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Development of a Java Programming Tool to Predict Meteorological Variables in Ibadan, Nigeria

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Abstract

Probability distribution model equations were developed for the forecasting of meteorological variables in Ibadan and its environs. A MIDlet 'IBMetro' was developed to use these probability distribution model equations for the computation of quantile estimates for various return periods. In order to overcome the limitation imposed on the Connected Limited Device Configuration (CLDC) platform due to the limited number of mathematical functions available on it, the series expansion of the needed functions were used in the development of the functions. The program was used to compute quantile estimates for the meteorological variables for return periods of 10, 20, 50, 100, 200, and 500 years. A worksheet was also developed in Excel to compute the same quantiles for the purpose of comparison and program verification and the performance and accuracy of the program was found to be excellent when compared to the outputs from the Excel. It was concluded that processing power and capabilities have gone up on modern mobile devices, even on low end handsets as earlier noted by Lee (2008), and hence recommended that the power of modern mobile devices be harnessed to solve engineering problems.

Keywords:

Meteorological variables, probability distribution model equations, IBMetro, MIDlet, CLDC, series expansion, quantile estimate.

1. Introduction

The development of software applications for mobile computers has been recently spurred by the availability of more powerful operating systems and the transfer of standardized programming languages on ever-smaller computing platforms. These developments have opened the door for creating new applications that bring computing power to field scientists and engineers (Vivoni et al., 2001). One potential application area explored in this paper is the prediction of future year meteorological events by computing quantiles of

meteorological variables for different return periods with the aid of a program resident on a handheld device. This program predicts future year events based on the probability distribution functions developed from the frequency analysis of meteorological variables for Ibadan, Nigeria.

In frequency analysis, an assumed probability distribution function is fitted to available data to estimate the magnitude corresponding to return periods and the appropriate distribution models that gives a good representation of the data is chosen. The choice of the probability distribution model is almost arbitrary as no physical basis is available to rationalize the use of any particular function and the search for the proper distribution function has been the subject of several studies (Abdulhameed, 2004; Olofintoye, 2007; and Anifowose and Salami, 2008). For instance Anifowose and Salami (2005) fitted various probability distribution models to the annual mean values of some meteorological variables (rainfall, temperature, sunshine hours, humidity, evaporation and wind speed) to evaluate the model that is most appropriate for the prediction of these variables. Gumbel probability distribution model was found to have the best fit for humidity, temperatures, evaporation and sunshine, while Log-Pearson distribution model was also found to have the best fit for rainfall and wind speed. Analysis of rainfall (and other meteorological) data requires handling of large volumes of data and repeated computation of a number of statistical parameters for distribution fitting and estimation of expected rainfall at different return periods. Development of software/expert system for the above purpose will reduce the monotonous and cumbersome computation to a great extent (Islam and Kumar, 2003).

The advent of the personal computer has led to the development of softwares like AutoCAD, CivilCAD, etc. for the solution of engineering problems. It has also spurred engineers into developing softwares for the solution of unique engineering problems. For example, Raji (2004) developed a Windows based computer program (using Visual Basic 6.0) to simplify the analysis and design of water storage tanks. Congenial to the topic at hand are softwares like RAINPACK, RainPLOT, and HYDRO which are programs developed specifically for the analysis of rainfall and other meteorological data. RAINPACK is a package of programs developed in BASIC for the handling and sorting of daily rainfall data in various possible ways, computation of frequency distribution and basic statistics, which can further be extended for fitting distributions and further applications. Islam and Kumar (2003) however noted that this package of programs does not include

some of the important features such as testing adequacy of the length of the record, fitting probability distributions using class-interval approach, different transformation methods such as power, SMEMAX etc. Thus 'HYDRO', a user-friendly software package for hydrological analysis of rainfall, evaporation and other similar data was developed (in FORTRAN-77) for the analysis of rainfall or other similar data, and used for the analysis of one day maximum rainfall data of selected locations of North Bihar. RAINPLOT is a custom Windows-based software program developed for the regional Middle East rainfall-intensity database project. It allows a user to connect to a relational database of choice, retrieve and display maximum rainfall intensities, rainfall summaries, and other data from the connected database, perform a wide range of statistical analyses on the retrieved data, fit the retrieved data to theoretical probability distributions, test the theoretical distributions for optimal fit, automatically graph and tabulate various statistical results, and automatically create and print customized rainfall-intensity and rainfall summary reports (Morin et al., 2006). Samawi and Sabbagh (2006), used RAINPLOT to analyse rainfall intensity data, together with daily data, for 9 sites in Mujib basin located in the central part of Jordan, for periods of data varying from about 20 years to more than 40 years and noted that the Log Pearson Type 3 and the GEV distributions fit the recorded data better than the Gumbel distribution.

In an attempt to ease the computational tedium involved in the estimation of quantiles using probability distribution model equations developed for twenty stations in Nigeria, Olofintoye et al., (2009) developed rainfall frequency atlases for the prediction of rainfall in Nigeria using Surfer8 (a contouring software). A further attempt is made in this work, at reducing the tedium involved by porting model equations on to the programming platform of a handheld device for easy and quick computation of required quantiles. Recent advances in scalable wireless telecommunications (especially the transfer of standardized programming languages on ever-smaller computing platforms), and the proliferation of hand-held computing devices has enabled the development of software tools to assist environmental and earth scientists in improving the collection of field data. Vivoni et al., (2001) developed a mobile software for environmental and geolocation data collection. The objective of the mobile software application is to streamline the collection process and improve the accuracy of environmental field data as compared to current practices. Hence the power of the JavaTM platform on a mobile handset was harnessed in this project (by developing a MIDlet – a program that runs on mobile devices) to compute quantiles for various return periods.

The Java programming language was conceived by James Gosling, Patrick Naughton, Chris Warth, Ed Frank, and Mike Sheridan at Sun Microsystems, Inc. in 1991. The primary motivation for the development of Java was the need for a platform-independent (that is, architecture neutral) language that could be used to create software to be embedded in various consumer electronic devices, such as microwave ovens and remote controls (Herbert, 2002). Collaboration between Sun Microsystems and major consumer device manufacturers (1999-2002) finally resulted in the creation of Java™ 2 Platform, Micro Edition (J2ME™) which is a highly portable, small-footprint Java™ application development environment for resource-constrained consumer devices such as cellular telephones, two-way pagers and personal organizers. The Connected, Limited Device Configuration (CLDC) is a configuration of J2ME that standardizes a highly portable, minimum footprint Java™ application development platform for resource-constrained, connected devices (Sun 2003a). CLDC is the core technology that will be used as the basis for one or more profiles. A J2ME profile defines additional libraries and features for a particular vertical market, device category or industry. The Mobile Information Device Profile (MIDP) v2.0 for the J2ME defines an enhanced architecture and the associated APIs required to enable an open, third-party, application development environment for mobile information devices, or MIDs (JSR118, 2002). MIDP is embedded on quite a number of handsets. A program written to run on the Mobile Information Device Profile is called a MIDlet. This study describes the development of a MIDlet (IBMetro) for the prediction of meteorological variables in Ibadan, Nigeria.

2. Materials and Methodology

2.1 Background

This work started on the premiss of the previous work done in 2008. Anifowose and Salami (2008) developed probability distribution model equations for the prediction of meteorological variables for Ibadan metropolis, Nigeria. These model equations are the main inputs for this study.

2.2 Summary of Previous Work

2.2.1 Data Collection

The meteorological data were obtained at the meteorological department of the International Institute of Tropical Agricultural Training and Research (IITA), Ibadan. The data collected include rainfall, relative humidity,

evaporation, sunshine hour, temperature, and wind speed. A total of 33 years data (1970 - 2002) were collected.

2.2.2 Data Analysis

The annual mean values of the meteorological data were determined from the collected data for each year and ranked according to Weibull’s plotting position to estimate corresponding return period. These meteorological data were then evaluated with six probability distribution functions to determine the best-fit model for each data. The models include; Gumbel (EVI type1), Log-Gumbel (LG), Normal (N), Log-Normal (LN), Log-Pearson type III (LP₃) and Exponential (E) probability distribution models. Mathematical expressions were obtained for the various probability distribution functions and used to predict meteorological data for various return periods used in performing the goodness-of-fit tests for the selection of the best-fit models. The goodness-of-fit tests adopted were chi-square (χ^2), t- distribution (t), probability plot coefficient of correlation (r), coefficient of determination (R^2) and standard error of estimate (Se). The probability distribution model is selected as best if the value of the ratio of calculated chi-square to the table chi-square ($\chi^2_{cal} / \chi^2_{tab}$) is less than one, the values of probability plot correlation coefficient and coefficient of determination, must be between -1 to +1. The closer the result of the test is to 1, the better the conformity of the variable to the probability distribution. For the standard error of estimate, the results of the tests are expected to be closer to zero.

2.2.3 Results

The selected best-fit model for each meteorological variable based on the analysis is presented in Table 1.

Table 1: Best-fit models for the meteorological variables for Ibadan, Nigeria.

S/N	Meteorological Variable	Best fit distribution model	Model Equation
1.	Rainfall (mm)	Log-Gumbel	$\text{Log } R_T = 2.021 + 0.082 (0.78 Y_T - 0.45)$
2.	Humidity (%)	Log-Gumbel	$\text{Log } Hu_T = 1.808 + 0.0344 (0.78 Y_T - 0.45)$
3.	Evaporation (mm)	Log-Normal	$\text{Log } E_T = 2.087 + 0.0348 K_T$
4.	Sunshine hour (Hr)	Log-Gumbel	$\text{Log } S_T = 0.758 + 0.046 (0.78 Y_T - 0.45)$

Table1 contd.

5.	Temperature (°C)	Normal	$T_T = 27.375 + 0.836 K_T$
6.	Wind speed (km/hr)	Normal	$W_T = 0.1903 + 0.105 K_T$

2.3 Methodology of Current Work

The main aim of this work is to develop a MIDlet for the prediction of meteorological variables in Ibadan, Nigeria. The MIDlet is named 'IBMetro'. IBMetro is the acronym for 'Ibadan Meteorology'. IBMetro computes quantiles for return periods based on the model equations presented in Table 1.

2.3.1 Prediction Using the Gumbel and Normal Distribution Models

Predictions with the Gumbel distribution model is based on the fact that the cumulative probability that any of the events would equal or exceed a particular value, having a return period (T_r) is given by the following equations (Sule, 2005):

$$P = 1 - e^{-e^{-Y_T}} \quad (1)$$

$$Y_T = -\ln(-\ln(1 - P)) \quad (2)$$

An event having a return period T_r (years) is described by the Gumbel model with a general equation of the form (Sule, 2005):

$$Q_{T_r} = Q_{av} + \sigma (0.78 Y_T - 0.45) \quad (3)$$

Where Q_{av} is the average of all observed values σ is the standard deviation of the series and Y_T is the reduced variant. An event having return period T (years) is described by normal distribution model with a general equation of the form:

$$Q_T = Q_{av} + k \sigma \quad (4)$$

Where k is the standard normal variate which may be obtained from Normal distribution tables. Q_{av} is the mean of the observed data, σ is the standard deviation of the observed data.

2.3.2 Manual Computation (Numerical Examples)

An example of the procedure using manual computation is presented next to serve as a guide to the step-by-step development of the program. For example, the prediction of the Rainfall value for a 120-year return period, and evaporation for a 200-year return period, is illustrated as follows:

Rainfall 120-year (Log-Gumbel):

1. Model Equation - $\text{Log } R_T = 2.021 + 0.082 (0.78 Y_T - 0.45)$
2. For $T = 120$ years, $P = 1/Y_T = 0.0083$
3. $Y_T = -\ln(-\ln(1-P)) = 4.7833$
4. $\therefore -\text{Log } R_T = 2.021 + 0.082 ((0.78 \times 4.7833) - 0.45) = 2.29$
5. $\therefore -R_T = \text{Antilog}(\text{Log } R_T) = 10^{2.29} = 195.00\text{mm}.$

Evaporation 200-year (Log-Normal):

6. Model Equation - $\text{Log } E_T = 2.087 + 0.0348 k_T$
7. For $T = 200$ years, $P = 1/Y_T = 0.005 = (0.50\%)$, $k = 2.58$ (from tables).
8. $\therefore -\text{Log } E_T = 2.087 + 0.0348 k_T = 2.087 + 0.0348(2.58) = 2.1766$
9. $\therefore -E_T = \text{Antilog}(\text{Log } E_T) = 10^{2.1766} = 150.19\text{mm}.$

2.3.3 MIDlet Development

This section describes in detail the development of the various functions that make up the MIDlet. Unlike full fledge desktop computer programming languages like C++, Visual Basic 6.0, Java2 Standard edition (J2SE) etc. with a myriad of mathematical functions, the Math Class of the CLDC 1.1 configuration is equipped with only 11 mathematical functions (viz. abs, ceil, cos, floor, max, min, sin, sqrt, tan, toDegrees, toRadians) (Sun 2003b). This imposes a major limitation on the use of the CLDC for the solution of engineering problems. Fortunately, Lee (2008) has noted that processing power and capabilities have gone up on modern mobile phones, even on low end handsets. Hence some of the main functions in this project were developed using the Numerical Approximation (Series Expansion) of the functions. The main functions developed for the computation of quantiles are LN, Power, and NormSDistINV. Detail of the functions and their sub-functions are described as follows:

2.3.3.1 Development of the LN Function

The LN function returns the natural logarithm of a number. Natural logarithms are based on the constant e (2.71828182845904). This function is used in section 2.3.2 in the computation of quantile using the Log-Gumbel

model (Line 3). The series expansion of the LN function is given by Chen and Liew (2003) as:

$$\text{Log}(x) = 2 \left[\left(\frac{x-1}{x+1} \right) + \frac{1}{3} \left(\frac{x-1}{x+1} \right)^3 + \frac{1}{5} \left(\frac{x-1}{x+1} \right)^5 + \dots \right] \quad (5)$$

The function was written to compute and add up the terms until the next term is $\leq 10^{-17}$. The flow chart of the program code written to compute the LN function is presented in Figure 1.

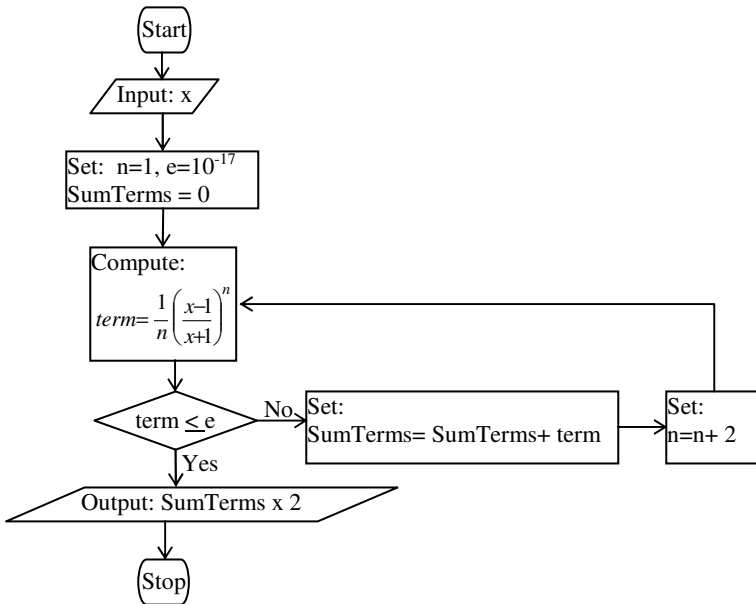


Figure 1: Flowchart for the LN Function program code.

2.3.3.2 Development of the Power Function

The Power function returns the result of a number raised to a power. This function is used in section 2.3.2 to find Antilogarithm in the computation of quantile using the Log-Gumbel model (Line 5). This function makes use of the Factorial sub-function. The series expansion of the Power function is given by Chen and Liew (2003) as:

$$a^x = 1 + x \log a + \frac{(x \log a)^2}{2!} + \frac{(x \log a)^3}{3!} + \dots \quad (6)$$

$$: a^x = \sum_{n=0}^{\infty} \frac{(x \log a)^n}{n!} \quad (7)$$

The function was written to compute and add up the terms until the next term is $\leq 10^{-12}$. The flow chart of the program code written to compute the Power function is presented in Figure 2.

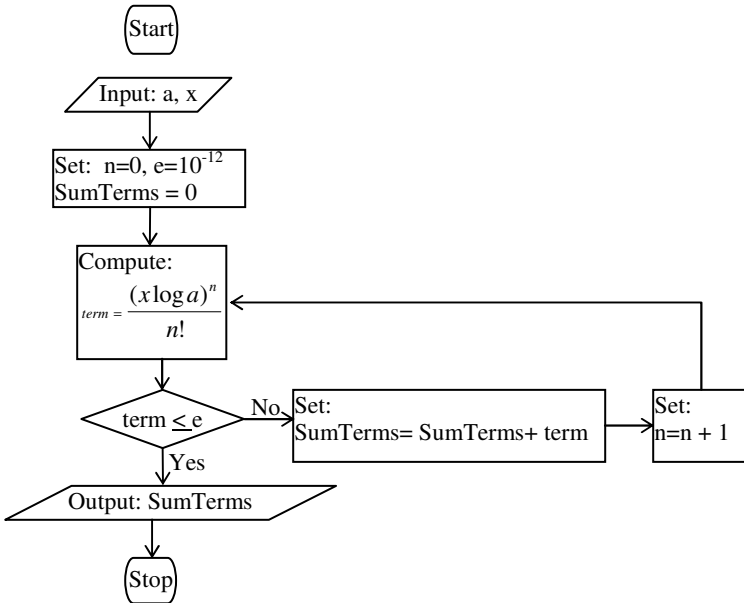


Figure 2: Flowchart for the Power Function program code.

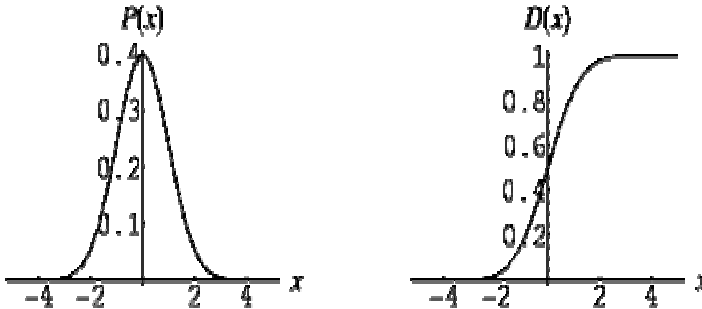
2.3.3.3 Development of the SNDFInv Function

The SNDFInv function returns the inverse of the standard normal cumulative distribution. The standard Normal distribution has a mean of zero and a standard deviation of one (Figure 3). This function is used in section 2.3.2 to obtain k in the computation of quantile using the Log-Normal model (Line 7). To avoid the use of tables in obtaining our k values, the use of integral calculus was employed. The probability density function $P(x)$ and

cumulative distribution function $D(x)$ of the standard Normal distribution as stated by (Mathworld, 2009) are:

$$P(x) = \frac{1}{\sqrt{2\pi}} e^{-x^2/2} \quad (8)$$

$$D(x) = \frac{1}{2} \left[\operatorname{erf} \left(\frac{x}{\sqrt{2}} \right) + 1 \right] \quad (9)$$



Source: (Mathworld, 2009).

Figure 3: Graphs of the Normal Distribution Function.

Over the domain: $x \in (-\infty, \infty)$, and erf is the error function encountered in integrating the equation of the Normal curve (Mathworld, 2009). $D(x)$ is the function that gives the area under the Normal distribution curve. It is obtained by integrating the function $P(x)$. Given a particular non-exceedence probability $D(x) = A$, the Normal deviate can be computed as:

$$Z = \sqrt{2} \times \operatorname{erf}^{-1}(2A - 1) \quad (10)$$

Where erf^{-1} is the inverse of the error function. The inverse error function has series (Wikipedia, 2009):

$$\operatorname{erf}^{-1}(z) = \sum_{q=0}^{\infty} \frac{c_q}{2^{q+1}} \left(\frac{\sqrt{\pi}}{2} z \right)^{2^{q+1}} \quad (11)$$

Where $c_0 = 1$ and

$$c_q = \sum_{m=0}^{q-1} \frac{c_m c_{q-1-m}}{(m+1)(2m+1)} = \left\{ 1, 1, \frac{7}{6}, \frac{127}{90}, \dots \right\} \quad (12)$$

The main sub-function of the SNDFInv function is ErfINV function. The ErfINV function was written to compute and add up the first 1200 terms of the series giving a very good approximation of the values obtained from the Normal distribution tables for the SNDFInv function. Z is the deviate for the non-exceedence probability while k is the exceedence probability deviate. Thus if P is the non-exceedence probability, then $Q = 1 - P$ is the exceedence probability. Thus $k = \text{SNDFInv}(Q)$.

2.3.3.4 Complete MIDlet Flowchart

Finally, the major and minor functions were compiled into a MIDlet (IBMetro). The flowchart for IBMetro is given Figure 4.

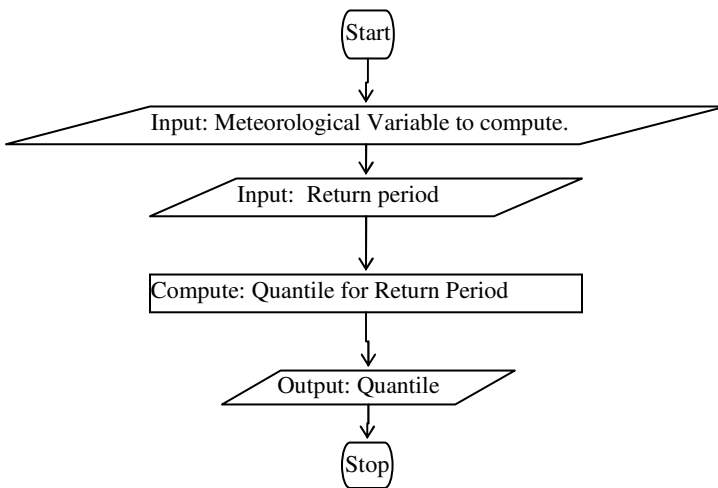


Figure 4: Flowchart for IBMetro.

3. Results and Discussion

3.1 Results

The compilation of the major and minor functions resulted in a mobile software 'IBMetro' for the prediction of meteorological variables in Ibadan Nigeria. The software is accurate, handy and easy to use because of its intuitive user interface. Figure 5 shows the user interface. A brief description of the program follows immediately.

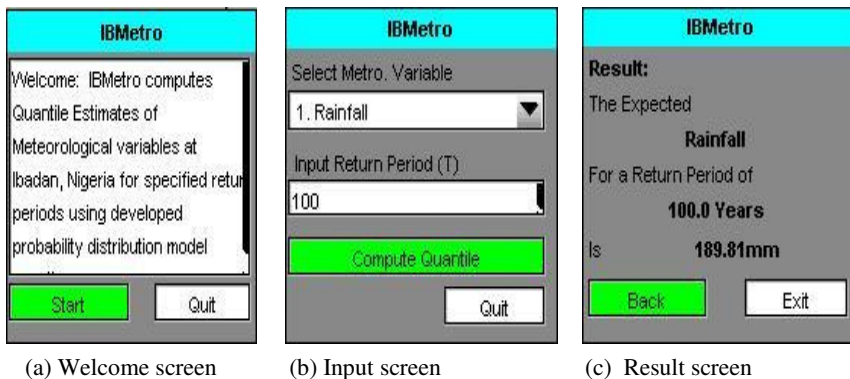


Figure 5 IBMetro's User Interface.

Figure 5a presents the welcome screen. This gives a brief description of the program. The user clicks on the start button to start using the program. Figure 5b is the main input screen of the program. The user selects the meteorological variable for which a quantile is to be obtained from the dropdown list box and enters the return period in the textbox below, after which he clicks on the compute button. The result screen (Figure 5c) is displayed after the computation is completed. The user may click on the back button to return to the input screen to change variable or enter a different return period.

IBMetro was used to predict quantiles for the meteorological variables for return periods of 10, 20, 50, 100, 200, and 500 years. A worksheet was also developed in Excel to compute the same quantiles for the purpose of comparison and program verification. The quantile estimates are presented in Table 2.

3.2 Discussion of results

IBMetro was used to predict quantiles for the meteorological variables for return periods of 10, 20, 50, 100, 200, and 500 years and it was found that the results of the program were correct when compared to the results generated from Excel. Slight discrepancies were noticed in the computation of the 200-year and 500-year return period for sunshine hour. While Excel gave 8.46 and 9.13 hours for the 200 and 500-years respectively, IBMetro gave 8.45 and 9.12 hours respectively. These discrepancies are minor (negligible) and are likely due to rounding errors on the different platforms. IBMetro

computes the LN function used in the computation of the Log-Gumbel distribution to an accuracy of 17 decimal places, Excel computes to 15 or 16 places of decimal. The results obtained for evaporation, temperature, and wind speed (Using the Normal, and Log-Normal distribution) were in perfect agreement with the once obtained from Excel. This shows that taking the first 1200 terms in the computation of the inverse error function is sufficient to obtain an accurate estimate for the Normal deviate z . Also a comparison of the results obtained for Rainfall, Relative Humidity, Sunshine Hour (Using the Log-Gumbel distribution) and Evaporation (using the Log-Normal distribution) were in perfect agreement, thus indicating that the antilogarithms computed from the Power function were correct. Hence computing the Power function to accuracy ≤ 0.00000000001 was sufficient for this work.

Table 2: Quantile estimates for various Return Periods.

S/N	Meteorological Variables	Return Period in Years											
		10		20		50		100		200		500	
		Exel	IBMetro	Exel	IBMetro	Exel	IBMetro	Exel	IBMetro	Exel	IBMetro	Exel	IBMetro
1	Rainfall (mm)	134.29	134.29	149.30	149.30	171.26	171.26	189.81	189.81	210.29	210.29	240.73	240.73
2	Humidity (%)	71.27	71.27	74.51	74.51	78.93	78.93	82.40	82.40	86.02	86.02	91.04	91.04
3	Evaporation (mm)	135.39	135.39	139.39	139.39	144.04	144.04	147.22	147.22	150.19	150.19	153.87	153.87
4	Sunshine hour (Hr)	6.58	6.58	6.98	6.98	7.54	7.54	7.99	7.99	8.46	8.45	9.13	9.12
5	Temperature (°C)	28.45	28.45	28.75	28.75	29.09	29.09	29.32	29.32	29.53	29.53	29.78	29.78
6	Wind speed (km/hr)	0.32	0.32	0.36	0.36	0.41	0.41	0.43	0.43	0.46	0.46	0.49	0.49

4. Conclusion

A MIDlet called IBMetro was developed (using Java programming language) to compute quantiles, using various probability distribution model equations developed for the meteorological variables of Ibadan. The performance and accuracy of the program was satisfactory. The handset used in the development of the program (Nokia 3110c) is relatively cheap and affordable, and of lower capacity when compared to more modern handsets and mobile devices, yet it was noted that the series approximations converges within a few seconds. Thus it may be concluded that processing power and capabilities have gone up on modern mobile devices, even on low end handsets, and the power of modern mobile devices may be harnessed to solve engineering problems. The limited number of mathematical functions of the CLDC platform is therefore not an insurmountable factor of the platform for solving engineering and scientific problems.

5. Acknowledgements

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