# RAINFALL RATE MODELING FOR LOS RADIO SYSTEMS IN SOUTH AFRICA

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**Abstract:** The cumulative distributions of rain intensity for 12 locations in South Africa are presented in this paper based on 5-year rainfall data. The rainfall rate having an integration time of 60 minutes is converted to the ITU-R recommended integration time of 1 minute for Durban in South Africa. Consequently, values of coefficients $a$ and b so determined are used to convert 60-minute into 1-minute rain rates for other regions of South Africa. The resulting cumulative rain intensities are compared with the relevant ITU-R Recommendation P837. Based on this, an additional three rain zones are determined alongside the five ITU-R rain zones for South Africa.

**Key words**: Rain rate models for South Africa. Rain zones for South Africa.

## 1. INTRODUCTION

The study of precipitation effects on line-of-sight SHF/EHF radio links has increased in recent years as a result of the need for broadband data/voice and video networks. The millimeter wave spectrum at 30-300GHz is of great interest to service providers and systems designers today because of the wide bandwidths available for communications in this frequency range. Such wide bandwidths are valuable in supporting applications such as high speed data transmission and video distribution [1]. However, radio signals at millimeter wavelengths suffer greatly from attenuation [2]; indeed, the major offender to propagation at millimeter wave is precipitation, rainfall being the principal one. It has been a common practice to express rainfall loss as a function of precipitation rate. Such a rate depends on the liquid water content and the fall velocity of the drops [3].

Daily rainfall accumulations are universally recorded and hourly data are also fairly widely available by national weather bureaus [4]. Ajayi and Ofoche 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 [5]. Therefore, there is a need to convert the available one-hour rain rates measured by most national weather bureaus to one-minute data. ITU-R Recommendation P-837 classifies the Southern Africa region into five climatic rain zones by using the median cumulative distribution of rain rate for the rain climatic region [6]. The same approach is used in this paper to classify the South Africa rain zones. This may be used to estimate the signal outages at 0.01% of the time on radio communication links, since it defines the rainfall rate recommended by ITU-R to evaluate the availability of terrestrial and satellite radio links [7-8].

According to Olsen [9], global ITU-R radioclimatic models of point rain-rate distributions within discrete rain zones have been available for prediction of annual cumulative distributions of rain attenuation on terrestrial and earth-space line-of-sight links since the early 1970's. The work of Crane has considerably influenced the zonal models of the ITU-R, and the Crane models have been used extensively in the United States [2, 9]. The work of Segal has also greatly influenced the ITU-R zonal models, and provided a systematic approach for obtaining a specified number of rain zones in countries such as Canada that have sufficiently large data bases of short-integration-time data [4, 6, 9]. According to Olsen, because of the discrete nature of the zonal approach and its inherent lack of precision to some degree, various other attempts have been made to predict point rain-rate distributions, or statistics on such distributions, at specific points within a region. Such approaches have normally used measured rain-rate distributions for as many locations in a region as possible, and then fitted contour maps for particular parameters of the distribution. Using this approach, Segal employed contour maps of two parameters of the rain rate distribution, based on data for 47 locations within Canada and adjacent regions of the United States [9, 10].

Watson *et al.* [11] later mapped rain rates exceeded for 0.1% and 0.01% of an average year based on data for 400 locations within Europe. Moupfouma [7, 9] developed two more general global models using two parameters, one of which was the rain rate exceeded for 0.01% of the time. Finally, the ITU-R has provided a global contour map of the rain rate exceeded for 0.01% of the year since 1982 [9,12], although it was derived in part from use of the zonal model, at least at the early stages. The accuracy of the global map of the ITU-R has of course always been quite variable because of the lack of data for several regions of world including Africa. Therefore while Recommendation P-837 classifies the Southern Africa region into five climatic rain zones, the scarcity of the mapping data renders this zonal classification inconclusive, and thus subject to further refinement.

A major issue to be considered is the data collection period. Tyson observes that over the period of 1910-1972, much of the summer rainfall area of South Africa experienced a quasi 20-year oscillation rainfall [13-14, 19]. The rainfall spectrum shows a clear peak at about 20 years as well as peaks in 2-3 and 3-4 year bands [14]. While several global measurement campaigns have reported measurement data covering 10-40 years (see, for example, Segal [4], Ajayi and Ezekpo [16], and Calla [21]) , it is observed that most recent campaigns in precipitation studies have taken two to five years (see, for example, [4], [5], [15], [20] reporting on Italy (2 years), Southern UK (5 years), Greece (2 years), Nigeria (2 years), and India (3 years)). We thus deem that year-to-year rainfall variability necessitates minimum measurement durations of 5 years, in order to cover the 3-4 year peaks; and this is therefore the duration adopted in this paper. However, for fuller radioclimatological classification of the region, 20-year rain rate statistics may be necessary.

## 2. TROPICAL RAIN MEASUREMENTS STATISTICS

Since rainfall is a natural and time varying phenomenon, there is, therefore, seasonal and year-to-year variability of the rainfall rate distribution. In a measurement campaign spearheaded by URSI, annual cumulative distribution of rain rate has been obtained at several locations in the tropical and sub-tropical regions in the world. In India, Sakar et al have produced the Reference Data Manual for rain rate distribution over the Indian sub-continent, making use of the heavy rainfall data of 5 minutes and 15 minutes available at 35 different geographical regions in India [15]. The rapid response rain gauges with 10-second integration time were used to measure the rain rate in Delhi, Shillong, Calcutta, Bombay and Tirupati. The resulting rain rates at 0.01% probability (denoted as $R_{0.01}$) are 130 mm/h for Shillong, 128 mm/h for Calcutta, 130 mm/h for Bombay, 120mm/h for New Delhi, and 80 mm/h for Tirupati [15].

At the same time, a rain rate measurement campaign in Africa in 1994 covered Cameroun, Nigeria and Kenya. Although the total rain accumulation was highest in Doula (Cameroun), the rain rate exceeded 0.01% of the time were comparable at Doula and Ile-Ife in Nigeria. The rainfall cumulative distributions in Doula and Nairobi in Kenya showed that the rain climate was not well described by the ITU-R predictive distributions [15]. Ajayi and Ezekpo used the Rice-Holmberg technique to predict short integration time (one-minute) rainfall rate from long-term precipitation data from 37 stations in Nigeria over a period of 30 years [16]. Adimula et al compared the cumulative rainfall rate distribution obtained at Ilorin and Ile-Ife (Nigeria), Belem (Brazil), and Brazzaville (Congo) with the ITU-R rainfall rate distribution [17]. Meanwhile measurements in Brazil showed that ITU-R recommended distribution overestimate the measured distributions for all sites, implying that the ITU-R rain climatic distributions always provide conservative estimates of attenuation 15].

As a result of the rapidly varying nature of rainfall at a given point, the cumulative rainfall rate distribution measured is dependent on the integration time of the rain gauge. 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 [4], Segal has defined a conversion factor, $\rho_\tau(P)$ for converting data obtained with a gauge having an integration time of $\tau$ minutes to equivalent one-minute statistics, as follows [4]:

$$\rho_\tau(P) = R_1(P) / R_\tau(P) \tag{1}$$

where $R_1$ and $R_\tau$ 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 $R_\tau$ [4,5]). The factor $\rho_\tau(P)$ is also given by the power law [4]:

$$\rho_\tau(P) = a.P^b \tag{2}$$

over the range $0.001\% \leq P \leq 0.03\%$, with $a$ and $b$ being constants that depend on the climatic zone. Watson et al [11] considered the conversion factors $C_R$ and $C_e$ for rain gauge integration times in the range of 10 seconds to 60 minutes, where:

$$\begin{aligned} C_e(R) &= e_T / e_\tau \\ C_R(t) &= R_T / R_\tau \end{aligned} \tag{3}$$

and where $C_e$ refers to the ratio of the exceedances (with the same probability P) for a given rain rate $R$ measured using gauges with integration times $T$ and τ; $C_R(t)$ refers to the ratio of rain rates exceeded for a given percentage of time $t$ as measured by rain gauges with integration times $T$ and $\tau$. Here, $C_R(t)$ depends on the percentage of time considered [5,11]. The conversion factors $C_R$ and $C_e$ obtained at Ile-Ife in Nigeria for the measurement period September 1979 to December 1981 using the rain rate data obtained from a fast response rain gauge with an integration time of 10 seconds are based on Watson's method [12]. It has also been found that a power law relationship exists between the equiprobable

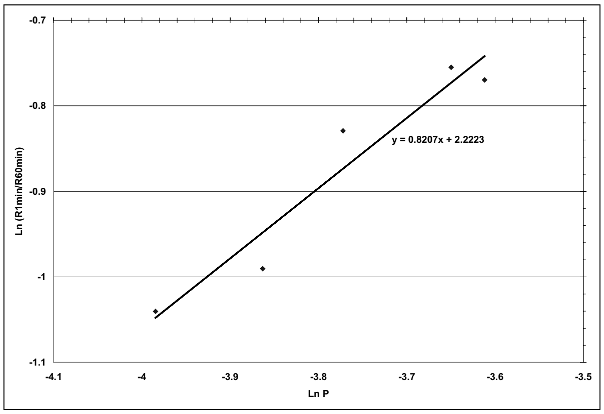

Figure 1. Determination of coefficients $a$ and $b$ for Durban, South Africa

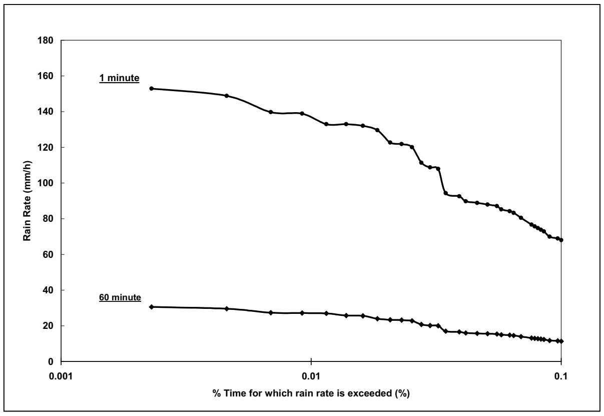

Figure.2. Cumulative Distribution of Rain-rate for Durban for 1-minute and 60-minute integration times

rain rates of two integration times. The power law relationship is given by [15]:

$$R_{\tau} = aR_{T}^{b} \tag{4}$$

where $R$ is the rain rate, $\tau$ is the integration time at which the rain rate is required, and $T$ the integration time at which the rain rate is available. Flavin [18] also sought a direct and universal expression between 1-minute and 5-minute rainfall rates by examining the cumulative distributions for four locations in Europe, four in North America and five in Australia. From a scatter plot of resulting data points a simple power-law fit was produced giving (as seen in equation (4) above):

$$R_1 = u.R_5^{v} \tag{5}$$

where $R_1$ and $R_5$ are the 1-minute and 5-minute rainfall rates exceeded with equal probability, $u$ and $v$ are the regression coefficients[1] [4]. The results obtained between 1-minute and 5-minute and 6-minute integration times at Ile-Ife have been compared with the results obtained by Flavin [18], and the following relationships were established [5]:

$$\begin{aligned} R_1 &= 0.991R_5^{1.098} \ (Ajayi \,\&\, Ofoche, Ile-Ife \ [5]) \\ R_1 &= 0.990R_6^{1.054} \ (Flavin, Austr, USA, Europe)[18]) \end{aligned} \tag{6}$$

where $R_1$ is the 1-minute rain rate, $R_5$ is the equiprobable 5-minute rain rate value, and $R_6$ is the equiprobable 6-minute value.

From the 5-year rain data measured with an integration time of 60 minutes for 12 different locations in South Africa, the Segal and the Ajayi approaches were used to determine the conversion factor to convert the 60-minute integration time to an effective 1-minute integration time (see equations (1) and (2)). Note that the conversion is only effected for Durban due to the fact that 1-minute data was only available for Durban for the year 2004, but was not available for the other 11 sites in South Africa. This approach is consistent with that of Ajayi and Ofoche, where conversion data for Ile-Ife was used [5]. This results in a linear scatter plot of data points, in which a simple power law fits, giving as is shown in Figure 1 (where Ln refers to natural logarithm):

$$R_{1\,\mathrm{min}} = 9.228R_{60\,\mathrm{min}}^{0.8207} \tag{7}$$

The Durban coefficients of $a$ and $b$ in equation (7) are used to convert other 60-minute rain rate data from other locations in South Africa to an effective 1-minute integration time [5]. As a matter of interest, the results obtained in the conversion of 60-minute into 1-minute integration time rain rates in Durban from January to December 2004 are further compared with those obtained by Ajayi and Ofoche [5]. The latter examined the effective 1-minute, 2-minute, 5-minute, 10-minute, and 20-minute cumulative distributions of rain rate for Ile-Ife. The 60-minute coefficients are obtained through extrapolation. Table 1 shows the comparison between the Durban coefficient of $a$ and $b$ and the corresponding coefficients obtained for Ile-Ife. Linear extrapolation gives a=11.565 for Ile-Ife for 60-minute integration time, while a logarithmic extrapolation gives b=0.7982. These results are quite close to the Durban values in (7). It has been reported that the coefficient $a$ may not be very

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[1] Although all of the data were merged into a single scatter plot, the integration time for the stations in Australia was actually 6 rather than 5 min. This discrepancy is believed to be negligible in comparison with the normal geographic and statistical variability [4]

dependent on climate, while the dependence of $b$ on climate may require further investigation [5]. Figure 2 shows, for Durban (using 2004 data), the values of equiprobable rain rate for integration times of 1-minute and 60-minute for occurrence probability of 0.1% or less. The figure confirms the power law relationship between equiprobable rain rates of two different integration times, as they are based on raw data. The figure shows that the longer integration time hides the probable rainfall peaks, during which the highest outages take place. Therefore outage probabilities and fade margins would be inaccurately determined if the 60-minutes integration data are used.

## 3. COMPARISON OF RAIN RATE STATISTICS FOR SOUTH AFRICA

We compare the rain rate statistics for 12 locations in South Africa over a period of 5 years. It has been reported that the main factors that cause the differences in the annual rain intensities in South Africa are the influence of the South Atlantic Ocean, Indian Ocean, and the topography [13-14, 19]. The combination of these effects causes the differences in the annual rain intensities among the South Africa climatic regions. The rainfall is unreliable and unpredictable throughout the country. Large fluctuations around the regions are compared in Figure 3, 4 and 5, which are based on conversion to 1-minute integration times. The locations are then classified according to the South Africa climatic regions. Table 2 shows the locations where precipitation data was obtained from South African Weather Service (SAWS), as well as the corresponding climatic categorization. The yearly 1-minute integration time rain rate statistics at 0.01% exceedance of the time for each location within the same climatic regions are compared. These give the variation in the annual rain intensity for the entire period of 5 years.

In Figure 3, Richards Bay consistently records the highest yearly rain rate in the initial three years (2000-2002), with a peak of 182.66 mm/h in 2001. Over these three years, Durban records the second highest of 139.66 mm/h in 2002, while Pietermaritzburg has a high value of 126 mm/h in 2000 and 115 mm/h in 2001. Despite the fact that Durban and Richards Bay lie in the same climatic region, there are differences in the rain intensity from year to year. The highest rain rate in the zone was recorded in the year 2004 with values of 211.38 mm/h and 202.16 mm/h for Ulundi and Pietermaritzburg, respectively. For three consecutive years, (2002 to 2004) Ulundi records a progressive increment in rain rate, as is also applicable to Pietermartzburg. And for two consecutive years 2000-2001, a decrement in rain rate is recorded in both locations. A measure of differences is also noticed between the two locations in this climatic region but the differences are not as large as that of the Coastal Savannah.

Table.1. Comparison of coefficients $a$ and $b$ for Durban, South Africa, with the Measurements in Ile-Ife, Nigeria ($\tau$=1 minute)

| **Integration time, T** | | **Value of Coefficient** | |
|---|---|---|---|
| **Station** | **T (minutes)** | $a$ | $b$ |
| Ile-Ife | 2 | 0.872 | 1.055 |
| Ile-Ife | 5 | 0.991 | 1.098 |
| Ile-Ife | 10 | 1.797 | 1.016 |
| Ile-Ife | 20 | 4.311 | 0.853 |
| Ile-Ife (extrapolation) | 60 | 11.565 | 0.798 |
| Durban | 60 | 9.228 | 0.8207 |

Table 2. Climatic zone classifications from South African Weather Service (SAWS), Pretoria, South Africa

| **Locations** | **Latitude South** | **Longitude East** | **Climatic Regions (SAWS)** |
|---|---|---|---|
| Durban | 29°.97' | 30°.95' | Coastal Savannah |
| Richards Bay | 28°.78' | 32°.02' | Coastal Savannah |
| Cape town | 33°.97' | 18°.60' | Mediterranean |
| Brandvlei | 30°.47' | 20°.48' | Desert |
| East London | 33°.03' | 27°.83' | Savannah |
| Ladysmith | 28°.57' | 29°.77' | Inland Temperate |
| Newcastle | 27°.77' | 29°.98' | Inland Temperate |
| Vryheid | 27°.78' | 30°.80' | Inland Temperate |
| Pretoria | 25°.73' | 28°.18' | Temperate |
| Bloemfontein | 29$^0$.10' | 26°.30' | Steppe |
| Ulundi | 28°.30' | 31°.42' | Inland Savannah |
| Pietermaritzburg | 29°.63' | 30°.40' | Inland savannah |

In Figure 4, we plot yearly rain rate variations for temperate and inland temperate regions. We observe that Newscastle and Pretoria record the two highest rates of 160mm/h (in 2000) and 157mm/h (in 2003), respectively. Vryheid recorded the lowest rates in this category, with a minimum rate of 76mm/h in 2003. On the other hand, the rain intensity in Ladysmith appears to be roughly uniform over four years between 2001 and 2004, with a mean value of 103mm/h. As already stated, Pretoria has a high rate of 160mm/h in 2000 while the rain intensities for 2001 and 2004 are quite close (115mm/h and 113mm/h,respectively), with the corresponding values for 2002 and 2003 also remaining almost the same at 101mm/h and 106mm/h, respectively.

Finally, in Figure 5, we compare four different climatic zones, namely: Mediterranean, Savannah, Steppe and dessert. East London in the savannah zone records the highest two rates over the five years, namely, 133mm/h in 2001 and 157mm/h in 2002. This is followed by Bloemfontein in the Steppe zone, which records two

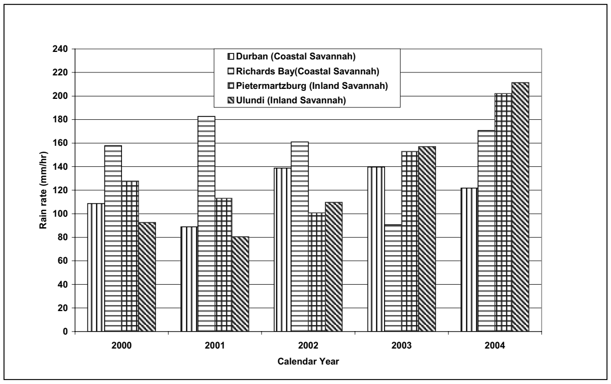

Figure.3. Variation in the Annual Rain Intensity (mm/h) Exceeded for 0.01% of the Time for South Africa (Coastal & Inland Savannah Regions)

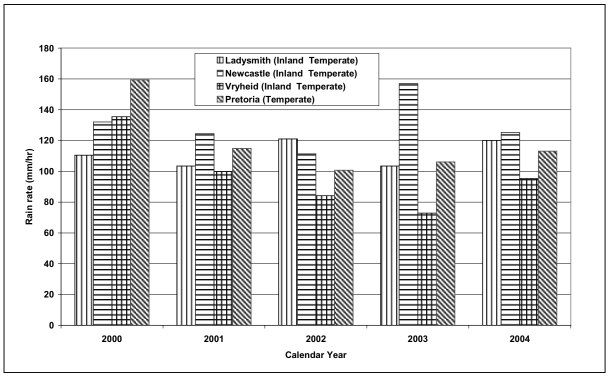

Figure.4. Variation in the Annual Rain Intensity (mm/h) Exceeded for 0.01% of the Time for South Africa (Temperate and Inland Temperate Regions)

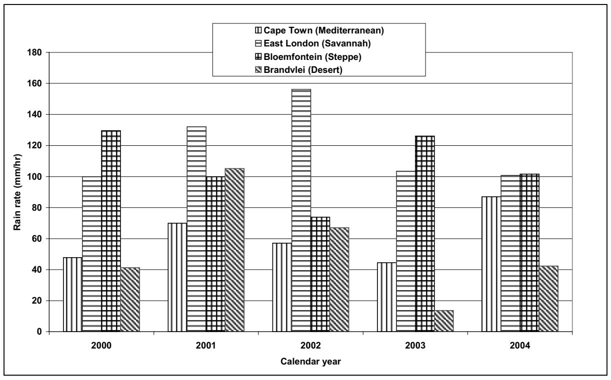

Figure.5. Variation in the Annual Rain Intensity (mm/h) Exceeded for 0.01% of the Time for South Africa (Mediterranean, Steppe, Savannah & Desert Regions)

similar highs in 2000 (130mm/h) and 2003 (127mm/h). Note that there is a discernible periodicity for Bloemfontein (with almost similar rates in 2000 and 2003, followed by similar ones in 2001 and 2004) and Cape Town. However, there is no obvious pattern for East London and Brandvlei (desert region). Cape Town which lies in the Mediterranean region of South Africa has its highest rain intensity of 87.04mm/h in the year 2004, with rain intensities in the other years being relatively low. Rain rate in the year 2000 and the year 2003 are almost the same (47.7mm/h and 44.5mm/h respectively).

The 5-year rain statistics with 1-minute integration time for the 12 locations in different climatic regions at 0.01% exceedance of the time are compared in Figure 6. It is seen that Richards Bay which lies in the coastal savannah has the highest rain intensity, followed by Ulundi, Pietermaritzburg and Durban. Ulundi and Pietermaritzburg lie in the Inland area of Coastal Savannah region. The high rain peaks that occur in these areas are mostly due to Indian Ocean influence in the region. The moist Indian ocean air masses which are the chief source of the rain over most of the countries gradually losses their moisture as they move towards the western interior .The very lowest rainfall occur on the west coast, with Brandvlei which is found in the desert area showing the lowest rain intensity. Cape Town which lies in the Mediterranean climate is seen to have low rain fall intensity, similar to that of Brandvlei which lies in the desert region of South Africa. This is because Cape Town is situated towards the western coast of South Africa ,and its rainfall mostly occurs during winter (June through August ) as opposed to other places in South Africa which have their rainfall during summer (November through March ) [17].

One concludes that the north-eastern zones of South Africa (which include the coastal Savannah and Inland Savannah climate zones) have higher rain rates than the western parts (which have Mediterranean and desert climate zones). In addition, one observes in Figures 3-5 that there is a peak quasi-periodicity every 3-4 years, as observed by Tyson et al; this therefore partially justifies the 5-year measurement period.

## 4. CUMULATIVE DISTRIBUTION OF RAIN INTENSITIES FOR SOUTH AFRICA

Cumulative distributions (CD's) of five-year 1-minute rain intensities for each climatic region in South Africa are plotted in Figure 7. 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 analysis is done for single site in each of the eight climatic regions in South Africa. For Durban, at the higher time percentage of 0.1%, the rain rate recorded is 68.98 mm/h; while for the lower time percentage 0.01%, the rain rate is 138.83 mm/h. Therefore the rain intensity for time percentage differences between 0.1% to 0.01% is 69.85 mm/h. At higher time percentage of 0.1% for Pietermaritzburg, the observed rate is 79.55 mm/h, with the difference in rain intensities between 0.1% and 0.01%

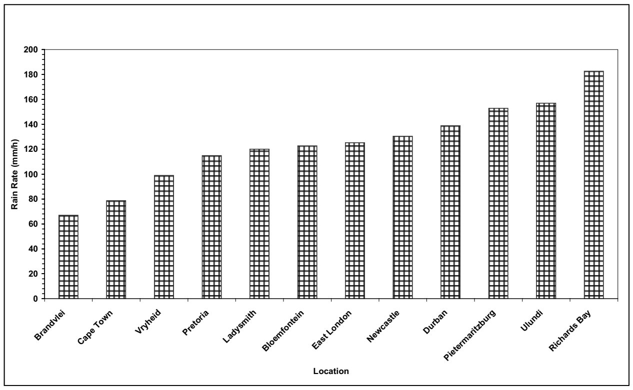

Figure.6. Comparison of the 5-year Rain rate (mm/h) exceeded for 0.01% of the time for 12 locations in South Africa

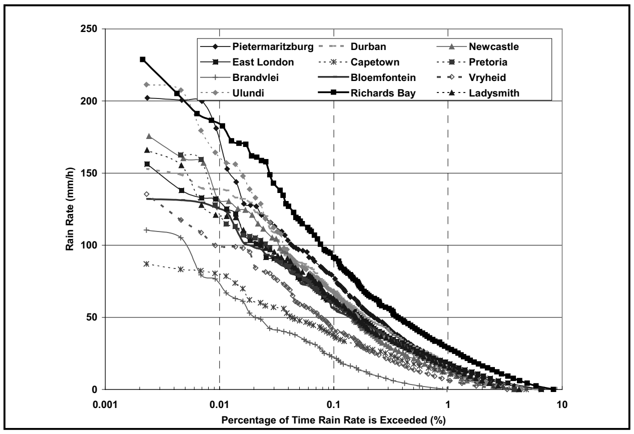

Figure.7. Cumulative Distribution of Rain Intensities for South Africa for an average of 5 years

being 73.37 mm/h. Similarly for Newcastle, for 0.1% of time percentage the rain intensities is 63.07 mm/h and the lower time percentage the rain intensity is 130.39 mm/h. The rate difference between 0.1% and 0.01% is 67.32 mm/h.

In the case of Pretoria, the distribution shows that at 0.1% the rain intensities is 61.07 mm/h and 0.01% has 114.90 mm/h. The rain rate difference between 0.1% and 0.01% of the time is 53.83mm/h. For Cape Town, we see that at the higher time percentage of 0.1% the rain intensity is 37.95 mm/h while at the lower time percentage of 0.01% the rain intensity is 78.60 mm/h. The rain intensity difference at higher and lower time percentage is 40.65 mm/h. This difference is almost close to that of Brandvlei. For East London, the time percentage of 0.1% has a rain intensity of 61.07% mm/h, while at 0.01% the rain intensity is 125.27mm/h. The difference in rain intensity between 0.1% and 0.01% is 64.20mm/h. At the higher time percentage of 0.1% the rain intensity is similar to Pretoria. In Bloemfontein at higher percentage of 0.1%, the rain intensity is 56.01mm/h, while at the lower time percentage of 0.01% the value is 122.70mm/h. The difference between the higher and lower time percentage recorded gives an intensity of 66.69 mm/h. Finally, for Brandvlei, at higher percentage of 0.1% the rain intensity is 25.19 mm/h, while at the lower time percentage of 0.01%, the intensity is 67.02 mm/h. The rain intensity difference between the higher and lower time percentages is 41.83 mm/h, which is close to the difference in Cape Town.

The conclusions drawn here are similar to those in section 4: that the north-eastern zones of South Africa have higher rain rates than the western parts, and are thus more prone to rain attenuation.

## 5. DETERMINATION OF SOUTH AFRICA RAIN CLIMATIC ZONES

The ITU-R climatic map for the world divides the whole globe into 15 climatic zones. This shows the rain intensity for the various climatic zones [6]. According to the ITU-R classification, Southern Africa has six rain zones, namely: C, D, E, J, K and N of which South Africa has five. These are: C, D, E, K and N. However, these ITU-R designations are not necessarily adequate, as discussed before in the case of India, China, and Brazil [9]; therefore there is need to redefine the ITU-R regional climatic zones based on the actual local data. From the 5-year actual rain data for 12 different geographical locations which is converted into 1 minute integration time in South Africa, the resulting rainfall rate distribution at 1.0%, 0.3%, 0.1%, 0.03% and 0.01% probability level (percentage of time ordinate exceeded) is shown in Figure 7. The rain intensity exceeded (mm/h) for the 12 selected geographical locations in South Africa is compared with the ITU-R rain climatic zone table. The errors obtained by comparing each location against different ITU-R climatic zones are determined; the ITU-R zone that gives the least recorded error value for each geographical location is chosen as the location’s rain climatic zone. The resulting climatic rain zones are shown in Table 3. From the local data measured by South Africa Weather Services for 12 locations, four climatic rain zones are determined, namely, N, M, P and Q. Hence three “additional” rain climatic zones are added to ITU-R rain Climatic zone for South Africa. One concludes that ITU-R zoning underestimates the precipitation in each zone, as evidenced by the fact that the “new” zones have higher precipitation rates that the zones prescribed by Recommendation P837. As more data is gathered a fuller picture of these recommendations will emerge.

## 6. CONCLUSIONS

The five-year rainfall data measured by the South Africa Weather Services for 12 different locations have been utilized to study the effect of integration time on the cumulative distribution of rain rate for South Africa. Values of equiprobable rain rate for 1-minute and 60-minute integration times for probabilities of 0.1% or less have been employed to confirm the power law relationship between the two integration times. The resulting coefficients $a$ and $b$ obtained from the conversion are comparable with the results of Ajayi and Ofoche for Ile-Ife in Nigeria.

Comparison of the 5-year rain intensities for the 12 locations shows the variability of the rain statistics from one location to another. Richards Bay which lies in the coastal area of South Africa has the highest rain intensity $R_{0.01}$ of 182.66 mm/h, and Brandvlei which is found in the desert region has the lowest rain intensity 67.02 mm/h. The cumulative distributions of 1-minute rain intensities for the 5-year period are obtained for each location that lies in the same climatic region. Based on the available 60-minute rain data (converted to 1-minute integration time), four climatic rain zones, N, M, P and Q are determined for South Africa, as against the ITU-R classifications of C, D, E, K and N. Thus an additional three rain zones have been identified for South Africa. Further measurements will be necessary to confirm these zones as well as the conversion coefficients $a$ and b for South Africa.

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Table.3. Comparison between Proposed and ITU-R Rain Climatic Zones for 12 Geographical Locations in South Africa

| Location | ITU-R P.837-1 | ITU-R P.837-4 | Proposed Zone |
|---|---|---|---|
| Durban | L | M | P |
| Richards Bay | N | M | P |
| Cape Town | E | E | N |
| Brandvlei | D | D | M |
| East London | K | K | Q |
| Ladysmith | K | L | Q |
| Newcastle | K | L | P |
| Vryheid | K | L | N |
| Pretoria | K | L | Q |
| Bloemfontein | K | L | P |
| Ulundi | L | L | P |
| Pietermaritzburg | L | L | P |

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