Rainfall Rate Characteristics for the Design of Terrestrial Link in South Africa

Pius A. Owolawi, Thomas J.O. Afullo, and S.B. Malinga

Abstract— **Rain attenuation can have a serious impact on the availability of radio communication system especially at centimeter and millimeter wavelengths. In order to predict reliable rain attenuation for a given location, it is therefore essential to determine characteristics of rainfall rate at the location of interest which is geographically dependent. In this paper, the cumulative distributions, seasonal variability, worst month of rainfall rate for four locations in South Africa are presented based on a five-year rainfall data. Consequently, new rain climatic zones are suggested and the relationship between average year (AY) and average worst month (AWM) are obtained.**

***Index Terms*—rain rate, integration time, cumulative distribution, climatic zone, worst month and average year.**

I. INTRODUCTION

SIGNAL transmission at frequencies above 10 GHz is influenced by various meteorological conditions, which impose severe limitations on the line-of-sight coverage distance of radio systems operating in the millimetric region of the spectrum[1]. Absorption and scattering of signal energy by rain, snow, fog, water vapour, oxygen and other gases in the atmosphere affect the propagation of radio waves at frequencies above 10 GHz, and these effects must be taken into consideration when designing a millimeter-wave system [2].

A number of ITU-R reports and recommendations have been published based on the available data. In this paper, the ITU-R.873-1, 2, 3 and 4 are investigated. According to ITU-R classification, Southern Africa has six climatic rain zones, namely: C, D, E, J, K and N out of which South Africa has five. However, these ITU-R designations are not adequate and there is need to redefine the ITU-R regional climatic zone based on the actual local data. The details of the additional climatic zones are shown in [3].

II. RAIN STATISTICS MEASUREMENT AND CUMULATIVE DISTRIBUTION IN SOUTH AFRICA

It is confirmed that rain gauges with 1- or 2-minute integration time resolve the small but significant cells, while gauges with longer averaging time miss the peak rain rate values [4]. For the five-year rain rate data measures with an integration time of 60-minutes for four different locations in South Africa, Segal [5], Watson et al [6] and Ajayi et al [7] approaches are used to determine the conversion factor and to convert from 60-minute integration time to an effective 1-minute integration time. The conversion factor and the procedure used to determine other locations based on the derived factors are presented in [3]. The rain rate cumulative distribution plays an important role in the assessment of the attenuation due to rainfall in the region in both satellite communications and line-of-sight communications [8]. Figure 1, shows detail of cumulative distributions (CD) for measure average (MA) and mean worst-month (MWM). The distributions are compared with ITU-R rain zone classifications using ITU-R P.837-1 and ITU-R.837-4. The two ITU-R classifications for Durban, Richards Bay, and Pretoria confirm differences, while Cape Town alligns with the two ITU-R rain zones classifications.

Table 1 shows discrepancy in the ITU-R P.837-1 and P.837-2 in classifications of rain climatic zones. The locations are Durban $(Lat.29^0 97^', Log.30^0 95^')$ coastal area, Richards Bay $(Lat.28^0 78^', Log.32^0 02^')$ coastal region, Cape Town $(Lat.33^0 97^', Log.18^0 60^')$ Mediterranean region and Pretoria $(Lat.25^0 73^', Log.28^0 18^')$ temperate region.

The discrepancy in ITU-R designated rainfall rate values as shown in Figure 1 is obvious, especially when compared with measure average (MA) and proposed zone. For example, in Durban the 0.1% and 0.01% percentage time rainfall rates are 68.98 mm/h and 138.83 mm/h, respectively in comparison with 15 mm/h and 60 mm/h for ITU-R P.837-1, while that of ITU-R P.837-4 gives 22 mm/h and 63 mm/h. The comparison of measure with ITU-R confirms that both ITU-R recommendations underestimate the cumulative distributions of rainfall rate which will definitely lead to underestimation of attenuation distribution. The discrepancies spread across the four selected locations. The rainfall cumulative distributions in four locations show that the rain climates are not well described by ITU-R predictive distributions. Thus, new climatic zones are suggested for Durban, Richards Bay, Cape Town and Pretoria which are P, P, N and Q respectively.

Rain occurrences are dynamic and distributed in time and space [9]. There is, therefore, month-to-month, season-to-season and year-to-year variability of rain rate distribution [10]. The need to design a radio communication system to meet performance and availability objectives in any month is a task that needs to be achieved. Propagation conditions vary considerably from month to month, and the monthly

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variability can change significantly from year to year. A radio propagation engineer must be able to design a link under the worst conditions for the ultimate determination of link availability [11]. In order to address this variability predicament, ITU propagation working groups have come up with the concept of worst month, as defined in Recommendation ITU-R P.58-1,2 [12].

The worst-month concept is relevant to the higher-grade telecommunications services and its data is determined from extended measurement periods so as to ensure that a representation of monthly variability is observed, particularly for the tails of the propagation distributions. The propagation worst month concentrates on calendar months. Once several years of data are available, the data for the individual calendar months from each year (e.g. all the individual January data sets) is averaged. The long-term averaged data for each of the twelve calendar months are then plotted together and the envelope of this set of monthly distributions provides the worst-month distribution [11]. This approach is used to determine cumulative distributions of average 1-minute rain rates for average year (AY) and average worst month (AWM). Then, the relations between them are derived and compared with ITU-R Recommendation. The relationship between the percentage of time of average year (P_{AY}) and average worst month (P_{AWM}) is optimized along with obtained rainfall rate distribution models by using the root mean square (RMS) error, average probability ratio (APR), and the chi-square statistic (χ^2). The calculation and results are fully described in [13].

III. VARIABILITY OF RAINFALL RATE DISTRIBUTION IN SOUTH AFRICA

Figure 1 in [13] shows four samples of seasonal variations of rainfall rate in South Africa, while Table 1 displays seasonal variation of rain rate for twelve locations at 0.1% of probability of exceedence with four climatological seasons. There are four major seasons in South Africa, namely: summer, autumn, winter and spring. The summer period (November-March) is characterized by higher rainfall rate than the other seasons [14]. In the summer rainfall region, light orographic rains are common along the windward slope of the eastern escarpment. Over most of the summer rainfall region, however, violent convection storms, accompanied by thunder, lightning, sudden squalls and often hail, are the source of most of the rainfall. The period between June and August (the winter period) is characterised by often long lasting and not very intense rains except along the mountains, where the orographic effect may induce heavy showers [14]. Between the winter and summer rainfall regions lies a transitional area where rain comes in milder measures.

From Figure 1 in [13], we observe that the seasonal variation of cumulative rain distribution for Durban, Bloemfontein, Ulundi, Pietermaritzburg, Vryheid and Brandvlei show a maximum rainfall rate in summer and a minimum in winter. The opposite is observed in Cape Town, Newcastle, Ladysmith and Pretoria which have their maximum rainfall rate in spring (September-October) and minimum rainfall rate in winter. Both East London and Richards Bay have their maximum rainfall rate in summer and their minimum in spring and autumn, respectively.

IV. STATISTICS OF THE WORST MONTH

Figure 1 shows the sample plots of cumulative distributions of mean worst month (MWM) and Table 1 in [13] give summary of seasonal variation of rainfall rate values. The month-to-month variability is observed for monthly cumulative distributions of 1-minute rainfall rate. For the percentage of time at 0.1% exceedence level, the maximum difference between rainfall rates reaches 184.97 mm/h. The maximum average worst month rainfall rate observed is 211.38 mm/h for the month of February in Ulundi and the minimum average worst month rainfall rate is 7.69 mm/h for the month of June in Newcastle. The maximum average worst month spreads from January to March when summer is pronounced. this is in contrast to Cape Town which has its maximum average worst month rainfall rate in August and minimum in December. The winter rainfall region is a relatively small area along the Cape West and South-West coasts, with a rainfall regime of Mediterranean type and a conspicuous winter maximum.

V. THE RELATIONSHIP BEWTEEN AY AND AWM

Cumulative distributions of 1-minute rainfall rate for average year (AY) and average worst month (AWM) for the twelve stations are obtained by statistically processing the rainfall rate data. The obtained dependence of percentage of time of the average year P_{AY} on percentage of time of the average worst month P_{AWM} for the same average 1-minute rainfall rate are shown in equations (1) and (2) which are validated by using the correlation coefficient R^2.

$$P_{AY} = a P^{b}{}_{AWM}\ (\%) \tag{1}$$

$$P_{AWM} = \alpha P^{\beta}{}_{AY}\ (\%) \tag{2}$$

Where a, b, α, and β are coefficients whose values are shown in Table 2.

In Figure 1, the average raw rainfall rate data are and equivalent worst month are plotted. The comparison between the two shows that the worst month is higher in rain rate values than the all month at the same percentage of time. These differences will surely account for discrepancy in radio link planning if the margin is not taking to consideration.

Figure 2 shows samples of models and ITU-R cumulative distributions of rainfall rates for average year (AY) and average worst month (AWM) for four stations. Table 3 shows statistical comparison between the percentage of time of derived model and ITU-R model based on AY and AWM. The RMS, APR and χ^2 values show a minimum value for the relations in all the sites. The RMS and APR show that the modeled relations are appropriate for obtaining relations between percentage of time of AY and AWM.

VI. CONCLUSION

The objective of this work was to study the characteristics of rain rate at millimetric bands in South Africa in order to provide communication system designers with propagation characteristics. The main rain characteristics studied were rain rate cumulative distribution, and worst-month distribution. The available Rain rate data collected at 60-minute integration time was converted to 1-minute by using Segal, Watson and Ajayi methods .Based on this 1-minute integration time rain rate, cumulative distribution were plotted for four chosen locations in South Africa.

Firstly, in the study, the two ITU-R recommendations gave different climatic rain zones except in Cape Town, where both classifications were identical. Both ITU-R recommendations were compared with measure and were found deficient. Thus, new climatic rain zone are suggested for studied locations. The suggested climatic rain zones for Durban, Richards Bay, Cape Town and Pretoria are P, P, N and Q respectively. The discrepancy between the ITU-R recommended distributions and measure cumulative distributions confirmed that ITU-R recommendations were underestimated.

Secondly, it was confirmed that South Africa seasonal classification comprises four major seasons namely: summer, autum, winter and spring. In this study, majority of locations had their maximum rain rate in summer with the exception of Cape Town whose peak rain rate was winter. Due to seasonal, monthly and yearly variability, worst-month statistics became handy in handling irregularity in radio link design. It was observed, in this paper, that the rain rate in cumulative distribution of worst month was higher compared with all-month at the same probability of exceedence. The worst-month statistics would provide the propagation engineers with the best means of achieving optimal link availability. In relation to season, all selected locations had their average worst month in summer except Cape Town which had it in winter.

Finally, a simple relation between average worst month and average year percentage of exceedence were obtained. The results were compared with ITU-R using three statistical parameters namely: root mean square, average probability ratio, and chi-square. The statistical test used to optimise the models and ITU-R recommendations showed that the models gave less RMS, APR and chi-square than the ITU-R recommendations.

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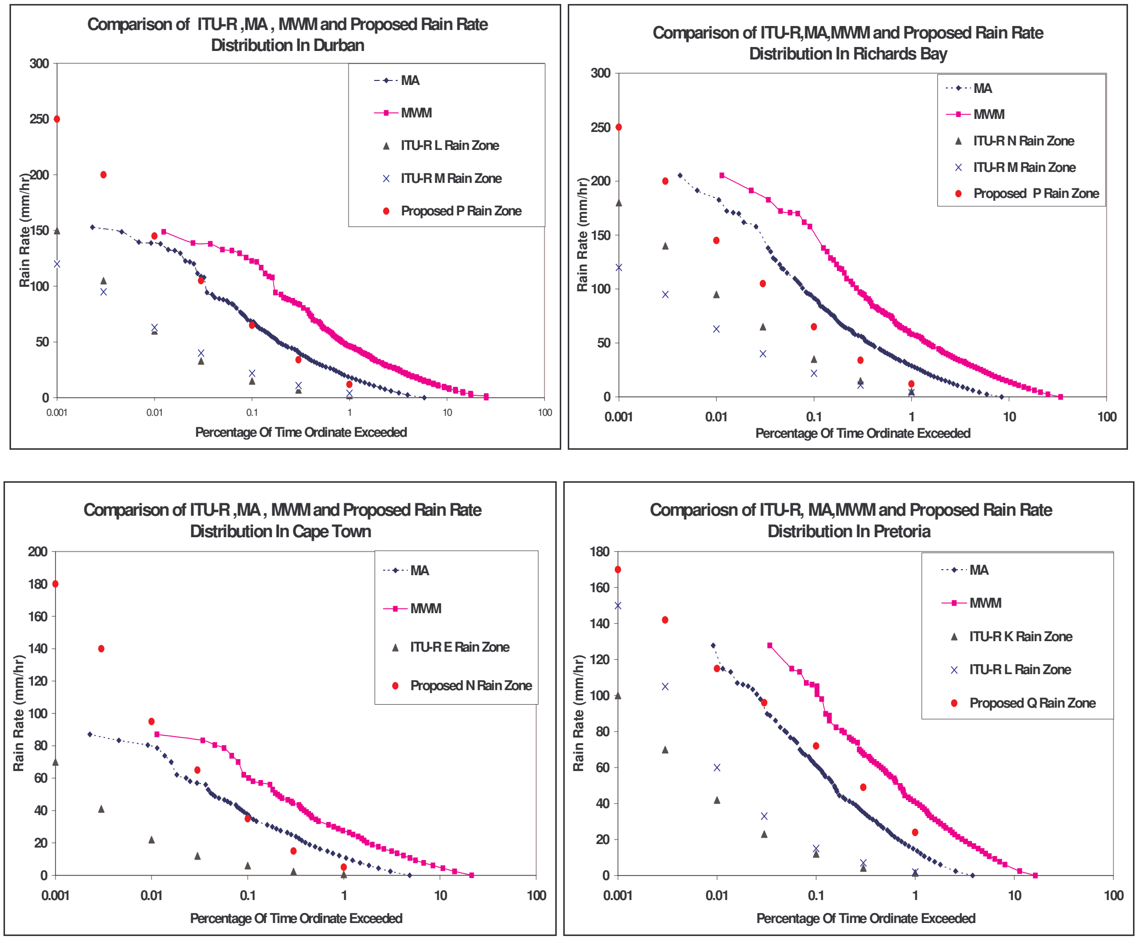

Fig.1: Comparison of ITU-R, MA, MWM and Proposed Rain Rate Distribution in South Africa.
Cumulative distributions of rainfall rate
MA: Measure average cumulative distribution
MWM: Mean worst-month cumulative distribution

TABLE 1: COMPARISONS OF ITU-R RAIN ZONES AND PROPOSED ZONES

Location	ITU-R P.837-1	ITU-R P.837-4	Proposed Zone	Climatic Region (SAWS)
Durban	L	M	P	Coastal Savannah
Richards Bay	N	M	P	Coastal Savannah
Cape Town	E	E	N	Mediterranean
Pretoria	K	L	Q	Temperate

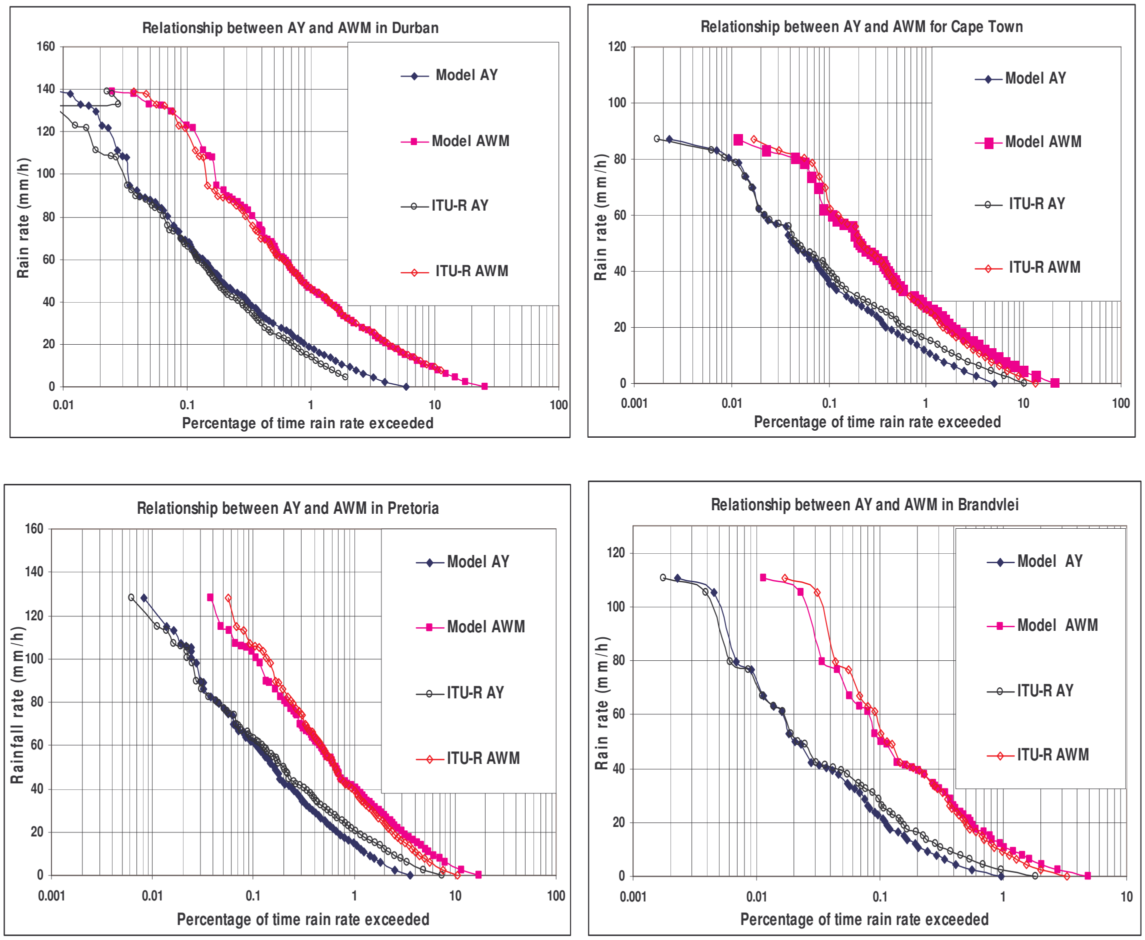

Figure 2: Modeled and ITU-R Cumulative Distributions of Rain rate for AY and AWM for 4 Sites

TABLE 2: COEFFICIENTS a , b , α , β , AND CORRELATION COEFFICIENTS R^2 VALIDITY FOR APPROXIMATION (1) AND (2).

Locations	a	b	α	β	R^2
Durban	0.2217	0.9593	4.7465	1.0353	0.9931
Bloemfontein	0.2188	0.9789	4.7097	1.0197	0.9981
East London	0.2542	0.9978	3.9358	1.0007	0.9985
Ulundi	0.2252	0.9969	4.0414	1.0016	0.9985
Richards Bay	0.2593	0.9631	4.0561	1.0373	0.999
Newcastle	0.2201	1.030	4.3085	0.9662	0.9958
Ladysmith	0.2448	0.8946	4.7797	1.1125	0.9952
Pietermaritzburg	0.2635	0.9484	4.0414	1.0481	0.9985
Pretoria	0.2298	0.9848	4.4291	1.0128	0.9974
Vryheid	0.2161	0.963	4.8787	1.0357	0.9973
Cape Town	0.2183	1.0197	4.4329	0.979	0.9983
Brandvlei	0.2016	1.0014	4.9488	0.9986	1

RAIN RATE RANGE $0.01 \leq R(1) \leq 211.38$

TABLE 3: COMPARISON BETWEEN THE MEASURED AND ITU-R CUMULATIVE DISTRIBUTIONS OF RAIN INTENSITIES FOR AY AND AWM FOR 8 STATIONS IN SA. (α =1% FOR χ^2 STATISTICS) [7]

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Sites		Model AY	Model AWM	ITU-R AY	ITU-R AWM
Durban	RMS	0.031	0.12	0.37	0.64
	APR	1.007	0.95	0.86	0.95
	χ^2	0.24	3.75	8.35	8.82
Bloemfontein	RMS	0.005	0.028	0.28	0.48
	APR	1.029	1.034	1.041	0.885
	χ^2	1.029	0.031	3.92	2.57
East London	RMS	0.055	0.23	1.015	1.52
	APR	1.01	1.024	1.15	1.088
	χ^2	0.021	0.088	1.85	1.20
Newcastle	RMS	0.004	0.022	0.138	0.22
	APR	1.015	0.99	1.019	1.05
	χ^2	0.0085	0.04	2.45	1.36
Pietermariztburg	RMS	0.016	0.081	0.22	0.43
	APR	1.021	1.024	1.085	1.086
	χ^2	0.059	0.29	3.91	4.07
Pretoria	RMS	0.0076	0.035	0.17	0.28
	APR	1.017	1.019	1.048	0.971
	χ^2	0.021	0.095	3.066	1.92
Cape Town	RMS	0.0083	0.038	0.14	0.23
	APR	0.995	1.011	1.0124	1.242
	χ^2	0.009	0.041	1.56	0.92
Brandvlei	RMS	0.00016	0.00081	0.029	0.045
	APR	1.034	1.033	1.066	1.091
	χ^2	0.025	0.088	1.85	1.20

Note t_α=112.3 for 80%, t_α=100.4 for 70%, t_α=50.9 for 30%, t_α=63.7 for 40% and t_α=76.2 for 50%.