22847184519035307];

% Output 1
y1_step1.ymin = -1;
y1_step1.gain = 2.82119205215806;
y1_step1.xoffset = 0.199530516;

% ===== SIMULATION ========

% Format Input Arguments
isCellX = iscell(X);
if ~isCellX, X = {X}; end;

% Dimensions
TS = size(X,2); % timesteps
if ~isempty(X)
   Q = size(X{1},2); % samples/series
else
   Q = 0;
end

% Allocate Outputs
Y = cell(1,TS);

% Time loop
for ts=1:TS

   % Input 1
   temp = removeconstantrows_apply(X{1,ts},x1_step1);
```

```
    Xp1 = mapminmax_apply(temp,x1_step2);

    % Layer 1
    a1 = tansig_apply(repmat(b1,1,Q) + IW1_1*Xp1);

    % Layer 2
    a2 = repmat(b2,1,Q) + LW2_1*a1;

    % Output 1
    Y{1,ts} = mapminmax_reverse(a2,y1_step1);
end

% Final Delay States
Xf = cell(1,0);
Af = cell(2,0);

% Format Output Arguments
if ~isCellX, Y = cell2mat(Y); end
end

% ===== MODULE FUNCTIONS ========

% Map Minimum and Maximum Input Processing Function
function y = mapminmax_apply(x,settings)
y = bsxfun(@minus,x,settings.xoffset);
y = bsxfun(@times,y,settings.gain);
y = bsxfun(@plus,y,settings.ymin);
end

% Remove Constants Input Processing Function
function y = removeconstantrows_apply(x,settings)
y = x(settings.keep,:);
end

% Sigmoid Symmetric Transfer Function
function a = tansig_apply(n,~)
a = 2 ./ (1 + exp(-2*n)) - 1;
end

% Map Minimum and Maximum Output Reverse-Processing Function
function x = mapminmax_reverse(y,settings)
x = bsxfun(@minus,y,settings.ymin);
x = bsxfun(@rdivide,x,settings.gain);
x = bsxfun(@plus,x,settings.xoffset);
end
```

APPENDIX B: Originality Report

ORIGINALITY REPORT

13%	8%	7%	11%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to Institute of Engineering, Pulchock Campus, Tribhuvan University Student Paper	2%
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7	www.scielo.org.za Internet Source	<1%
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