Development of Wind Mapping Based on Artificial Neural Network (ANN) for Energy Exploration in Sarawak

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Abstract- The exponential rise in global population and rapidly depleting reserves of fossil fuels and pollution that is occurring as a result of burning hydrocarbons have drawn the attention of researchers, engineers and designers in searching for clean and emission free sources of energy. Wind energy is naturally replenished which comes from wind and produce electricity using natural power of wind to drive a generator. The power is clean and inexhaustible that will sustain and maintained the environment. The most important parameter of the wind energy is the wind velocity. A couple number of wind speed prediction models have been published in scientific literatures that are related to estimation of wind speed values. This paper presents Neural Network (NN) techniques for the prediction of wind speed in the areas where wind speeds velocity does not exist. The ANN model has been designed using the NN Toolbox in Matlab environment. A total of ten years data from five locations starting from 2003 to 2012, and five years data from a period of 2008-2012 were used for the network training, testing and validation. Topographical parameters (latitude, longitude and elevation) and meteorological variables that results in wind formation have been considered in this study. Comparison techniques based on statistical measures between the references measured and simulated wind speed indicated that the ANN model correlated well with reference measured data.

Keywords- Renewable energy, Wind energy, Wind mapping, Artificial neural network, Sarawak.

1. Introduction

Malaysia is a developing nation strategically located in the Southeast Asia, between latitude 2^0 and 7^0 north of the equator. The general weather condition of the country is hot and humid, and the annual mean temperature ranges from 22^0C to 37^0C and relative humidity ranging from 80-90% with the exception of highlands. The country experienced three seasons namely, Northwest monsoon, which begins from about November to April while, the Southwest monsoon occurs from June to September. On the other hand, the inter-seasonal monsoon occurs in October and May [1, 2].

For a long time hydrocarbon based fuels are the primary sources of energy that satisfy the consumer need in the country. Burning of fossil fuel is associated with many challenges like greenhouse gasses, indeed when these gasses are released into the environment it affects climate and hence increase global warming. Traditionally, Malaysia energy policy is turned around four fuels strategy that is oil, natural gas, coal and hydropower. Nevertheless, the conventional source in Malaysia and other countries of the world is finite. The oil reserve is anticipated to last at least for the next fifteen years or so while the gas reserves can last for the next forty-two years [1].

This focuses the attention of Malaysia Government to introduce renewable energy in the fifth fuel diversification policy under vision 2020. At present, the government of Malaysia has lunched Small Renewable Energy Programme (SREP) to develop utilization of renewable energy under the fifth fuel policy with a target of 5% (600MW) from renewable energy input in electricity mix by the year 2005 [2, 3]. Currently, over one decade, the contribution has remained on lower recede; with only 1% of the total energy mix has been achieved so far [4]. To further enhance the programme, the government is also committed to find a long-lasting solution to this through the adoption of the 9th Malaysian Plan (2006-2010) which also lay down an additional goal of 5% from renewable energy in the country's energy mix [5].

Malaysia as a developing nation has endowed with renewable energy resources such as hydro, solar, biomass, wave tidal, geothermal and wind. Currently, wind energy is given a serious attention in the country due to its unique characteristics of clean, inexhaustible and exhaust free. The usage of wind power in Malaysia remains to be at beginnings level. Till date, there is no track record for large scale wind power plants have been installed in the country. Very few numbers of small scale wind driving system for stand-alone applications happen to be mounted in Terumbu layang-Layang at Sabah as far back as early 2005 [6]. Presently, iWind Energy (M) Sdn Bhd has effectively installed 40 of its small ratings (300w-10000w) iWind Vertical Axis Wind Turbine (VAWT) in some locations of the country [7].

Wind speed modeling and simulation plays an important role in an assessment of wind energy potential due to complexity and variability nature of wind speed, coupled with the need to reduce the uncertainty in the energy production. Determination of wind characteristics is considered as the first step need to be carried out during the preparation stage, so detailed knowledge of wind behaviour is prerequisites requirement in the design and Micrositing of wind turbine plants.

Wind energy utilization is currently at the scale up development stage in developed nations. The best examples cases are, the United Kingdom (UK) offshore wind power sector had increased from 1,858MW to 3,321MW within a period of one year (2012-2013) [8]. Similarly, in United State of America (USA) the wind energy industry had achieved a record of installing 13.1GW power plants in 2012, and this exceeding 60GW of the total wind power capacity in the country [9].

Even though, China and India are developing nations, but the countries have attained remarkable successes within the past one decade. From the time when renewable energy law was enacted, China wind power has cross the threshold large-scale development within the period of 2006-2009, the country total installed wind power capacity had double every happened each year [10]. This is similar in India, as the country it ranked fifth among the largest wind power producer after Germany, Spain, US and China [11].

The success behind this development is based on the current methods used in those countries to carry out wind data observations work, by utilizing existing geostationary satellite network or airborne platform and other sophisticated ground based equipments. Also, the measurements were conducted that involved the use of high end state of the art equipment that makes this possible for the station to be located in many locations. The monitored data are used in the research and development of wind energy. In recent times, much attention has been devoted in the research and development of wind powerat differentlocation of the world, especially in the developed nations. However, in various developing countries, the assessment and investigation of wind energy potential is still yet to be addressed.

In Malaysia, the Malaysia Meteorological Department (MMD) is an agency founded under the Ministry of Science and Technology (MOSFET) in 1978, the department has given a mandate of saddled responsibilities for monitoring, observing and archiving of weather parameters in the country. In the eastern part of the country Sabah and Sarawak, most of the wind stations are located in the cities where there is limited interest of wind energy. Hence, insufficient wind data and other meteorological variables are the major frictions facing engineers, designers and researchers in the area of renewable energy systems and applications. Lack of Meteorological data such as wind speed and direction in some many places has steered to inadequate study, and for this reason; the potential of wind energy in Sarawak has not yet fully been investigated.

A small number of research works have been conducted at different locations of Malaysia, since the country lies in the equatorial belt, and the availability of wind resource varies depending on the locations [12-15].The authors in those studies investigated the potential of having wind energy by modeling wind speed profile using diverse flexible and usefulness tool such as statistical model to describe the wind characteristics for instance Lognormal, Rayleigh, Pearson, Weibull and Gamma functions, and judged the suitability using coefficient of determination R2, Anderson –Darling (AD) and Kolmogrov-Smitnov (KS) tests. Others used stochastic simulation, liner and multiple regression analysis [16, 17]. The models utilised are site specific and hence the scope is limited within the study areas. Moreover, the accuracy was restricted due to intermittency and non-variability behaviour of wind in time and space. Due to reduction of wind turbine prices and also, for resourceful and utilization of wind energy in Sarawak a wind mapping is required to identify the suitable places to install wind energy systems.

An assessment of wind energy in Malaysia has been reported in few literatures. Among the research work conducted, Daut et. al. [18] have reported the suitability of using hybrid/solar in northern part of Perils. In their study, one year wind data for the year 2006 has been statistically analyzed. The research works achieved probability density of 86.1%, stability indicator k = 2.49, and its mean annual wind speed of 1.01m/s at 10m height was reported. In a similar study [19] demonstrated the possibility of integrating wind system and other renewable energy for electricity generation in Pulau a resort island in Malaysia. An extensive research work carried out proposed the use of accurate distribution model in order to reduce the uncertainty of wind speed at different regions of Malaysia [20].Wind energy potential estimation was performed using Monte-Carlo simulation; the analyzed wind power is then processed using semivariogram, the results obtained shows lack of spatial relationship of wind power density at different locations of Malaysia.

The potential of wind energy based on 2-parameter Weibull in three locations of west Malaysia have been investigated and reported in [21]. The results found in the study indicated that Mersing possessed a high wind energy density of 234.42kWh/m^2/year in 2008. In a related research work, Siti et al. [22] have also confirmed that the wind power densities are higher in the east coast of Malaysia. Furthermore, Mersing experienced high wind power density of approximately 62w/m^2 during the northeast monsoon season. For the fact that Malaysia is located in the low latitude region, wind power potential can provide a significant contribution to household load requirements at higher altitudes [23]. Authors in [24] have also reported that the wind speed in the east coast of Peninsular varies from 15.40W/m^2 to 84.60W/m^2 between the southeast and northeast monsoons.

Quite a few attempts for wind map technology in Malaysia have also been described, as an illustration, Young et al. [25]have made use of power law and Inverse Distance Weighting (IDW) solutions for the development of Malaysia spatial wind mapping. They also discovered that a small low wind speed driving system can be run conveniently in the region of Mersing and Kudat. Further to this, Albani et al. [26] have also employed IDW interpolation algorithm to generate a wind map of Malaysia. In both studies, a twelve months wind data were analyzed, and the developed wind map shows clearly the possible high and low windy areas.

In Sarawak, there is an insufficient number of research work performed, with two studies reported at this point. An unpublished research performed by Wahab et al. [27] reported a regional study of wind energy assessment and potential in Sabah and Sarawak. Wind data for 10 meteorological stations starting from 1995 to 2004 were used to generate a wind map based on the seasonal and annual wind speed. For the fact that the five stations considered in Sarawak are not located in the interior position of the state, wind data of Bario, Belaga and Kapit have been established through strength correlation between these places and the existing wind stations in Sarawak and Labuan.

A recently published study reported in [28] focuses on the solar with little interest on wind energy evaluation. The researchers investigated the potential of wind energy at five locations using short-term data. The power densities achieved in the study were obtained from the analytical solution without using any distribution model, moreover the scope does not cover the eastern part of the state, and hence the study recommended the installation of wind station.

Wind map development requires an adequate number of wind stations in order to show clearly the distribution of wind speed and details of potential areas. The use of insufficient observation stations couple with variability nature of wind speed with time underscore the accuracy and usability of the developed map. To modify the usefulness of the map more stations and assessment at more affordable horizon periods are required. Since the existing wind stations are located near the sea coast, a prediction network is requisite to create artificial stations in a relatively large area that will provide additional wind data for the development of a more accurate map with high resolution quality.

Artificial Neural Network (ANN) is a powerful modeling tool for solving non-linear problems based on the techniques of input variables with the analogous random output variable, and is considered as an uneven learning model, that doesn't need any mathematical formulation [29]. The use of ANN provides an accurate presentation in terms of prototype identification. Nowadays, ANNs have been used in a wide variety of applications including: data analysis, control automation, pattern recognition, function approximation, vector quantization, pattern matching, prediction, data clustering and optimization [29-31].

ANN's have been used widely to model meteorological parameters. ANN have successfully applied to predict wind speed values based on weather data at 50m and 60m heights in [32]. Fadere [33] has applied NN to predict wind speed profile and developed wind map for Nigeria. Solar irradiance potential has been map in turkey using NN [34]. In an experimental comparison study performed in [35] results of testing showed that ANN has superior strength and outperformed compared to Autoregressive Integrated Moving Average (ARIMA). It was also found that the ANN givesbetter-quality prediction compared to Autoregressive Moving Average (ARMA), ARIMA and curve fitting techniques prediction offers considerable lag [36]. A detail review on ANN applications in the area of renewable energy systems have been systematically described in [37-39]. Furthermore, information on general topology architecture, theoretical aspects and applications of ANNs can be found in [40]. This paper aims to apply neural network for modeling and prediction of wind speed data in the areas with inadequate wind stations and also, to generate a wind map at 10m height for energy applications.

2. Material and Methods

2.1. Study Area Description

Sarawak is among the two States of Malaysia strategically located in the island of Borneo. The state is popularly known as Bumi-Kenyalang, a Malay word meaning, ("Land of Hornbill"). The administrative capital is situated in Kuching, Sarawak has a population of over 2,400,000 with a density concentration of 22 people per square kilometre as of 2010 house population census [41]. The State is located in north of the equator between latitude $0^0 5^0$'N and 50N and longitude $109^0 36$'E and$115^0 40$' (Fig. 1), it has a land mass area of approximately 124,000 square kilometres. It's elongates about 800km along the east coast of Borneo, the state is separated from the Peninsular by a distance of 600km, on the island of Borneo it is directly adjoins to Sabah. Inland, the State of Sarawak borders with Kalimantan and Indonesia [41]. Being in the tropic, the State has an equatorial rainforest and there is no separate monsoon season. Sarawak is generally sunny; the average annual temperature ranges from 29^0C-33^0C in the upland regions. Rainfall varies from approximately 3000 to over 5500 mm per year [42].

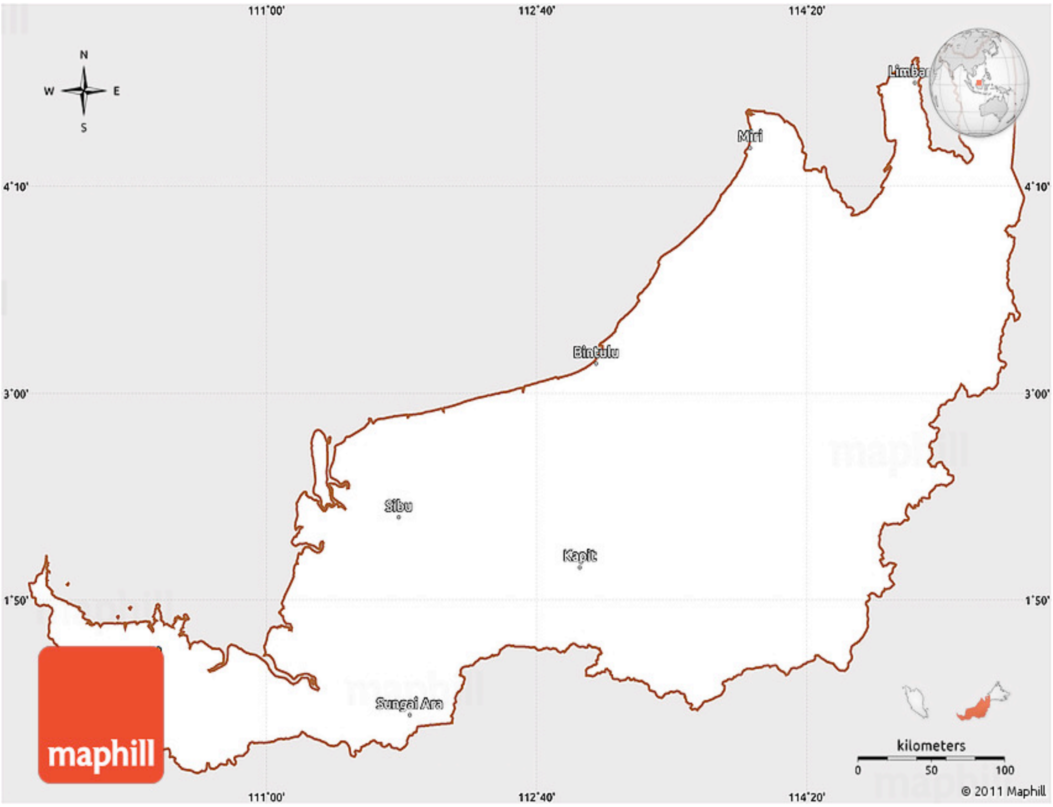

Figure 1. Geographical location of Sarawak

2.2. Data Collection

Wind Data for the eight (8) existing ground based observation stations in Sarawak was obtained from Malaysia Meteorological Department (MMD) at Petaling Jaya, Selangor for a period of ten years (2002-2013) and five years (2008-2012) respectively. The description of each stations and duration of observations are summarized in table1.The data were captured at 10m height mast, with top mounted anemometer and wind vane made from solid hollow steel for measuring surface wind velocity and wind direction. The temperature and relative humidity values were measured by means of a thermometer and a hydrometer. The geographical coordinate's latitude, longitude, elevation, observation hours have been considered as input to the model, in addition to the parameters that causes the wind formation, in three cases (input, hidden and output layer) whereas the average hourly mean wind speed at the target areas was utilized as the output of the network.

The nearby neighbour wind stations were being used for the training and testing of the networks. The network descriptions are listed in table 2, while Fig. 2 shows the existing locations of the wind stations of principal wind monitoring stations in the state.

Table 1. Description of existing wind stations in Sarawak.

Station Name	Latitude (^{0}N)	Longitude (^{0}E)	Altitude (m)	Period of measurement
Kuching	1^0 20'	110^0 21'	27.0	2002-2012
Miri	4^0 20'	113^0 59'	11.0	2002-2012
Sibu	2^0 20'	115^0 50'	37.0	2002-2012
Bintilu	3^0 12'	113^0 02'	22.6	2002-2012
Sri Aman	1^0 13'	111^0 27'	11.0	2002-2012
Kapit	2^0 00'	112^0 55'	20.0	2002-2012
Limbang	4^0 48'	115^0 20'	8.84	2002-2012
Mulu	4^0 55'	115^0 00'	85.0	2008-2012

The nearby neighbour wind stations were used for the training and testing of the networks. The network descriptions are listed in table 2, while Fig. 2 shows the existing locations of the wind stations of principal wind monitoring stations in the state.

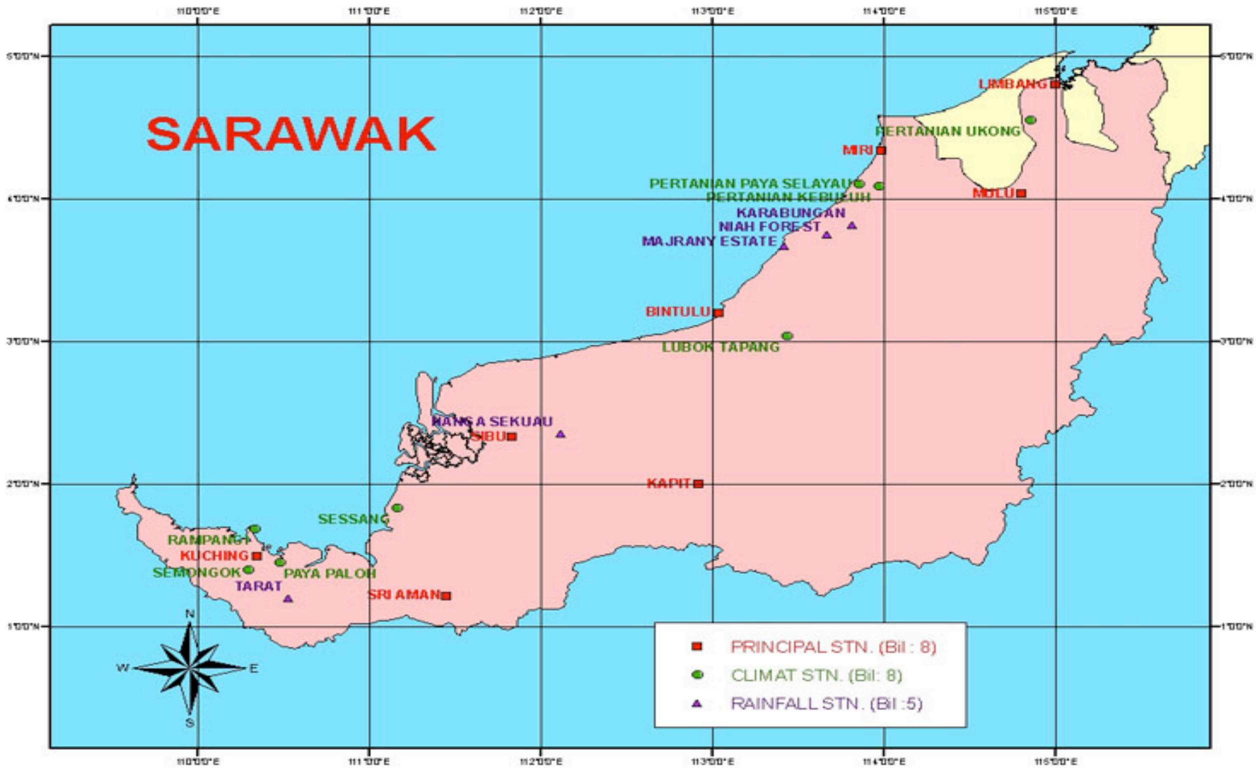

Figure 2. Principal Stations of Sarawak

2.3. System Modelling

Generally, three difficulties are faced in the design and implementation of ANN. In the design phase, the requirement of the size and number of neurons, the selection of suitable values that have a major control of the training algorithm and the number of experiments required to appropriately select the best parameter values that gives the uppermost accuracy. Trial and error method is recurrently employed to find out the correct values for these parameters. This approach decelerates the process of training the network.

The parameters need to consider are; the initial weight functions, activation function, number of training iterations and the input and output encoding techniques [43]. An adequate and proper number of training datasets is also necessary to describe the nature of a particular problem. In this paper, the back-propagation learning iterative algorithm has been used to control the weights in the feedforward network. The network consisted of three layers: input layer; hidden layer and output layer as shown in the ANN structure in Fig. 3 were designed using Mat lab 7.8.0 commercial neural network software.

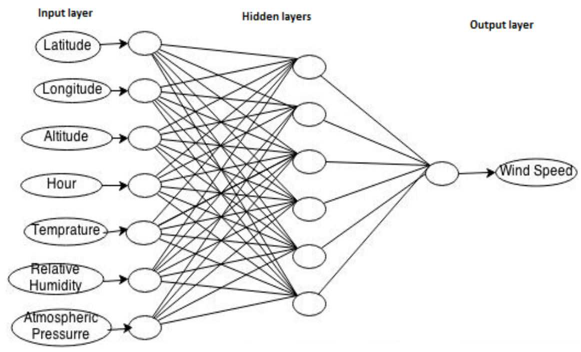

Figure 3. ANN Model

2.4. Model Training, Testing and Validation

Table 2. Network description

Network Type	Feed-Forward back propagation
Training Function	Gradient Descent back propagation with adaptive learning rate (TRAINGDX)
Performance	Mean Square Error (MSE)
Transfer Function	Log-Sigmoid (LogSig)

The results achieved from these trail during the normalization process shows that the most excellent range is from [-1.0-1.0]. Two most vital parameters target error and Eta η that control the effectiveness and precision of the neural network has been taken into consideration. The learning rate eta has been set to control the degree of the modification in the weights in response to the error output during each cycle. The average hourly wind speed, temperature, relative humidity and atmospheric pressure were selected based on the high strength correlation between the target area and reference stations, the number of neurons in the hidden layer in the developed network, training and testing patterns and type of transfer functions applied in hidden layer and output layer activation functions are summarized in table 2.

Simulations were carried out to calculate approximately the wind speed values in the target regions. During the learning process the weights are set one at a time using surface roughness data between the reference area and a target position, so that the desired input/output relation of the network is achieved.

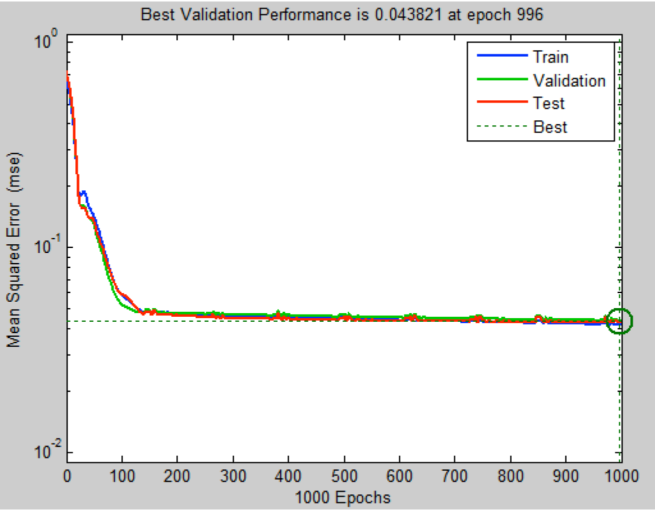

Figure 4. Model training error

The iteration is executed repeatedly until the difference between the real output of the network and the preferred output is equal to a negligible value, which signifies no additional advancement in the network was achieved. Fig.4 displays the difference of mean square error (MSE) as a function of epochs.

It is very clear from figure 4, right after 1000 epochs, MSE between the ANN predictions and test data were steadily minimized to 0.043821, which signifies the finest validation effectiveness. Expanding the learning process could run to the ANN to memorize the training data sets and behaves in poor generalization capability of the ANN model. The model function, weights and biases of the ANN are obtained once the preparation is completed.

3. Results and Discussion

The training process for all the networks was systematically investigated. The model performance was evaluated based on statistical approaches correlation coefficient and Mean Absolute Percentage Error (MAPE). These values are obtained mathematically using equation 1 and 2 respectively. Table 3 indicates the summary of the network based on training and the network with optimum perdition accuracy is also presented in figure 5.

$$R = \frac{\sum_{i=1}^{N}(t_i - \bar{t}) * (o_i - \bar{o})}{\sqrt{\sum_{i=1}^{N}(t_i - \bar{t})^2} * \sqrt{\sum_{i=1}^{N}(o_i - \bar{o})^2}} \quad (1)$$

$$MAPE(\%) = \left[\frac{1}{N} \sum_{i=1}^{N} \left| \frac{t_{i\_} o_i}{t_i} \right| \right] * 100 \quad (2)$$

N represents the number of data, and ti, oi stands for target (reference) value and ANN predicted value accordingly of the data point i and bars indicates average value.

Table 3. ANN network summary

S/No	No of hidden layer	No neurons in the hidden layer	Training data sets MSE	R
1	1	8	0.089146	0.6875
2	1	10	0.078543	0.6968
3	2	12	0.063783	0.7256
4	2	14	0.051004	0.7821
5	2	15	0.043821	0.8276

The summarized results shown in table 3 clearly illustrates that the proposed ANN has superior accuracy and reliability for predicting the values of surface wind velocity. It is also essential to notice that the model robustness (generalization ability) are one of the most significant requirements in model design and development process. The number of neurons in the hidden layer varies from 8-15, while during the learning process the best performance realized R of 0.8276 is obtained, this indicated that the network will predict values close to the measured values for all the datasets. The higher MSE realized in the training sequence 1 is as a result of insufficient number of neurons in the hidden layer.

Table 4 shows the statistical values (MSE, R and MAPE) of the network performances for all the reference stations used to predict the values of wind speed at the target locations. The MAPE for all the stations varied from 2.83%-7.56%, for Tatau and Marudi. The minimum and upper limit values of 6.7% and 19.1% has been reported in [33].

Table 4. Statistical and errors values of ANN

Reference Station	Target Areas	R	COV	MAPE
	Samarahan	0.812	0.006	5.01
Kuching	Serian	0.627	0.007	5.63
	Lundu	0.876	0.007	4.28
Miri	Marudi	0.691	0.009	7.56
	Kula Baram	0.862	0.006	6.08
Sibu	Mukah	0.643	0.005	6.29
	Sarikie	0.543	0.003	6.46
	Kanowit	0.724	0.008	5.51
Bintulu	Matu	0.518	0.004	5.56
	Tatau	0.950	0.002	2.83
Sri Aman	Betong	0.653	0.002	5.98
	Saratok	0.691	0.003	5.88
	Lubok Antu	0.662	0.002	5.95
Kapit	Belaga	0.650	0.002	5.94
	Song	0.861	0.003	5.38
Limbang	Lawas	0.698	0.002	5.07
	Sundar	0.618	0.002	5.47
Mulu	Bario	0.733	0.008	5.24
	Ramudu	0.693	0.009	6.13

A comparison between the monthly measured wind speed obtained from the reference station and the one acquired from ANN predicted optimum network for the city of Kuching is shown in fig. 6. The correlation value between the reference station (Kuching) and predicted stations (Samarahan, Serian and Lundu) were found to be 0.812, 0.627 and 0.876, while the MAPE of 5.0, 5.63 and 4.28 was realized.

A new model using ANN has been designed and developed, the input parameters consist of geographical (latitude, longitude, hour and altitude) and meteorological parameters (temperature, atmospheric pressure, and relative humidity) was used to realize the average hourly wind speed of the targeted 19 locations within the state of the 8 ground based station and an additional station where wind velocity does not exist has been produced, the average monthly wind speed was calculated.

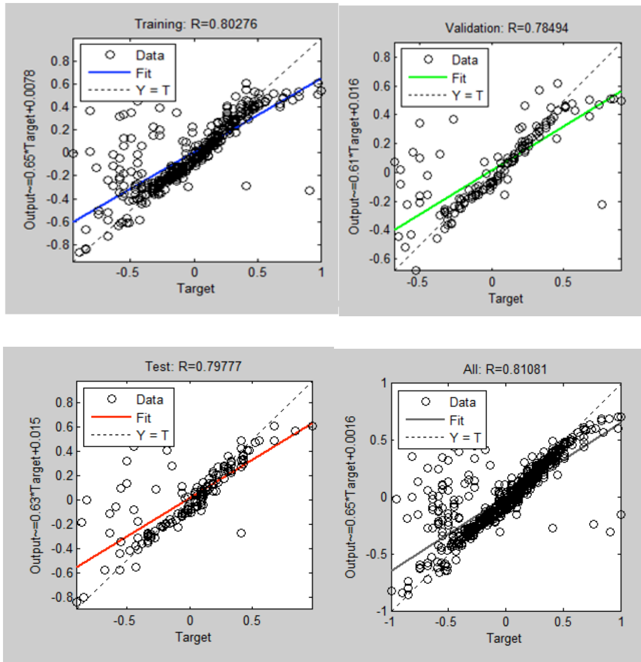

Figure 5. Correlation between the ANN and reference wind speed

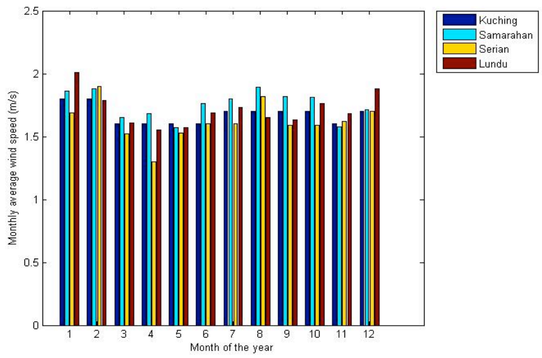

Figure 6. Predicted wind speed and measured average monthly wind speed for the Kuching

The map of wind resource assessment (WRA) potential of Sarawak at 10m was given in figure 7. As viewed within the figure, parts of Miri have higher adequate wind energy potential for wind driving systems (300-20000W) with 1.0-2.0m/s start up speed and cut-in wind speed of 1.5-2.0 can run conveniently in the areas. Likewise, other areas such as Kuching, Serian, Samarahan, Mulu, Bintulu, Sibu, Matu, Tatau, Mukah, Bario and Ramudu are experiencing wind speed in the range of 1.5-1.9m/s., this also indicated that low wind speed turbine technology of 300-600W ratings can be used in those countries. However, in the case of remaining areas where wind speed falls below 1.5m/s, it is not technically feasible to harness the energy content in a wind. For the fact that the map was generated based on representative surface level measurement of 10m height, this indicates wind energy potential at upper heights 20-40m [44]-[45] for small scale application can be operated conveniently in the state.

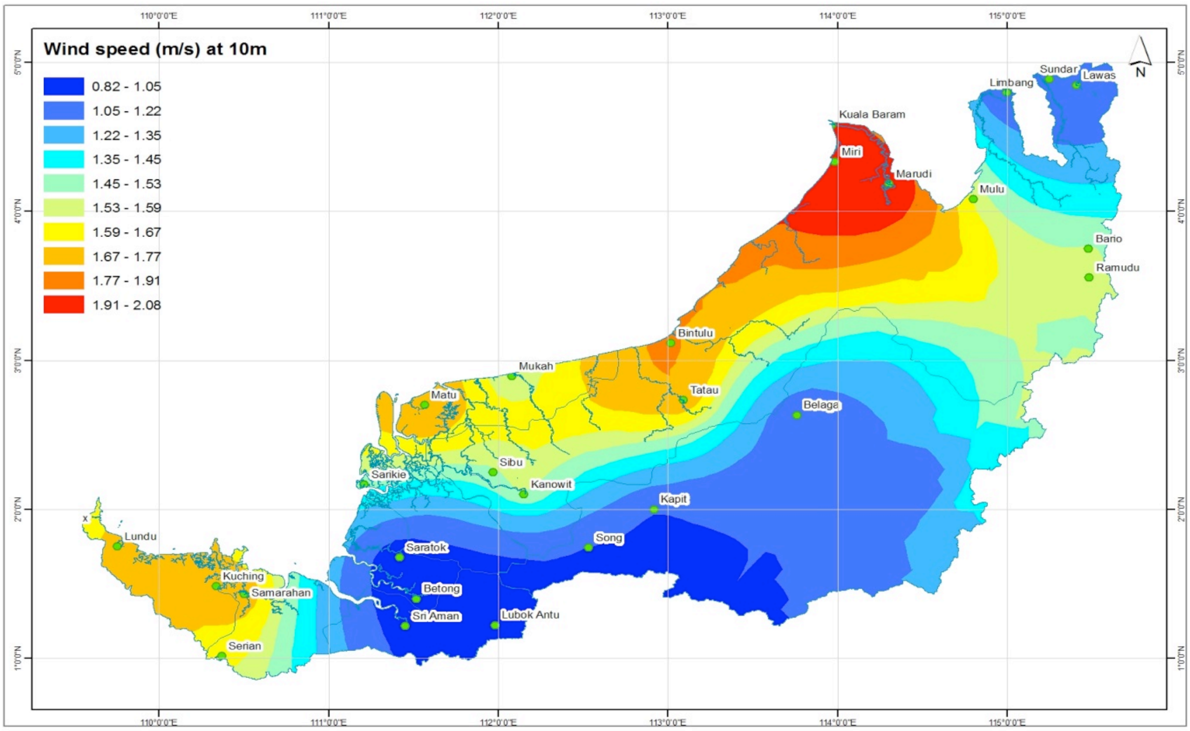

Figure 9. Sarawak-Annual average wind speed onshore wind speed map at 10m

4. Conclusion

This research suggests an ANN technique for modeling the relationship between geographical, meteorological parameters and wind velocity. The ANN with optimum architecture 7 inputs, 2 hidden layer and 1 output layer trained with gradient descent back propagation algorithm with adaptive learning rate was presented successfully to map the actual input/output relationships. Statistical measures MSE, R and MAPE show that the results the developed model is robust as compared with the reference measured values in the areas.

It can be concluded that the proposed ANN method can be applied efficiently for mathematical modeling and analysis of wind speed prediction process in the areas where wind speed monitoring is not available in Sarawak. The other training algorithm can be matched with the model in order to determine optimal prediction in future studies.

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