Rainfall Rate Distribution for LOS Radio Systems in Botswana

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***Abstract*—The estimated cumulative distributions (CDFs) of rainfall rate for 4 locations in Botswana are reported in this paper based on 10-year rainfall data. The daily rainfall sampled over 24 hours is converted to the ITU-R recommended integration time of one minute. The method used is based on cumulative distribution identity of known one-minute rain-rate sites with their corresponding daily integration time compared with sites having unknown one-minute integration time. Consequently, values of coefficients a and b so determined are used to convert daily rain rates into one-minute rain rates for corresponding similar CDF sites of the target regions of Botswana. The resulting cumulative rainfall rate and relations between them are compared with the relevant ITU-R Recommendation P.837-1 and P.837-4. Based on this, an additional two rain zones are proposed alongside the seven ITU-R rain zones for Southern Africa.**

***Index Terms*—Cumulative distribution, Rain zones, integration time.**

I. INTRODUCTION

THE progressive saturation of the spectrum at lower microwave frequencies and the increasing demand for new services have resulted in pressures to utilize frequencies above 10 GHz for both terrestrial and satellite communication links [1]. In order to predict reliable rainfall attenuation for a given location, an appropriate distribution of rainfall rate at 1-minute integration time is needed for the site under studied. The rainfall rate cumulative distribution plays an important role in the assessment of the attenuation due to rainfall in the region of interest especially in Southern Africa where little work has been done.

Daily rainfall accumulations are universally recorded and hourly data are also fairly widely available by national weather bureaus [2]. Ajayi and Ofoche [3] and other authors [4, 5] determined that the use of one-minute rain rates gives the best agreement with the ITU-R stipulations for the design of microwave radio links. Therefore, there is a need to convert the available one-hour rain rates measured by most national weather bureaus to one-minute data. In this paper a simple approach is used to determine the conversion factors for the Botswana sites which lack one-minute exceedence, the cumulative identity is employed to find the conversion factor for Botswana which has daily rainfall data. Botswana's daily cumulative distributions are compared with South African daily cumulative distributions. South African is chosen because both daily, hourly, five-minute and one-minute rainfall results are available. ITU-R Recommendation P-837-1 and P-837-4 classifies the Southern Africa region into seven climatic rain zones by using the median cumulative distribution of rain rate for the rain climatic region [6]. The same method is employed in this paper to classify the Botswana regions into their classes of rain zones.

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II. INTEGRATION TIME DEPENDENCE OF CDF IDENTITY

As a result of the rapidly varying nature of rainfall at a given point, the cumulative rainfall rate distribution measured is dependent on the sampling time of the rain gauge.

There are some existing methods to convert 1-minute rainfall rate distribution from various time rainfalls. They are Canadian model suggested by Segal [2], French model by Moupfouma [7] and Japanese model by Karasawa [8]. Since in radio wave prediction techniques, an integration time of one minute has been adopted by the ITU-R as the most desirable compromise for attenuation prediction [2], Segal has defined a conversion factor, $\rho_\tau(P)$ for converting data obtained with a gauge having an integration time of τ minutes to equivalent one-minute statistics, as follows [2]:

$$\rho_\tau(P) = R_1(P) / R_\tau(P) \qquad (1)$$

where R_1 and R_τ are the rainfall rate exceeded, with equal probability P, for the two integration times (referred to as equiprobable rain rates of the two different integration times R_1 and R_τ [2,3]. The factor $\rho_\tau(P)$ is also given by the power law [4]:

$$\rho_\tau(P) = a.P^b \qquad (2)$$

over the range $0.001\% \leq P \leq 0.03\%$, with a and b being constants that depend on the climatic zone. It has also been found that a power law relationship exists between the equiprobable rain rates of two integration times. The power law relationship is given by [9]:

$$R_\tau = aR_T^b \qquad (3)$$

where R is the rain rate, τ is the integration time at which the rain rate is required, and T is the integration time at which the rain rate is available. Figure 1a to 1d show cumulative distribution identities which are optimized by root mean square (RMS) criterion in order to determine location in Botswana that has the closest rain rate distribution to those in South Africa. For example in the case of Gaborone, the closest CDFs in South Africa are Nongoma, Langgewacht, Middelwater and Victoria. In this case, the CDF which gives the lowest RMS value is determined to be Middelwater; we thus conclude that for Gaborone, the closest CDF is that of Middelwater. The other three Botswana sites, namely, Francistown, Kasane and Selebi Phikwe have least RMS values of 7.27, 2.59, 6.76, respectively, corresponding to South Africa sites of Langgewacht, Victoria and Stanger respectively.

Next, the Segal and the Ajayi approaches are used to determine the conversion factor to convert from daily integration time to an effective one-minute integration time [2,3]. Note that only the South African data is used to effect this conversion due to the fact that 1-minute data was only available for South Africa for the 5 years, but was not available for the other 4 sites in Botswana. This results in a linear scatter plot of data points, in which a simple power law fits, giving as shown in Figure 2a and 2b:

$$R_{1\min} = \alpha R_{Daily}^{\beta} \tag{4}$$

Thus, the corresponding coefficients of α and β in equation (4) are used to convert daily rain rate data from locations in Botswana to an effective 1-minute integration time. Figure 2a and 2b show conversion factors graphs with their coefficients shown in Table 1. R^2 is the correlation coefficient which is close to one.

III. ESTIMATED CUMULATIVE DISTRIBUTION OF RAIN RATE FOR BOTSWANA

Cumulative distributions (CD's) of ten-year 1-minute rain intensities for four regions in Botswana are plotted in Figure 3. The cumulative distribution is based on rain intensities and percentages of time: the higher the rain intensity the lower the corresponding percentage of time recorded, while the lower the rain intensity the higher the percentage of time. The analyses are done for four sites out of the fourteen sites in Botswana. For Selebi-Phikwe, at the higher time percentage of 0.1%, the rain rate recorded is 100.83 mm/h; while for the lower time percentage 0.01%, the rain rate is 137.06 mm/h. Therefore the rain intensity difference for time percentage differences between 0.1% to 0.01% is 36.23 mm/h. At the higher time percentage of 0.1% for Francistown, the observed rate is 65.3 mm/h, with the difference in rain intensities between 0.1% and 0.01% being 20.94 mm/h. Similarly for Gaborone, at 0.1% of time percentage, the rain intensity is 52.64 mm/h, while at the lower time percentage the rain intensity is 68.9 mm/h. This results in a rain rate difference between 0.1% and 0.01% of 16.26 mm/h.

In the case of Kasane, the distribution shows that at 0.1% the rain intensity is 48.95 mm/h, while at 0.01% the intensity is 64.4 mm/h. The rain rate difference between 0.1% and 0.01% of the time is thus 15.45 mm/h.

IV. DETERMINATION OF BOTSWANA RAIN CLIMATIC ZONES

The ITU-R climatic map for the world divides the whole globe into 15 climatic zones. This shows the rain intensities for the various climatic zones [10]. According to the ITU-R837-1 and ITU-R 837-4 classification, Southern Africa has seven rain zones, namely: C, D, E, J, K, L and N; out of these, Botswana has three, namely, J, L and N. However, these ITU-R designations are not necessarily adequate, as they need further refinement; thus there is need to redefine the ITU-R regional climatic zones based on the actual local data. From the 10-year actual rain data for four different geographical locations in Botswana (which are converted into one-minute integration time based of cumulative frequency identity with one-minute South Africa data), the resulting rainfall rate distributions at 1.0%, 0.3%, 0.1%, 0.03% and 0.01% probability level (percentage of time ordinate exceeded) are shown in Figure 3. The rain intensity exceeded (mm/h) for each of the four selected geographical locations in Botswana are compared with the ITU-R rain climatic zone table. The errors obtained by comparing each location against different ITU-R climatic zones are determined; and the ITU-R zone that gives the least recorded RMS error value for each geographical location is chosen as the location's rain climatic zone. The resulting climatic rain zones are shown in Table 2. From the local data measured by Botswana Weather Services for the four locations, two climatic rain zones are determined for Botswana based on the analysis on four sites out of fourteen locations, namely, M and Q.

V. CONCLUSION

The ten-year rainfall data measured by the Botswana Weather Services for 14 different locations have been utilized to study the effect of integration time on the cumulative distribution of rain rate for Botswana. The cumulative distribution identities of different regions in South Africa with daily data are compared with Botswana daily data. The closest cumulative distributions of both countries are compared using root-mean-square (RMS) values, and thus the CDF giving the least RMS value in South Africa is taken as the comparable site with a corresponding Botswana site. Values of equiprobable rain rate for 1 minute and 24 hours integration times for probabilities of 0.1% or less have been employed to confirm the power law relationship between the rain rates at 1-minute and 24-hours integration times. Selebi-Phikwe which lies in the border of South Africa and Zimbabwe has the highest rain intensity $R_{0.01}$ of 137.06 mm/h, and Kasane which is found in the border region of Zambia has the lowest rain intensity 64.4 mm/h. The

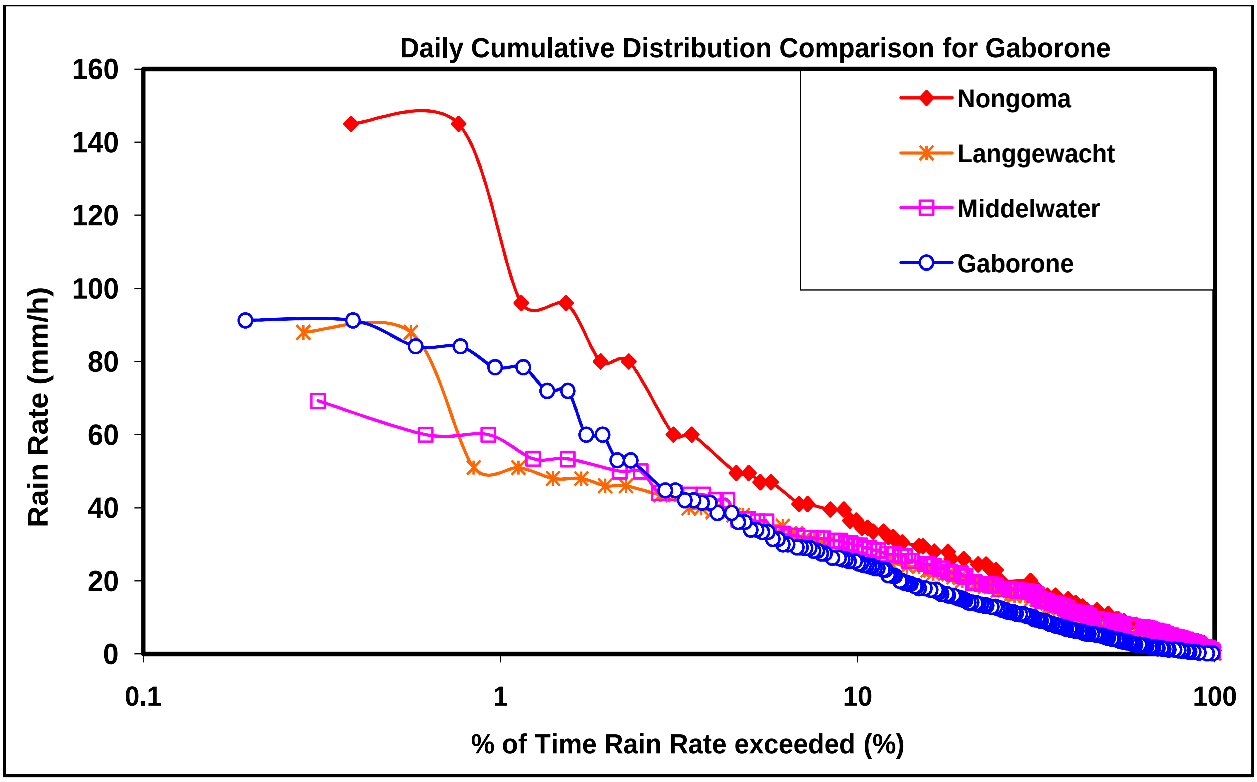

Figure 1a: Cumulative Distribution of Rain Rate Identity for Gaborone

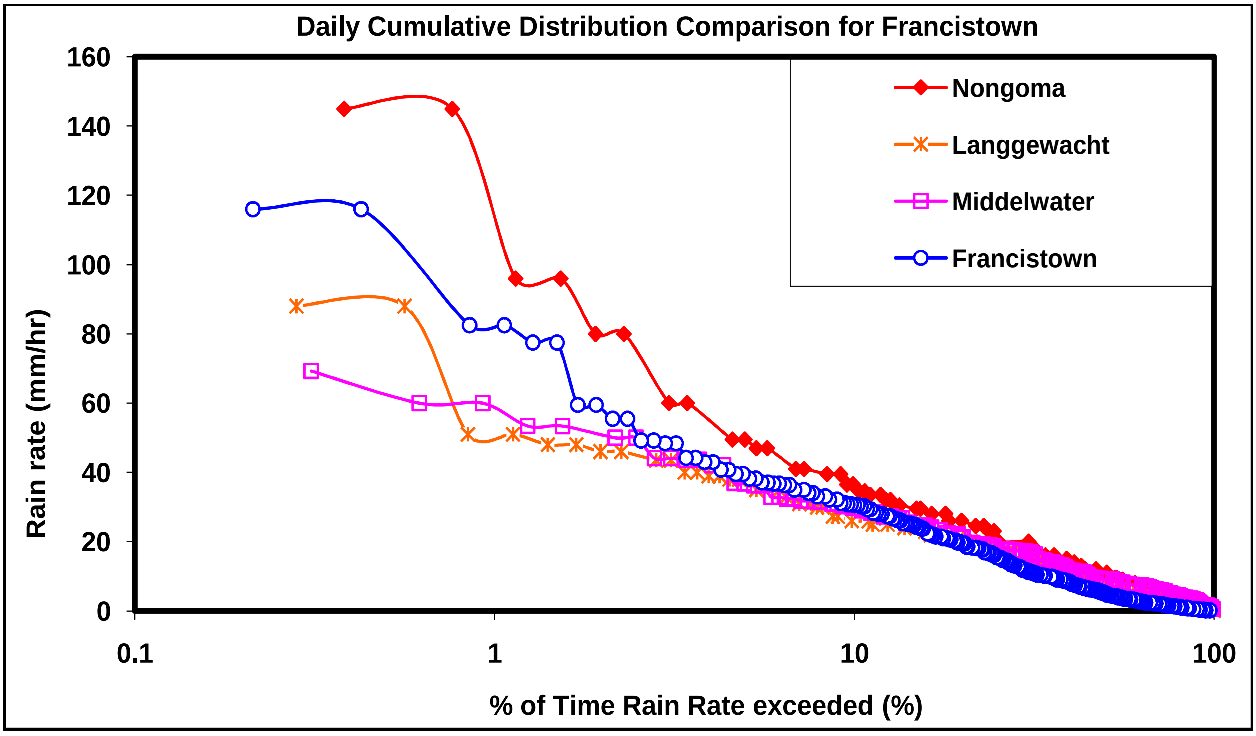

Figure 1b: Cumulative Distribution of Rain Rate Identity for Francistown

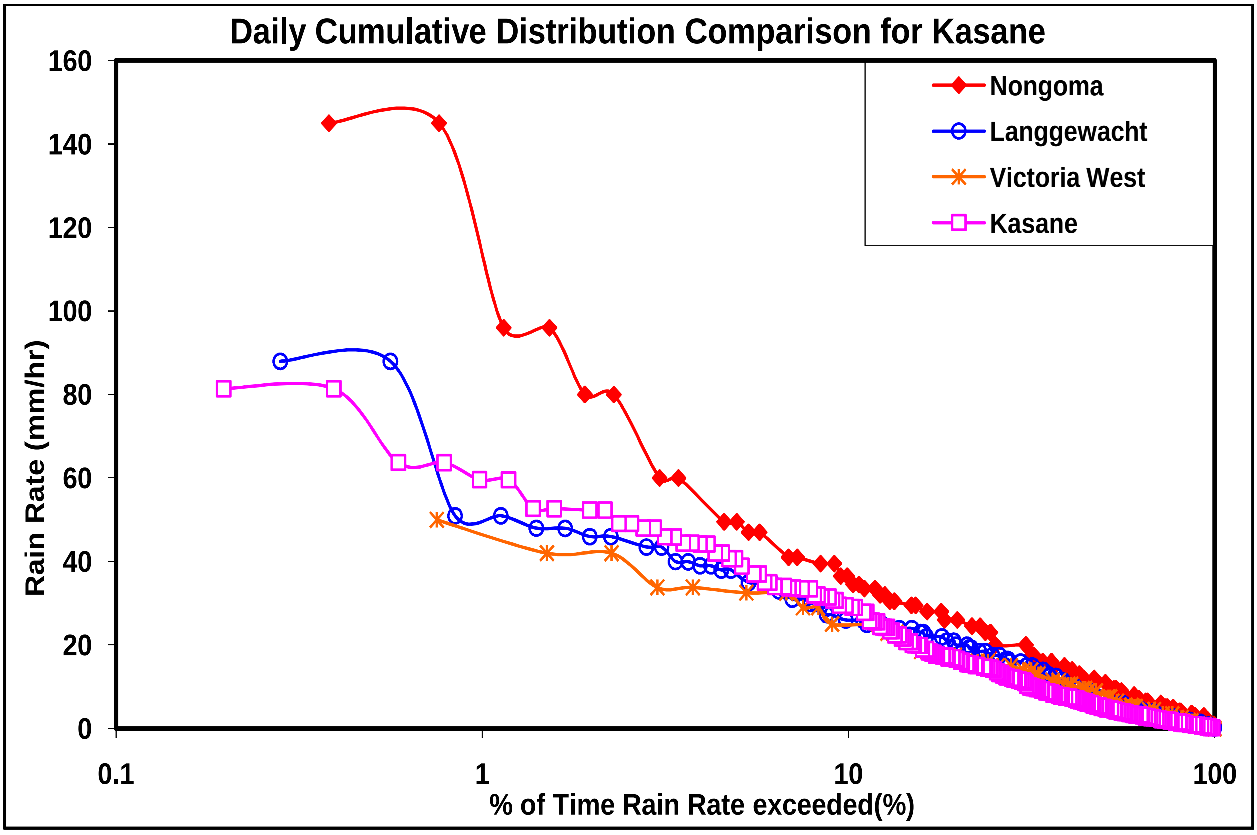

Figure 1c: Cumulative Distribution of Rain Rate Identity for Kasane

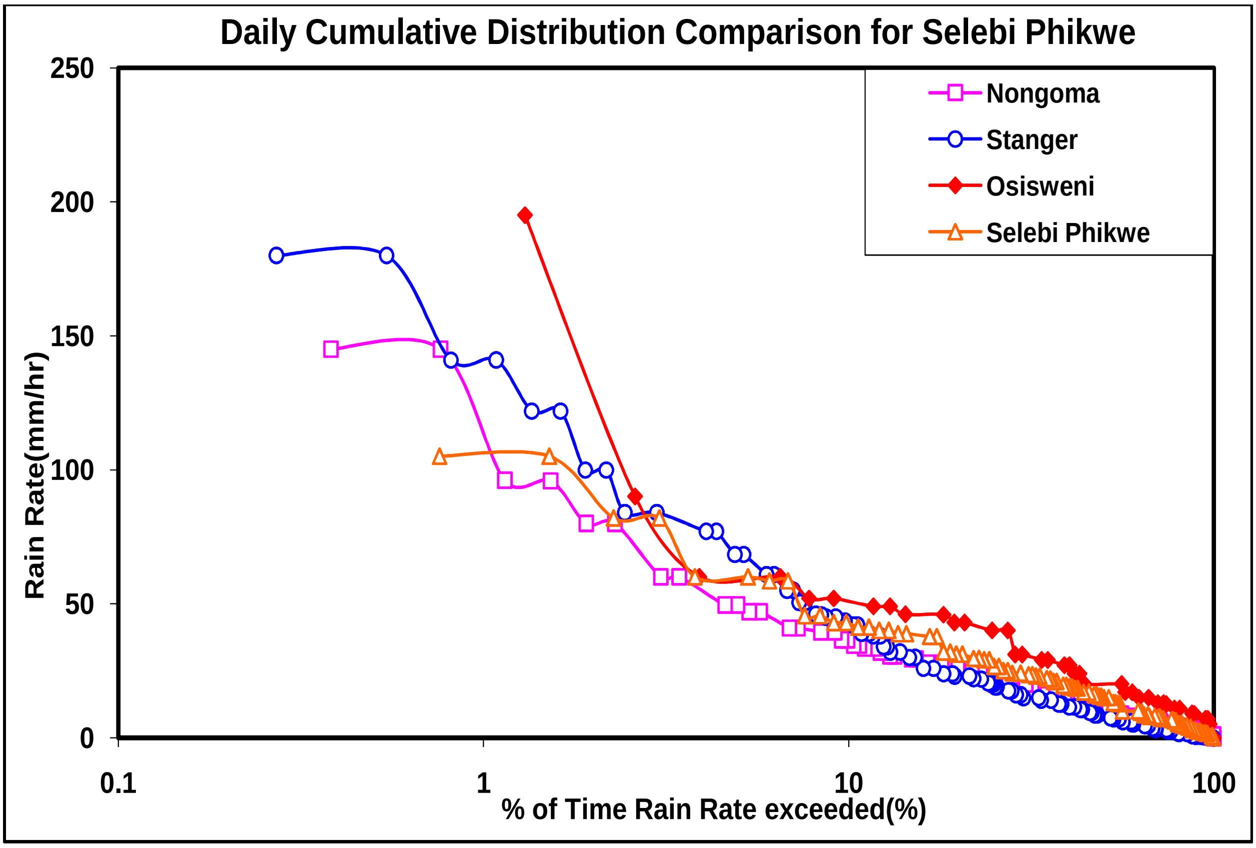

Figure 1d: Cumulative Distribution of Rain Rate Identity for Selebi Phikwe

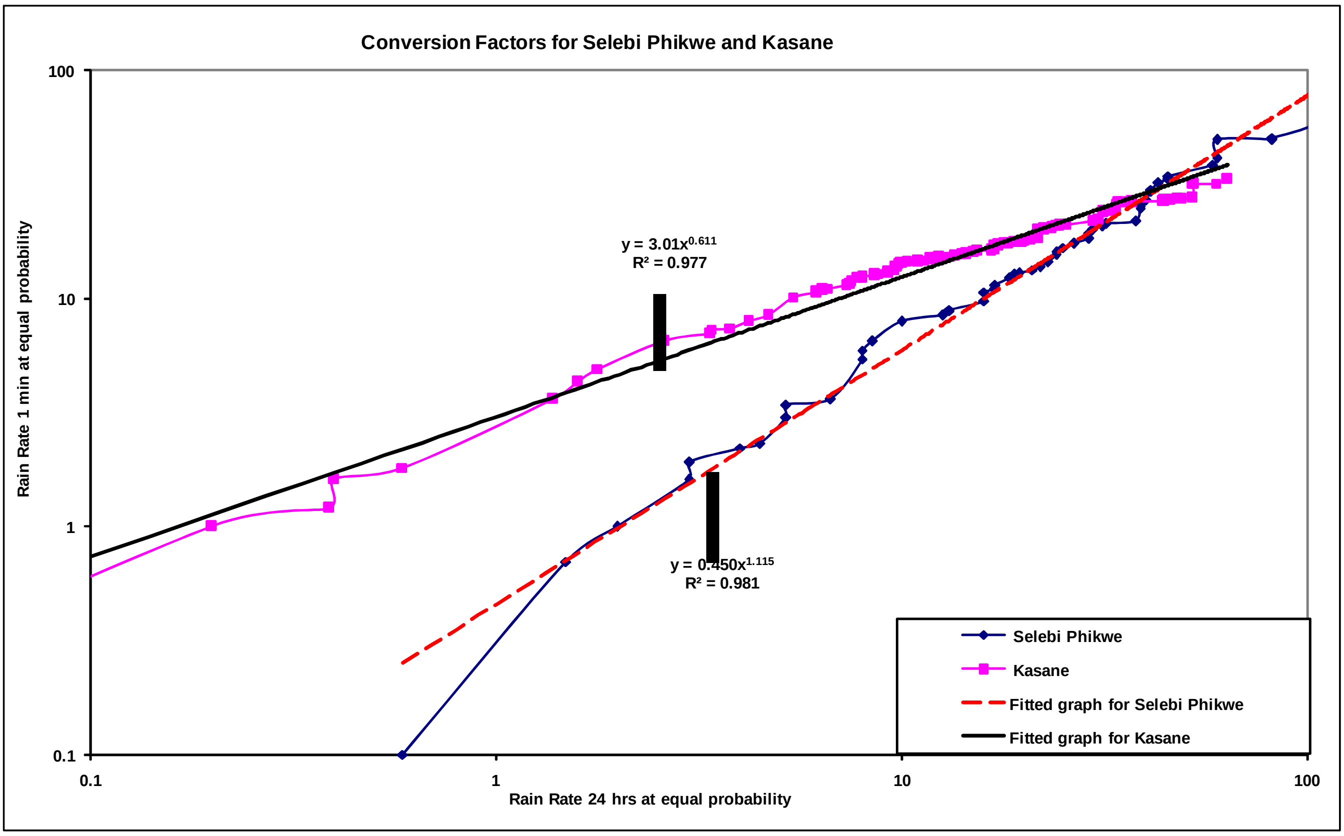

Figure 2a: Conversion factors for Selebi Phikwe and Kasane

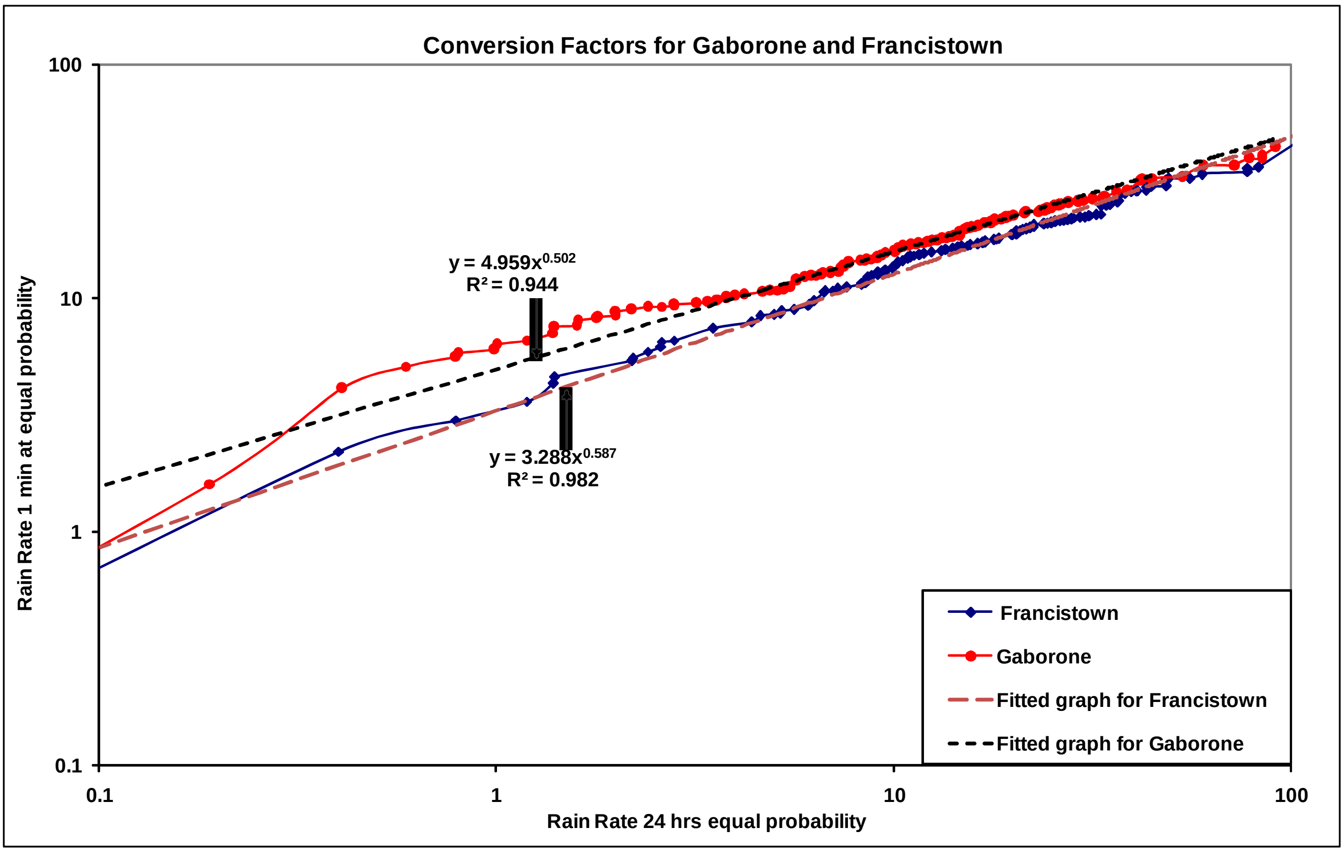

Figure 2b: Conversion factors for Francistown and Gaborone

TABLE I: COEFFICIENTS FOR $R_\tau = \alpha R_T^\beta$ FOR τ = 1 MIN AND T= 24HRS

Station	α	β	R^2
Gaborone	4.9592	0.5028	0.9442
Francistown	3.2882	0.5877	0.9822
Kasane	3.01	0.6117	0.9776
Selebi Phikwe	0.4508	1.1159	0.9817

TABLE 2: PROPOSED RAIN CLIMATIC ZONES FOR 4 GEOGRAPHICAL LOCATIONS IN BOTSWANA

Location	ITU-R P.837-1	ITU-R P.837-4	Proposed Zone
Gaborone	J	L	M
Francistown	J	N	M
Kasane	J	N	M
Selebi Phikwe	J	N	Q

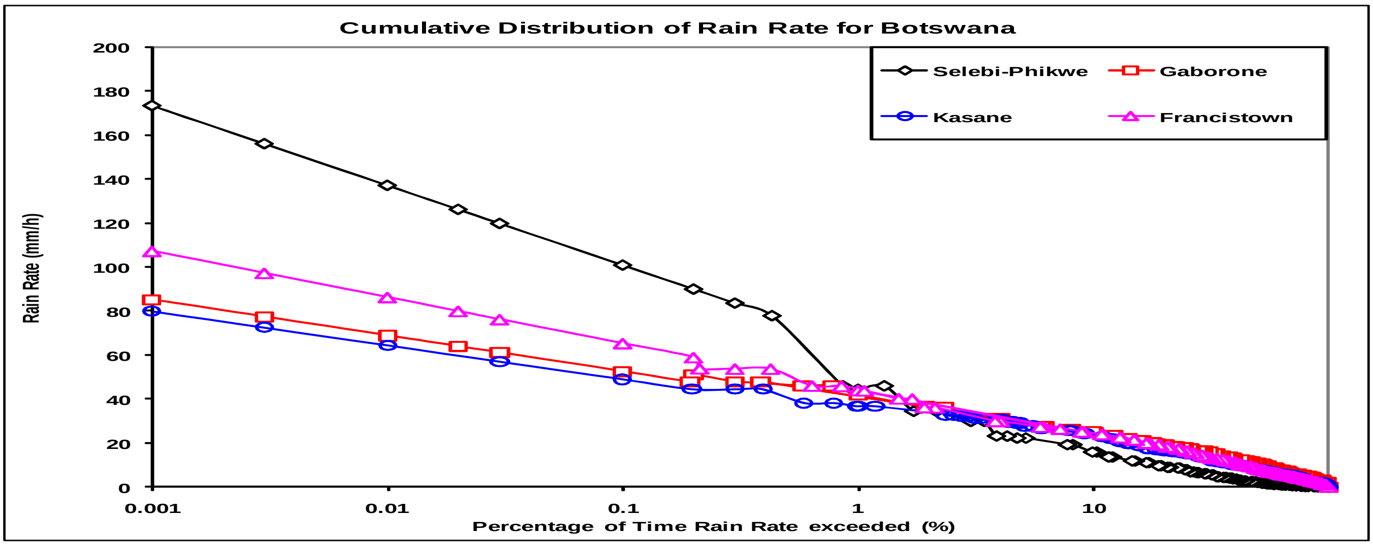

Figure 3: Cumulative Distribution of Rain Rate for Botswana for average of 10 years

cumulative distributions of 1-minute rain intensities for a period of 10 years are obtained for each location that lies in the same climatic region. Based on the available 24-hour rain data converted to 1-minute integration time, two climatic rain zones M and Q are determined for Botswana, as against the ITU-R classification of J, L and N based on the examined four sites.

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