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WIND ENERGY MAPPING BASED ON QUANTUM GIS, MEASURED AND PREDICTED WIND SPEED IN KATSINA STATE

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ABSTRACT
Before a wind energy system is installed, modelling and prediction of wind speed plays an important role during wind energy planning stage. The short term wind speed of Katsina was measured at 5 m elevation at different locations using hand held digital rotating cup. In order to obtain long term wind speed, a prediction model using artificial neural network (ANN) was developed. The model was implemented using Matlab/Simulink 2019, which consists of 3 layers with back propagation algorithm. The model has 5 inputs which were selected using trial and error techniques. The model was trained, tested and validated using available 1 year data obtained from Katsina state agricultural and rural development agency KATARDA in 34 ground stations situated in each local government. After, the development of the ANN wind speed prediction model, the best architecture has root mean square error (RMSE) of 8.9%, mean biased error (MBE) 4.3% while the optimum correlation value of 0.9380 was realized. The predicted annual wind speeds are in the range of 0.9-13.1 m/s and the yearly evaluated wind speed are 3.2, 2.6 and 4.7 m/s for Katsina central, Katsina south and Katsina north respectively. The wind speed map of the study area was developed; the map shows the locations wind high, moderate and low wind energy potential. The map will serve as a reference for wind energy development in the state and will provide the policy makers and potential investors as a blue print for wind energy development.

***Keywords**:* Wind, Wind energy, ANN, Wind Mapping and Katsina State

INTRODUCTION
Despite the fact that Nigeria is blessed with fossil fuels, the country energy needs is higher than the current generation capacity. The country relies on fossil fuels to generate 5000-7000 MW. It is very important to join other countries of the world to reduce the application of using fossil polluted fuels to generate electricity due to environmental problems. Shifting of paradigm from dirty to clean energy is of utmost important now a days. Though, there is rapid development of renewable energy in the world, particularly in the developed and some developing countries. Nigeria was left behind in developing natural resources for energy generation. The demand of electricity is high, while the supply is inadequate. So to ensure socio economic development, development of clean energy is very important. The country witnessed first electricity generation in 1898, fifteen years after it was generated in England. Despite, long term energy generation history in the country, the development of electricity in Nigeria is developing at slow rate (Muhammad Lawan and Wan Zainal Abidin 2018).

Wind is considered as one of the clean source that will solve the energy crisis faced in Nigeria. The wind energy can be used during day and night; it has been applied in different countries of the world for electrical energy generation. Considering the facts that Nigeria has substantial population living in the rural areas, application of wind energy could help to increase the nation energy generation via clean technology without polluting the environment (Lawan, Abidin, and Masri 2019) and .

In Nigeria, many attempts have been made in order to study the potential of wind energy; study conducted in Uyo, Akwa Ibom capital shows the wind power density is 19.91W/m^2 (Lawan, Abidin, and Hotoro 2020). Efforts to electrify the country via wind energy was studied, the outcomes showed how wind energy can be used to generate electricity in rural and remote areas (Omojola and Ekiti 2015). Authors (Ajao et al. 2009) have shown that decentralized renewable energy sources could help to solve the energy problems in the country. A study conducted showed the economic potential of using wind energy for pumping water in some parts of the south-south region of Nigeria (Abam and Ohunakin 2017). Distribution of wind speed and energy in Abia was evaluated, the results showed the viability of using 11.5kw wind turbine based on hourly wind speed of 2.0 m/s (Oriaku et al. 2007). Assessment and evaluation of wind energy at Katsina, Warri and Calabar was conducted using wind speed distribution models (Gumbel and Weibull). At the end of the investigation, findings show high wind energy in Katsina, while Calabar and Warri have moderate wind energy potential (Okeniyi, Ohunakin, and Okeniyi 2015).

Wind power in the six states in the south-south region of Nigeria was evaluated, the average annual maximum wind speed are in the range of 4.0-4.1 m/s at 10 m altitude. Calabar was found to be potential site to install wind energy for small scale purposes (Eboibi et al. 2018). Wind energy evaluation conducted in southwest Nigeria shows Lagos and Oyo could be a potential site to installed large scale wind turbine based on twenty four years wind speed data. The wind speed varies from 4,8- 5,8 m/s (Ajayi et al. 2014). While a sensitivity analysis conducted shows wind power can be generated in the southwest Nigeria at the cost of 0.06997 and 0.11195 $/(kW$h) to 2.86611 and 4.58578 $/(kW$h) (Address 2012). Wind speed distribution and turbine analysis was conducted in Kano State, northwest Nigeria (Ajayi et al. 2013). The study demonstrates the viability of using commercial wind turbine at elevation above 10m height.

Wind energy in 22 states of Nigeria was reported in an investigation conducted by (Agbetuyi et al. 2012). Their outcomes showed state with high and low wind energy potential, though the purpose is to integrate the wind energy into Nigeria energy mix. In an extensive research work conducted in three selected locations of southeast Nigeria was reported (Oyedepo, Adaramola, and Paul 2012), detailed performance analysis shows the wind energy can be harnessed to pump water in the selected locations. Evaluation of wind turbine in some location of Oyo state was conducted, the study reported annual wind power densities of 67.28 W/m^2 and 106.60 W/m^2(Adaramola and Oyewola 2011). Wind power potential in the northeast Nigeria was reported the potential of wind energy using 37 years wind speed data measured at 10 m height. The study proved Maiduguri and Bauchi to be the best location to install wind turbine (Ohunakin 2011b).

The early work conducted in Nigeria could probably started since 1992. (Anyanwu and Iwuagwu 1995). Wind energy potential at six high altitude locations in Nigeria was examined and reported. Kano and Potuskum have the maximum and minimum win power density (Ohunakin 2011a). Authors(Chineke 2009) in covered the whole 36 states plus nation capital Abuja. The best location to install wind turbine based on region are Bayelsa and Rivers in south-south, Plateau and Bauchi in north central, Katsina in northwest. Wind characteristics are generally low across the country, which is not suitable for large wind energy farms. The research work conducted by (Adekoya L.O. and Adewale A.A. 1992) evaluated wind energy at 30 locations, the average annual wind speed and wind power density are 1.5 to 4.l m/s and 5.7 to 22.5 W/m^2, respectively. In a researched conducted (Okeniyi, Moses, and Okeniyi 2015), the 11 years wind speed data of Akure was analysed, the study applied Weibull and Rayleigh wind speed distribution where measurements are not valuable. In this paper an attempt is made to study wind energy of Katsina State, Nigeria and to come up with energy maps that will guide

model to examine the wind speed characteristics. The Weibull and Rayleigh wind power density of 18.51W/m^2 22.26 W/m^2 shows the area falls within low wind energy yield. The available and extractable wind power of Jos, north central Nigeria was examined and reported (Ajayi et al. 2011). The available monthly wind speed data from 1987 to 2007 were used to judge the wind power potential. The wind speed data was analysed in terms of monthly, seasonal and yearly. The outcomes show an average wind speed of 6.7 and 11.8 m/s which is suitable for large wind energy farm (Ajayi et al. 2011) and (Muhammad Lawan, Azlan Wan Zainal Abidin, and Abubakar 2018).

The wind energy assessment at two sites in the south-south was reported, the wind speed and wind power density for Abeokuta varies from 2.2 to 5.0 m/s. For Ijebu-Ode which extended from 2.0 to 5.0 m/s, 4.26 to 24.51W/m^2 for Abeokuta and from 8.54 to 76.46W/m^2. To determine the potential of wind energy as alternative source of energy, the authors in (Ohunakin, Adaramola, and Oyewola 2011) have selected seven locations in Nigeria with the objective to find the optimum location to install wind turbine. The findings of the study shows Sokoto, Katsina and Kano are best sites for wind turbine installations with yearly mean wind speeds of 7.61, 7.45 and 7.77 m/s, respectively. Using arch view and artificial neural network, the predicted wind speed of Nigeria was reported by (Fadare 2010). The same author (Fadare and State 2008) in different work examined the wind power potential based on Weibull in Ibadan southwest Nigeria, and reported the annual wind speed and wind power density of 2.947 m/s and 15.484 Wm^{-2}, The low and high windy areas were depicted in the developed maps. Analysis of wind speed data and wind energy evaluation was carried out at three positions of (Enugu, Owerri and Onitsha) the southeast Nigeria. The obtained results show the minimum wind turbine required to power the aimed areas.

From the reported reviews hereof, it will be observed that many published encourage the application of wind energy based on the evaluation conducted in different parts of the country. Even though, the study tends to be more narrow focuses on the whole country using secondary data to achieve the desired objectives. A narrow study is required to use primary data as well, in addition, using a reliable approach such as computational intelligence is also needed to reduce time and cost in the rural and remote areas

wind turbines manufactures, policy makers and renewable energy investor

METHODOLOGY

During the planning stage of wind energy development, it is of utmost important to measure wind speed accurately and in precise manner. This is to ensure error-free or high degree of accuracy, because a small deviation of wind speed will lead to a large energy loss. Because of aforementioned reasons, some researchers showed different method of wind speed data collection. Among them are direct measurement on site, published data, meteorological data and wind data generation using reliable prediction model with acceptable validation and accuracy (Teknologi et al. n.d.). Nowadays, prediction is considered as reliable method in the area of soft computing. Different model are being done by many researchers. In this

OVERVIEW

paper a cost effective neural network will be developed using experimental and ground station metrological data.

STUDY AREA DESCRIPTION

The study area of this research work is Katsina state which is divided into three zones namely: Daura zone, Funtua and Katsina Central. The state occupies an area of about 24,192 kilometres square. It is situated on latitude between 1100’49N’ 1302257” and longitude 6052’30E, it boarders Kaduna state to the south, Jigawa and Kano states to the east, Zamfara state to the west and Niger republic to the north. Figure 1 shows the descriptive map of the study area (Sambo 2009).

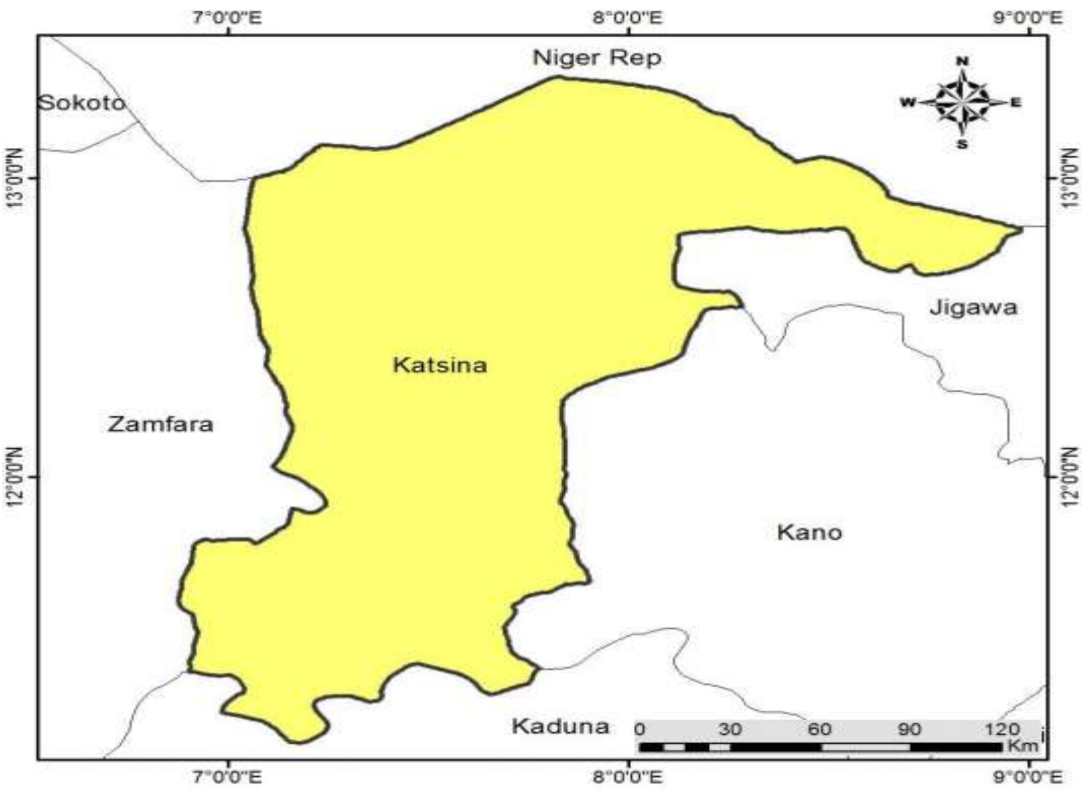

Fig. 1. Study area map with the latitude, longitude and altitude of Katsina State

DATA COLLECTION

In this paper, three types of data were collected, in the first instance, experimental, secondary meteorological data obtained from Katsina State Agriculture and Rural Development Agency (KTARDA). Figure 2 shows the type of anemometer used in each study site to carry out experiential measurements. While Figures 2 and 3 show how the anemometer was mounted at different horizons to carry out wind speed measurement. The figure shows three

Fig. 2 Sample of the Anemometer Used

Fig. 3. Sample of the study site used to carryout measurements

DATA SCREENING AND PRE-PROCESSING

After the data were collected from the excremental set up, the secondary data were also collected from KATARDA; the validity data check was performed. The purpose of doing this is to ensure a reliable data is used in the research. All null or omitted data were regenerated using simple moving average. Where the data was zero, missing or absent a global value of 2.5 m/s was inputted as reported in many studies. To ensure the data is reducing to 0, 1 minimum maximum approach was used as shown in Equation 1. The purpose is to harmonize the data before it was inputted into the model so as not to confuse the model.

$$Xi = \frac{Xi - X\min}{X\min - X\max} \quad (1)$$

Where *Xi* is the bin data, *Xmin*= Minimum value in the data while *Xmax* is the maximum value of the data.

This method rescales the range of the data to [0,1]. In most cases, standardization is used feature-wise as well.

STEPS USED IN MODEL DEVELOPMENT

Information concerning wind speed is very important during model development. This paper proposed to apply artificial neural network (ANN), because of its reliability, robustness and ability to deal with chaotic problems. ANNs have been applied in any science, engineering and social science problems. ANN mimic brain it works based on how the model is trained; moderate training will make the model to predict the outcomes with high degree of accuracy. ANN has capability to model linear and non-linear system without developing a mathematical model. Based on classification ANN can be feed-forward or feedback which is known as recurrent.

To build an acceptable ANN model, it is utmost important to get a metrological data of the study area where a wind turbine is expected to work. Some countries of the world have developed a wind speed prediction model, and this helps them to harness the energy content in a wind, but fortunately in Nigeria it was developed by Fadare (Fadare 2010), which covers the whole country, limited and old data used, coupled with application of out-dated GIS method (Archview) is the drawback of the work. Furthermore, the work does not pay emphasis on each state of the federation. This paper used temperature, relative humidity, and moisture and air density. The data was obtained from KATARDA or a period of five years from 2015-2019 and based on the short term site experiment conducted in one week. In this paper the following steps were used to develop ANN prediction model as depicted in Figure: 4

- Data collection: in this work the mixed mode data were used
- Data pre-processing, which involve data scaling and normalization
- ANN building using Matlab
- Model training, testing and validation

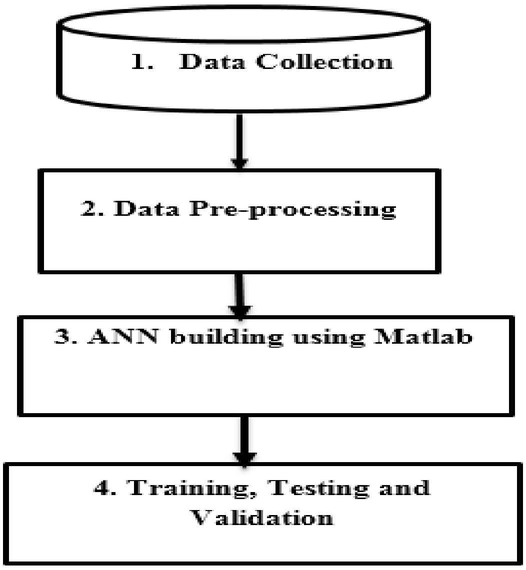

Figure 4: Model Development Process

As shown in Figure 6, the model development consist of 4 steps, data collection and data pre-processing were discussed in section 2.3 and 2.4 respectively. During the ANN design, a three layer feed forward with back propagation network was selected. The network has four inputs, temperature, relative humidity, moisture and air density .The selection was carried out using cross correlation matrix, the best correlated variable with wind speed of 0.89 and above were selected. The hidden layer was varied carefully from 2-5, the output layer has one variable which is the wind speed. The number of neurons in the hidden layer was varies but in line with 2/3 of the size of the input layer. The network was trained using 70% of the data measured in the study area and the data collected from the KATARDA for a period of five years. Figure 5 shows the structure of the developed ANN. All the build-in training algorithm in the Matlab were tested in and was found that levenberg marquardt (algorithm (LMA) is the optimized and fast tracked the training, among the algorithmic tested. while gradient descent algorithm slow the training process. The transfer function used in this study is hyperbolic tangent sigmoid, because is good choice for must researchers (Lawan et al. 2019) and work based on multivariable inputs. To test the performance of the developed prediction model, the remaining unseen 30% data were used. The training was performed using 2018-2019 data observed and collected data from the KATARDA. The reasons of doing this are to evaluate the model under new data so as to judge it performance. Two performance statistical measure were used for determination R^2 , Mean Bias Error and Root Mean Square Error (*RMSE*) whose lower value shows short term performance .The expression of the two statistical measures are given below in Equation 2 and 3 respectively:

$$MBE=\frac{1}{n}\sum_{i=1}^{n}(I_{p,i}-I_i) \quad (2)$$

$$RMSE=\sqrt{\frac{1}{n}\sum_{i=1}^{n}(I_p-i_p)^2} \quad (3)$$

where : $Ip_{,I}$ denotes the predicted GSR on horizontal surface in kWh/m^2, I_i denotes the measured GSR on horizontal surface in kWh/m^2, and n denotes the number of observations

WIND MAP DEVELOPMENT

All of the components of GIS are gathered to develop a model for this paper. Figure 6 shows the overall circulation development process model. This process reiterates until all the objectives of this paper is met. In the following sections, explanations are focused on the collection of data and the development of this project using Quantum GIS (QGIS). Digital map of Katsina State is retrieved from the Land and Survey Department of Katsina. Meanwhile, the detailed local census data are readily available via the 2006 Population and Housing Census of Nigeria (Census 2006) published by Department of Statistics Nigeria. The database was designed to ensure all the data (predicted and measured wind speed) are saved in appropriate rows and columns for easy retrieval using querry language (SQL) structure. The data are such as the item identification number, site name, wind speed, zone, district, height, structure's type, address, and XY-coordinate. The predicted and measured wind speed were inputted into display of GIS thematic map in which, The standard vector file format used n QGIS is the ESRI Shape file. A shape file actually consists of several files. Then, *a Query Builder* allows definition a subset of a table using *SQL where clause* and display the result in the main window.

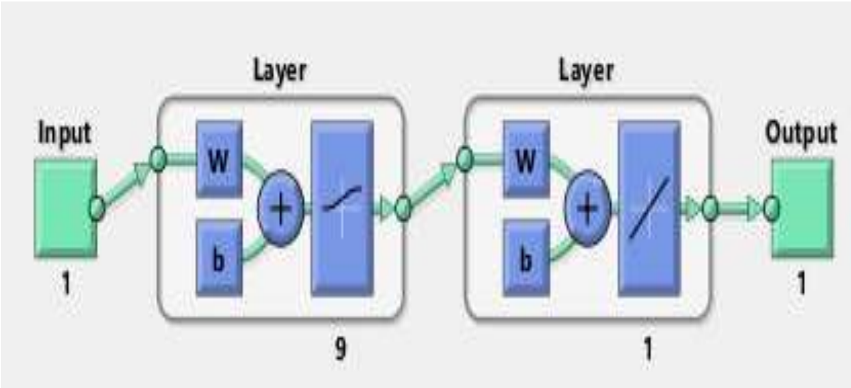

Fig. 5. ANN Model and it equivalent developed in Matlab 2019a

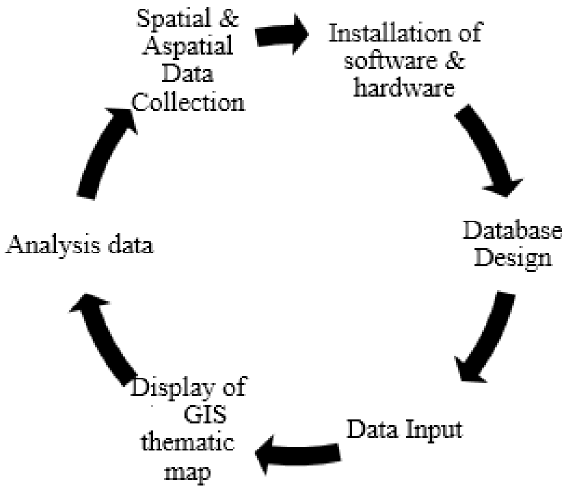

Fig. 6. ANN Model and it equivalent developed in Matlab 2019a

In QGIS, the default projection or Coordinate Reference Systems (CRS) is WGS84 Geographic Coordinate System. Keyhole Markup Language (KML) is a single file that is essentially an XML version of the SHP file. A layer was saved as KML format as later the KML file that can be used on Google Earth. The information consisted in each study site is achieved by clicking an area of the state. The KML file can also edited using the text editor. The KML can be compressed to KMZ format. The developed wind speed map is ready for publishing should contain the title, legend, scale, and north arrow. The *Print Composer* in QGIS provides a canvas to structure the map and add these data fields. The standard map procedure used to develop the wind map is reported in [16].

RESULTS AND DISCUSSION

MEASURED AND PREDICTED WIND SPEED

The measured wind speed in some selected local government in Katsina State is shown in the Figure 7 the wind speed was measured at 2.5 meters height. It can be seen at that height the wind varies across the regions, the minimum wind speed is 1.5 m/s which is recorded in Mani local government and the maximum is 4.9 m/s which is observed in Matazu local government. This shows that the wind speed in the southern Katsina is higher than that of Katsina central and Katsina north.

The optimum network has correlation coefficient values of 0.9817, 0.3017, and 0.85122 for the training, testing and whole dataset respectively shown in the figure below. This shows that the ANN predicted wind speed values were very close to the measured values for all datasets, the number of iterations during the process for the optimum network was 1000. The comparison between the prediction optimum network and the measured wind speed of Katina central shows an error of 0.142 after which the average predicted wind speed of the location is obtained is 3.2m/s. Similarly, the same procedure was applied in Katsina south, the outcomes are shown in Figures 8 and 9. Figure 8 shows the whole training conducted, while Figure 9 shows the training performance iterations.

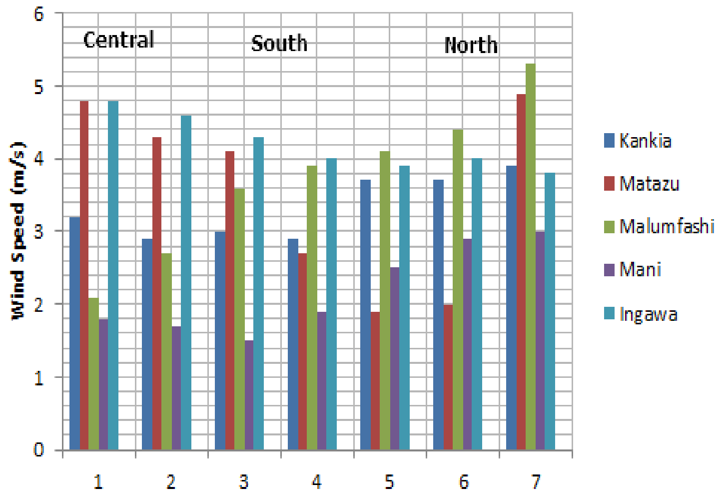

Fig.7 Characteristics of measured wind speed in Katsina central, south and north

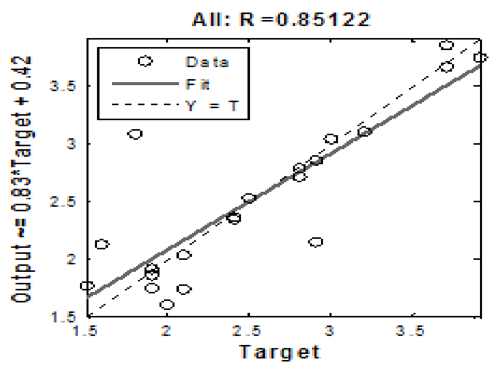

Fig. 8. Regression outcome of the whole training

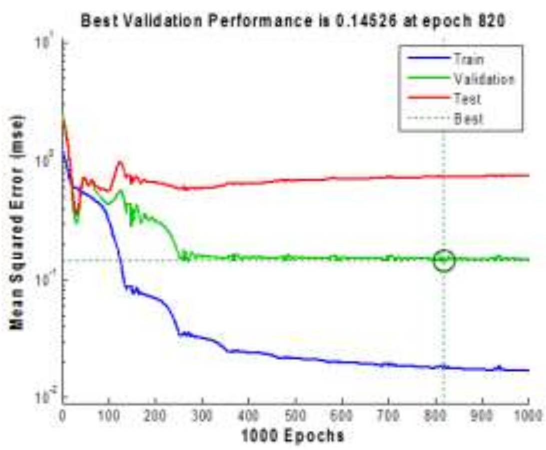

Fig. 9. Training and performance of the data used for Katsina

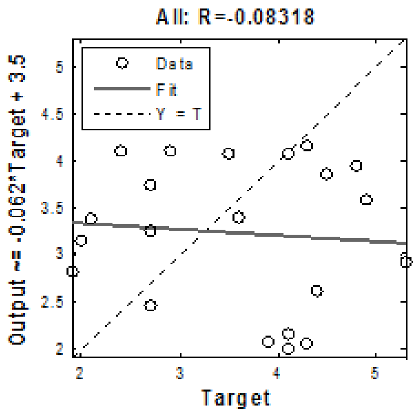

Fig. 10. Regression outcome of the whole training in Katsina south

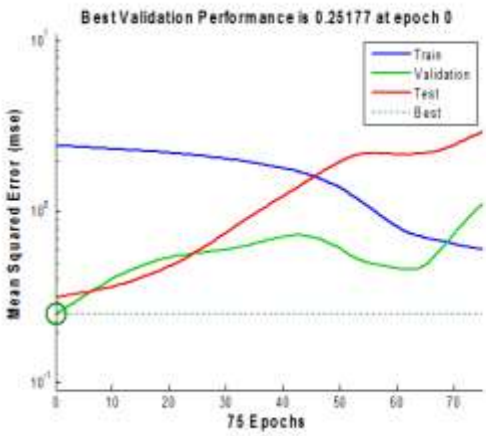

Fig. 11. Training and performance of the data used for Katsina south

The prime network has correlation coefficient values of 0.9817, 0.3017, and 0.85122 for the training, testing and whole dataset respectively shown in the figure below. This shows that the ANN forecast wind speed values were very close to the measured values for all datasets, the number of iterations during the process for the best network was 1000. The comparison between the prediction optimum network and the measured wind speed of Katsina central shows an error of 0.142 after which the average predicted wind speed of the location is obtained is 3.2m/s. Similarly, the same procedure was applied in Katsina south; the outcomes are shown in Figures 10 and 11. Figure 10 shows the whole training conducted, while Figure 11 shows the training performance iterations. The prediction optimum network and the measured wind speed for Katsina south shows an error of 0.25177 after which the average predicted wind speed of the location is obtained as 2.6m/s at 2.5 m height. In Katsina north, the developed predicted model results is depicted in Figures 12 and 13. The optimum network has correlation coefficient values of 0.95375, 0.94829, and 0.93183 for the training, testing and whole dataset respectively shown in the figure below. This shows that the ANN predicted wind speed values were very close to the measured values for all datasets, the number of iterations during the process for the optimum network was 1000. The comparison between the prediction optimum network and the measured wind speed for Katsina North shows an error of 0.204 after which the average predicted wind speed of the location is 4.7m/s.

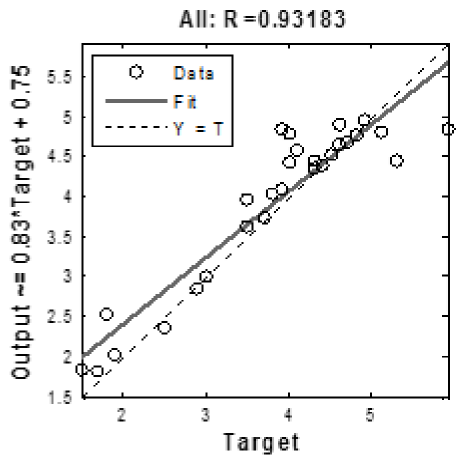

Fig. 12. Regression outcome of the whole training in Katsina north.

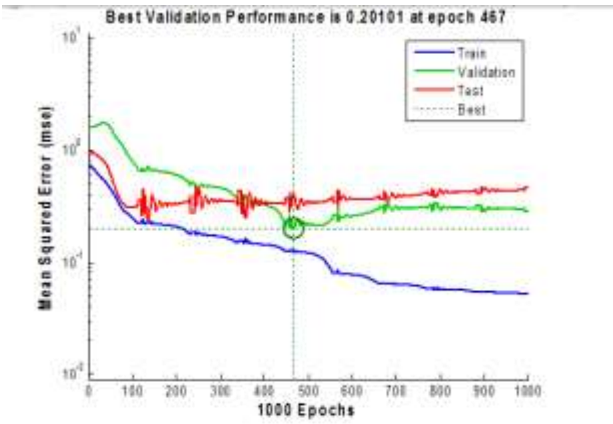

Fig. 13. Training and performance of the data used for Katsina north

WIND SPEED MAP OF KATSINA AT 2.5 M HEIGHT

The Wind Mapping project was conceived to be an opportunity to deliver important information, at a macro level, to local officials. The information is not intended to be used as a site-specific locator where wind generation sites are viable, rather to provide a tool to identify potential areas where further exploration should be conducted if a wind generation or wind related bylaws development is desired. The map in Figure 14 shows the result of wind speed obtained based on the three zones in Katsina state. It is clear the wind speed in Katsina varies between three regions randomly. As shown every region has low, medium and high wind potential sites. This map will serve as a guide for wind turbines manufacturers, potential renewable energy investors and policy makers. It is clear at 2.5 m height the maximum wind speed could reach up to 6.5 m, if the wind speed is recorded or predicted at 10-40m heights where wind generator is expected to work, more wind power could be generated. In the map, the minimum wind speed of 2.0 m/s is enough for the low wind speed turbine to operate in the rural and remote areas. This wind speed is at 2.5 m height at extrapolating height with natural ground condition the wind speed could be 3-4 m/s at 10m/s. This demonstrates the viability of wind energy application in Katsina.

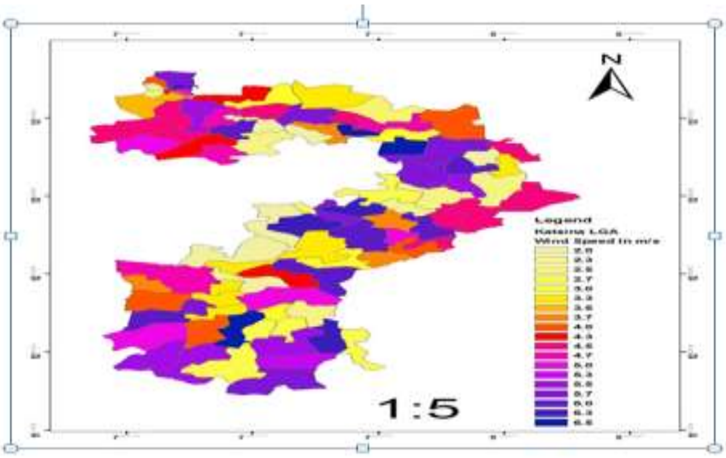

Fig. 14. Developed wind map of Katsina at 2.5 m height

CONCLUSION

This paper demonstrates wind speed map of Katsina based on measured and predicted data. The study shows a cost effective procedure to measure wind speed and to apply neural computing to predict the wind speed using Matlab 2019a. The work has shown that the ANN based model has suitable accuracy with root mean square error (RMSE) of 8.9%, mean biased error (MBE) 4.3% and correlation coefficient (R-value) of 0.9380 was obtained for forecast of wind speed profile in Katsina. The predicted monthly wind speed of 2.6, 3.2 and 4.7 m/s was obtained for Katsina south, Katsina central and Katsina north respectively. The model is promising and can be used to forecast wind speed for locations where there are no monitoring stations. The data were then mapped to show the visualization of wind speed across Katsina State.

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REFERENCES

Abam, Fidelis I., and Olayinka S. Ohunakin. 2017. 'Economics of Wind Energy Utilisation for Water Pumping and CO2 Mitigation Potential in Niger Delta, Nigeria'. *International Journal of Ambient Energy* 38(3):229–39.

Adaramola, M. S., and O. M. Oyewola. 2011. 'Evaluating the Performance of Wind Turbines in Selected Locations in Oyo State, Nigeria'. *Renewable Energy* 36(12):3297–3304.

Adekoya L.O. and Adewale A.A. 1992. 'W I N D E N E R G Y P O T E N T I A L Of N I G E R I A'. Energy Journal 2(1):3–7.

Agbetuyi, A. F., T. .. Akinbulire, A. Abdulkareem, and C. O. .. Awosope. 2012. 'Wind Energy Potential in Nigeria'. *International Electrical Engineering Journal* 3(1):595–601.

Ajao, K., H. Ajimotokan, O. Popoola, and H. Akande. 2009. 'Electric Energy Supply in Nigeria, Decentralized Energy Approach'. *Cogeneration and Distributed Generation Journal* 24(4):34–50.

Ajayi, O. O., R. O. Fagbenle, J. Katende, and J. O. Okeniyi. 2011. 'Availability of Wind Energy Resource Potential for Power Generation at Jos, Nigeria'. *Frontiers in Energy* 5(4):376–85.

Ajayi, Oluseyi O., Richard O. Fagbenle, James Katende, Samson A. Aasa, and Joshua O. Okeniyi. 2013. 'Wind Profile Characteristics and Turbine Performance Analysis in Kano, North-Western Nigeria'. *International Journal of Energy and Environmental Engineering* 4(1):1–15.

Ajayi, Oluseyi O., Richard O. Fagbenle, James Katende, Julius M. Ndambuki, David O. Omole, and Adekunle A. Badejo. 2014. 'Wind Energy Study and Energy Cost of Wind Electricity Generation in Nigeria: Past and Recent Results and a Case Study for South West Nigeria'. *Energies* 7(12):8508–34.

Anyanwu, E. E., and C. J. Iwuagwu. 1995. 'Wind Characteristics and Energy Potentials for Owerri, Nigeria'. *Renewable Energy* 6(2):125–28.

Chineke, Chidiezie Theo. 2009. 'Boosting Electricity Supply in Nigeria : Wind Energy to the Rescue ?' *Pacific Journal of Science and Technology* 10(2):553–60.

Eboibi, B., O. Eboibi, E. Okubio, and C. Iyasele. 2018. 'Evaluation of Wind Energy Potential in the South-South Geopolitical Zone of Nigeria'. *Journal of Applied Sciences and Environmental Management* 21(7):1301.

Fadare, D. a. 2010. 'The Application of Artificial Neural Networks to Mapping of Wind Speed Profile for Energy Application in Nigeria'. *Applied Energy* 87(3):934–42.

Fadare, D. A., and Oyo State. 2008. 'A Statistical Analysis of Wind Energy Potential in Ibadan, Nigeria, Based on Weibull Distribution Function.' 9(1):110–19.

Lawan, S. M., W. A. W. Z. Abidin, and M. Y. Hotoro. 2020. 'Development of an Improved Hybrid Back Propagation ANN for Low Wind Speed Prediction and Wind Energy Evaluation'. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 75(1).

Lawan, S. M., W. A. W. Z. Abidin, and T. Masri. 2019. 'Implementation of a Topographic Artificial Neural Network Wind Speed Prediction Model for Assessing Onshore Wind Power Potential in Sibu, Sarawak'. *Egyptian Journal of Remote Sensing and Space Science*.

Muhammad Lawan, Salisu, Wan Azlan Wan Zainal Abidin, and U. Abubakar. 2018. 'Wind Speed Prediction in Non-Monitored Areas Based on Topographic Radial Basis Neural Network (T-RBNN)'. in *IOP Conference Series: Earth and Environmental Science*. Vol. 168. Institute of Physics Publishing.

Muhammad Lawan, Salisu, and Wan Azlan Wan Zainal Abidin. 2018. 'Wind Energy Assessment and Mapping Using Terrain Nonlinear Autoregressive Neural Network (TNARX) and Wind Station Data' edited by Q. Ai. *Cogent Engineering* 5(1).

Ohunakin, O. S., M. S. Adaramola, and O. M. Oyewola. 2011. 'Wind Energy Evaluation for Electricity Generation Using WECS in Seven Selected Locations in Nigeria'. *Applied Energy* 88(9):3197–3206.

Ohunakin, Olayinka S. 2011a. 'Wind Resource Evaluation in Six Selected High Altitude Locations in Nigeria'. *Renewable Energy* 36(12):3273–81.

Ohunakin, Olayinka S. 2011b. 'Wind Resources in North-East Geopolitical Zone, Nigeria: An Assessment of the Monthly and Seasonal Characteristics'. *Renewable and Sustainable Energy Reviews* 15(4):1977–87.

Okeniyi, Joshua Olusegun, Ime Friday Moses, and Elizabeth Toyin Okeniyi. 2015. 'Wind Characteristics and Energy Potential Assessment in Akure, South West Nigeria: Econometrics and Policy Implications'. *International Journal of Ambient Energy* 36(6):282–300.

Okeniyi, Joshua Olusegun, Olayinka Soledayo Ohunakin, and Elizabeth Toyin Okeniyi. 2015. 'Assessments of Wind-Energy Potential in Selected Sites from Three Geopolitical Zones in Nigeria: Implications for Renewable/Sustainable Rural Electrification'. *Scientific World Journal* 2015:7–9.

Omojola, Awogbemi, and Ado Ekiti. 2015. 'Harnessing Wind Energy to Solve Nigeria ' s Energy Crisis'. (September).

Oriaku, C. I., J. C. Osuwa, A. D. Asiegbu, G. U. Chukwu, and C. O. Kanu. 2007. 'Frequency Distribution Analysis of Available Wind Resources in Umudike, Abia State Nigeria for Wind Energy Conversion System Design'. *Pacific Journal of Science and Technology* 8(2):203–6.

Oyedepo, Sunday O., Muyiwa S. Adaramola, and Samuel S. Paul. 2012. 'Analysis of Wind Speed Data and Wind Energy Potential in Three Selected Locations in South-East Nigeria'. *International Journal of Energy and Environmental Engineering* 3(1):1–11.

Sambo, Abubakar S. 2009. 'Strategic Developments In Renewable Energy In Nigeria'. *International Association for Energy Econonmics* (June):15–19.

S. M. Lawan, W. A. W. Z. Abidin, A. M. Lawan, M. Mustapha, and S. L. Bichi. 2015 Teknologi, Jurnal, 'Ann And Gis-Assisted Methodology For Wind Resource Assessment (Wra) In Sarawak'. 18-19.