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Evaluation of net radiation using the autoregressive models with higher orders over Nigeria

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ABSTRACT

In this study, monthly surface net radiation data were collected from the Nigeria Meteorological Agency, Lagos covering a duration of 31 years (1983- 2013) spatially distributed across the four climatic regions: Semi-Arid (SAR), Sub-humid Dry (SHD), Sub-humid Humid (SHH) and Humid (HUM) regions. The net radiation was evaluated using different forms of Auto-Regressive models – AR {p} where p is the number of orders of the auto-regressive. The analysis showed that AR {4} performed best in all the regions and stations investigated. Regionally, AR {4} has maximum values of coefficient of determination of 0.8127 in HUM, 0.7876 in SHH, 0.5765 in SHD and 0.7973 in SAR regions. It can be concluded that the higher the order of auto-regressive models, the more accurate estimation of net radiation it will give irrespective of location in Nigeria.

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1. Introduction

Net radiation is the amount of the difference between upward and downward components of long wave and shortwave radiation; a central component of the Earth's equilibrium surface energy. It is the primary source of energy for the physical and chemical processes, which occur in the surface-atmosphere interface [1]. It has served as an input parameter for the global modeling of hydrological budgets, photosynthesis, and evapotranspiration [2]. The near energy balance and precision of evapotranspiration estimation algorithms are especially affected by the net radiation [3]. For meteorology, hydrology, global change and agriculture, the accurate estimate of net radiation is critical [4]-[6]. While net radiometer can measure net radiation in a station accurately, its use is complex and time consuming for large-scale measurement, given the fact that numerous soil systems are necessary. As a result, most national weather stations focus on only small regional measurements due to economic and technological constraints that result in insufficient net radiation data for practical investigations [1].

Consequently, several scientific researchers have developed various alternative methods for estimating net radiation for multifunctional research in radiation study such as the application of satellite-derived reanalysis and analytical model of few available regional in situ data. Golkar et al. [7] investigated the net radiation estimates in Iranian arid and semi-arid climates. They evaluated multiple data sources in order to obtain a higher-space-time-resolution net radiation estimate from the International Satellite Cloud Climatology

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Project Fluxes D-series (ISCCP-FD) data set. The study concluded that global estimates, based on satellite data sets, of surface net radiation that resolve regional and weather variability, are available with reasonable precision. Krishna et al. [8] investigated the satellite-based net radiation for India. They contrasted direct computational net radiation with that of satellite data from the Cloud and Earth Radiant Energy System (CERES). It was concluded that estimated all-Sky daily net radiation was compared well with the R-squared values of the order 0.7 and the root mean square error (RMSE) of the order 8-16 W/m^2. The uncertainty of surface net radiation derived from Landsat images was also studied in [9]. The paper found that there is little uncertainty between measured data and satellite data based on the root mean square analysis. The empirical assessment of daytime net radiation from shortwave and auxiliary information were studied in [10]. A new model of the day-time net radiation assessment was developed and radiation measurements were used to assess seven commonly existing models. The study found that in the globalization models, the suitable RMSE of the newly developed model is well compared.

This present work, meanwhile, applies the auto-regression models of the first, second, third and fourth orders to evaluate net radiation time series across four climatic regions in Nigeria.

2. Materials and Methods

2.1. Data Source and Acquisition

The *in situ* daily data of surface net radiation were collected from the Nigerian Meteorological Agency (NIMET), Lagos spanning 31 years (1983 - 2013) spatially distributed across the climatic zones in Nigeria as shown in Fig. 1. The Nigerian Meteorological Agency, initiated by an Act of the National Assembly, was enacted on 21st of May 2003 and came into force on 19 June 2003 after the President's assents known as the NIMET (Establishment) ACT 2003. It is an agency of the government which is responsible for advising the Federal Government on all meteorological aspects; forecasting, planning, and interpreting government policies on meteorology; and making meteorological and climate forecasts on the safe operation of airplanes, ocean-going vessels, and oil facilities.

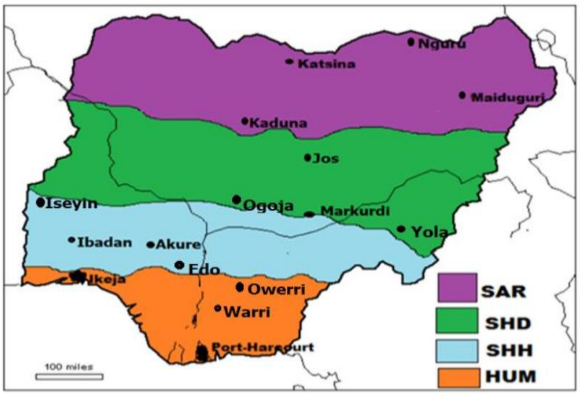

Fig. 1. Study locations in Nigeria [13].

The *in-situ* net radiation was used to developed the first, second, third and fourth-order autoregressive models (AR {1}, AR {2}, AR {3} and AR {4}) respectively using the XLSTAT 2016 edition software.

2.2. Relevant Auto-Regressive (AR) Theory

The AR model is a generalized model fitted to time series data either to understand the data or to estimate future points in the series based on a weighted sum of past values [11]. The dependent variable is forecasted using a linear combination of past values. AR models are generally denoted as $AR(p)$ where parameters *p* is the order (number of time lags) of the autoregressive model [12]. The general expression is given by:

$$y_t = \alpha + \emptyset_1 y_{t-1} + \emptyset_2 y_{t-2} + \cdots + \emptyset_p y_{t-p} + \varepsilon_t, \quad (1)$$

where $\emptyset_p$ is the parameter estimate of autoregressive p^{th} order, α is the constant, ε_t is error term and y_t is the estimated variable.

AR parameters can be obtained using the least-squares approach, which can be written in compact form on k-step ahead prediction for p^{th} order AR process as [14], [15]:

$$\hat{Y} = U\hat{\beta}, \quad (2)$$

where,

$$\hat{Y} = \begin{bmatrix} y_t \\ y_{t+1} \\ \vdots \\ y_{t+k} \end{bmatrix}, \quad (3a)$$

$$U = \begin{bmatrix} y_{t-1} & y_{t-2} & \vdots & y_{t-p} \\ y_t & y_{t-1} & \vdots & y_{t+1-p} \\ \vdots & \vdots & \ddots & \vdots \\ y_{t+k-1} & y_{t+k-2} & \cdots & y_{t+k-p} \end{bmatrix} \quad (3b)$$

$$\hat{\beta} = \begin{bmatrix} \emptyset_1 \\ \emptyset_2 \\ \vdots \\ \emptyset_p \end{bmatrix} \quad (3c)$$

Using the matrix notation, AR parameter $\hat{\beta}$ can be evaluated as:

$$\hat{\beta} = (U^T U)^{-1} U^T \hat{Y} \quad (4)$$

In this paper, the monthly data sets used were sub-divided into two such that the first data set A consist of twenty-five years (1983 –2007) data and data set B consists of six years (2008 – 2013) data. The first data set was used for development of $AR(p)$ models while the second part was used for evaluation of the performance of the model following the method described in [16].

2.3. Performance Evaluation of AR(p) Model

The performance of the $AR(p)$ model developed in this study was assessed using the mean squared error (MSE), root mean squared error, coefficient of determination (R^2), mean absolute percentage error (MAPE) and Akaike's information criterion (AIC) as expressed in Equations (5) to (9). Several studies used $AR(p)$ techniques to evaluate the global solar radiation [17]-[20], total ozone content [21] and ocean current [22]. The method was found to predict the variables very well with great accuracy compared to ground measurement.

$$MSE = \frac{1}{n}\sum_{n=1}^{n}(P_i - O_i)^2, \quad (5)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{n=1}^{n}(P_i - O_i)^2}, \quad (6)$$

$$R^2 = \left(\frac{n(\sum P_i O_i) - (\sum P_i)(\sum O_i)}{\sqrt{(n\sum O_i^2) - (\sum O_i^2)\,[(n\sum P_i^2) - (\sum P_i^2)]}}\right)^2, \quad (7)$$

$$MAPE = \frac{1}{n}\sum_{n=1}^{n}\left|\frac{P_i - O_i}{O_i}\right|, \quad (8)$$

$$AIC = -2(\text{Log} - \text{likelihood}) + 2K, \quad (9)$$

where O_i is the observed values and P_i is the predicted values, n is the number of observations, K is the number of model parameters (the number of variables in the model plus the intercept) and Log-likelihood is a measure of model fit.

For the purpose of error analysis, the MSE and RMSE is a measure of the quality of an estimator; it is always non-negative, and values closer to zero are better [23]-[24]. The R^2 is the proportion of the variance in the dependent variable, which can be estimated from the independent variables. Its value normally ranges from 0 to 1 and the closer to unity is desirable [12], [25]. The AIC index compares the quality of a set of statistical models to each other. The lower the value, the better the model but it does not say anything about the absolute quality of the model [17], [26].

3. Results and Discussion

3.1. Developed AR Models

Tables 1 - 4 show the parameter estimates of four different AR {p} order models over the four climatic regions and some selected stations in each of the regions. These values formed models with lag numbers that can be used to evaluate net radiation in each of regions and their respective stations over Nigeria. For instance, in the entire Semi-Arid region, the first, second, third and fourth-order autoregressive models of the form shown in Equations (10) to (13) respectively were formed from the parameter estimates presented in Table 1.

Table 1 Model parameter of the ARMA (p,q) model for Semi-Arid (SAR) Region

Stations	Model	Parameter				
		C	$\emptyset_1$	$\emptyset_2$	$\emptyset_3$	$\emptyset_4$
Semi-Arid	ARMA (1,0)	98.7498	0.7866	-	-	-
	ARMA (2,0)	99.2495	1.2619	-0.6100	-	-
	ARMA (3,0)	99.3007	1.1295	-0.3356	-0.2183	-
	ARMA (4,0)	99.3268	1.0544	-0.4500	0.1713	-0.3470
Maiduguri	ARMA (1,0)	71.1822	0.7925	-	-	-
	ARMA (2,0)	71.4069	1.1864	-0.4960	-	-
	ARMA (3,0)	71.4524	0.9744	0.0111	-0.4260	-
	ARMA (4,0)	71.4391	0.8302	0.0165	-0.0987	-0.3358
Kastina	ARMA (1,0)	94.4578	0.8154	-	-	-
	ARMA (2,0)	95.2160	1.3837	-0.6989	-	-
	ARMA (3,0)	95.2726	1.1097	-0.1565	-0.3906	-
	ARMA (4,0)	95.2750	1.0170	-0.1962	-0.1221	-0.2402
Kaduna	ARMA (1,0)	113.2804	0.6383	-	-	-
	ARMA (2,0)	113.6051	0.9932	-0.5680	-	-
	ARMA (3,0)	113.6067	0.9901	-0.5625	-0.0056	-
	ARMA (4,0)	113.6337	0.9892	-0.6266	0.1067	-0.1155
Nguru	ARMA (1,0)	116.4764	0.7232	-	-	-
	ARMA (2,0)	116.9072	1.1325	-0.5743	-	-
	ARMA (3,0)	116.9208	1.1119	-0.5339	-0.0360	-
	ARMA (4,0)	116.9664	1.1049	-0.6565	0.2178	-0.2300

Table 2 Model parameter of the ARMA (p,q) model for Sub-humid Dry (SHD) Region

Stations	Model	Parameter				
		C	$\emptyset_1$	$\emptyset_2$	$\emptyset_3$	$\emptyset_4$
SHD	ARMA (1,0)	125.8921	0.4997	-	-	-
	ARMA (2,0)	126.0284	0.8177	-0.6535	-	-
	ARMA (3,0)	126.0472	0.7225	-0.5383	-0.1435	-
	ARMA (4,0)	126.0373	0.7359	-0.4834	-0.2145	0.0997
Jos	ARMA (1,0)	115.3656	0.5679	-	-	-
	ARMA (2,0)	115.5692	0.9241	-0.6386	-	-
	ARMA (3,0)	115.5770	0.8998	-0.6040	-0.0379	-
	ARMA (4,0)	115.5749	0.9002	-0.5962	-0.0493	0.0129
Yola	ARMA (1,0)	119.1401	0.5755	-	-	-
	ARMA (2,0)	119.3792	0.8749	-0.5368	-	-
	ARMA (3,0)	119.3910	0.8450	-0.4884	-0.0561	-
	ARMA (4,0)	119.3893	0.8456	-0.4830	-0.0656	0.0114
Makurdi	ARMA (1,0)	143.1686	0.7003	-	-	-
	ARMA (2,0)	143.2292	0.9824	-0.4016	-	-
	ARMA (3,0)	143.0801	0.8456	-0.0760	-0.3110	-
	ARMA (4,0)	143.0812	0.8136	-0.0899	-0.2133	-0.1110
Ogoja	ARMA (1,0)	144.0111	0.7744	-	-	-
	ARMA (2,0)	143.8506	1.0914	-0.4112	-	-
	ARMA (3,0)	143.8952	0.8774	0.1390	-0.4978	-
	ARMA (4,0)	143.8944	0.7559	0.1585	-0.2589	-0.2604

Table 3 Model parameter of the ARMA (p,q) model for Sub-humid Humid (SHH) Region

Stations	Model	Parameter				
		C	$\emptyset_1$	$\emptyset_2$	$\emptyset_3$	$\emptyset_4$
SHH	ARMA (1,0)	128.6180	0.7916	-	-	-
	ARMA (2,0)	128.4837	1.2506	-0.5826	-	-
	ARMA (3,0)	128.5146	1.0395	-0.1327	-0.3596	-
	ARMA (4,0)	128.5148	0.9978	-0.1502	-0.2357	-0.1182
Ibadan	ARMA (1,0)	125.1214	0.8038	-	-	-
	ARMA (2,0)	124.9540	1.2958	-0.6161	-	-
	ARMA (3,0)	124.9818	1.0830	-0.1700	-0.3448	-
	ARMA (4,0)	124.9842	1.0234	-0.2008	-0.1558	-0.1744
Iseyin	ARMA (1,0)	136.3767	0.7589	-	-	-
	ARMA (2,0)	136.3536	1.2055	-0.5876	-	-
	ARMA (3,0)	136.3711	1.1017	-0.3755	-0.1758	-
	ARMA (4,0)	136.3784	1.0877	-0.4053	-0.0889	-0.0790
Edo	ARMA (1,0)	119.8012	0.7916	-	-	-
	ARMA (2,0)	119.5801	1.1858	-0.5026	-	-
	ARMA (3,0)	119.5932	0.9570	0.0323	-0.4509	-
	ARMA (4,0)	119.5727	0.8327	0.0338	-0.1745	-0.2843
Akure	ARMA (1,0)	133.1837	0.7598	-	-	-
	ARMA (2,0)	133.0980	1.1086	-0.4611	-	-
	ARMA (3,0)	133.1271	0.9294	-0.0353	-0.3838	-
	ARMA (4,0)	133.1250	0.8862	-0.0415	-0.2752	-0.1154

These can be applied to estimate net radiation in the Semi-Arid region.

$$Q_t = 98.7498 + 0.7866Q_{t-1} \quad (10)$$

$$Q_t = 99.2495 + 1.2619Q_{t-1} - 0.61Q_{t-2} \quad (11)$$

$$Q_t = 99.3007 + 1.1295Q_{t-1} - 0.3356Q_{t-2} - 0.2183Q_{t-3} \quad (12)$$

$$Q_t = 99.3268 + 1.0544Q_{t-1} - 0.45Q_{t-2} + 0.1713Q_{t-3} - 0.3470Q_{t-4} \quad (13)$$

Also, for the entire Sub-humid Dry (SHD) region, the equations of the form shown in Equations (14) to (17) can be applied to estimate net radiation as shown in Table 2.

$$Q_t = 125.8921 + 0.4997Q_{t-1} \quad (14)$$

$$Q_t = 126.0284 + 0.8177Q_{t-1} - 0.6535Q_{t-2} \quad (15)$$

$$Q_t = 126.0472 + 0.7225Q_{t-1} - 0.5383Q_{t-2} - 0.1435Q_{t-3} \quad (16)$$

$$Q_t = 126.0373 + 0.7359Q_{t-1} - 0.4834Q_{t-2} + 0.2145Q_{t-3} - 0.0997Q_{t-4} \quad (17)$$

Table 4 Model parameter of the ARMA (p,q) model for Humid (HUM) Region

Stations	Model	Parameter				
		C	$\emptyset_1$	$\emptyset_2$	$\emptyset_3$	$\emptyset_4$
Humid	ARMA (1,0)	131.0781	0.8002	-	-	-
	ARMA (2,0)	130.8208	1.2291	-0.5382	-	-
	ARMA (3,0)	130.8547	0.9816	0.0192	-0.4495	-
	ARMA (4,0)	130.8760	0.8351	0.0180	-0.1191	-0.3313
Port Harcourt	ARMA (1,0)	125.7165	0.8022	-	-	-
	ARMA (2,0)	125.2572	1.2239	-0.5287	-	-
	ARMA (3,0)	125.2444	1.0090	-0.0351	-0.4000	-
	ARMA (4,0)	125.2626	0.8399	-0.0499	0.0229	-0.4174
Warri	ARMA (1,0)	130.3512	0.7232	-	-	-
	ARMA (2,0)	130.2431	0.9861	-0.3643	-	-
	ARMA (3,0)	130.2328	0.8721	-0.0583	-0.3093	-
	ARMA (4,0)	130.2484	0.7772	-0.0748	-0.0474	-0.3001
Owerri	ARMA (1,0)	130.8932	0.8047	-	-	-
	ARMA (2,0)	130.5314	1.2229	-0.5223	-	-
	ARMA (3,0)	130.5638	0.9718	0.0573	-0.4681	-
	ARMA (4,0)	130.5954	0.7861	0.0707	-0.0690	-0.4030
Ikeja	ARMA (1,0)	124.4185	0.7408	-	-	-
	ARMA (2,0)	124.3811	1.0949	-0.4793	-	-
	ARMA (3,0)	124.4039	0.9594	-0.1718	-0.2815	-
	ARMA (4,0)	124.4142	0.9083	-0.2033	-0.1074	-0.1819

In the same vein, for the entire Sub-humid Humid region, the equations of the form shown in (18)–(21) can be applied to estimate net radiation as presented in Table 3.

$$Q_t = 128.6180 + 0.7916Q_{t-1} \quad (18)$$

$$Q_t = 128.4837 + 1.2506Q_{t-1} - 0.5826Q_{t-2} \quad (19)$$

$$Q_t = 128.5146 + 1.0395Q_{t-1} - 0.1327Q_{t-2} - 0.3596Q_{t-3} \quad (20)$$

$$Q_t = 128.5148 + 0.9978Q_{t-1} - 0.1502Q_{t-2} + 0.2357Q_{t-3} - 0.1182Q_{t-4} \quad (21)$$

Finally, for the entire Humid region, the equations of the form shown in (22) – (25) can be applied to estimate net radiation as presented in Table 4.

$$Q_t = 131.0781 + 0.8002Q_{t-1} \quad (22)$$

$$Q_t = 130.8208 + 1.2291Q_{t-1} - 0.5382Q_{t-2} \quad (23)$$

$$Q_t = 130.8547 + 0.9816Q_{t-1} + 0.0192Q_{t-2} - 0.4495Q_{t-3} \quad (24)$$

$$Q_t = 130.8760 + 0.8351Q_{t-1} + 0.0180Q_{t-2} - 0.1191Q_{t-3} - 0.3313Q_{t-4} \quad (25)$$

Those of other stations in the SAR, SHD, SHH and Humid region can be formed in the same manner. Those set of equations were used to estimate and predict net radiation in the stations within the respective region as shown in Table 5a.

3.2. Assessment and Validation of AR Models

Table 5 shows the result of the application of the AR{p} models over Nigeria. From the table, it can be observed that the estimated net radiation from each of the four AR{p} equations were very close to the observed values with differences less than 3.50 W/m^2 in all regions and their respective stations. The R-squared values were found to be more than 0.30 threshold value, proposed for the suitability of the model in [27]. The only exception is the value of the AR{1} model in the Sub-humid Dry with a value of 0.2455. These good fits also attest to the significance of all other statistical indicators. It can also be established from Table 5 that the higher the orders of the AR{p}, the better the performance of the model. Therefore, AR{4} showed the best performance in all the stations and the four regions. That is, it has the highest values of R^2 (Table 5a) and lowest values of MSE, RMSE, MAPE and AIC (Table 5b).

3.3. Comparison of Observed and Predicted Net Radiation over Nigeria.

Figs. 2 – 5 show the scatter plots of comparison between observed and AR {p} net radiation over four climatic regions in Nigeria. The observations show that the auto-regressive model of order 4 (AR{4}) has the highest R^2 values in the SAR, SHD and HUM regions having magnitudes of 0.7973, 0.5765 and 0.8127 respectively but AR{2} has the highest value in SHH region having a magnitude of 0.8011. The AR{p} performed best in the Humid region followed by SHH but it has the worst performance in the SHD region.

Table 5a Assessment of observed and predicted net radiation over sixteen stations across four regions in Nigeria using the AR (p) Model

	Net Radiation					AR (p) Models Test Parameters							
						R^2				MSE			
Stations	Observed	AR {1}	AR {2}	AR {3}	AR {4}	AR {1}	AR {2}	AR {3}	AR {4}	AR {1}	AR {2}	AR {3}	AR {4}
SAR	101.0236	97.5434	99.3882	99.5847	99.7422	0.6154	0.7579	0.7694	0.7973	100.4789	63.2570	60.2370	52.9561
Maiduguri	76.9432	70.6348	71.6000	71.8030	71.7859	0.6307	0.7217	0.7725	0.7983	89.3172	67.3146	55.0205	48.7823
Kastina	97.8225	93.0589	95.8129	95.9048	95.9093	0.6653	0.8284	0.8544	0.8628	197.6089	101.2884	85.9319	80.9913
Kaduna	114.2277	112.5326	113.6891	113.6962	113.8362	0.4021	0.5932	0.5932	0.5986	142.9692	97.2698	97.2668	95.9801
Nguru	115.1008	115.3494	116.9107	116.9637	117.1964	0.5172	0.6753	0.6758	0.6929	137.1871	92.2429	92.1236	87.2661
SHD	124.0316	125.5812	126.1390	126.2370	126.1750	0.2455	0.5641	0.5725	0.5765	62.8828	36.3317	35.6294	35.2975
Jos	115.1431	114.9809	115.6929	115.7251	115.7143	0.3189	0.5948	0.5954	0.5954	96.5803	57.4587	57.3777	57.3685
Yola	114.1320	118.5987	119.4461	119.4967	119.4884	0.3251	0.5167	0.5182	0.5183	106.6166	76.3515	76.1139	76.1042
Makurdi	142.8195	143.0419	143.5310	143.1395	143.1851	0.4934	0.5743	0.6067	0.6113	99.8550	83.9211	77.9146	76.9875
Ogoja	144.8967	143.0435	143.2020	143.8948	143.9993	0.5952	0.6627	0.7420	0.7586	108.2238	90.1687	68.9753	64.5173
SHH	130.7683	127.8657	128.3438	128.6889	128.7319	0.6258	0.7530	0.7847	0.7876	99.9853	65.9885	57.5322	56.7324
Ibadan	127.0126	124.3741	124.9563	125.2767	125.3616	0.6447	0.7796	0.8056	0.8115	100.2706	62.1979	54.8568	53.1912
Iseyin	139.3202	135.9300	136.4060	136.5531	136.6103	0.5784	0.7247	0.7332	0.7349	110.0616	71.8725	69.6462	69.2080
Edo	120.9932	118.9285	119.1999	119.6428	119.6736	0.6217	0.7167	0.7734	0.7914	111.0305	83.1139	66.4877	61.1944
Akure	135.7472	132.4298	132.8329	133.2394	133.2699	0.5765	0.6666	0.7153	0.7191	116.5678	91.7744	78.3662	77.3294
HUM	132.8384	130.1367	130.1813	130.6790	130.9010	0.6366	0.7405	0.7907	0.8127	99.5950	71.1040	57.3518	51.3144
Port-Harcourt	129.0480	125.1225	124.5091	124.8576	125.2098	0.6384	0.7376	0.7777	0.8144	135.8628	98.5713	83.5075	69.7273
Warri	130.9401	129.4809	129.6362	129.8636	130.0939	0.5201	0.5829	0.6223	0.6559	147.4002	128.0920	115.9926	105.6726
Owerri	133.5132	129.8945	129.6703	130.2488	130.5877	0.6423	0.7377	0.7917	0.8234	121.2313	88.8603	70.5727	59.8478
Ikeja	125.7941	123.9288	124.3313	124.5831	124.6876	0.5499	0.6534	0.6807	0.6913	91.0370	70.1057	64.5733	62.4323

Table 5b Assessment of observed and predicted net radiation over sixteen stations across four regions in Nigeria using the AR (p) Model

	AR (p) Models Test Parameters											
	RMSE				MAPE				AIC			
Stations	AR {1}	AR {2}	AR {3}	AR {4}	AR {1}	AR {2}	AR {3}	AR {4}	AR {1}	AR {2}	AR {3}	AR {4}
SAR	10.0239	7.9534	7.7612	7.2771	8.7564	6.4965	6.2047	5.8940	2239.3117	2103.4086	2090.8841	2054.7710
Maiduguri	9.4508	8.2045	7.4176	6.9844	11.5184	9.7056	8.5708	8.0134	2204.0104	2121.7324	2063.8262	2030.1912
Kastina	14.0573	10.0642	9.2699	8.9995	13.3470	8.4581	8.0795	8.0517	2442.3434	2245.1844	2198.3417	2182.8030
Kaduna	11.9570	9.8625	9.8624	9.7969	9.2490	7.3002	7.3008	7.2429	2344.6753	2231.9017	2233.8925	2231.9558
Nguru	11.7127	9.6043	9.5981	9.3416	8.6447	6.7378	6.7197	6.5480	2332.5072	2216.2198	2217.8366	2203.8153
SHD	7.9299	6.0276	5.9690	5.9412	5.2435	3.7288	3.6726	3.6879	2098.0320	1936.5648	1932.7781	1931.9987
Jos	9.8275	7.5801	7.5748	7.5742	7.2381	5.3812	5.3755	5.3763	2226.8649	2074.1135	2075.6963	2077.6481
Yola	10.3255	8.7379	8.7243	8.7238	7.3064	6.0156	6.0124	6.0079	2256.5370	2159.0388	2160.1153	2162.0773
Makurdi	9.9927	9.1608	8.8269	8.7742	5.7254	5.2178	5.0394	5.0052	2237.1530	2187.3539	2167.3283	2165.7827
Ogoja	10.4031	9.4957	8.3051	8.0323	6.0406	5.3095	4.5643	4.3756	2261.5392	2209.1498	2131.5803	2113.7952
SHH	9.9993	8.1233	7.5850	7.5321	6.5325	5.1469	4.7764	4.7141	2237.8551	2116.0160	2077.2842	2075.1399
Ibadan	10.0135	7.8866	7.4065	7.2932	6.7503	5.1857	4.8494	4.6991	2238.7637	2098.4438	2063.1459	2056.0243
Iseyin	10.4910	8.4778	8.3454	8.3191	6.3959	4.9865	4.8467	4.8390	2266.5329	2141.5378	2134.1906	2134.3222
Edo	10.5371	9.1167	8.1540	7.8227	7.5310	6.3119	5.6283	5.3352	2269.2896	2184.9840	2120.6989	2098.1449
Akure	10.7967	9.5799	8.8525	8.7937	6.6904	5.8979	5.3513	5.3142	2283.7661	2214.4986	2169.5871	2167.6433
HUM	9.9797	8.4323	7.5731	7.1634	6.3980	5.2682	4.7036	4.4158	2236.7192	2138.3074	2076.4684	2045.5381
Port-Harcourt	11.6560	9.9283	9.1382	8.3503	7.6470	6.3645	5.8910	5.4161	2329.8886	2236.2771	2189.0260	2137.6532
Warri	12.1408	11.3178	10.7700	10.2797	7.9178	7.3193	6.8836	6.3728	2354.0489	2314.2118	2286.7424	2261.1557
Owerri	11.0105	9.4266	8.4008	7.7361	7.0275	5.8778	5.1744	4.8436	2295.7158	2205.1566	2138.7284	2091.9397
Ikeja	9.5413	8.3729	8.0358	7.9014	6.1970	5.4765	5.2600	5.0911	2209.5388	2133.6801	2111.2665	2103.2883

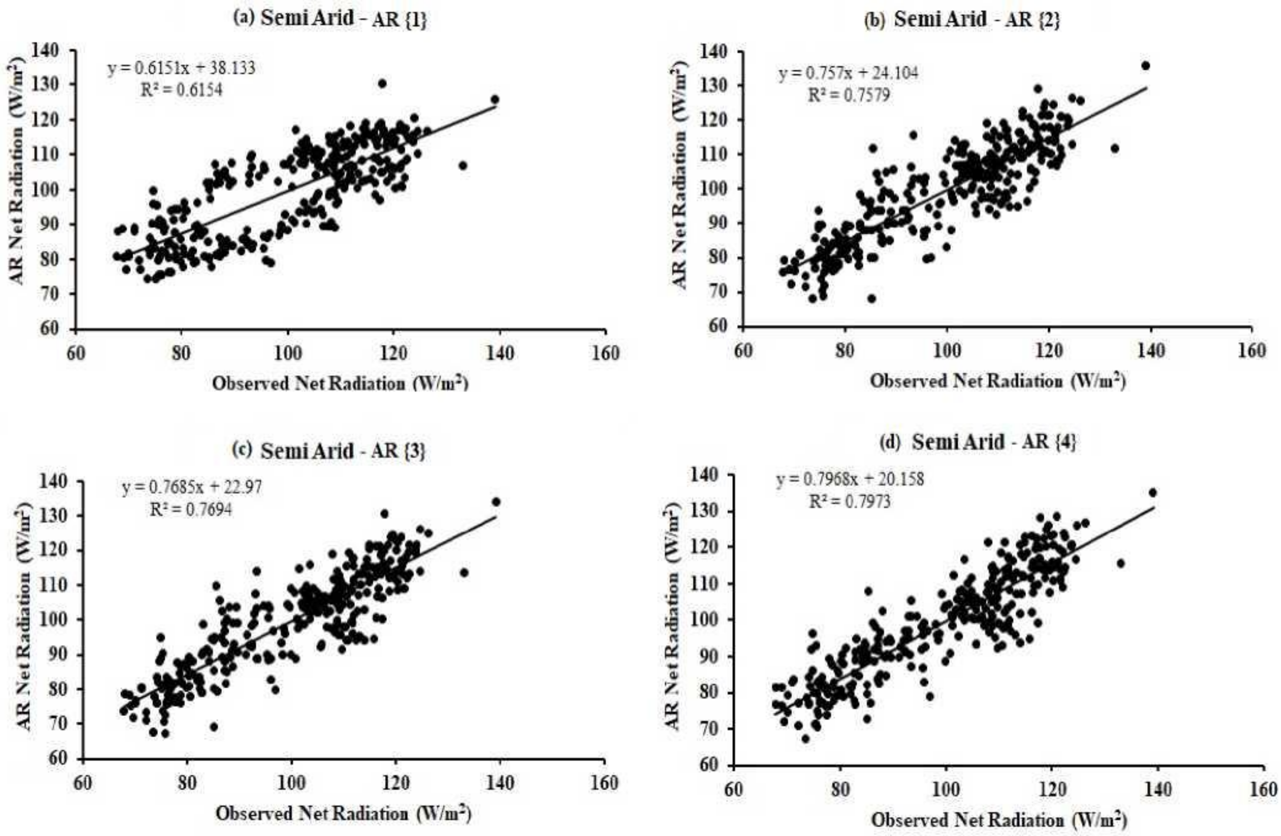

Fig. 2 Scatter plots of the observed net radiation and AR net radiation over SAR zone in Nigeria

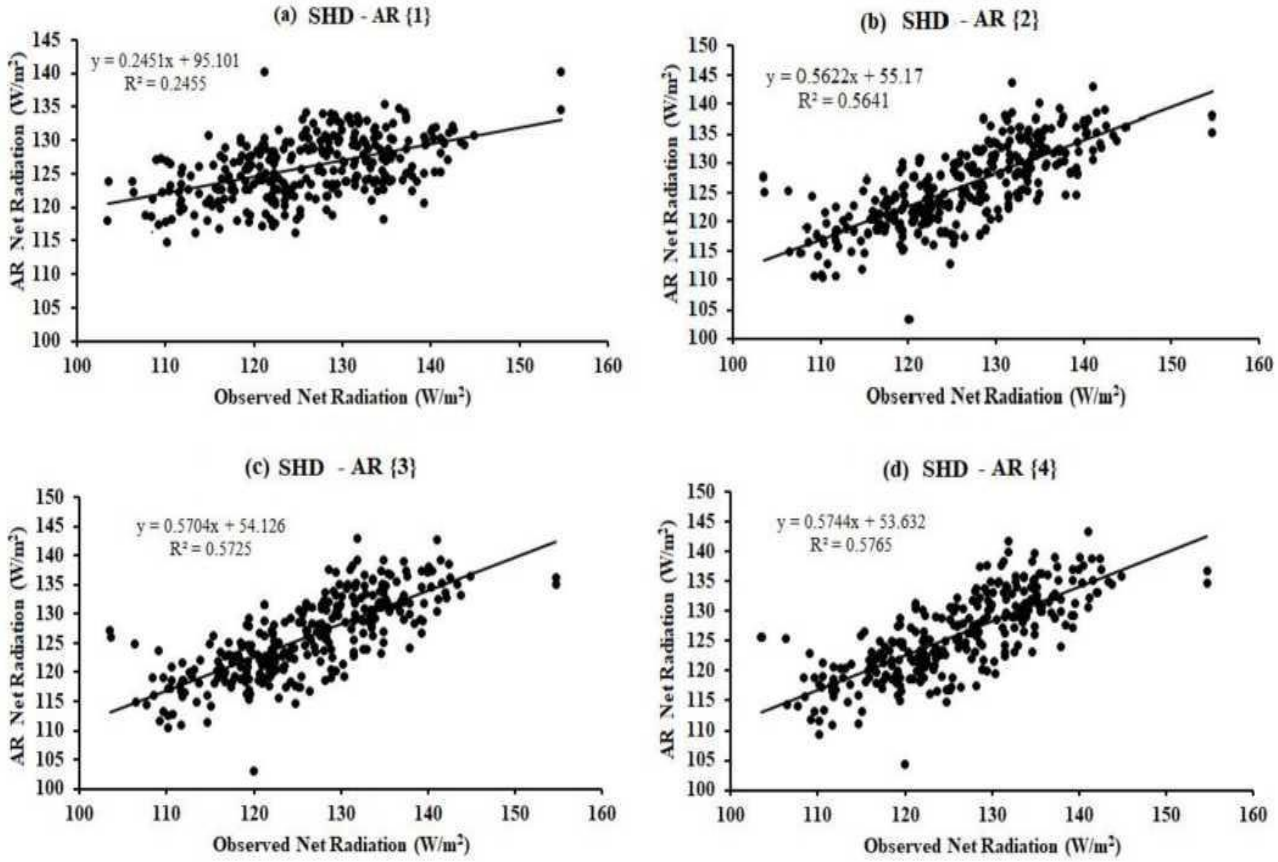

Fig. 3 Scatter plots of the observed net radiation and AR net radiation over SHD zone in Nigeria

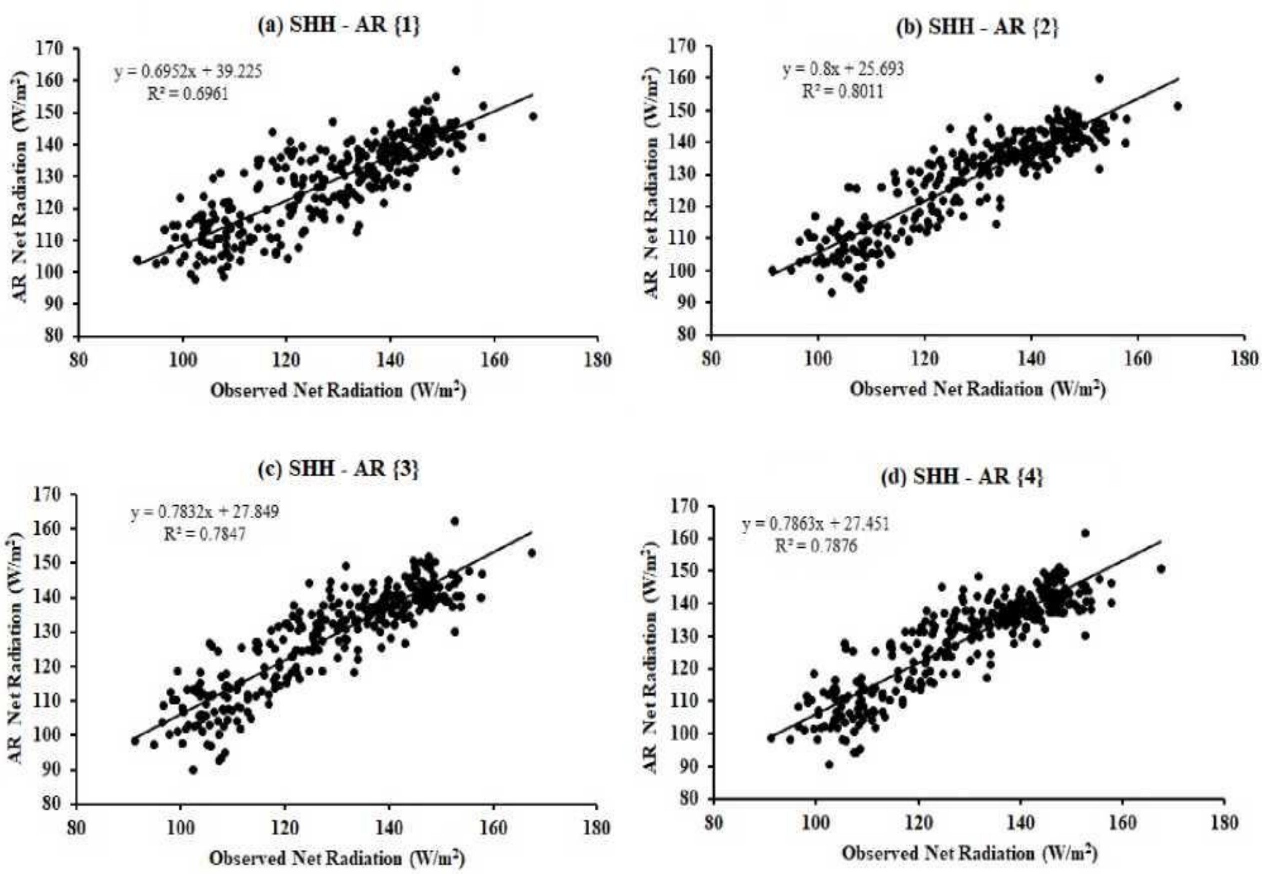

Fig. 4 Scatter plots of the observed net radiation and AR net radiation over SHH zone in Nigeria

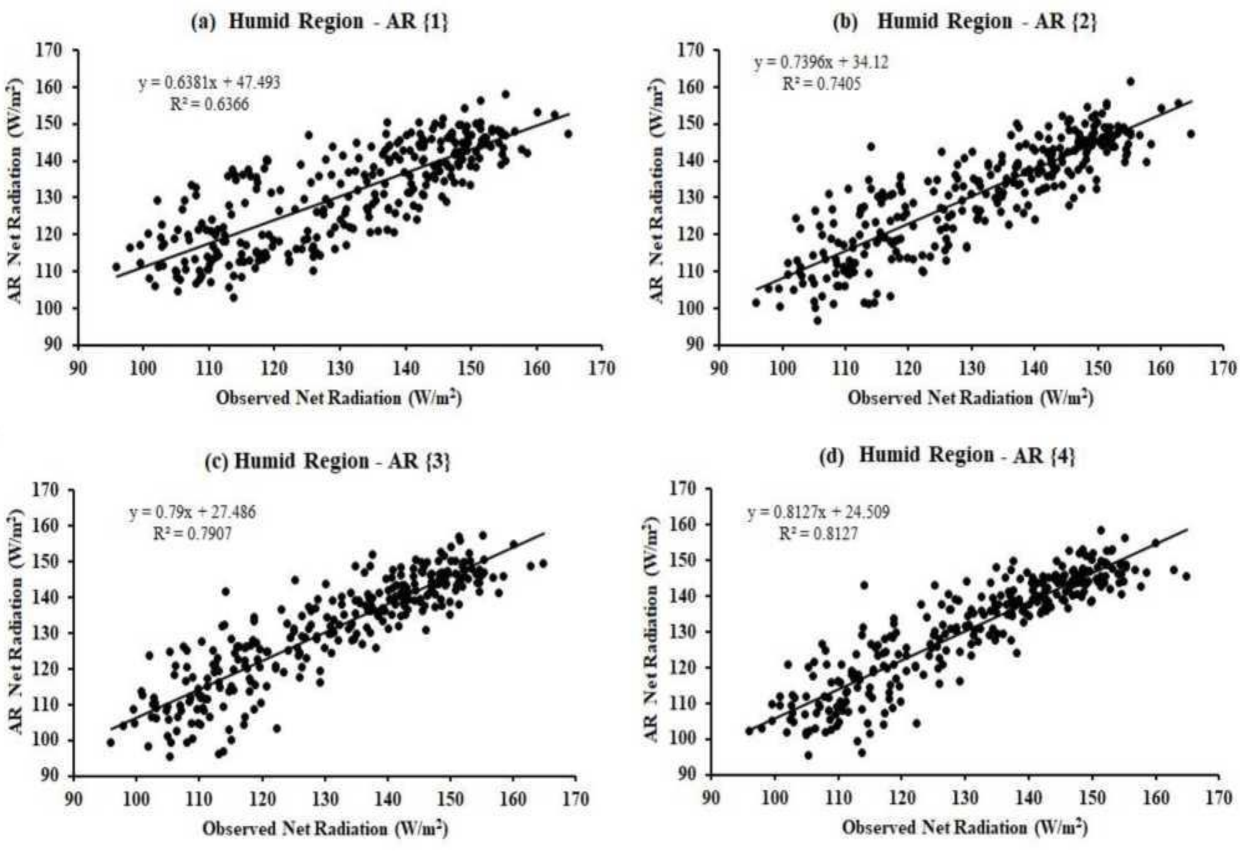

Fig. 5 Scatter plots of the observed net radiation and AR net radiation over HUM zone in Nigeria

Figs. 6 – 9 show the variograms of observed net radiation with AR {p} estimated net radiation over four climatic regions in Nigeria.

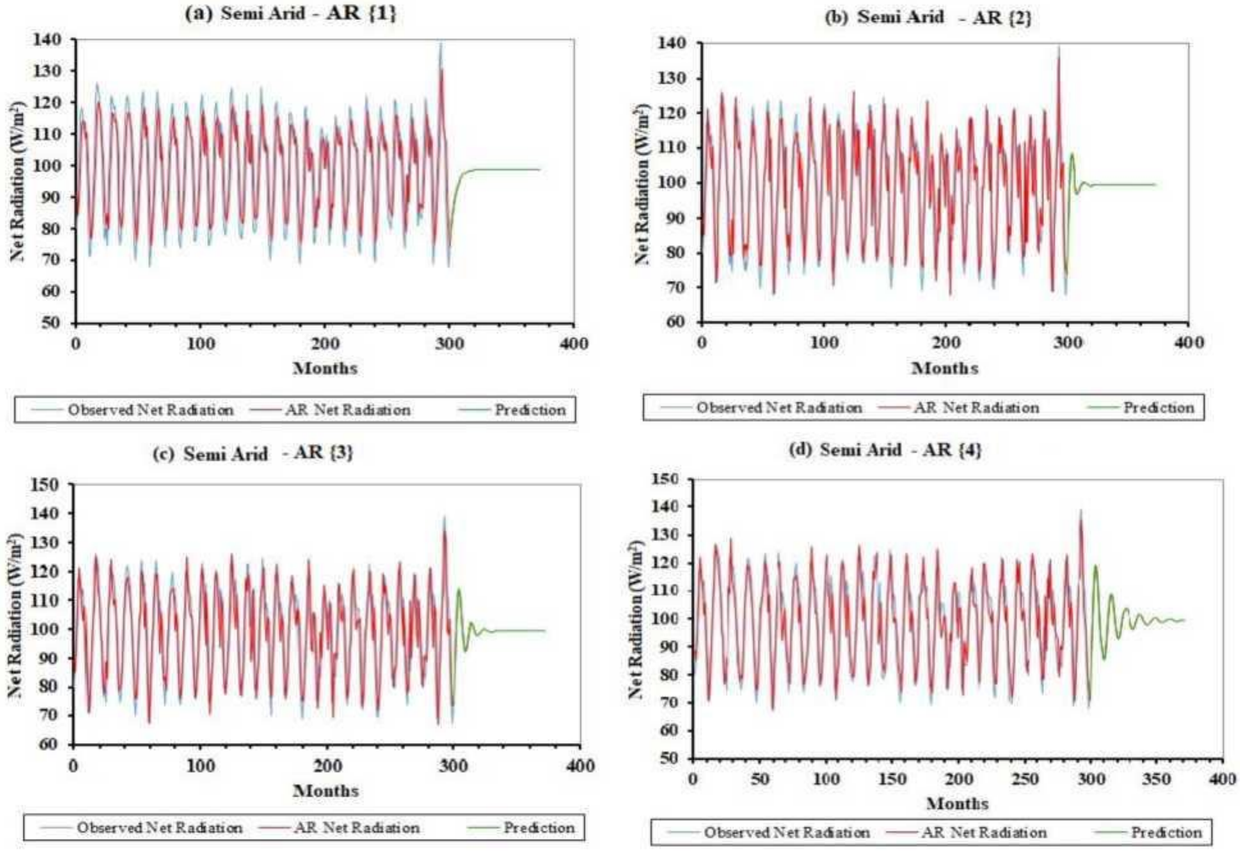

Fig. 6 Variation of the observed net radiation with AR predicted net radiation over SAR region in Nigeria

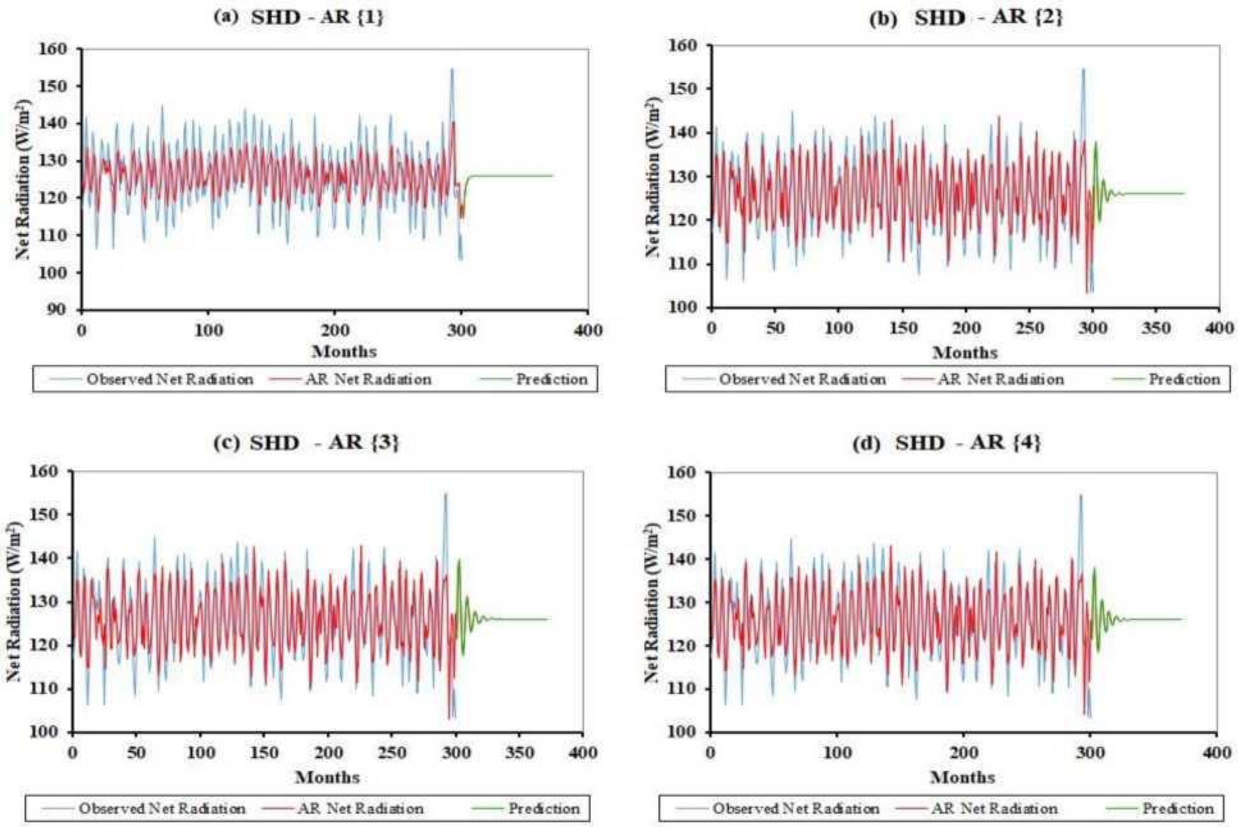

Fig. 7 Variation of the observed net radiation with AR predicted net radiation over SHD region in Nigeria

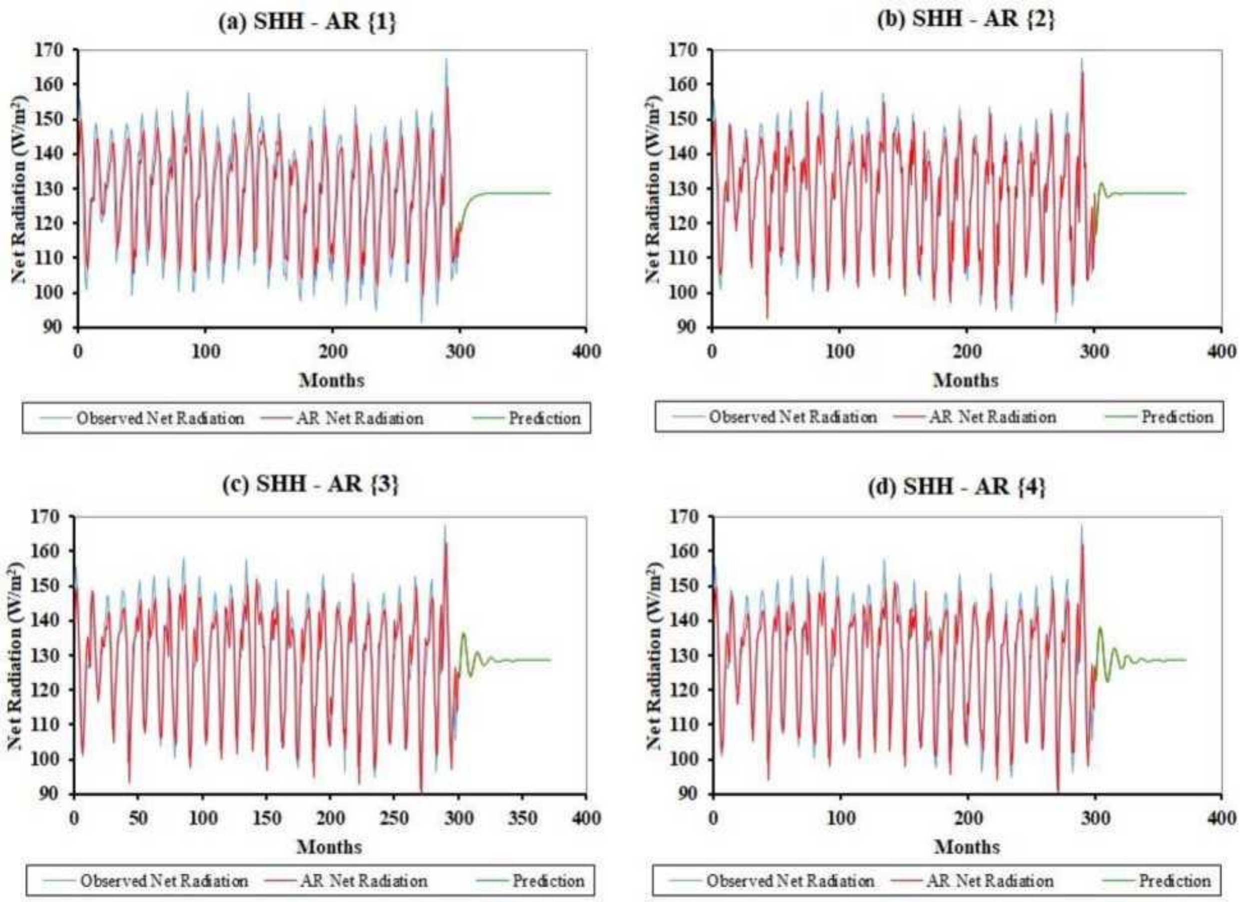

Fig. 8 Variation of the observed net radiation with AR predicted net radiation over SHH region in Nigeria

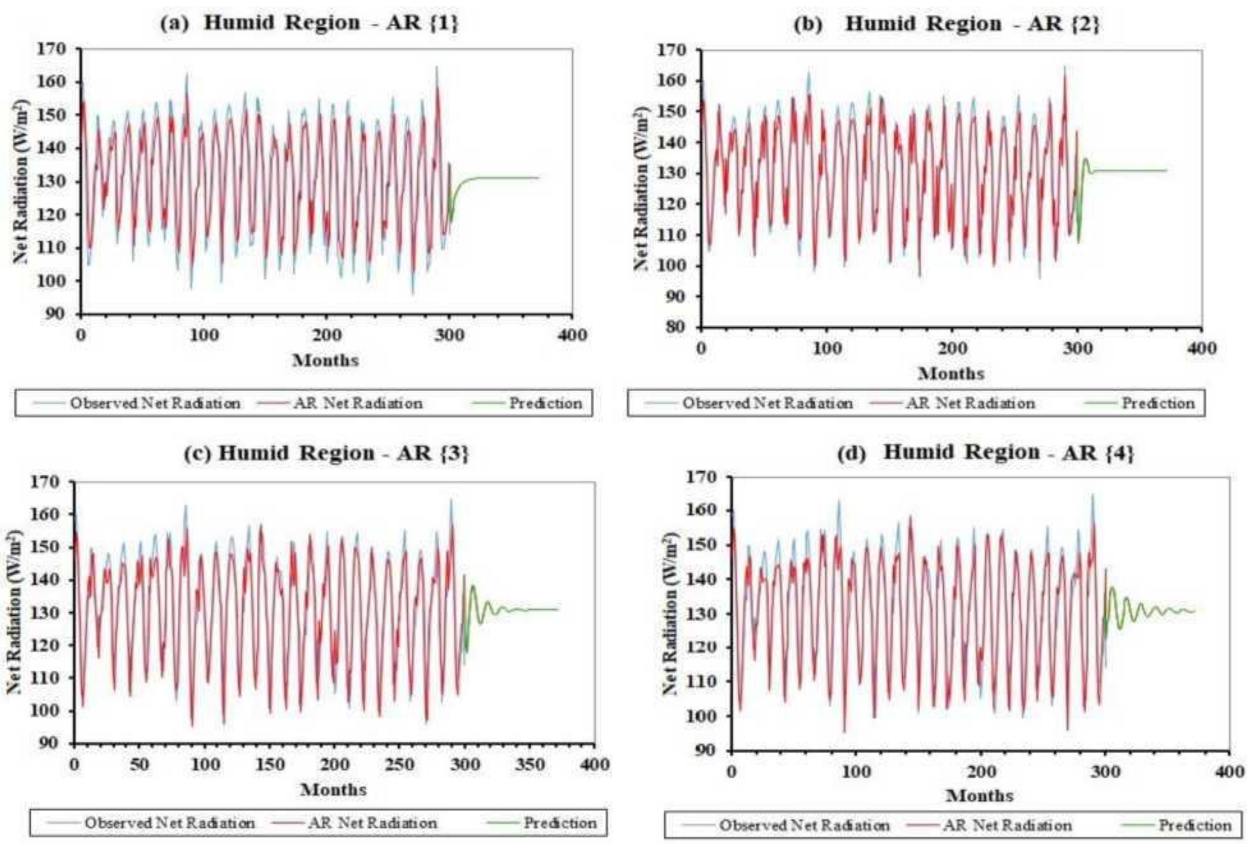

Fig. 9 Variation of the observed net radiation with AR predicted net radiation over HUM region in Nigeria

In all the figures (6 – 9), variations between observed and AR{p} net radiation showed similar patterns and they were also closely monitored to each other. The future prediction made by the AR {p} model for 72 next months (2008 – 2013) showed that they would be decreased in the magnitude of net radiation in agreement with recommendation in [28].

4. Conclusion

Autoregressive models with four different orders were developed to deduce the net radiation over four climatic regions in Nigeria using in situ data from NIMET, Lagos. The parameter estimates of each of the models were obtained using XLSTAT software (2016 version) to develop the models for the four regions and some of their selected stations over Nigeria. The developed models were used to predict the net radiation for the period of 72 months (2008 – 2013). The predicted values of net radiation were compared with the observed values using the scattergrams and variograms with correlation equations. Analyses showed that the autoregressive models of the fourth order (AR{4}) gave maximum values of the coefficient of determination of 0.8127 in the HUM, 0.7876 in the SHH, 0.5765 in the SHD and 0.7973 in the SAR regions. The performance of other metrics such as the mean squared errors, root mean square errors, mean absolute percentage error and the Akaike's information criterion gave good values for all models especially for AR{4}. It can be established that the AR model of higher orders will give an accurate estimation of net radiation in any location in Nigeria. That is, the autoregressive (AR {p}) models will be a good model for the estimation of net radiation to a high degree of accuracy at higher orders.

Conflict of Interests

The author declares that there is no conflict of interests regarding the publication of this paper.

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