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

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Abstract
Nepal having significant topographical variation requires micro level of modeling for wind energy resource assessment to find out the potential of a particular sites to generate wind power. The objective of current study is to predict wind speed of 1 location of all the 7 provinces of Nepal. In this study, total seven number of Artificial Neural Network based model are proposed which is formulated in neural network fitting tool in MATLAB R2016b environment. The model uses numerous combination of Meteorological variables from Tribhuvan International airport for the period of 2008 - 2017 such as maximum temperature, minimum temperature, mean temperature, atmospheric pressure, relative humidity, solar radiation, wind direction, altitude as an input and wind speed as an output of the model whereas model 8 is sketched by averaging the output of all the previously developed model. Root Mean Square error and Coefficient of Determination achieved for the formulated model 7 are found to be (0.067632686) and (99.06045008%) respectively. Model is justified by predicting the wind speeds of entirely different locations Pokhara Airport. Root mean square error is found to be (0.400391163) and coefficient of determination as (97.68231929%) showing extreme level of prediction precision of the proposed ANN model.

Keywords
Nepal, Meteorological variable, Artificial neural network model, wind speed prediction

1. Introduction

Nepal has been facing energy crisis problem and has to depend on costly fossil fuel as well as imported electricity to meet the daily electricity demand.Wind speed can be predicted in five different ways, they are persistence method, physical method, statistical method, spatial correlation method, and artificial intelligence method [1].

Assessment of Wind power Potential of a particular Site will help to increase the access percentage of electricity access to local population of Nepal which is now about 78% if developed appropriately [2]. The wind power generated by wind turbine is analytically based on random nature of wind speed and an unforeseen divergence in generated wind power results in rise in the managing cost of the overall electrical set-up under consideration [3]. An approach paper to the thirteenth plan presented by the national planning commission, Government of Nepal (GON) have stated, “To upgrade Nepal from least developed to developing country by 2022” as a long term vision. To achieve it series of goals have been formulated by the National planning commission, Government of Nepal. One of the goal is to increase the installed capacity of electricity generation from 758 MW to 1426 MW by 2022 [4].

Nomenclature

Tmax Maximum temperature
Tmin Minimum temperature
Tmean Mean temperature
Patm Atmospheric pressure
RH Relative humidity
SR Solar radiation
WD Wind Direction
ALT Altitude
WS Wind speed
LAT Latitude
LON Longitude

In final report of Solar and Wind Energy Resource Assessment (SWERA) recommends for the further analysis and research which is required for assessing the whole and micro-level potential of the wind resource of Nepal [5]. Due to the topographical variation of the country micro level of modeling is required for wind energy resource assessment. Thus, Wind resource assessment specific to the site is needed. Neural network have been used excessively for meteorological application [6]. The method proposed in this study can acts as accompanying tool that could 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. "The share of renewable energy in power sector would increase from 25% in 2017 to 85% by 2050, mostly through growth in solar and wind energy generation"[7].

The cumulative wind power will increase more than three-fold by 2030 and nine-fold by 2050 to 5044 GW compared to installed capacity in 2018 [8].The main reason to choose ANN over other prediction is that they learn from experience and interpolate results, even when their inputs are contradictory or incomplete and its performance is great if there is enough amount of data sets are available [9]. ANN is excellent tool for researching field; it can solve non-linear function, data classification, clustering, simulation, prediction, load forecasting and restoring missing wave measurement [10].

2. Description of case study sites

Nepal officially the federal democratic republic of Nepal is a landlocked country. 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. Nepal is divided into seven provinces. The location of Nepal which was chosen for the formulation of model and finding of the best model among the different model formed is Tribhuvan International Airport (TIA). TIA was chosen for this purpose because the model requires meteorological data from year 2008 to 2018 and data can be obtained for TIA is of comparatively better quality. The location of Nepal which was chosen for validation of the model is Pokhara Airport the data chosen for the purpose of validation of the model is of the year 2018.

Table 1: Description of selected case study sites

Location	LAT.(°N)	LON.(°E)	ALT.(m)
TIA	27.42	85.22	1337
Pokhara	28.13	84.00	827
Okhaldhunga	27.19	86.30	1720
Janakpur	26.70	85.92	90
Nagarkot	27.45	85.31	2163
Gorkha	28.00	84.37	1097
Tansen	27.52	83.22	1067
Jumla	29.17	82.10	2300
Bajura	29.23	81.19	1400

3. Methodology

3.1 Meteorological variable database

This study is be based on the 9 different meteorological variables namely: maximum temperature, minimum temperature, mean temperature, atmospheric pressure, relative humidity, solar radiation, wind direction, altitude and wind speed. Daily meteorological variable were collected for the study purpose. All the nine meteorological variables were used during the model formulation using artificial neural network. The meteorological data for Tribhuvan International Airport was collected for period of 2008 to 2018 and for all the rest of all the eight case study sites meteorological data is collected for period of one year only, 2018. Thus, the total number of meteorological variables collected for the study was 62,712. The meteorological variables were collected from the Department of Hydrology and Meteorology (DHM), Government of Nepal (GON).

3.2 Artificial Neural network

Artificial neuron network architecture is a computational model of a biological brain [11]. ANNs are constructed in a layer that connects to one or more hidden layers where factual processing is performed through weighted connections. Each neuron in the hidden layer joins to all neuron in the output layer. Learning in ANN is achieved through particular training algorithm that are expanded in accordance with learning laws, assumed to simulate the learning mechanisms of a biological system [12]. In Matrix Laboratory R2016b Artificial Neural Network Fitting Tool (nftool) was used for the development of the ANN model and to predict the wind speed from the best validated model. The nftool consist of two layer feed forward neural network.

Neuron in the input layer only act as buffers for disturbing the input signals to neurons in the hidden layer. Each neurons in the hidden layer sums up to its input signals after weighting them with the strengths of the respective connections from input layer and computes its output [13].

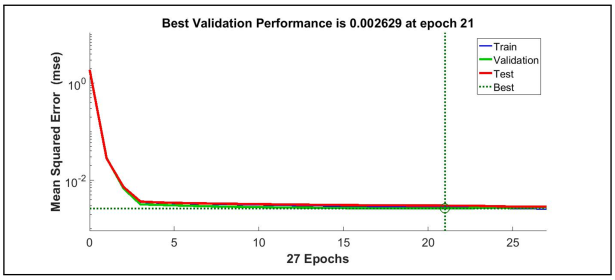

Figure 1: Performance plot of model 7

Levenberg – Marquardt (LM) algorithm was used during the formation of ANN model in this study. All the meteorological variables was mapped between -1 to 1 so that the size of the variables do not vary largely from one another such as the accuracy of the proposed system could be enhanced during the model formulation process. Out of 100% data, 70% of the data were used for the training, 15% were used for the validation and rest 15% were used for the testing of the developed ANN model. The main purpose of the training data is to modify neural network weight according to the error between the target and measured meteorological variable [14]. Validation data compute network generalization plus terminate training when generalization fails to improve any more. The sole purpose of using 15% of the total meteorological variable as a testing data during the neural network model formulation was to find out the network performance throughout and afterwards training of the proposed neural network model.

The number of hidden layer neurons (H_n) to be used during the making of the ANN architecture for the model formulation is given by the equation:

$$H_n = \frac{I_n + O_n}{2} + \sqrt{S_n} \tag{1}$$

Where, I_n indicates number of input parameter, O_n indicates number of output parameter and S_n indicates number of data sample used in proposed ANN model[15].

3.3 Modeling of the proposed system

The input meteorological variables were following 8 parameters: maximum temperature, minimum temperature, mean temperature, atmospheric pressure, relative humidity, solar radiation, wind direction and altitude. The output variable was wind speed. The ANN architecture of one of the model which is model 7 shown in Figure [2] is 8 – 67 – 1 in page number [83].

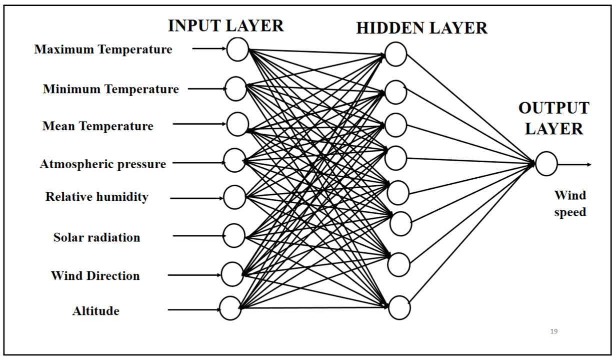

Figure 2: Neural network architecture of model 7

The total of 7 different neural network model with different number of input combination was formulated during this study out of which only proposed neural network architecture of model 7 is shown in this paper. All the other 6 model were formulated in similar fashion. The model number with meteorological parameter used in the various proposed model and the network architecture is shown in the Table [2] in page number [84].

Table [2] shown in page number [84] shows the various model having same number of input and output parameter found to have different number of hidden layer this is because the sensitivity test was executed so that the number of hidden layer neurons can be validated in context of least statistical error. The number of hidden layer neuron was changed to +3 to -3 and the performance of the model were checked and the best model was saved as the model desired.

Model 8

Proposed algorithm for model 8
Step 1. Start
Step 2. Get the ANN model wind speed output from all the 7 proposed neural network model developed in this study.
Step 3. Perform the simple averaging of all the output of 7 different model.

Table 2: Network architecture with meteorological variable

SN	Model	Meteorological Variable	Network Architecture
1	Model 1	Tmean + Patm + RH + SR	4-63-1
2	Model 2	Tmax + Tmin + Tmean + Patm + RH	5-63-1
3	Model 3	Tmax + Patm + RH + WD + ALT	5-63-1
4	Model 4	Tmax + Tmin + Tmean + Patm + SR + ALT	6-64-1
5	Model 5	Tmax + Tmean + Patm + RH + SR + WD + ALT	7-64-1
6	Model 6	Tmax + Tmin + Tmean + Patm + RH + SR + WD	7-65-1
7	Model 7	Tmax + Tmin + Tmean + Patm + RH + SR + WD + ALT	8-67-1

Step 5. Store the result of the simple averaging as predicted wind speed output for the model 8.
Step 6. Perform the statistical error analysis on the output obtained.
Step 7. Decide the performance of the model developed.
Step 8. Stop

This model 8 was basically formulated to test the assumption that if output obtained from all the seven proposed neural network model is simply averaged will it generate better output in overall scenario or not.

3.4 Performance evaluation

Network was tested using meteorological parameter wind speed for the year 2018. Statistical indicator was used to test the artificial neural network performance. These statistical indicator are root mean square error (RMSE), Mean bias error (MBE), Mean Percentage Error (MPE) and Coefficient of Determination (R^2). The measured wind speed of the place was compared with the actual wind speed to compute all the statistical error RMSE, MBE, MPE and R^2. The extent of the error in the predictions were assessed using RMSE. where MBE was used to describe how much the artificial neural network under-estimate or over-estimate the actual data. Lower the value of RMSE better will be the artificial neural network model performance where as higher value of coefficient of determination is desirable.

$$RMSE = \sqrt{\frac{1}{n} * \sum_{i=1}^{n} (W_i - W_{pi})^2} \quad (2)$$

$$MBE = \frac{1}{n} * \sum_{i=1}^{n} (W_i - W_{pi}) \quad (3)$$

$$MPE = \frac{1}{n} * \frac{\sum_{i=1}^{n} (W_i - W_{pi})}{W_{pi}} * 100 \quad (4)$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n} * \mid (W_i - W_{pi})^2 \mid}{\sum_{i=1}^{n}} \quad (5)$$

Where, W_i is the measured data of wind speed and $W_p i$ are the predicted value of the wind speed [16].

3.5 Validating ANN Architecture

The best model was chosen based on the minimum value of RMSE and maximum value of R^2. For validation, best ANN model was used to predict wind speed of Pokhara Airport. 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 meteorological parameter available to us with different latitude, longitude and altitude. If the statistical analysis shows that it could predict the wind speed of Pokhara Airport with minimum value of RMSE and reasonable value of accuracy then we can use the proposed neural network model to find the wind speed of any other location of Nepal.

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

The one location from all seven province were chosen based on the availability of the meteorological data. All the meteorological parameters were obtained for all the selected places which were required for the prediction of wind speed and then those parameter were fed as an input to the best model developed and validated then the output of the each place were saved as an output predicted for that particular place.

4. Result and discussion

4.1 Comparison of Measured and Predicted Values of Wind Speed of formulated models

There are altogether eight different models formulated 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.

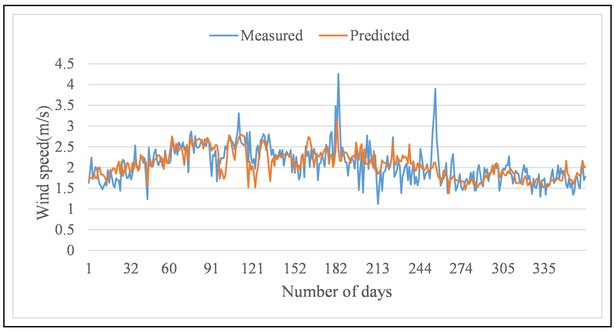

Figure 3: Comparison between measured and ANN predicted wind speed obtained from model 1

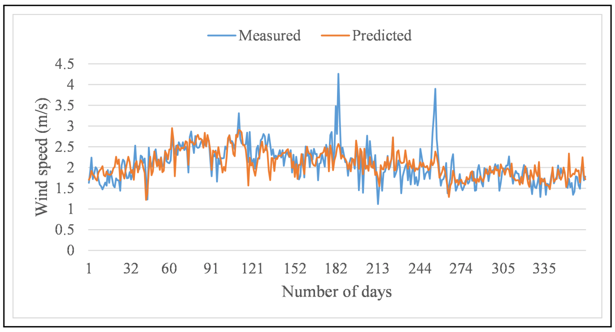

Figure 4: Comparison between measured and ANN predicted wind speed obtained from for model 2

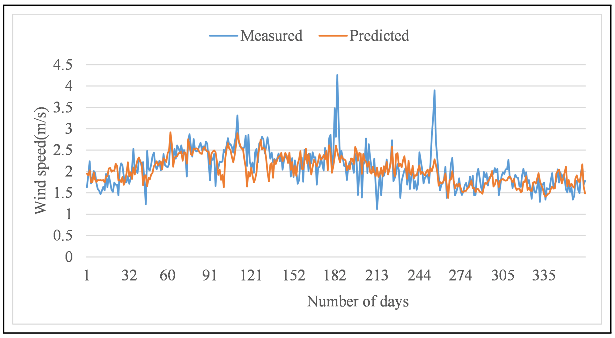

Figure 5: Comparison between measured and ANN predicted wind speed obtained from for model 3

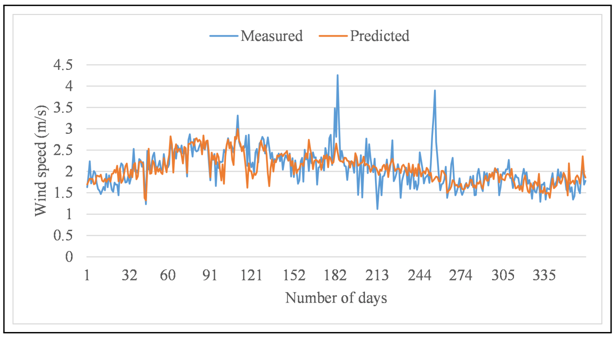

Figure 6: Comparison between measured and ANN predicted wind speed obtained from for model 4

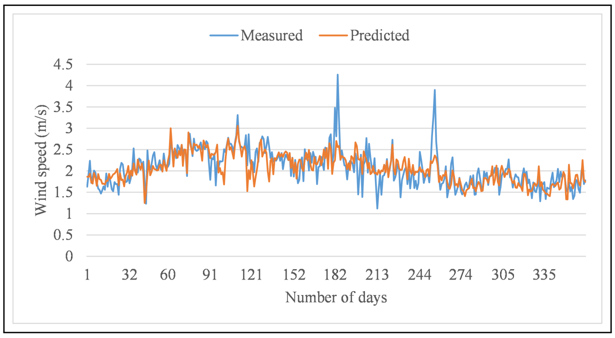

Figure 7: Comparison between measured and ANN predicted wind speed obtained from for model 5

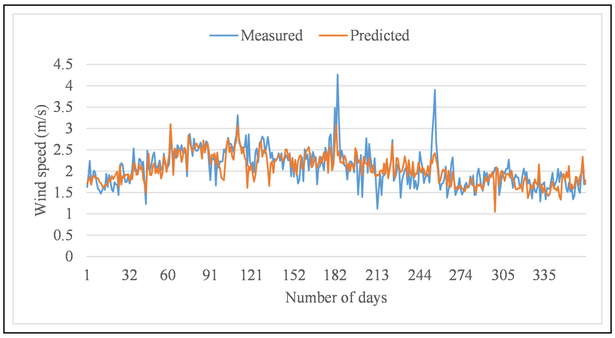

Figure 8: Comparison between measured and ANN predicted wind speed obtained from for model 6

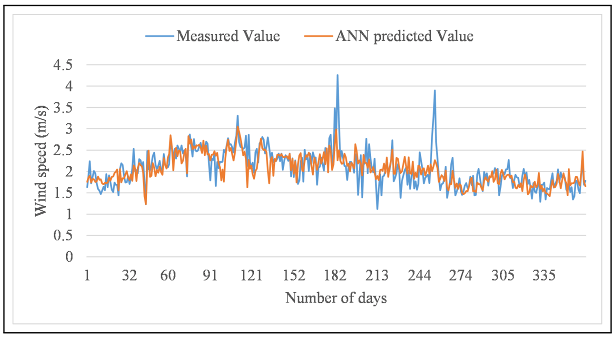

Figure 9: Comparison between measured and ANN predicted wind speed obtained from for model 7

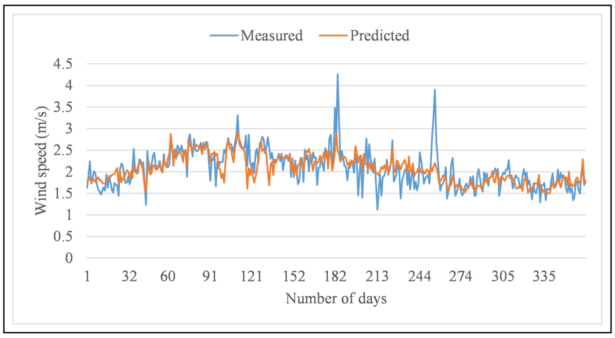

Figure 10: Comparison between measured and ANN predicted wind speed obtained from for model 8

4.2 Statistical Errors of All the eight Different Models

The analysis of the value of wind speed obtained from Artificial Neural Network model developed in this paper and the statistical analysis done using the measured and predicted wind speed which includes Root Mean Square Error, Mean Bias Error, Mean Percentage Error and Coefficient of Determination shows that the developed Model 7 provide the best results this is because it has lowest value of RMSE and highest value of R^2 which are taken as the criteria to select the best model. The model which predict value of wind speed in poorest way among all models is model 1.

Table 3: Statistical error analysis of proposed model

Models	RMSE	MBE	MPE	R^2
Model 1	0.076	0.001	1.564	0.988
Model 2	0.070	0.001	1.590	0.989
Model 3	0.073	0.007	0.214	0.989
Model 4	0.074	0.004	0.927	0.988
Model 5	0.067	0.005	0.367	0.990
Model 6	0.068	0.006	0.142	0.990
Model 7	0.067	0.0057	0.370	0.990
Model 8	0.068	0.003	0.950	0.990

4.3 Validation of ANN architecture using Best Obtained Model

For validation Artificial Neural Network model 7 is used to predict the wind speed of entirely new location, Pokhara Airport while Artificial Neural Network model was formed using meteorological variable of Tribhuvan International Airport. All the meteorological variables were available for the year 2018. The meteorological variable used in the validation process were not used during the formation of neural network model.

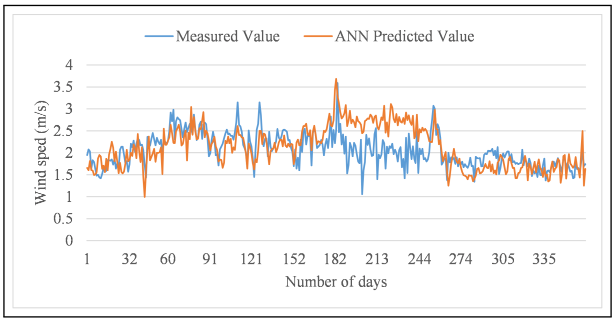

Figure 11: Comparison between measured and ANN predicted wind speed of Pokhara airport

The validation test was performed to test the ability of the model to see to what extent the model can predict the wind speed of any other location correctly.

Table 4: Statistical error analysis of validation model

Models	RMSE	MBE	MPE	R^2
Validation	0.400	-0.017	4.314	0.976

Since R^2 evaluates the scatter of the data points around the fitted regression line the higher value of coefficient of multiple regression is expected because for the same data set, higher R^2 values represent smaller differences between the observed data and the fitted values. 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 shows that ANN model can be used for prediction of wind speed for Nepal's different location.

4.4 Prediction of Wind speed of One Location of All the 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 predict 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.

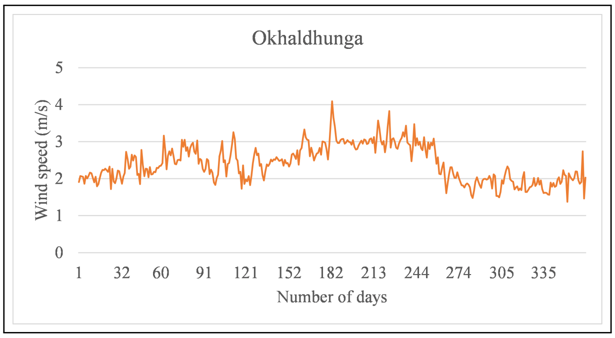

Figure 12: Prediction of daily wind speed of Okhaldhunga

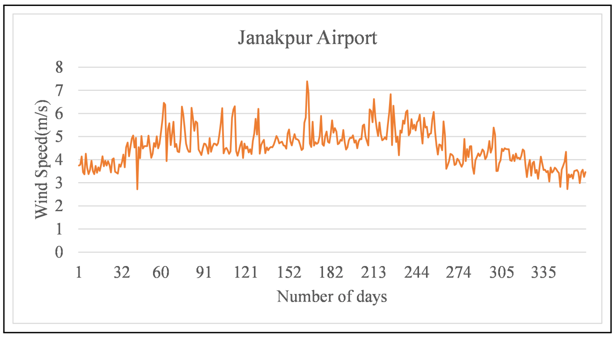

Figure 13: Prediction of daily wind speed of Janakpur

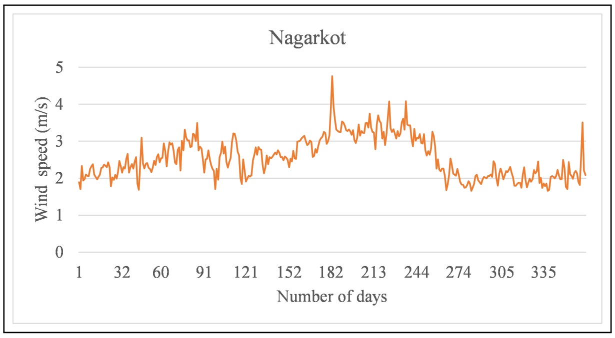

Figure 14: Prediction of daily wind speed of Nagarkot

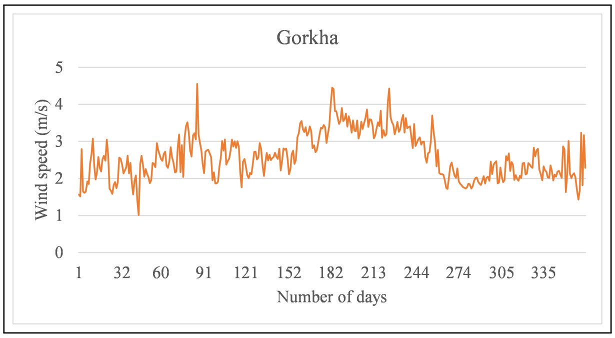

Figure 15: Prediction of daily wind speed of Gorkha

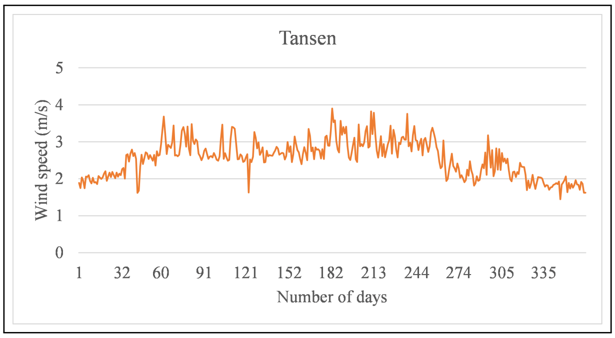

Figure 16: Prediction of daily wind speed of Tansen

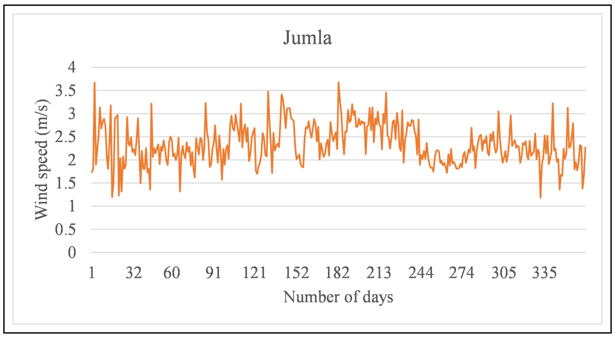

Figure 17: Prediction of daily wind speed of Jumla

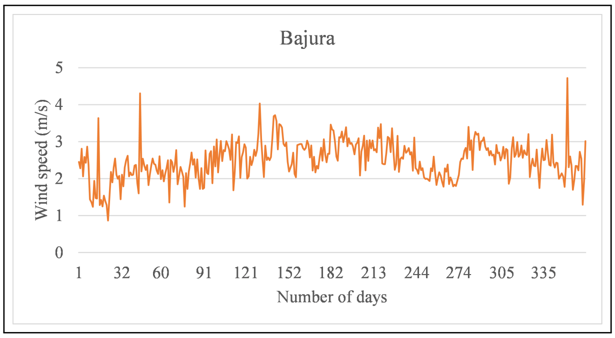

Figure 18: Prediction of daily wind speed of Bajura

5. Conclusions and future works

The neural network model is formulated with Artificial Neural Network Fitting Tool (nftool) for predicting wind speed of one location of all the seven provinces of Nepal. The Root Mean Square error (RMSE) and Coefficient of Determination (R^2) achieved for the best proposed model which is Model 7 for the 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 location, Pokhara Airport. RMSE is found to be (0.400391163) and coefficient of determination as (97.68231929%) articulating extreme level of prediction accuracy of the proposed

Artificial Neural Network (ANN) model to predict wind speed of any new location. Same number of input meteorological parameter can give different statistical result. Thus meteorological variable should be chosen by being very careful so that higher accuracy and less error can be obtained in the final predicted wind speed as seen from model 2 and model 3. As number of meteorological parameter increases error decreases and accuracy increases as seen from model 6 and model 7. This study also suggest using only less input parameters may give better accuracy than using more parameters if meteorological variable are chosen with out most care as seen from the statistical results (RMSE) and (R^2) of the proposed model 3 and model 4. Model 8 gives the better prediction of wind speed in comparison to the Model 1, Model 2, Model 3, and Model 4 which uses 4, 5, 5 and 6 number of meteorological parameter in various combination. The wind speed available at all the case study sites indicates there is possibility of wind power generation since the cut-in speed starts around 3 m/s for most wind turbines. Additional research will be concentrated on the study of the potential of a particular sites to generate aggregate wind power and solar power by using artificial neural network.

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