International Journal of Technology (2012) 2: 110-120
ISSN 2086-9614

SOLAR IRRADIATION ESTIMATION WITH NEURAL NETWORK METHOD USING METEOROLOGICAL DATA IN INDONESIA

Meita Rumbayan[1,2*], Ken Nagasaka[1]

[1] *Department of Electrical and Informatics Engineering, Tokyo University of Agriculture and Technology, Tokyo, Japan*
[2] *Faculty of Engineering, Sam Ratulangi University, Manado, Indonesia*

(Received: October 2011 / Revised: December 2011 / Accepted: July 2012)

ABSTRACT

The objective of this study is to determine the solar energy potential in Indonesia using artificial neural networks (ANNs) method. In this study, the meteorological data during 2005 to 2009 collected from 3 cities (Jakarta, Manado, Bengkulu) are used for training the neural networks and the data from 1 city (Makasar) is used for testing the estimated values. The testing data were not used in the training of the network in order to give an indication of the performance of the system at unknown locations. Fifteen combinations of ANN models were developed and evaluated. The multi layer perceptron ANNs model, with 7 inputs variables (average temperature, average relative humidity, average sunshine duration, longitude, latitude, latitude, month of the year) are proposed to estimate the global solar irradiation as output. To evaluate the performance of ANN models, statistical error analysis in terms of mean absolute percentage error (MAPE), mean absolute bias error (MABE) and root mean square error (RMSE) are conducted for testing data. The best results of MAPE, MABE, RMSE are found to be 7.4%, 1.10 MJ/m^2 and 0.17 MJ/m^2 respectively as 7 neurons were set up in the hidden layer. The result demonstrates the capability of ANN model to generate the solar irradiation estimation in Indonesia.

Keywords: Artificial neural network; Indonesia; Multi layer perception; Renewable energy; Solar irradiation

1. INTRODUCTION

Indonesia consists of five big islands (namely Sumatera, Kalimantan, Java, Sulawesi and Papua) surrounded by small islands, all of which are facing energy problems. The archipelago faces problems in energy demand for island communities characteristically because of their dependency on fossil fuel supply from island to island that causes high cost for transportation. Therefore, the utilization of self sufficient energy is worthwhile to be considered. One of the alternative energy solutions that can be utilized is solar energy which is available locally.

Utilizing solar energy system requires knowledge about solar irradiation potential in different locations. In order to set up solar energy technology, the knowledge about solar energy potential is important. In addition, solar irradiation potential is also required for crop models (in agriculture engineering field) as well as building thermal performance (in agriculture field).

Indonesia lies on the equator, located between 6°N and 11°N latitudes and in between 95 °E and 141°E longitudes. Most of the locations in Indonesia receive abundant solar energy throughout all the year. Average annual temperature is 26.5°C and the yearly average solar radiation is 14.5 MJ/m^2 day, and the total yearly sunshine duration is about 2500 hours/year. Indonesia has a tropical climate which varies from area to area. Commonly, the dry season

[*]Corresponding author's email: meitarumbayan@yahoo.com, Tel. +81-809-3938-1905

occurs from June to September, while the rainy season occurs from December to March. Indonesia has a great potential for solar energy harnessing due to the high level of solar irradiation and the length of sunshine duration.

In a developing country which has geographical conditions such as islands and remote areas, the measurement of solar irradiation on the ground becomes difficult and expensive. There are large areas in the islands of Indonesia that spread over from east to west that do not have any weather stations. Estimation of solar irradiation data using appropriate models can be an alternative solution for developing country, such as Indonesia. This paper studies about the development and usage of the ANN models in such location.

In Indonesia, many meteorological stations only have relative humidity, temperature, wind speed, and sunshine duration recorders. Measurement of solar irradiation with reliable and calibrated pyranometers is not available or only available in limited areas/locations. Based on a previous study by Rumbayan and Nagasaka (2010a), application of PV in remote areas in Indonesia is least costly compared to gasoline generated electricity due to high costs in transportation. Since the design of any cost effective solar energy system depends on reliable data, and since measuring solar irradiation is costly, methods to estimate solar irradiation should be explored.

This study proposes the ANN based method for estimating the solar irradiation potential in many locations in Indonesia. The proposed approach can be used as a method to estimate the solar irradiation potential in the remote and rural locations in the islands with no direct measurement devices.

The main objective of this study is to investigate the feasibility of using ANN to model the non-linear relationship between global solar irradiation and other meteorological parameters. Therefore, the model can be used to estimate the monthly average solar irradiation potential for specific locations in Indonesia where the locations have no records on solar irradiation at the meteorological ground stations.

2. LITERATURE REVIEW AND PREVIOUS WORK

Artificial Neural Networks are computational systems in which their modelling and functionality is inherited from the recently acquired knowledge of the biological computational units, namely, the brain’s neurons. An ANN consists of many interconnected identical neurons. A typical neural network usually has 3 layers of neurons, each of which is connected to the neurons in the next layer. These connections are weights which are applied to values passed from one neuron to the next. Input values in the first layer are weighted and passed to the second (hidden layer). Neurons in the hidden layer produce outputs that are based upon the sum of weighted values passed to them. The hidden layer passes values to the output layer and the output layer produces the desired result. Basic theories and applications of ANN can be found in reference texts such as in Kermanshahi (1999).

Artificial Neural Networks consist of an interconnection of a number of neurons. There are many varieties of connections under study, however, this study only discusses about one type of the network which is called the multi-layer perceptron (MLP). The MLP is the most popular learning rule based in the error back propagation algorithm. Back Propagation (BP) learning is a kind of supervised learning. The BP algorithm minimizes the mean square difference between the network output and the desired output. The MLP has the ability to learn complex relationships between input and output patterns.

Artificial Neural Networks learn by example. They cannot be programmed to perform a specific task. The examples must be selected carefully otherwise it takes time to simulate or even worse it might be functioning incorrectly. The disadvantage is that because the network finds out how to solve the problem by itself and its operation can be unpredictable. The effort is made to identify the best fitted network for the desired model according to the characteristics of the problem and ANN features (Azadeh et al., 2009).

Basically there are many parameters in the ANN, which the designer of the ANN should assign, such as learning rate, momentum rate, weight and so forth. Here, we only explain about three important parameters in MLP type of ANN model. Learning rate term, L, indicates how much the weight changes to have an effect on each pass. This is typically is a number between 0 and 1. Momentum term, M, indicates how much a previous weight change should influence the current weight change. As neuron pass values from one layer of the network to the next layer, the values are modified by a weight value in the link that represents connection strengths between the neurons. The weights of connection between neurons are adjusted during the training process to achieve the desired input and output relation of the network. ANNs perform in many different forms, some require models with total interconnection among neurons and others require arrangement in layers.

The advantage of neural networks is their learning ability to perform specific tasks. Learning is accomplished by adjusting the weights of the connections between neurons. Weights are adjusted so that the network can be producing the outputs as closely as possible to the known correct answers of training data. During the training stage, the network is learning the rule for associating the inputs with the target outputs. Due to the generalization capabilities of the neural networks, it performs similarly on data for testing that have not been used for training (Mohandes et al., 1998).

There are several studies to predict monthly average global solar irradiation potential based on ANN method. Since ANN are highly nonlinear and require no prior assumption concerning the data relationship, they have become useful tools for estimating solar irradiation. Particularly, in the meteorological and solar energy resources fields, ANN based models have been successfully developed to model different solar radiation variable in many locations. Jiang (2008) developed estimation of monthly mean daily global solar irradiation using ANN method in China. The data period used are from 1995 to 2004 and the inputs for the networks are latitude, altitude and mean sunshine duration.

Alawi and Hinai (1998) developed ANN model in Oman for analyzing the relationship between the solar irradiation and climatologically variables in areas not covered by direct measurement instrumentation. Zhou et al (2005) found the estimation of solar irradiation in China based on ANN is superior to other available models. Result proved that ANN model could be used to evaluate the solar potential; however that model is only suitable for Beijing.

Mohandez et al., (1998) used a neural network technique for modeling monthly mean daily values of global solar radiation for locations in Saudi Arabia based on data: latitude, longitude, altitude and the sunshine duration as inputs. The result obtained MAPE for 10 locations used for testing, such as 10.7% for Tabuk station, 6.5% for Al-Ula station, 14.6% for Unayzah station, 10.5% for Shaqra station, 13.4% for Dawdami station, 10.1% for Yabrin station, 16.4% for Turabah station, 11.3% for Heifa station, 19.1% for Kwash station, 13.5% for Najran station.

From the above literature reviewed, ANN models have successfully demonstrated the potential in estimating monthly average global solar irradiation by many researchers in many countries. However, these ANN models are location dependent and specific to each location. So far, there are no reports about the estimation of solar irradiation potential for Indonesia by using ANN method in many locations (except previous work by authors). In the previous work, Rumbayan and Nagasaka (2010b) have developed the ANN model to estimate solar radiation in Manado location, a city in Indonesia. The input data to the network were monthly average temperature, monthly average relative humidity, monthly average wind speed and monthly average sunshine duration. Results performed with the ANN model were estimated with a good accuracy of about 93% and a MAPE of 7.3.

This study aims to develop neural network models for estimating monthly average global solar irradiation potential in many locations of Indonesia based on meteorological data available. Solar mapping as spatial potential for the further research is being considered to be developed.

3. METHODOLOGY

The data were gathered from meteorological station in four cities namely Manado, Jakarta, Bengkulu, Makasar that represent one region in the four big islands of Indonesia that are spread over in the parts of eastern and central Indonesia.

Figure 1 Map of Indonesia and location of the data

The geographical condition (in term of latitude, longitude, altitude and location) as well as the city and island location of these 4 station data taken are presented in Table 1.

Table 1 Geographical information of data taken

Station name (city)	Latitude	Longitude	Altitude (m)	Island Location
Baai (Bengkulu)	3º 51‘ S	102º 18‘ E	8.5	Sumatera
Pondok Betung (Jakarta)	6º 15‘ S	106º 45‘ E	67	Java
Kayuwatu (Manado)	1º 3‘ N	124º 09‘ E	8.5	North Sulawesi
Maros (Makasar)	4º 59‘ S	119º 34‘ E	67	South Sulawesi

The database consists of measured values of solar irradiation, average temperature, average relative humidity, average sunshine duration covering the four cities in Indonesia for 5 years (2005-2009) recorded by meteorological stations. The typical average sunshine duration, temperature and relative humidity for these locations for the one year period selected are shown in Figures 2(a), 2(b) and 2(c) respectively. The data were split into two, as 3 cities (Manado, Jakarta, Bengkulu) and were used for training a neural network and in one city (Makasar) for testing.

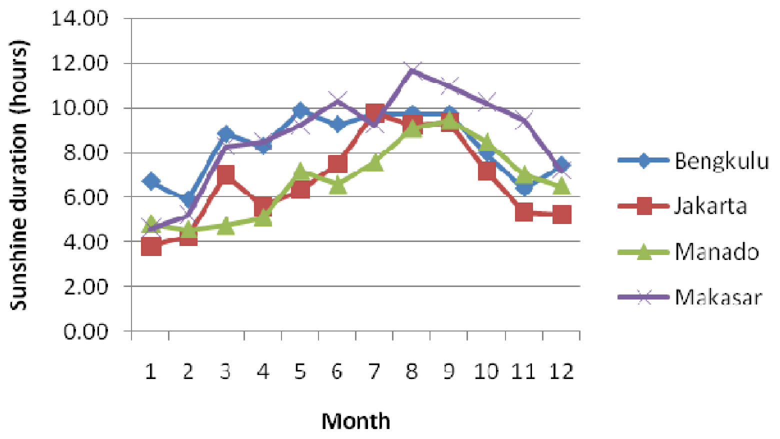

Figure 2(a) Typical sunshine duration for four cities

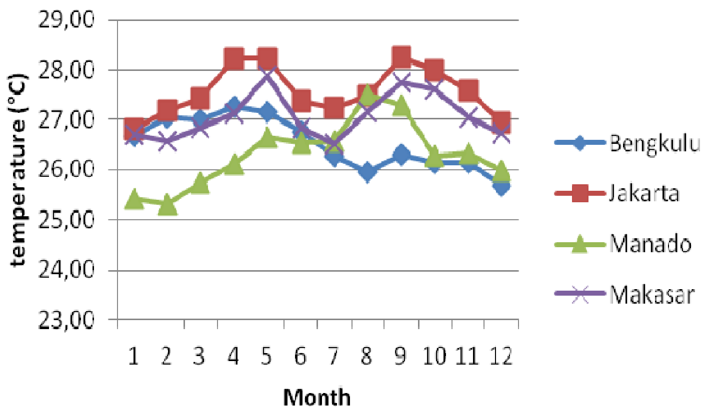

Figure 2(b) Typical temperature for four cities

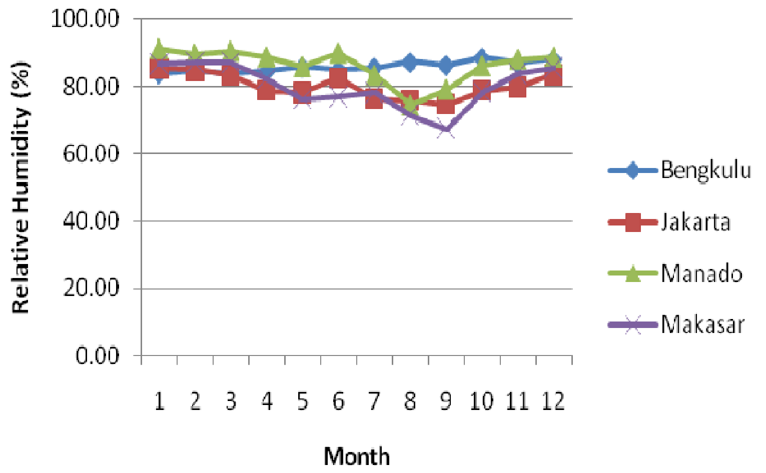

Figure 2(c) Typical relative humidity for four cities

In this study, the training of the models uses a feed-forward neural network with Back Propagation training algorithm. The inputs are monthly average sunshine duration, monthly average relative humidity, monthly average temperature, latitude, longitude, altitude and month of the year. The output is the monthly average global solar irradiation potential. Training the model is done using a neural net simulator known as “NeuroShell”. The steps are used in this study is described in Figure 3.

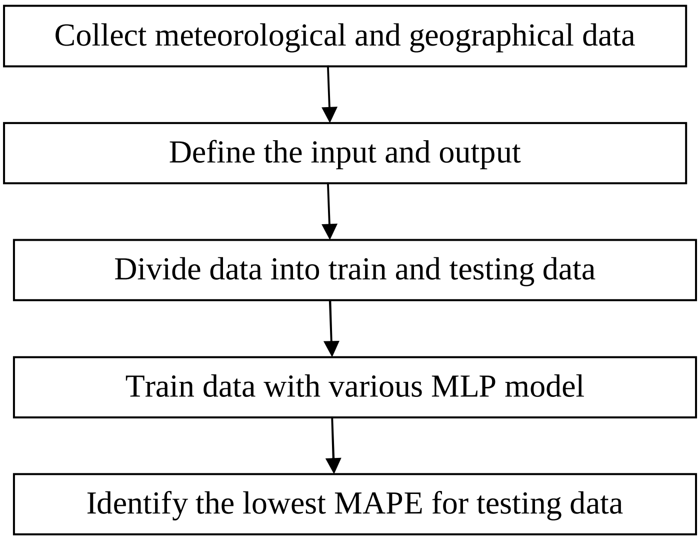

Figure 3 The methodology used in this study

Since there is no method to predetermine the best combination of neuron and layers, as this depends on the specific model, the physical process and the training data that the network will simulate. From references, there are some empirical relationships to solve this problem but the best method is up to the researcher to build several models and choose the best suited for the particular application (Sen, 1998).

Based on the references, the training in this study starts with defining the parameters with minimum error by trial and error using fixed and change parameters one by one, then using the selected parameter in the neural network for several cases of the number of neurons in the hidden layer. Then the model of ANN was used for training and testing. This configuration is used to present the network model to be reported in this study.

In this study, the process of neural networks for estimating the monthly global solar irradiation potential is divided into two sections, i.e training and testing. First, training data, (the group of data by which the network adjusts, in order to reach the test fitting of the nonlinear function) is used to represent the phenomenon. In this case, the recorded data at 3 cities (Manado, Jakarta, Bengkulu) in Indonesia during the period of 2005-2009 are selected as a training set.

Second, testing data, (a set of data which is not included in training data in order to estimate whether the model has effectively approached the general function representative of the learning pattern phenomenon) is used. In this case, the data recorded at Makasar, Indonesia during the period of 2005 to 2009 is used as a testing data. Data for Makasar are not included as a part of training set in order to make sure that the results can demonstrate the generalization capability of this approach and its ability to produce accurate estimation for solar irradiation.

The feed-forward back propagation algorithm with single hidden layer is used in this analysis. Several attempts of ANNs model by changing the number of neurons at the hidden layer in order to find the best MAPE. Estimated values of global solar irradiation are compared with measured values taken from meteorological data through analysis of error, in terms of Mean Absolute Percentage Error (MAPE), Mean Absolute Bias Error (MABE) and Root Means Square Error (RMSE).

Models are evaluated in terms of errors that are given by Equations (1), (2) and (3) where H_{mi} is measured values and H_{pi} is estimated values for monthly average global solar irradiation, and *n* is the number of testing examples.

The mean absolute percentage error (MAPE) is defined by Equation (1).

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{H_{mi} - H_{pi}}{H_{mi}}\right| \tag{1}$$

In MAPE, sign of errors are neglected and percentage errors are added up to obtain the average. MAPE is commonly used in quantitative forecasting methods because it produces a measure of relative overall fit. It usually expresses accuracy as a percentage. The mean absolute bias error (MABE) is defined by Equation (2).

$$MABE = \frac{1}{n}\sum_{i=1}^{n} H_{mi} - H_{pi} \tag{2}$$

The MABE represents the absolute value of the bias error and is a measure of the goodness of correlation. The root mean square error (RMSE) is defined by Equation (3).

$$RMSE = \frac{1}{n}\sqrt{\sum_{i=1}^{n}\left(H_{pi} - H_{mi}\right)^2} \tag{3}$$

The RMSE gives information on short-term performance by allowing a term by term comparison of actual deviations between estimated and measured values. The RMSE is the fundamental measure of accuracy, as the lower the RMSE, the more accurate the estimate

4. RESULTS AND DISCUSSION

This section presents the results of ANN model simulation and evaluation by comparing between measured and estimated neural network values based on statistical error.

The neural networks with multilayer perceptron (MLP) type were trained to estimate global solar irradiation potential for Makasar as testing. Data testing are not included as part of ANN training data. Hence, these results demonstrate the generalization capability of this method over unseen data.

One hidden layer was used in order to minimize the complexity of the proposed ANN model. One hidden layer is chosen to simplify the network architecture proposed. The parameters of learning rate, momentum, initial weight are selected from trial and error attempts, by setting 2 parameters fixed and vary 1 parameter in the simulation. These parameters are optimized during learning step of the ANN, with criteria of statistical error based on MAPE, MABE and RMSE. The parameter selection of learning rate, momentum, initial weight of 0.1, 0.3, 0.5 respectively were used as optimum parameter of ANN model for reporting the result of estimation. The above parameter has been used for training the ANN models with varying neurons in single hidden layer by MLP type.

This study explores 15 models of MLP structures i.e 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16 and 17 neurons at hidden layer. To evaluate the performance of ANN models, statistical error analysis in terms of mean absolute percentage error (MAPE), mean absolute bias error (MABE) and root mean square error (RMSE) are conducted for testing data. The evaluations of predicted and measured values for fifteen ANN models were presented in the Table 2.

Table 2 Statistically error for testing data with different structures of ANN model proposed

MLP structure	MAPE (%)	MABE (MJ/m^2)	RMSE (MJ/m^2)
7-3-1	8.1	1.21	0.19
7-4-1	10.8	1.61	0.24
7-5-1	11.7	1.74	0.26
7-6-1	8.3	1.24	0.19
7-7-1	7.4	1.10	0.17
7-8-1	12	1.78	0.26
7-9-1	7.5	1.12	0.17
7-10-1	9.9	1.48	0.22
7-11-1	10.7	1.59	0.23
7-12-1	7.6	1.14	0.18
7-13-1	10.9	1.63	0.24
7-14-1	9.1	1.35	0.2
7-15-1	8.71	1.29	0.19
7-16-1	8.25	1.22	0.18
7-17-1	9.8	1.45	0.21

It is found that, the best proposed ANN model is predicted the monthly average global solar irradiation with MAPE of 7.4%, MABE of 1.10 MJ/m^2, RMSE of 0.17 MJ/m^2 for testing data. The performance of the neural network model in term of MAPE versus number of hidden layer is presented in Figure 4.

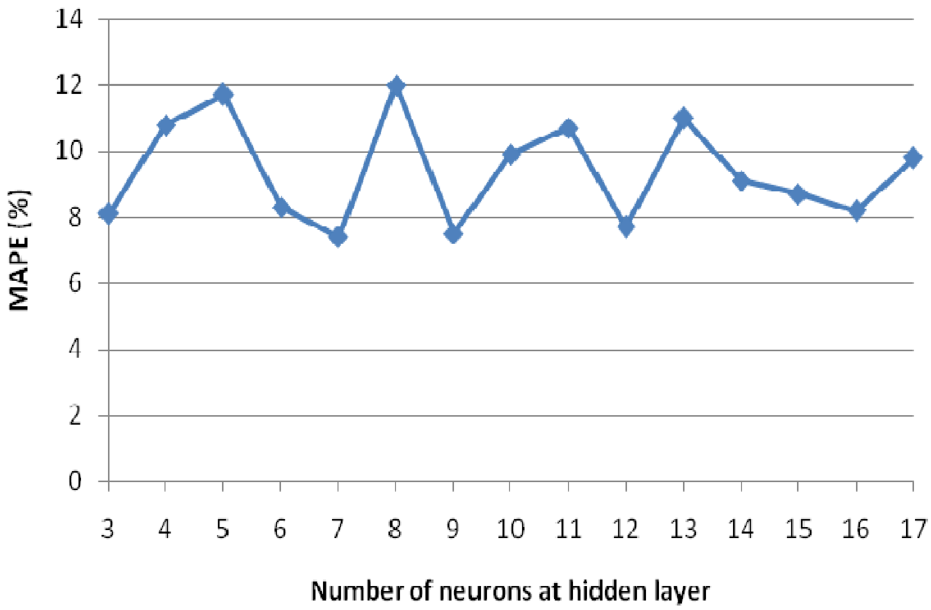

Figure 4 The MAPE versus number of neurons at hidden layer

After several trials in varying the number of hidden neurons, it was found that 7 amounts of neurons were the least error prone for the testing process in the neural network. The best estimator with the minimum error with 7 neurons at the hidden layer is chosen to be presented in this paper as described in Figure 5.

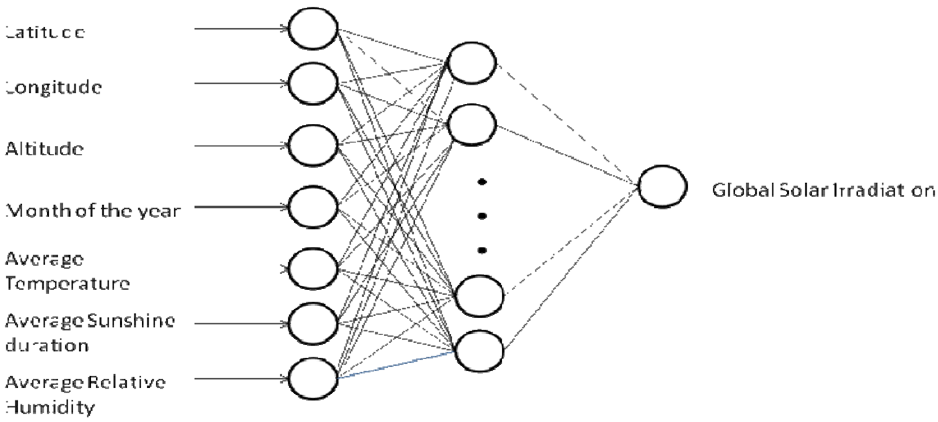

Figure 5 ANN model developed for estimating monthly global solar irradiation potential in Indonesia

Performance of the best ANN model (i.e 7 neurons as the input layer, 7 neurons as the hidden layer, 1 neuron as the output layer) between measured and estimated values of monthly average global solar irradiation for Makasar as testing data for 5 years (2005 to 2009) is presented graphically in Figure 6.

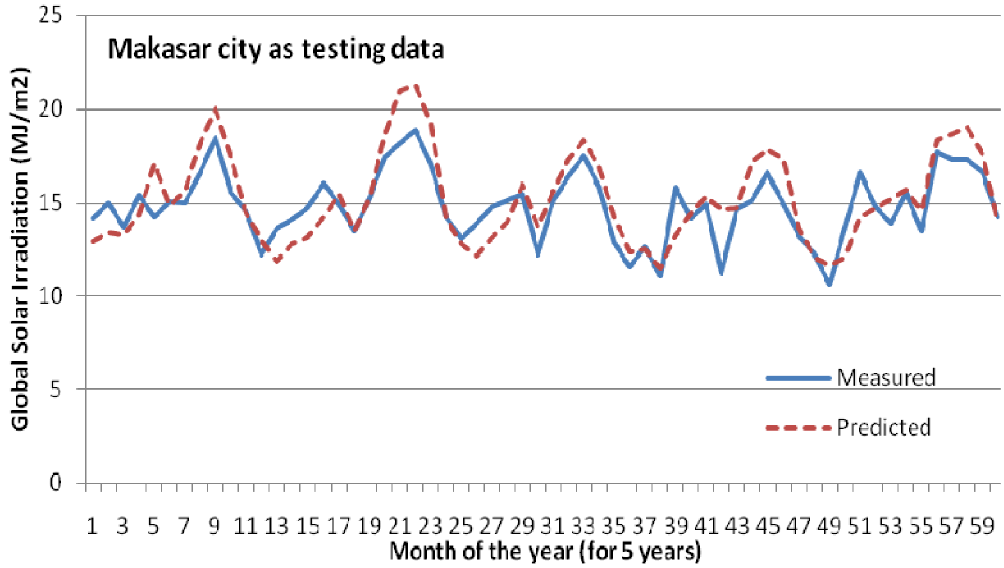

Figure 6 Measured and predicted values with 7-7-1 MLP structure for Makasar

It is found that the prediction of global solar irradiation obtained for the testing data compared well with the actual measured value, giving a correlation coefficient of 0.86 and MAPE is 7.4% for testing data. It can be seen that in general, there is a good agreement between measured and predicted value of monthly global solar irradiation potential in Indonesia. This result shows the potential of ANN method to estimate monthly global solar irradiation in island area of Indonesia to a reasonable degree of accuracy.

5. CONCLUSION

The model of ANN to estimate monthly average global solar irradiation in islands of Indonesia has been developed and analyzed. The results of this study indicate that the neural networks model for solar irradiation potential can achieve 92% accuracy. The ANN model can be used to estimate solar irradiation for any region provided with meteorological and geographical parameters such as: latitude, longitude, altitude, month of the year, mean sunshine duration, average temperature and average relative humidity.

After several attempts a Multi Layer Perceptron model has been developed, the results have been compared with measured data on the basis of MAPE, RMSE and MBE. In this research, a mean absolute percentage error of 7.4% can be achieved by the best estimator with MLP structure that consists of 7, 7, 1 neurons in input layer, hidden layer and output layer respectively. A correlation coefficient of 0.86 was obtained with mean absolute bias error of 1.10 MJ/m^2 and RMSE of 0.17 MJ/m^2. Result from this ANN model has shown good agreement between the estimated and measured values of the monthly average global solar irradiation. The result indicates a good agreement between measured and estimated values for solar energy potential in island of Indonesia.

This study proves that ANN can be used for estimating global solar irradiation potential in some locations in Indonesia by using meteorological data. The use of ANN method can be useful in the remote locations for islands sites in Indonesia in which there are no solar measurement devices. For further work, the estimated solar irradiation potential values by ANN method were presented in the form of solar mapping for the entire country.

6. ACKNOWLEDGEMENTS

We would like to thank Meteorological and Climate Biro (BMKG) of Indonesia for providing meteorological data.

7. REFERENCES

Alawi, A., Hinai, H.A., 1998. An ANN-based approach for predicting global radiation in locations with no direct measurement instrumentation. *Renewable Energy*, Volume 14**,** pp. 199–204.

Azadeh, A. Maghsoudi, A. Sohrabkhani, S., 2009. An integrated artificial neural networks approach for predicting global radiation, *Energy Conversion and Management*, Volume 50, pp 1497-1505.

Jiang, Y., 2008. Prediction of monthly mean daily diffuse solar radiation using artificial neural networks and comparison with other empirical models. *Energy Policy,* Volume 36, pp. 3833-3837.

Kermanshahi, B., 1999. Design and Application of Neural Networks. Shokodo Publishing Company.

Mohandes, M., Rehman, M.S and Halawani, T.O., 1998. Estimation of Global Solar Radiation Using Artificial Neural Networks. *Renewable Energy*, Volume 14, pp.179-184.

Rumbayan, M., Nagasaka, K., 2010b. Prediction of Solar Irradiation Potential in Island Area of Indonesia Using Artificial Neural Network (ANN) Method. *The Official Journal of ISESCO Centre for Promotion of Scientific Research (ICPSR),* Volume 7, No.10.

Rumbayan, M., Nagasaka, K., 2010a. Resource and Economic Assessment of Solar Irradiation Potential in an Island Community, Tokyo University of Agriculture and Technology, *In*: Proceeding of the4th Indonesia Japan joint Scientific Symposium (IJJSS), Bali, Indonesia.

Sen., 1998. Fuzzy algorithm for estimation of solar irradiation from sunshine duration. *Journal of Solar Energy*. Volume 63, pp. 39–49.

Zhou, J., Wu, Y.Z., Yan, G., 2005. Solar radiation estimation using artificial neural networks. *Journal of Solar Energy,* Volume 26, Number 4, pp.509-512.