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**SHORT COMMUNICATION**

# DEVELOPMENT OF RAIN RATE PREDICTION MODEL FOR NIGERIA

*Semire Folasade Abiola[1,2] and Rosmiwati Mohd-Mokhtar[1]
[1]School of Electrical and Electronic Engineering, Universiti Sains Malaysia
Engineering Campus, 14300 Nibong Tebal, Pulau Pinang, Malaysia
[2]Department of Electronic and Electrical Engineering
Ladoke Akintola University of Technology, P.M.B. 4000, Ogbomoso, Nigeria

## ABSTRACT

A model for predicting rain rate for Nigeria climate is presented. In the formulation of the proposed model, rainfall intensities data were collected from Nigeria meteorological center and LAUTECH. The comparison results show that, in all the models considered, rain rate is underestimated for low availability range of 1.0%. The proposed model therefore, shows a significant improvement over the entire existing models considered in terms of prediction error and RMS values.

**Keywords**: Rain rate, rain attenuation, prediction error.

## INTRODUCTION

Accurate measurement of rainfall intensities are very important for several applications such as microwave link budget estimation, rain fade mitigation techniques, flood warning prediction, urban drainage planning and fresh water management etc. ( Dutton, and Dougherty,1997). Attenuation due to rainfall is one of the most fundamental limitations on the performance of satellite links above 10GHz. Rain attenuation is caused by scattering and absorption by water droplets, causing large variations in the received signal power, with no or little predictability (Moupfouma, 1994). Since the tropical climate is generally characterized by high intensity rainfall, knowledge of the rain rate and its corresponding attenuation at frequencies above 10GHz is very crucial and extremely required for the design of a reliable communication system at a particular location (Freeman, 1997).

Rain rate statistics is specified on a percentage of time basis, that is the percentage of time in a year or a month that the rain rate equals or exceeds a specific value and is equally used in the rain attenuation prediction model. The ITU-R rain attenuation prediction model for example is based on 0.01% of a year rain rate parameters (ITU-R P. 618-7, 2008) i.e, a good communication system must provide at least 99.99% reliability. This means the system can only be unavailable for not more than 52.6 minutes per year.

Several models have been proposed for prediction of rain rate at low and high attitude. Among such Crane model, ITU-R model, Hosaya, Chebil and host of others (Chebil, 1997, ITU-R P.837-5, 2007). Majority of these mentioned models are developed in the temperate region of the world (Crane, 1985; ITU-R, 2007). Research, however have shown that most of these models either underestimate or over estimate rain rate prediction of a certain area. Therefore, Ajayi and Olsen (1985) and others suggested that rain events are rather localized and models need to be formulated based on local data (Ajayi and Olsen, 1985; Assis, 1990; Bandera *et al*., 1999).

## DATA ANALYSIS AND RESULTS

Rainfall data for the period of 10 years (1990-2009) were collected at Nigeria Meteorological station, Osodi, Lagos. The data cut across all the four regions of the country which provides a faithful representation of Nigerian climate. The South-South region of the country is the Coastal region with an annual average rainfall of about 3000mm, the South-West of the country falls under the rain forest zone with average annual accumulation of 1500-2000mm. The middle belt region has about 1200mm, while the Northern area is the Savannah /Arid area with an average accumulation less than 1000mm. The average annual rainfall and its corresponding rain rate for the period of 10 years are shown in table 1.

Using the curve fitting toolbox available in MATLAB, the best-fit equation for the data in Table 1 is obtained. This window is invoked using "cftool" command in the MATLAB command window. From the fitting of the curve-fit line, the best –fit equation is given as shown in figure 1.

This gives the rain rate model in term of annual rain volume at 0.01% of time. The model equation as

*Corresponding author email: folasemire@yahoo.com

Table 1. Average annual rainfall accumulation and rate at different percentage of time.

| Towns in Nigeria | Average annual rainfall accumulation (mm) | 0.001 Rain rate (mm/hr) | 0.01 Rain rate (mm/hr) | 0.1 Rain rate (mm/hr) | 1.0 Rain rate (mm/hr) |
|---|---|---|---|---|---|
| Nguru | 522 | 168 | 69.3 | 26.5 | 10.5 |
| Borno | 560 | 173 | 72.5 | 28 | 11.5 |
| Katsina | 580 | 178 | 74.9 | 29.4 | 12.1 |
| Gusau | 650 | 185 | 78.1 | 30.6 | 12.6 |
| Sokoto | 667 | 187 | 78.8 | 33.5 | 13.6 |
| Dikwa | 687 | 192 | 81.7 | 32 | 13.5 |
| Maiduguri | 724 | 198 | 84 | 34 | 13.6 |
| Gombe | 795 | 206 | 86.1 | 35.5 | 13.9 |
| Bauchi | 940 | 212 | 90.8 | 37.7 | 14.8 |
| Adamawa | 1012 | 218 | 94.2 | 39 | 15 |
| Kano | 1124 | 223 | 98.8 | 41 | 15.4 |
| Kaduna | 1183 | 227 | 101.5 | 42.9 | 15.7 |
| Minna | 1197 | 231 | 101.9 | 43.4 | 15.9 |
| Ile-ife | 1215 | 235 | 106 | 43.9 | 16.2 |
| Ilorin | 1233 | 238 | 103.4 | 44 | 16.5 |
| Abuja | 1267 | 244 | 104.5 | 44.3 | 16.6 |
| Jos | 1317 | 247 | 108.4 | 44.7 | 16.7 |
| Makurdi | 1337 | 252 | 110 | 45.5 | 16.9 |
| Ogbomoso | 1362 | 256 | 114.1 | 45.8 | 17.1 |
| Lokoja | 1376 | 258 | 115.7 | 47 | 17.2 |
| Saki | 1401 | 261 | 118.2 | 46.3 | 17 |
| Osogbo | 1446 | 263 | 120.1 | 50.6 | 17.6 |
| Abeokuta | 1483 | 267 | 121.9 | 51.6 | 17.7 |
| Akure | 1572 | 271 | 122.6 | 52.3 | 17.8 |
| Lagos | 1854 | 275 | 124.2 | 59.4 | 18.1 |
| Abia | 2053 | 277 | 127.3 | 62 | 18.3 |
| Enugu | 2066 | 279 | 129.8 | 62.9 | 18.6 |
| Benin | 2128 | 281 | 131 | 65.2 | 18.9 |
| Calabar | 2616 | 287 | 139.3 | 72.3 | 19.3 |
| Port Harcourt | 2803 | 289 | 140.8 | 75.5 | 20.1 |
| Warri | 3019 | 291 | 145.2 | 77.8 | 20.2 |

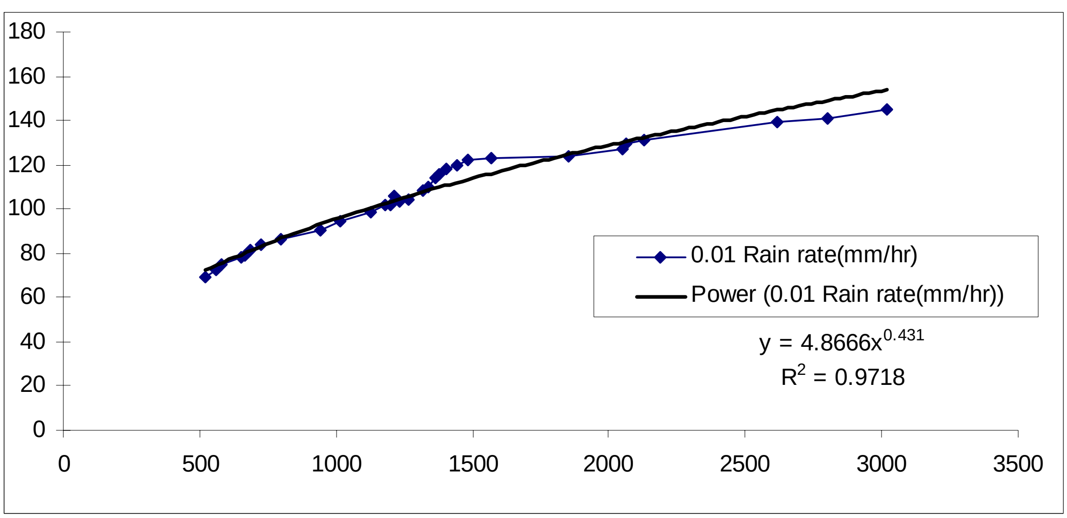


Fig. 1. Measured Rain rate at 0.01 percentage of time against Annual accumulated rainfall.

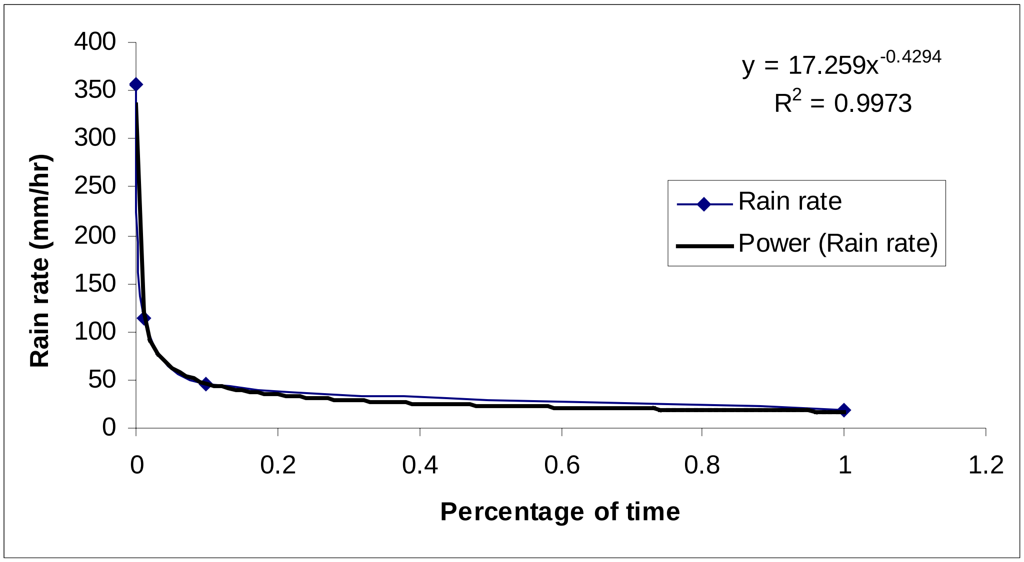


Fig. 2: The graph of rain rate against percentage of time.

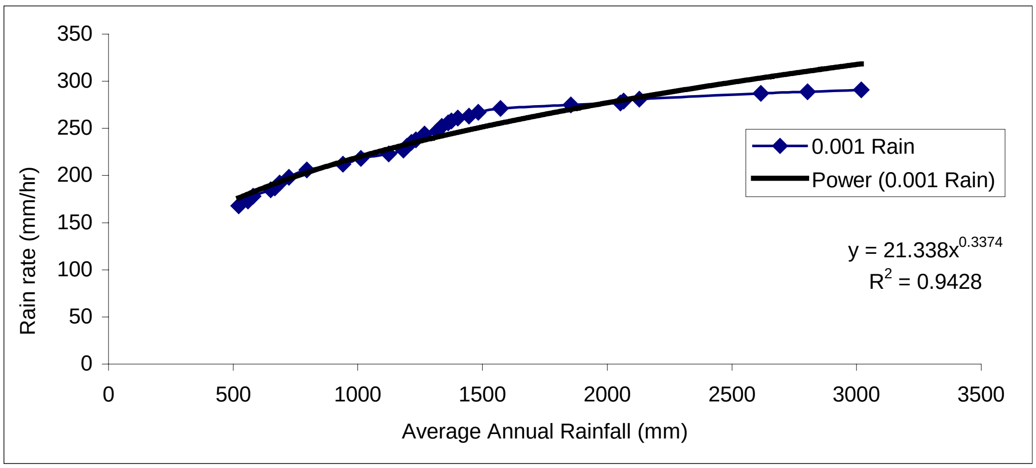


Fig. 3. Measured Rain rate at 0.001 percentage of time against Annual accumulated rainfall.

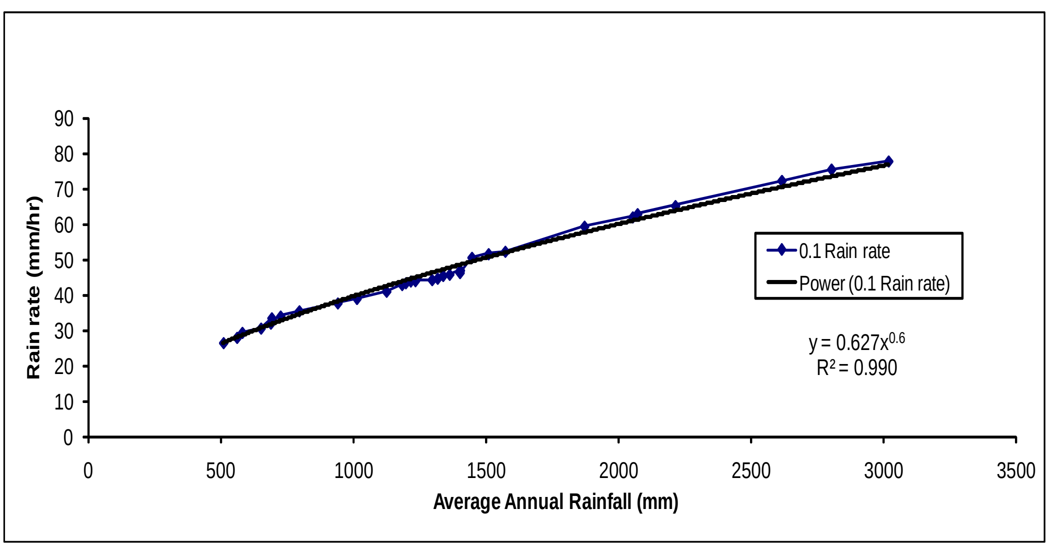


Fig. 4. Measured Rain rate at 0.1 percentage of time against Annual accumulated rainfall.

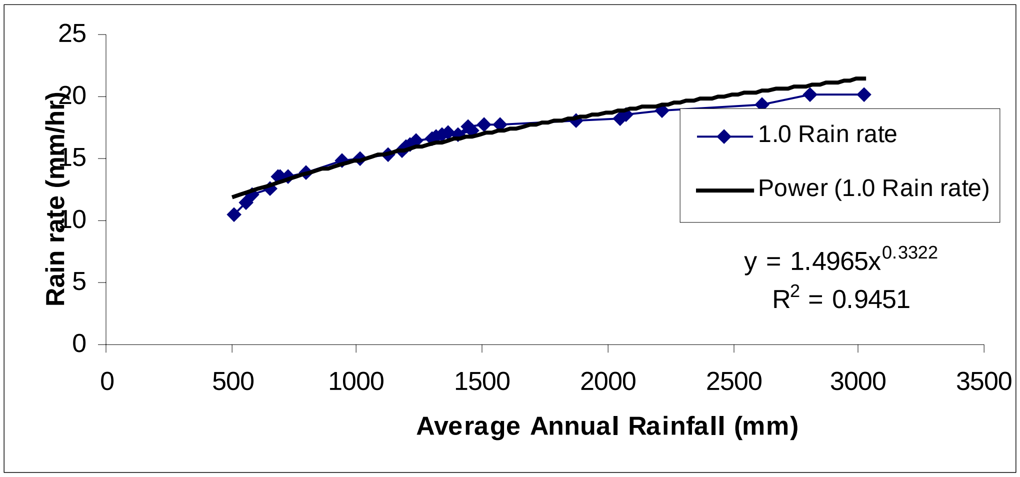


Fig. 5. Measured Rain rate at 1.0 percentage of time against Annual accumulated rainfall.

Table 2. Percentage error and RMS values of test variable for 0.001 percentage of time.

| Town | Measured 0.001 | proposed 0.001 rain | ITU-R rel | Indian reg rel | Crane rel | Hosaya rel | propd rel |
|---|---|---|---|---|---|---|---|
| Nguru | 168 | 176.19 | 7.14 | -16.07 | -60.71 | -47.62 | 4.87 |
| Borno | 173 | 184.14 | 4.05 | -15.03 | -61.85 | -46.24 | 6.44 |
| Katsina | 178 | 184.75 | 1.12 | -16.85 | -62.92 | -47.75 | 3.79 |
| Gusau | 185 | 189.80 | -2.70 | -17.84 | -64.32 | -47.57 | 2.59 |
| Sokoto | 187 | 191.45 | -3.74 | -18.18 | -64.71 | -47.59 | 2.38 |
| Dikwa | 192 | 193.39 | -6.25 | -19.27 | -65.63 | -48.44 | 0.72 |
| Maiduguri | 198 | 196.84 | -9.09 | -20.71 | -66.67 | -48.99 | -0.58 |
| Gombe | 206 | 198.87 | -12.62 | -22.82 | -67.96 | -50.00 | -3.46 |
| Bauchi | 212 | 207.70 | -15.09 | -21.70 | -68.87 | -48.58 | -2.03 |
| Adamawa | 218 | 220.37 | -17.43 | -19.27 | -69.72 | -46.33 | 1.09 |
| Kano | 223 | 228.29 | -19.28 | -18.39 | -70.40 | -44.84 | 2.37 |
| Kaduna | 227 | 232.25 | -20.70 | -18.50 | -70.93 | -44.49 | 2.31 |
| Minna | 231 | 233.17 | -22.08 | -19.48 | -71.43 | -45.45 | 0.94 |
| Ile-ife | 235 | 234.38 | -23.40 | -20.43 | -45.11 | -45.96 | -0.26 |
| Ilorin | 238 | 235.51 | -24.37 | -21.01 | -45.80 | -46.22 | -1.04 |
| Abuja | 244 | 237.67 | -26.23 | -22.13 | -72.95 | -47.13 | -2.59 |
| Jos | 247 | 240.81 | -27.13 | -22.27 | -73.28 | -46.56 | -2.51 |
| Makurdi | 252 | 242.08 | -28.57 | -23.41 | -48.81 | -47.22 | -3.94 |
| Ogbomoso | 256 | 243.57 | -29.69 | -24.22 | -49.61 | -47.66 | -4.86 |
| Lokoja | 258 | 244.44 | -30.23 | -24.42 | -50.00 | -48.06 | -5.26 |
| Saki | 261 | 245.90 | -31.03 | -24.90 | -50.57 | -48.28 | -5.78 |
| Osogbo | 263 | 248.55 | -31.56 | -24.71 | -50.95 | -47.91 | -5.49 |
| Abeokuta | 267 | 250.67 | -6.37 | -25.09 | -5.99 | -47.94 | -6.12 |
| Akure | 271 | 255.65 | -7.75 | -24.72 | -7.38 | -47.60 | -5.66 |
| Lagos | 275 | 270.29 | -9.09 | -21.82 | -8.73 | -44.36 | -1.71 |
| Abia | 277 | 279.74 | -9.75 | -19.49 | -9.39 | -42.24 | 0.99 |
| Enugu | 279 | 280.34 | -10.39 | -20.07 | -10.04 | -42.29 | 0.48 |
| Benin | 281 | 283.17 | -11.03 | -19.57 | -10.68 | -41.99 | 0.77 |
| Calabar | 287 | 303.56 | -12.89 | -15.68 | -12.54 | -37.98 | 5.77 |
| PortHarcourt | 289 | 310.73 | -13.49 | -14.53 | -13.15 | -36.33 | 7.52 |
| Warri | 291 | 318.60 | -14.09 | -12.71 | -13.75 | -34.71 | 9.48 |
| AVERAGE | | | -14.96 | -20.17 | -46.61 | -45.62 | 0.04 |
| STANDEV | | | 10.71 | 3.34 | 25.05 | 3.67 | 4.17 |
| RMS | | | 18.40 | 20.45 | 52.91 | 45.77 | 4.17 |

Table 3. Percentage error and RMS values of test variable for 0.01 percentage of time.

| Town | Measured 0.01 rain | proposed 0.01 | ITU-R rel 0.01 | Crane rel 0.01 | Chebil rel 0.01 | Hosaya rel 0.01 | indain reg rel 0.01 | Prosd 0.01 rel |
|---|---|---|---|---|---|---|---|---|
| Nguru | 69.3 | 72.18 | 37.09 | -66.81 | 14.00 | -6.20 | 22.66 | 4.15 |
| Borno | 72.5 | 76.36 | 31.03 | -68.28 | 13.10 | -6.21 | 21.38 | 5.33 |
| Katsina | 74.9 | 76.69 | 26.84 | -69.29 | 9.48 | -7.88 | 17.49 | 2.38 |
| Gusau | 78.1 | 79.37 | 21.64 | -70.55 | 7.55 | -9.09 | 15.24 | 1.63 |
| Sokoto | 78.8 | 80.26 | 20.56 | -70.81 | 7.87 | -9.90 | 15.48 | 1.85 |
| Dikwa | 81.7 | 81.30 | 16.28 | -71.85 | 5.26 | -11.87 | 12.61 | -0.49 |
| Maiduguri | 84 | 83.16 | 13.10 | -72.62 | 3.57 | -11.90 | 10.71 | -1.01 |
| Gombe | 86.1 | 84.25 | 10.34 | -73.29 | 2.21 | -12.89 | 9.18 | -2.15 |
| Bauchi | 90.8 | 89.06 | 4.63 | -74.67 | 0.22 | -13.00 | 6.83 | -1.92 |
| Adamawa | 94.2 | 96.06 | 0.85 | -75.58 | 1.91 | -10.83 | 7.22 | 1.97 |
| Kano | 98.8 | 100.49 | -3.85 | -76.72 | 0.20 | -10.93 | 5.26 | 1.71 |
| Kaduna | 101.5 | 102.72 | -6.40 | -77.34 | -0.49 | -12.32 | 3.45 | 1.20 |
| Minna | 101.9 | 103.24 | -6.77 | -77.43 | -0.88 | -11.68 | 4.02 | 1.31 |
| Ile-ife | 106 | 103.93 | 8.49 | -36.79 | -3.77 | -15.09 | 0.00 | -1.96 |
| Ilorin | 103.4 | 104.57 | 11.22 | -35.20 | -1.35 | -11.99 | 2.51 | 1.13 |
| Abuja | 104.5 | 105.79 | -9.09 | -77.99 | -1.44 | -11.96 | 2.39 | 1.24 |
| Jos | 108.4 | 107.58 | -12.36 | -78.78 | -4.06 | -14.21 | -0.37 | -0.76 |
| Makurdi | 110 | 108.30 | 4.55 | -39.09 | -5.45 | -14.55 | -0.91 | -1.54 |
| Ogbomoso | 114.1 | 109.16 | 0.79 | -41.28 | -7.98 | -17.62 | -4.47 | -4.33 |
| Lokoja | 115.7 | 109.65 | -0.61 | -42.09 | -9.25 | -17.89 | -5.79 | -5.23 |
| Saki | 118.2 | 110.49 | -2.71 | -43.32 | -10.32 | -19.63 | -6.94 | -6.52 |
| Osogbo | 120.1 | 112.02 | -4.25 | -44.21 | -10.91 | -19.23 | -7.58 | -6.73 |
| Abeokuta | 121.9 | 113.24 | 18.95 | 20.59 | -11.40 | -19.61 | -8.12 | -7.11 |
| Akure | 122.6 | 116.12 | 18.27 | 19.90 | -10.28 | -18.43 | -7.83 | -5.28 |
| Lagos | 124.2 | 124.68 | 16.75 | 18.36 | -7.41 | -13.85 | -4.99 | 0.39 |
| Abia | 127.3 | 130.27 | 13.90 | 15.48 | -6.52 | -12.80 | -4.95 | 2.34 |
| Enugu | 129.8 | 130.63 | 11.71 | 13.25 | -8.32 | -14.48 | -6.78 | 0.64 |
| Benin | 131 | 132.32 | 10.69 | 12.21 | -8.40 | -14.50 | -6.87 | 1.01 |
| Calabar | 139.3 | 144.61 | 4.09 | 5.53 | -8.11 | -12.42 | -7.39 | 3.81 |
| PortHarcourt | 140.8 | 148.99 | 2.98 | 4.40 | -7.67 | -11.22 | -6.96 | 5.82 |
| Warri | 145.2 | 153.82 | -0.14 | 1.24 | -8.40 | -11.16 | -7.71 | 5.94 |
| AVERAGE | | | 8.34 | -41.07 | -2.16 | -13.08 | 2.22 | -0.04 |
| STDEV | | | 12.09 | 37.46 | 7.28 | 3.56 | 9.51 | 3.60 |
| RSM | | | 14.69 | 55.58 | 7.59 | 13.55 | 9.76 | 3.60 |

Table 4. Percentage error and RMS values of test variable for 0.1 percentage of time.

| Town | Measured 0.1 Rain rate | Proposed 0.1 rain | ITU-R 0.1 rel | Crane 0.1 rel | indain reg 0.1 rel | Hosaya 0.1 rel | prosd 0.1 rel |
|---|---|---|---|---|---|---|---|
| Nguru | 26.50 | 26.82 | 32.08 | -79.25 | 9.43 | -81.13 | 1.20 |
| Borno | 28.00 | 29.01 | 25.00 | -80.36 | 10.71 | -78.57 | 3.62 |
| Katsina | 29.40 | 29.18 | 19.05 | -81.29 | 5.44 | -79.59 | -0.74 |
| Gusau | 30.60 | 30.62 | 14.38 | -82.03 | 4.58 | -80.39 | 0.06 |
| Sokoto | 33.50 | 31.10 | 4.48 | -83.58 | -4.48 | -82.09 | -7.18 |
| Dikwa | 32.00 | 31.66 | 9.38 | -82.81 | 3.13 | -81.25 | -1.07 |
| Maiduguri | 34.00 | 32.67 | 2.94 | -83.82 | 0.00 | -79.41 | -3.90 |
| Gombe | 35.50 | 33.28 | -1.41 | -84.51 | -4.23 | -80.28 | -6.27 |
| Bauchi | 37.70 | 35.95 | -7.16 | -85.41 | -4.51 | -81.43 | -4.64 |

*Continued…*

Table 4 continued…

| Town | Measured 0.1 Rain rate | Proposed 0.1 rain | ITU-R 0.1 rel | Crane 0.1 rel | Indain reg 0.1 rel | Hosaya 0.1 rel | Prosd 0.1 rel |
|---|---|---|---|---|---|---|---|
| Adamawa | 39.00 | 39.95 | -10.26 | -85.90 | 0.00 | -79.49 | 2.44 |
| Kano | 41.00 | 42.55 | -14.63 | -86.59 | 0.00 | -78.05 | 3.77 |
| Kaduna | 42.90 | 43.87 | -18.41 | -87.18 | -2.10 | -79.02 | 2.25 |
| Minna | 43.40 | 44.18 | -19.35 | -87.33 | -3.23 | -79.26 | 1.79 |
| Ile-ife | 43.90 | 44.59 | 64.01 | -49.89 | -4.33 | -79.50 | 1.57 |
| Ilorin | 44.00 | 44.97 | 63.64 | -50.00 | -2.27 | -79.55 | 2.21 |
| Abuja | 44.30 | 45.71 | -20.99 | -87.58 | -2.93 | -79.68 | 3.18 |
| Jos | 44.70 | 46.79 | -21.70 | -87.70 | -1.57 | -77.63 | 4.68 |
| Makurdi | 45.50 | 47.23 | 58.24 | -51.65 | -3.30 | -78.02 | 3.80 |
| Ogbomoso | 45.80 | 47.75 | 57.21 | -51.97 | -3.93 | -78.17 | 4.26 |
| Lokoja | 47.00 | 48.05 | 53.19 | -53.19 | -4.26 | -78.72 | 2.24 |
| Saki | 48.70 | 48.57 | 47.84 | -54.83 | -7.60 | -79.47 | -0.28 |
| Osogbo | 50.60 | 49.50 | 42.29 | -56.52 | -9.09 | -80.24 | -2.17 |
| Abeokuta | 51.60 | 50.26 | 25.97 | -1.16 | -10.85 | -80.62 | -2.60 |
| Akure | 52.30 | 52.05 | 24.28 | -2.49 | -10.13 | -78.97 | -0.48 |
| Lagos | 59.40 | 57.48 | 9.43 | -14.14 | -14.14 | -79.80 | -3.24 |
| Abia | 62.00 | 61.10 | 4.84 | -17.74 | -14.52 | -79.03 | -1.45 |
| Enugu | 62.90 | 61.34 | 3.34 | -18.92 | -15.74 | -79.33 | -2.48 |
| Benin | 65.20 | 62.44 | -0.31 | -21.78 | -17.18 | -80.06 | -4.23 |
| Calabar | 72.30 | 70.68 | -10.10 | -29.46 | -18.40 | -79.25 | -2.24 |
| PortHarcourt | 75.50 | 73.68 | -13.91 | -32.45 | -19.21 | -80.13 | -2.41 |
| Warri | 77.80 | 77.03 | -16.45 | -34.45 | -19.02 | -79.43 | -0.98 |
| AVERAGE | | | 13.13 | -58.26 | -5.28 | -79.60 | -0.30 |
| STDEV | | | 27.49 | 29.15 | 8.03 | 1.03 | 3.20 |
| RSM | | | 463.96 | 2121.64 | 46.20 | 3168.55 | 5.15 |

Table 5. Percentage error and RMS values of test variable for 1.0 percentage of time.

| Town | Measured 1.0 rain rate | proposed 1.0 rain | ITU-R 1.0 rel | Crane 1.0 rel | indain reg 1.0 rel | Hosaya 1.0 rel | Prosd 1.0 rel |
|---|---|---|---|---|---|---|---|
| Nguru | 10.50 | 11.96 | -52.38 | -92.38 | -14.29 | -66.27 | 13.92 |
| Borno | 11.50 | 12.49 | -56.52 | -93.04 | -21.74 | -67.72 | 8.63 |
| Katsina | 12.10 | 12.53 | -58.68 | -93.39 | -25.62 | -69.21 | 3.58 |
| Gusau | 12.60 | 12.87 | -60.32 | -93.65 | -28.57 | -69.57 | 2.15 |
| Sokoto | 13.60 | 12.98 | -63.24 | -94.12 | -33.82 | -71.54 | -4.55 |
| Dikwa | 13.50 | 13.11 | -62.96 | -94.07 | -33.33 | -71.02 | -2.89 |
| Maiduguri | 13.60 | 13.34 | -63.24 | -94.12 | -33.82 | -70.68 | -1.91 |
| Gombe | 13.90 | 13.48 | -64.03 | -94.24 | -35.25 | -71.00 | -3.05 |
| Bauchi | 14.80 | 14.06 | -66.22 | -94.59 | -32.43 | -71.47 | -4.97 |
| Adamawa | 15.00 | 14.91 | -66.67 | -94.67 | -33.33 | -70.01 | -0.61 |
| Kano | 15.40 | 15.44 | -67.53 | -94.81 | -35.06 | -69.66 | 0.24 |
| Kaduna | 15.70 | 15.70 | -68.15 | -94.90 | -36.31 | -69.69 | 0.00 |
| Minna | 15.90 | 15.76 | -68.55 | -94.97 | -37.11 | -69.94 | -0.87 |
| Ile-ife | 16.20 | 15.84 | 48.15 | -77.16 | -38.27 | -70.33 | -2.21 |
| Ilorin | 16.50 | 15.92 | 45.45 | -77.58 | -39.39 | -70.72 | -3.53 |
| Abuja | 16.60 | 16.06 | -69.88 | -95.18 | -39.76 | -70.61 | -3.25 |
| Jos | 16.70 | 16.27 | -70.06 | -95.21 | -40.12 | -70.38 | -2.58 |
| Makurdi | 16.90 | 16.35 | 42.01 | -78.11 | -40.83 | -70.56 | -3.23 |

*Continued…*

Table 5 continued…

| Town | Measured 1.0 rain rate | proposed 1.0 rain | ITU-R 1.0 rel | Crane 1.0 rel | indain reg 1.0 rel | Hosaya 1.0 rel | Prosd 1.0 rel |
|---|---|---|---|---|---|---|---|
| Nguru | 10.50 | 11.96 | -52.38 | -92.38 | -14.29 | -66.27 | 13.92 |
| Borno | 11.50 | 12.49 | -56.52 | -93.04 | -21.74 | -67.72 | 8.63 |
| Katsina | 12.10 | 12.53 | -58.68 | -93.39 | -25.62 | -69.21 | 3.58 |
| Gusau | 12.60 | 12.87 | -60.32 | -93.65 | -28.57 | -69.57 | 2.15 |
| Sokoto | 13.60 | 12.98 | -63.24 | -94.12 | -33.82 | -71.54 | -4.55 |
| Dikwa | 13.50 | 13.11 | -62.96 | -94.07 | -33.33 | -71.02 | -2.89 |
| Maiduguri | 13.60 | 13.34 | -63.24 | -94.12 | -33.82 | -70.68 | -1.91 |
| Gombe | 13.90 | 13.48 | -64.03 | -94.24 | -35.25 | -71.00 | -3.05 |
| Bauchi | 14.80 | 14.06 | -66.22 | -94.59 | -32.43 | -71.47 | -4.97 |
| Adamawa | 15.00 | 14.91 | -66.67 | -94.67 | -33.33 | -70.01 | -0.61 |
| Kano | 15.40 | 15.44 | -67.53 | -94.81 | -35.06 | -69.66 | 0.24 |
| Kaduna | 15.70 | 15.70 | -68.15 | -94.90 | -36.31 | -69.69 | 0.00 |
| Minna | 15.90 | 15.76 | -68.55 | -94.97 | -37.11 | -69.94 | -0.87 |
| Ile-ife | 16.20 | 15.84 | 48.15 | -77.16 | -38.27 | -70.33 | -2.21 |
| Ilorin | 16.50 | 15.92 | 45.45 | -77.58 | -39.39 | -70.72 | -3.53 |
| Abuja | 16.60 | 16.06 | -69.88 | -95.18 | -39.76 | -70.61 | -3.25 |
| Jos | 16.70 | 16.27 | -70.06 | -95.21 | -40.12 | -70.38 | -2.58 |
| Makurdi | 16.90 | 16.35 | 42.01 | -78.11 | -40.83 | -70.56 | -3.23 |
| Ogbomoso | 17.10 | 16.45 | 40.35 | -78.36 | -41.52 | -70.72 | -3.78 |
| Lokoja | 17.20 | 16.51 | 39.53 | -78.49 | -41.86 | -70.77 | -4.01 |
| Saki | 17.00 | 16.61 | 41.18 | -78.24 | -41.18 | -70.24 | -2.30 |
| Osogbo | 17.60 | 16.78 | 36.36 | -78.98 | -37.50 | -70.92 | -4.63 |
| Abeokuta | 17.70 | 16.93 | -32.20 | -63.84 | -37.85 | -70.82 | -4.38 |
| Akure | 17.80 | 17.26 | -32.58 | -64.04 | -38.20 | -70.37 | -3.05 |
| Lagos | 18.10 | 18.23 | -33.70 | -64.64 | -39.23 | -69.07 | 0.71 |
| Abia | 18.30 | 18.86 | -34.43 | -65.03 | -39.89 | -68.27 | 3.04 |
| Enugu | 18.60 | 18.90 | -35.48 | -65.59 | -40.86 | -68.71 | 1.59 |
| Benin | 18.90 | 19.08 | -36.51 | -66.14 | -41.80 | -68.87 | 0.97 |
| Calabar | 19.30 | 20.44 | -37.82 | -66.84 | -37.82 | -67.16 | 5.89 |
| Port Harcourt | 20.10 | 20.91 | -40.30 | -68.16 | -40.30 | -67.67 | 4.04 |
| Warri | 20.20 | 21.43 | -40.59 | -68.32 | -40.59 | -66.96 | 6.10 |
| AVERAGE | | | -31.90 | -82.35 | -36.05 | -69.71 | -0.16 |
| STDEV | | | 42.48 | 12.55 | 6.26 | 1.39 | 4.41 |
| %RSM | | | 53.12 | 83.30 | 36.59 | 69.72 | 4.42 |

Table 6. RMS values of test variable for all the models considered.

| Percentage of time | ITU-R model | Crane globa modell | Indian Reg. model | Hosaya model | Chebil model | Proposed |
|---|---|---|---|---|---|---|
| 0.001 | 18.4 | 52.91 | 20.44 | 45.77 | | 4.16 |
| 0.01 | 14.68 | 55.58 | 9.7 | 13.55 | 7.59 | 3.603 |
| 0.1 | 463.96 | 2121 | 46.2 | 3168.5 | | 5.152 |
| 1 | 53.12 | 83.3 | 36.59 | 69.72 | | 4.41 |

determined from the figure is given as $R_{0.01} = 4.866\ M^{0.431}$ and the resulting interpolating model is as shown in figure 2. The model for other percentage of time is $R_{0.001} = 21.338\ M^{0.3372}$, $R_{0.1} = 0.627M^{0.6}$ and $R_{1.0} = 1.496M^{0.332}$ respectively. The respective curves are as shown in figure 3-5

## COMPARISON OF PERFORMANCE OF EXISTING RAIN RATE MODEL WITH THE PROPOSED MODEL

The proposed model is used to compare some selected rain rate models viz: ITU-R, Crane global, Indian regression, Hozaya, and Chebil . The proposed model was tested using the test suggested by the ITU-R recommendation (ITU-R, 1997). The test variable for percentage error and RMS values are given by

$$R_{rel} = \frac{\left(R_{predictrd} - R_{measured}\right)\times 100}{R_{measured}}$$

where $R_{predicted}$ and $R_{measured}$ are predicted and measured rain rate values exceeded for a given percentage of time respectively. The mean error μ and standard deviation σ are used to calculate the Root Mean Square (RMS). The parameter is defined as follows

$$rms = \sqrt{\left[(\mu e)^2 + (\partial e)^2\right]}$$

According to evaluation procedures adopted by the ITU-R P 618-6, the preferred prediction method is the one producing the smallest RMS values. Tables 2-6 shows the results of comparison in terms of percentage error and RMS values between the proposed model and other existing models mentioned above for all the 32 states.

The comparison shows that virtually all the models considered underestimated the measured rain rate at low availability range of 1.0%. At 0.001% of time, Indian regression and ITU-R model overestimate rain rate for all the stations while Crane and Hosaya model underestimate in this region. Only ITU-R model overestimate at 0.01% of time, other models except Chebil model underestimate rain rate. Also at 0.1% of time, ITU-R and Indian regression model overestimate and other underestimate.

In table 6, Crane global model predicts the highest percentage of RMS value followed by the Hosaya , Indian regression , ITU-R and the proposed model for 0.001 and 0.01 percentage of time. In the 0.1 percentage of time, Hosaya model predicts the highest, followed by the Crane global model with ITU-R coming up in between the other two models and Indian regression. Therefore, evident from the Tables 3-6 presented above, it can be seen that the proposed model shows a significant improvement in terms of prediction error and RMS values over all the considered models.

## CONCLUSION

The suitability of different existing rain rate models for prediction of rain intensities in Nigeria climate is studied. Results analysis shows that virtually all the models considered underestimated the measured rain data at low availability range of 1.0%. The proposed model shows a better performance in terms of prediction error and RMS values.

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