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Effective Earth Radius Factor Prediction and Mapping for Ondo State, South Western Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author AOA designed the study, wrote the protocol, and wrote the first draft of the manuscript. Authors RAB, ATA and SAO managed the literature searches and data preparation. Author KHM prepared the map. All authors read and approved the final manuscript.

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ABSTRACT

Accurate prediction and determination of the effective earth radius factor (k-factor) is critical for optimal performance in the design and planning of terrestrial line of sight communication links. In this work an artificial neural network (ANN) model is developed and used to predict k-factor values for four towns in Ondo State using satellite derived data. The towns are Okitipupa (6.5°N, 4.78°E), Ondo (7.11°N, 4.83°E), Akure (7.25°N, 5.2°E) and Ikare (7.52°N, 5.75°E). A feed forward back propagation ANN was implemented, thereafter trained, validated and tested using satellite derived data for the period from 1984 to 2002. Mean absolute error (MAE) was used to evaluate the performance of the ANN. The MAE values obtained were 0.0024, 0.0014, 0.002 and 0.003 for Okitipupa, Akure, Ikare and Ondo towns respectively. Contour map showing the predicted k-factor values interpolated over the map of Ondo state was plotted using Geographical Information System (GIS) techniques. The study concluded that ANN presents an effective means of predicting the average k-factor values over a geographical location.

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1. INTRODUCTION

Radio waves may bend while propagating through different atmospheric layers due to variations of refractivity. These variations are determined by meteorological conditions, mainly temperature, atmospheric pressure and humidity, which vary strongly with the geographical location and time of the year [1]. In terrestrial microwave link design, accurate prediction of the effective earth radius factor (k-factor) distribution, for the location where propagation is intended, is vital to optimal performance [2]. Therefore errors in prediction techniques must be minimal for optimal performance.

Artificial neural networks (ANNs) are one of the most accurate and widely used predictive models [3] that have enjoyed fruitful applications in time series forecasting [3], weather forecasting [4], radio refractivity prediction [5,6], and stream flow prediction [7]. Several distinguishing features of artificial neural networks make them valuable and attractive fora predictive task. First, as opposed to the traditional model-based predictive methods, ANNs are data-driven and self-adaptive methods. Secondly, ANNs can generalize; after learning the data presented to them they can correctly infer the unseen part of the data even if the sample data contain noisy information. Thirdly, ANNs are accurate universal functional approximators [3]. It has been shown that ANNs can approximate any continuous function to any desired accuracy. Finally, artificial neural networks are nonlinear, making them appropriate model for real world systems which are often nonlinear [3]. Existing predictive models for effective earth radius include stochastic model [8], cumulative distribution model [9], curve fitting and kernel density estimation models [2]. However, the capability of ANNs to extract the relationship between the inputs and outputs of a process, even when there exist no empirical relationship between the parameters, because ‘ physics behind’ will entail more than just the equation and their ability to predict any continuous function to any desired accuracy makes ANNs better suited to predicting k-factor values.

In this paper, a neural network model for monthly k- factor prediction for four selected towns in Ondo State, southwest Nigeria was designed and implemented. The towns are Okitipupa (6 .5°N, 4 .78°E), Ondo (7. 11°N, 4. 83°E), Akure 9 (7. 25°N, 5 .2°E) and Ikare (7 .52°N, 5 .75°E). A contour map showing the predicted k-values interpolated over a point map of Ondo State was produced using Geographic Information System (GIS) based techniques.

2. EFFECTIVE EARTH RADIUS (K-FACTOR)

The ratio of the effective earth radius to the actual earth radius is called the *k* factor. The choice of values for link design must be appropriate for the particular topographical setting in order to avoid loss of signal at the receiver [10]. In determining the k-factor, the relationship between the radius of curvature of the ray, ρ, and the radio refractivity, N, with height, h, must be known. The first step involves calculating refractivity (N), which is defined as the amount by which the real part of the refractive index *n* exceeds unity. According to [11], it can be expressed mathematically as

$$N = (n-1) * 10^6 = \frac{77.6p}{T} - \frac{5.6e}{T} + \frac{3.75*10^5}{T^2} \qquad (1)$$

Where p is the atmospheric pressure (hPa), e is the water vapour pressure (hPa) and T is the absolute temperature (Kelvin). This relationship is valid for all radio frequencies up to 100 GHz with error less than 0.5%. If the relative humidity (RH) is known, then the water vapour pressure can be calculated using equation 2 [11].

$$e = \frac{RH}{100} a e^{\left(\frac{bT}{T+C}\right)} \quad , \qquad (2)$$

where temperature is in ℃ and the coefficients a, b and c (valid for all radio frequencies up to 100GHz and error is less than 0.5%) take the following values.

a) For water (-20 ℃to $+ 50$ ℃): $a = 6.11,\ b = 17.50,\ c = 240.97$
b) For ice (-50 ℃to 0 ℃): $a = 6.11,\ b = 22.45,\ c = 272.55$

Refractivity can be expressed as a function of height as

$$N_s = N_o e^{-0.1057 \mathrm{h_s}} \qquad (3)$$

Where N_o is the radio refractivity and $\mathrm{h_s}$ is altitude above sea level (in km).

Effective earth radius, ρ, can be calculated using equation 4 [12].

$$\rho = \frac{a}{(1-0.04665e^{0.005577N_S})} \quad (4)$$

where $a = 6375$ km is the actual earth radius. N_s is surface radio refractivity calculated for a layer one km high.

The k-factor is obtained from equation 5 [12]

$$k = \frac{1}{1-\frac{a}{\rho}} \quad (5)$$

substituting equation 4 into equation 5, we have

$$k = \frac{a}{(1-0.04665e^{0.005577N_S})}. \quad (6)$$

Hence, k-factor was obtained using equation 6.

The effective earth radius factor k is used in characterizing refractive conditions as normal refraction, sub-refraction, super-refraction and ducting respectively. When

$$k = \frac{4}{3} \quad (7a)$$

normal refraction is said to occur. Here radio signals travel on a straight line path along the earth's surface and go out to space unobstructed [13]. If

$$\frac{4}{3} > k > 0 \quad (7b)$$

sub refraction occurs, meaning that radio waves propagate abnormally away from the earth's surface [13]. When

$$\infty > k > \frac{4}{3} \quad (7c)$$

In this case, super-refraction occurs and radio waves propagate abnormally towards the earth's surface thus extending the radio horizon [13]. Finally if

$$-\infty < k < 0 \quad (7d)$$

ducting occurs and the waves bend downwards with a curvature greater than that of the earth [13].

3. ARTIFICIAL NEURAL NETWORK IMPLEMENTATION

The designed ANN model consists of input layer, two hidden layers and an output layer. A linear function was used in the output layer as non-linear functions may introduce distortions to the predicated output [3,14]. Similarly, non-linear functions like log-sigmoid and hyperbolic transfer functions are commonly used in the hidden layer because they are differentiable [3]. In this work, log sigmoid transfer function was used for the hidden layers while linear transfer function was used in the output layer. The total number of neurons in the hidden layer was ninety (90) and this number of neurons was obtained through trial and error as this remains one of the most effective and popular ways for determining the appropriate number of neurons in the hidden layer [7]. For training, the Levenberg-Marquardt back propagation algorithm was used because of its computing efficiency and good performance [7]. Fig. 1 illustrates the neural network training process. MATLAB 7.12.0 (R2011a) neural network toolbox was used to implement the neural network. Mean Absolute Error (MAE), an error estimating technique, was used in evaluating the performance of the ANN [15].

4. DATA PREPARATION

The data used for the study consist of monthly average values of temperature, relative humidity and atmospheric pressure for the four towns: Okitipupa, Ondo, Akure and Ikare, studied. The dataset covers the period from January 1984 to December 2002 and where obtain from [16] and [17]. The calculated values of effective earth radius factor (K factor) were divided into training and testing data sets. The training dataset is from 1984 to 2000 and the testing dataset was from 2001 to 2002. The training data was used to develop the model for k-factor prediction, while the testing data was used to validate the performance of the model from training data. The towns were selected to give a proportionate distribution of k-factor values for the state.

5. RESULTS AND DISCUSSION

Fig. 2 displays the plot of the predicted and actual k-value for Okitipupa during the training state, a close correlation between the predicted and actual values during training gives a cue that the ANN prediction will be accurate. The training state is for a period of 204 months. The MAE value for the training state was 0.0034. Figs. 3, 4, 5 and 6 displays the plot of predicted and actual values of Radio Refractivity for Okitipupa, Ondo, Akure and Ikare respectively for a period of twenty four months (2001-2002). From the plots, there is a close correlation between the actual values and the predicted values. Table 1 shows the percentage difference between the actual and predicted values for the first eight months of 2001 for Ikare. The percentage difference was calculated using equation (8)

$$Difference = (A - P) \times 100\% \quad (8)$$

where A = actual value, P = predicted value.

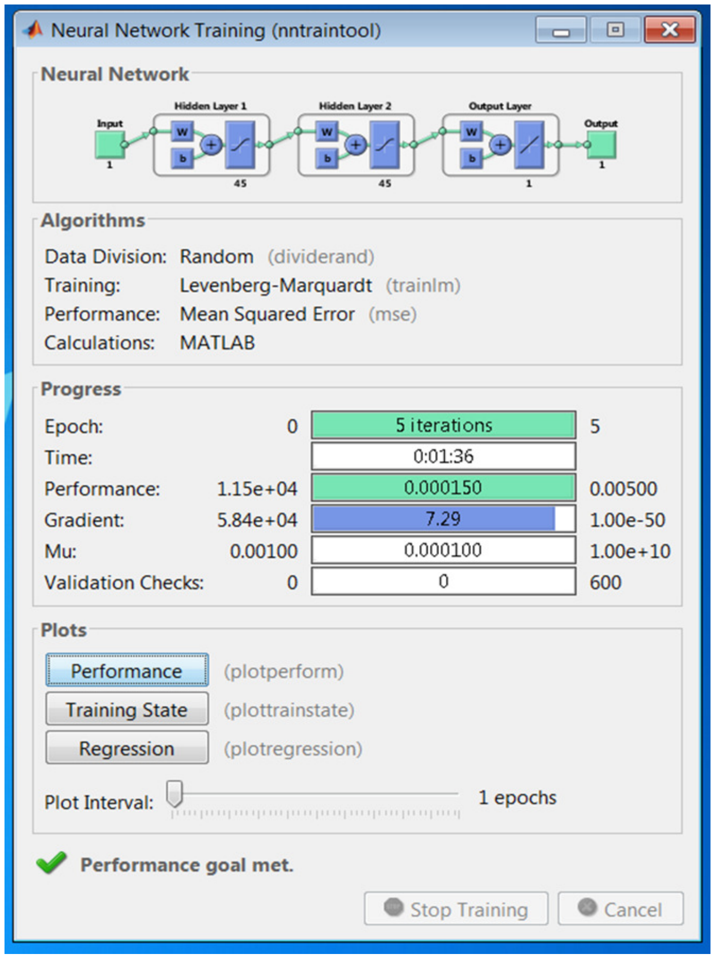

Fig. 1. Neural network training process

Table 1. Table of predicted and actual values of refractivity for the first ten months (Ikare)

Actual value (A)	Predicted value (P)	% Difference (A-P)
1.40	1.40	0.00
1.40	1.40	0.00
1.65	1.70	-0.05
1.62	1.62	0.00
1.59	1.59	0.00
1.55	1.55	0.00
1.56	1.56	0.00
1.54	1.53	0.01
1.55	1.55	0.00
1.54	1.54	0.00

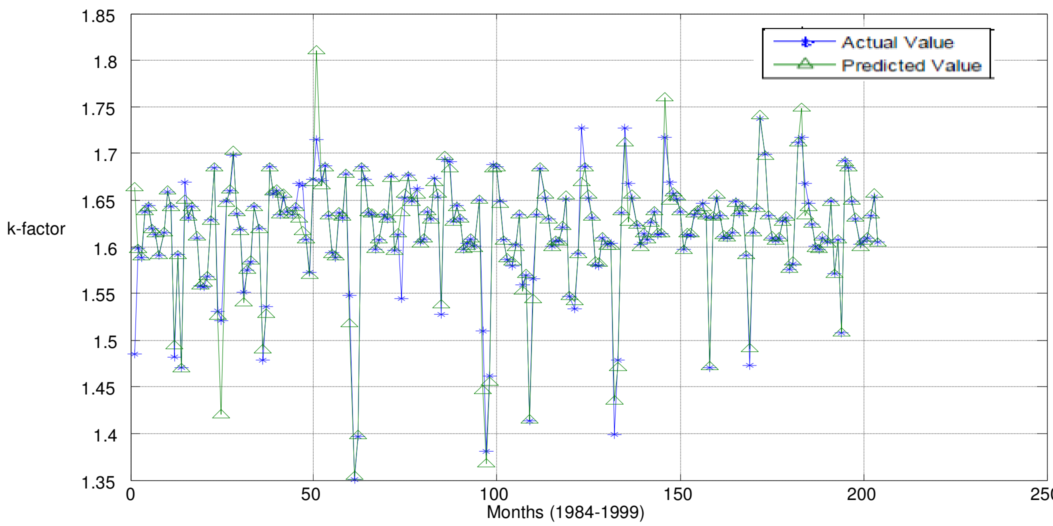

Fig. 2. Plot of predicted and actual values for Okitipupa (Training state)

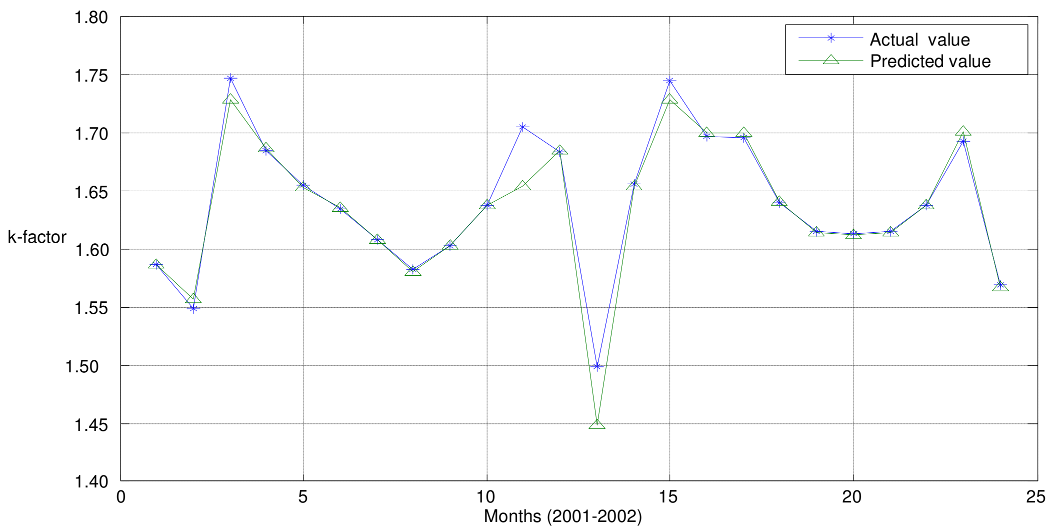

Fig. 3. Plot of predicted and actual values of k-factor for Okitipupa

It is observed that the large number of neurons used in the hidden layer produces an over fitting effect. This effect makes the model to have a good fit to the data used for building and testing the model but with poor generalizability to data from other locations. Since accurate prediction of k-factor values for the location, where propagation is intended, is optimal, the use of an over fitted ANN that ensures accurate prediction of k-factor values is justified.

5.1 Evaluation of Ann Performance

Mean absolute error performance technique was used to evaluate the performance of the ANN for the selected towns as shown in Table 2.

The output MAE shows that the developed ANN model is suitable for predicting k-factor values for the study area.

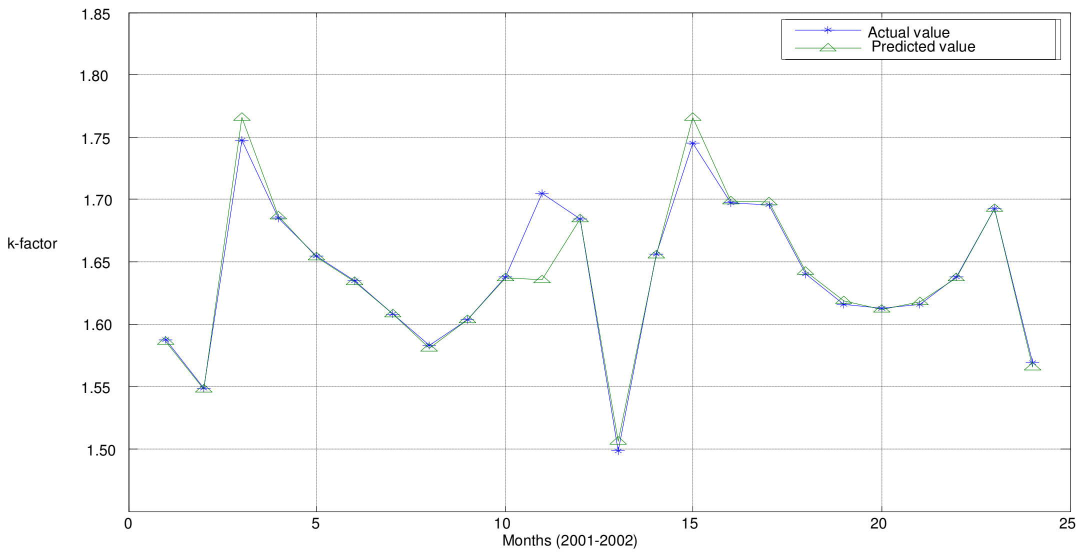

Fig. 4. Plot of predicted and actual values of k-factor for Ondo

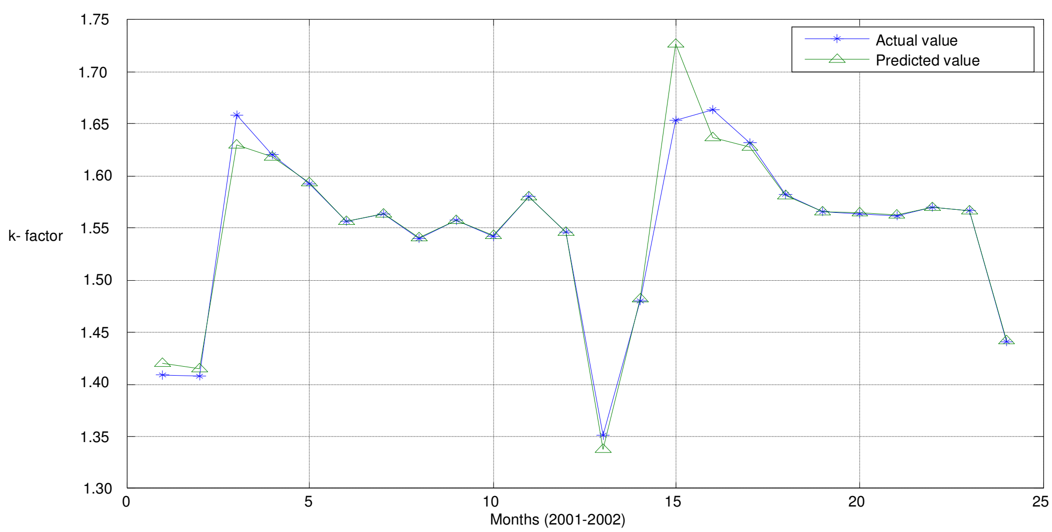

Fig. 5. Plot of predicted and actual values of k-factor for Ikare

5.2 Mapping

The map was produced by first creating a geo-referenced map of Ondo State. Thereafter, a point map showing the point locations of the towns of interest was produced. The towns of interest were located on the geo-referenced map by using their position coordinates. The predicted values of k-factor for the month of January 2001 were interpolated using inverse distance weighted, over the point map of Ondo State. Fig. 7 displays the k-factor map of Ondo State for the month of January 2001. The legend displays the variation of k-factor over the state for the month of January 2001.

Table 2. Performance evaluation of the ANN

Town	Output (MAE)
Okitipupa	2.4376e-003
Akure	1.4001e-003
Ikare	2.0733e-003
Ondo	3.0733e-003

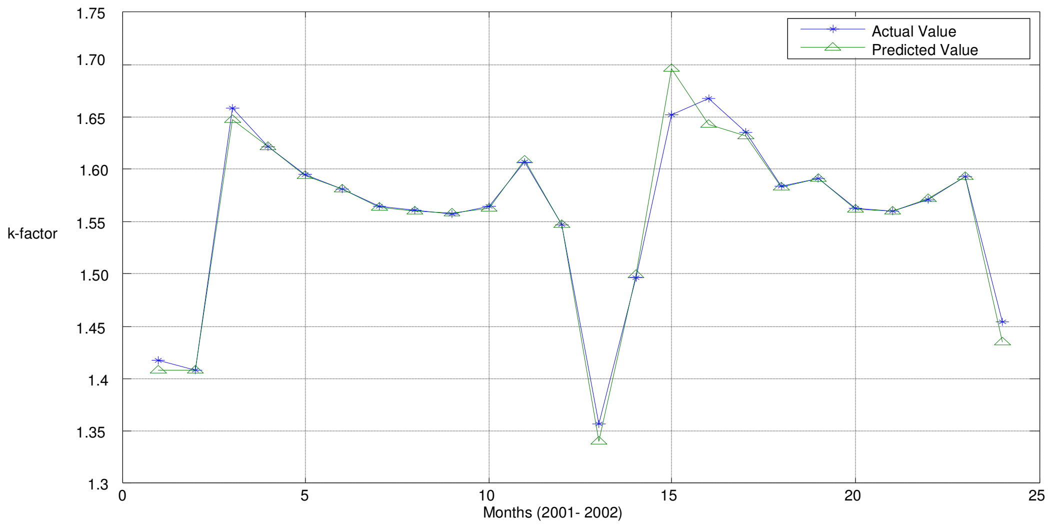

Fig. 6. Plot of predicted and actual values of k-factor for Akure

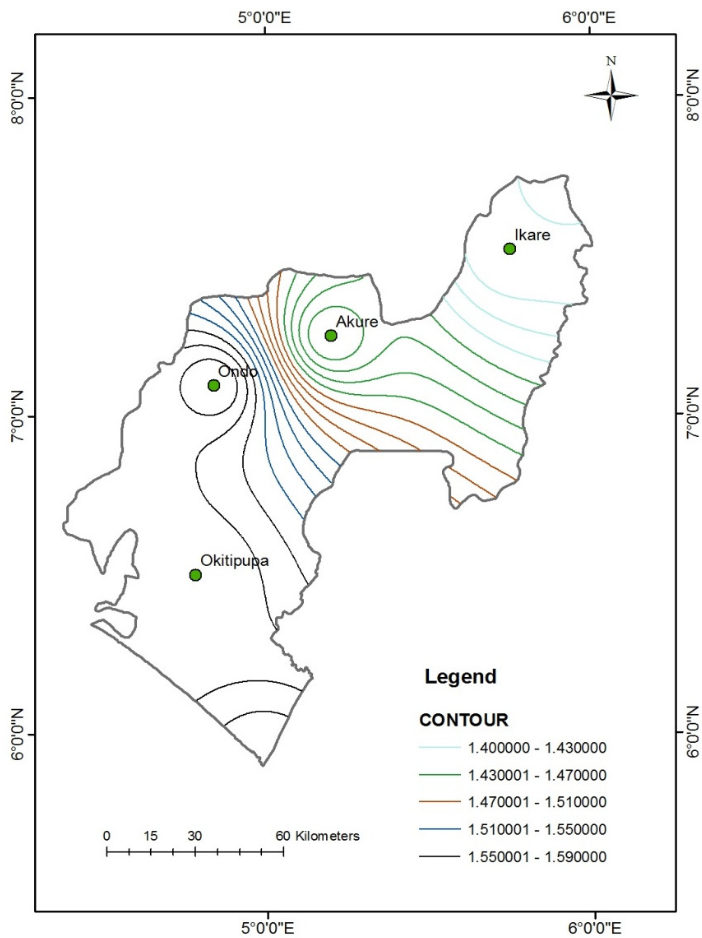

Fig. 7. k-factor map for the month of January 2001

6. CONCLUSION

Accurate prediction and determination of k-factor is critical for optimal terrestrial microwave communication link performance and availability. This work developed an ANN for predicting k-factor values for four towns in Ondo State, Nigeria. Contour map showing the predicted k-factor values interpolated over a point map of Ondo State was plotted using GIS techniques. It was observed that over fitting the ANN by using a large number of neurons produced more accurate results. Although this may lead to poor generalizability to data from other locations, the use of an over fitted ANN is justified by the accurate prediction of k-factor values over the study area. The average MAE value of the ANN predictions over the study area was 0.0022. This work concludes that ANNs presents an effective means of accurately predicting the k-factor values for a geographic location. This would be of great value in telecommunication planning for better microwave link performance and availability. In future, this could be extended to other geographic areas and generation of contour maps showing k-factor distribution over the geographic area.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Adediji AT, Mandeep JS, Ismail M. Metrological characterization of effective earth radius factor (k-factor) for wireless radio link over Akure, Nigeria. Journal of Metrology Society of India. 2014;29(2): 131-132.
2. Nyete AM, Afullo TJO. Non-parametric and parametric modeling and characterization of the effective earth radius factor for South Africa. Progress in Electromagnetics Research Symposium Proceedings, Taipei. 2013;653.
3. Khashei M, Bijari M. An artificial neural network (p, d, q) model for time series forecasting. Expert Systems with Applications. 2010;37(1):479-489.
4. Santhanam T, Subhajini AC. An efficient weather forecasting system using radial basis function neural network. Journal of Computer Science. 2011;*7*(7):962-963.
5. Atijosan A, Eguaroje O, Jesuleye I, Muhammed S. Radio Refractivity Prediction and Mapping for Ondo State, South-Western Nigeria. RNIS: Research Notes in Information and Service Sciences. 2013;12:34–40.
6. Ibeh GF, Agbo GA. Estimation of tropospheric refractivity with artificial neural network at Minna, Nigeria. Global Journal of Science Frontier Research. 2012;12(1-E):9-11.
7. Yonaba H, Anctil F, Fortin V. Comparing sigmoid transfer functions for neural network multistep ahead stream flow forecasting. Journal of Hydrologic Engineering. 2010;15(4):275-283.
8. Ogunjo ST, Ajewole MO, Adediji AT, Ojo JS. Predicting radio refractivity using a stochastic model. In General Assembly and Scientific Symposium (URSI GASS). 31th URSI. 2014;1-4.
9. Palmer AJ, Baker DC. Predicting the long-term average of the effective earth radius factor for South Africa using ground-based observations. In AFRICON, 2004. 7th AFRICON Conference in Africa. 2004;2: 1003-1006.
10. Nyete AM, Afullo TJO. Seasonal distribution modeling and mapping of the effective earth radius factor for microwave link design in South Africa. Progress In Electromagnetics Research B. 2013;51:1-32.
11. Recommendation ITU-R P.453-9, The radio refractive index: its formula and refractivity data. Available:http://www.itu.int/rec/R-REC-P/en
12. Afullo TJ, Odedina PK. Effective earth radius factor measurement and modelling for radio link design in Botswana. South African Institute of Electrical Engineers. 2008;99(3):78.
13. Adediji AT, Ajewole MO, Falodun SE. Distribution of radio refractivity gradient and effective earth radius factor (k-factor) over Akure, South Western Nigeria. Journal of Atmospheric and Solar-Terrestrial Physics. 2011;*73*(16):2300-2304.

14. Özkan C, Erbek FS. The comparison of activation functions for multispectral Landsat TM image classification. Photogrammetric Engineering & Remote Sensing. 2003;69(11):1225-1234.
15. Sheela KG, Deepa SN. Review on methods to fix number of hidden neurons in neural networks. Mathematical Problems in Engineering. 2013;1-3.
16. NASA surface meteorology and solar energy daily averaged data. Available:https://eosweb.larc.nasa.gov/cgi-bin/sse/daily.cgi Accessed on 12th of June, 2012.
17. International Water Management Institute, world water and climate atlas. Available:http://www.iwmi.cgiar.org/resources/world-water-and-climate-atlas (Accessed on 25th of May, 2012)

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