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Estimation of rain attenuation based on ITU-R Model for Terrestrial link in Libya

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Abstract—**In this paper, ITU-R P. 530-16 model is used to estimate the rain attenuation for terrestrial link for three cities in Libya, that named Shahat, Tripoli, and Sabha.**
Depending on locally data of the rain rate exceeded for 0.01% in these cities, the specific attenuation for vertical and horizontal polarization is presented with changing the operating frequency.
For horizontal polarization, the rain attenuation is founded with changing the path distance based on the rain rate that locally measured and that obtained from the ITU-R P.837-5 climatic zone map for 0.01% time exceeded; and by using the local data of the rain rate, the rain attenuation is obtained with variation of the percentage of time exceeded.

***Keywords*—rain attenuation, terrestrial link, path distance, percentage of time exceeded, ITU-R P.530-16 model.**

I. INTRODUCTION

Rainfall is a natural and time varying phenomenon that varies from location-to-location and from year to year. Above a certain threshold of frequency, attenuation due to rainfall becomes one of the most important limits of the performance of line-of-sight (LOS) microwave links [1]. Generally, at frequencies below 7 GHz, excess attenuation due to rainfall and atmospheric gaseous, frozen particles such as snow, ice crystals is very small and can be neglected in radio system design [2]. When designing line-of-sight (LOS) microwave link or satellite link operating at frequency above 10 GHz, the occurrence of rain along the transmission path is considered as a main impairment factor for microwave system degradation. Absorption and scattering of radio waves due to rain drops result in signal attenuation and in reduction of overall system availability and performance [3].

However, at frequencies above 7 GHz liquid rain drops in the form of absorption and scattering do become serious contributes to transmission losses. The rainfall causes absorption and scattering of radio waves which result in the reduction of the receive signal level [2].These problems have forced the research community to balance the trade-off between bandwidth availabilities and rain attenuation issues at higher frequencies. The attenuation on any given path depends on the value of specific attenuation, frequency, polarization, temperature, path length and latitude [3].

Due to this great effect of rain attenuation on terrestrial point-to-point and point-to-multipoint radio communication systems for frequency bands above 10 GHz, several efforts have however led to the development of rain rate and rain attenuation models[4].

Therefore, in the planning of terrestrial line-of sight systems, a fairly precise rainfall-rate statistics data is essential for the proper prediction of rain induced attenuation on propagation paths.

Several models have been proposed for the prediction of attenuation due to rain on terrestrial radio paths. These models are intended for the estimation of rain attenuation in cases when adequate direct measurements are not available. Most of the methods proposed for predicting rain induced attenuation make use of the long term cumulative distribution of point rainfall measurement [5].

There are two broad classes of rain attenuation predictions on any microwave link: The analytical models which are based on physical laws governing electromagnetic wave propagation and which attempt to reproduce the actual physical behavior in the attenuation process; and the empirical models which are based on measurement databases from stations in different climatic zones within a given region [6].

Various rain attenuation estimation models are available depending on the climatic and geographical conditions. The important models are Crane global model, Two-component model, Simple Attenuation model, Excell model, Misme Wald teufel model, Garcia model, International Telecommunication Union Radio Communication sector (ITU-R) model, Bryant model, Dissanayake, Allnutt and Haidara model, and Moupfouma model . Among these models, ITU-R model provides the most accurate statistical estimate of attenuation on slant paths. [7].

This paper aims to estimate the rain attenuation in microwave range using the ITU-R P.530-16.[8] rain model for three cities in Libya, based on the rain rates that obtain from the measured local data and from the climatic map of ITU-R P.837-5 [9].

II. RAIN ATTENUATION MODELS

Along with the rain rate measurement campaigns, it is necessary to obtain measurements of the attenuation experienced by signals so as to compare these data with the results of the existing prediction models. Rain attenuation over a terrestrial path is defined as the product of specific attenuation (dB/km) and the effective propagation path length (km). The

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effective path length is determined from the knowledge of the link length and the horizontal distribution of the rain along the path. The rain attenuation *A* (dB) exceeded at *p* per cent of time is calculated as

$$A_{0.01} = deff\ \gamma R = \ gR\ \mathrm{d}r \qquad (1)$$

The recommendation of the ITU-R P.838-3 establishes the procedure of specific attenuation from the rain intensity. The specific attenuation, γR (dB/km) is obtained from the rain rate *R* (mm/h) exceeded at *p* percent of the time using the power law relationship as

$$\gamma R \ = \ kR^{\alpha} \qquad (2)$$

where$k$ and α depend on the frequency and polarization of the electromagnetic wave. The constants appear in recommendation tables of ITU-R P. 838-3.[10] and also can be obtained by interpolation considering a logarithmic scale for k and linear for α[3].

Some techniques are needed to cope with the temporal and special variation of rain characteristics. A number of rain attenuation prediction models Each of these models proposes different techniques to predict the rain attenuation of the link path. Examples of rain attenuation prediction models for terrestrial microwave prediction are ITU model , Moupfouma model , Crane Global model, and Silva Mello model [11].

1. ITU-R prediction method

The ITU-R recommendation (ITU-R P. 530-16) suggests the path attenuation exceeded for 0.01% of the time as the product of specific attenuation, γR (dB/km) and effective path length, d_{eff} for the consideration of time-space variability of rain intensity along the terrestrial path. The obtained value is scaled by the empirical formula to other percentages of time between 1% and 0.001% whose detail approach can be found in (ITU-R P. 530-16). This method is advised to be used in all parts of the world which stated that the rain attenuation needs to be considered for any operating frequency beyond 5 GHz and for frequencies up to 100 GHz with path lengths up to 60 km. [12].

The following simple technique may be used for estimating the long-term statistics of rain attenuation:

1. Obtain the rain rate $R_{0.01}$exceeded for 0.01% of the time (with an integration time of 1 min). If this information is not available from local sources of long-term measurements, an estimate can be obtained from the information given in Recommendation ITU-R P.837.
2. Compute the specific attenuation, γR (dB/km) for the frequency, polarization and rain rate of interest using Recommendation ITU-R P.838.
3. Compute the effective path length, d_{eff}, of the link by multiplying the actual path length d by a distance factor r. An estimate of this factor is given by [5].

   $$deff = r\ d \qquad (3)$$

   where$d$ is the actual path length, and r is a factor which reduces in magnitude as *d* increases. It is given by:

   $$r = \frac{1}{1+{}^{d}/_{do}} \qquad (4)$$

   The quantity d_0 is a rainfall-rate-dependent factor introduced, to reflect the fact that the greater the intensity of rainfall in a storm, the smaller the physical dimensions of the storm are.

   $$d_0 = 35e^{-0.015}\ R_{0.01} \qquad (5)$$

   for$R_{0.01} \leq 100$ mm/h. for $R_{0.01} > 100$ mm/h, the value 100 mm/h is used in place of $R_{0.01}$ [1].
4. An estimate of the path attenuation exceeded for 0.01% of the time is given by:

   $$A_{0.01} = deff\ \gamma R \qquad (6)$$

The attenuation $A\%p$ (in dB) exceeded for other time percentages, p of an average year may be calculated from the value of $A_{0.01}$ by using the following:

$$Ap = 0.12 * A_{0.01} * p^{-(0.546+0.043\ log10(p))} \qquad (7)$$

The major short coming of the extrapolation approach of Equation (7) is that it does not perform well in tropical regions, especially at higher rain rates [13].

2. Moupfouma rain attenuation model

Moupfouma proposed an empirical model for predicting rain-induced attenuation on terrestrial paths from the knowledge of 1 min rain intensities recorded in a broad range of geographical areas and the corresponding percentages of time *p* during which these rain rates are exceeded. The rain-induced attenuation on a LOS path can be expressed as

$$A(dB) = kR^{\alpha}\ l_{eff} \qquad (8)$$

With

$$l_{eff} = rl \qquad (9)$$

Where *l* (km) is the actual path length, L_{eff} the effective path length and *r* a reduction coefficient given by

$$r = \frac{1}{1+C\ l^{m}} \qquad (10)$$

The attenuation *A* (dB) and the 1 min rain rate R (mm/h) are calculated for the same time percentage; *k* and *a* are the regression coefficients depending on frequency and polarization. To derive *C* and *m*, the author used experimental data obtained from 30 terrestrial radio links in the 7–38 GHz band range with path length up to 58 km, located in Congo, Japan, the US and European regions. It was found that *C* depends on probability level $\mathcal{P}$ (in percentage) of interest for which data are available, and *m* depends on the radio link path length and its frequency. The resultant formula for the path length reduction factor is given by

$$r = \frac{1}{1+0.03(\frac{P}{0.01})^{-\beta l^{m}}} \qquad (11)$$

With

$$m(f,l) = 1 + \psi(F) log_{e} l \qquad (12)$$

And

$$\psi(f) = 1.4 \times 10^{-4} F^{1.76} \tag{13}$$

Here *f* is the frequency in GHz and the β coefficient is given as a result of a best fit by [14]:

$$l < 50\ km$$

$$\beta = 0.45 \text{ , for } 0.001 \leq \mathrm{P} \leq 0.01$$

$$\beta = 0.6 \text{ , for } 0.01 \leq \mathrm{P} \leq 0.1$$

$$l \geq 50\ km$$

$$\beta = 0.36 \text{ , for } 0.001 \leq \mathrm{P} \leq 0.01$$

$$\beta = 0.6 \text{ , for } 0.01 \leq \mathrm{P} \leq 0.1$$

3. Crane Global rain attenuation model

The Crane Global model was developed for use on terrestrial paths. The model is based entirely on geophysical observations of the rain rate, the rain structure and the vertical variation of atmospheric temperature. The model was developed based on data analyzed for path lengths of 5, 10 and 22.5 km. To obtain a sufficient sample size at 22.5 km, Crane assumed that for point rates in excess of 25 mm/h, their occurrence probabilities were independent over distances greater than 10 km. This assumption was based upon experience with weather radar data. The assumption was also in agreement between observations at path lengths of 10, 15, 20 and 22.5 km and with the power law approximation. Crane accomplished this model by a piecewise representation of the path profile by exponential functions. An adequate model results when two exponential functions are used to span the 0–22.5 km distance range, one from 0 to δ(R) km and the other from δ(R) to 22.5 km. The resulting attenuation model for a given rain rate is given by

$$A_T(R,D) = \gamma(R)\left(\frac{e^{y\delta(R)}-1}{y} + \frac{e^{zD}-e^{z\delta(R)}}{z} e^{\alpha\beta}\right) \tag{14}$$

$$\delta(\mathrm{R}) < D < 22.5$$

$$A_T(R,D) = \gamma(R)\left(\frac{e^{y\delta(R)}-1}{y}\right),\ 0 < D < \delta(\mathrm{R}) \tag{15}$$

Where A_T is the horizontal path attenuation (dB), *R* the rain rate (mm/h), *D* the path length (km) and *γ(R)* the specific attenuation. The remaining coefficients are empirical constants of the piecewise exponential model [11].

$$B = ln(b) = 0.83 - 0.17ln(R) \tag{16}$$

$$C = 0.026 - 0.03ln(R) \tag{17}$$

$$\delta(R) = 3.8 - 0.6\ln(R) \tag{18}$$

$$u = \frac{B}{\delta(R)} + c \tag{19}$$

$$y = \alpha u \tag{20}$$

$$z = \alpha c \tag{21}$$

4. Silver Mello et al.

A modified method that addressed some of the problems found in the current ITU-R method but retains the general expression for d_{eff} (which is the basis of the model,) and uses the full rainfall rate distribution at the links region as input for the prediction of the cumulative distribution of rain attenuation was proposed by [15].

The dependence of the reduction factor on link parameters was investigated, using experimental data from concurrent long-term measurements of point rainfall rate and rain attenuation in terrestrial links available in the ITU-R databanks. *A* correction factor r_p was introduced to accommodate all percentages of time for available data with the expression:

$$r_p = \frac{A_p}{k{R_p}^{\alpha} d} \tag{22}$$

Where A_p and R_p are respectively the rain attenuation and the point rainfall rate exceeded at p% of the time.

It was found that r_p decreases with the path length and the point rainfall rate . A power-law relationship was obtained for the equivalent cell diameter, d_0 as :

$$d_{0=} 1.763 \times R^{-0.244} \tag{23}$$

The dependence of the effective rain rates on link parameters was also investigated, using experimental data from concurrent long-term measurements of point rainfall rate and rain attenuation in slant path links available in the ITU-R databanks, with only data from beacon measurements with concurrent measurements of rainfall rates considered.

$$R_{eff} = \left(\frac{A_P\ d_0}{k \times \frac{d}{d_0 + d}}\right)^{\alpha} \tag{24}$$

After series of trials with different functions to obtain the best regression fit, the general expression for terrestrial rain attenuation prediction given in (25) was eventually arrived at.

$$A_P = k\left[1.736\ R^{0.753 + \frac{0.197}{d}}\right]^{\alpha} \left(\frac{d}{1 + \frac{d}{119R^{-0.244}}}\right) \tag{25}$$

One-minute rain rate and rain attenuation data from 64 links in 15 different countries for a period of 74 years was tested over terrestrial links and the results showed that the proposed model out-performed the ITU-R Recommendation P.530-13 model for prediction of rain attenuation over terrestrial links [4].

5. SST rain attenuation model.

The SST method has been successfully used to predict rain attenuation in terrestrial LOS radio links. The SST converts a rain rate time series at a given location into a signal attenuation time series. This conversion requires a knowledge about the length of the signal path through the rain cell, the velocity (advection speed) of the rain cell and the rain rate at the location under investigation. Assuming that this location is at a specific point on the x_0-axis (the projection of the link on the ground) and that a rain rate, R (mm/h), is measured at that location on the ground, the specific rain attenuation (dB/km) at this point is given by

$$\gamma(x_0) = kR^{\alpha} \tag{26}$$

according to ITU-R Recommendation P.838 , where k and α are two constants depending on the frequency and the polarization of the signal traversing the rain cell. For a terrestrial path of length (km) along the x-axis, the attenuation because of rain is given by

$$A(x_0) = k \int_{x_0-l/2}^{x_0+l/2} R^{\alpha}(x)dx \qquad (27)$$

The variation of signal attenuation with time can be taken into account by changing x_0 according to the advection speed, v (km/h), of the rain cell

$$x_0 = vt \qquad (28)$$

The signal path through the atmosphere and the motion of the storm are assumed to be on the same plane. With the above equations, the signal attenuation at x_0 can be expressed in terms of $R^{\alpha}(x)$ of the convolution with a rectangular pulse of unit amplitude and length L

$$A(x_0) = k \int_{-\infty}^{+\infty} R^{\propto}(x_0 + x)rect\left(\frac{x}{L}\right) dx$$

$$A(x_0) = k \int_{-\infty}^{+\infty} R^{\propto}(x)rect\left(\frac{x_0-x}{L}\right) dx \qquad (29)$$

Equation (29) represents the essence of the SST[11].

III. SIMULATION RESULTS AND DISCUSSION

A) Rain Rate Distribution In Libya.

Libya is characterized by a semi-desert type of weather, and rainfall rates differ from one city to another so that it is high in the east of the country and less in the west and almost non-existent in the south. In this study, three cities were selected to study the effect of rain attenuation on terrestrial microwave link, these cities are Tripoli, Shahat and Sabha.

The measured values of rain rate exceeded for 0.01% that taken from the Libyan meteorological organization, and that obtained from ITU-R P.837-5 model are summarized in Table I.

TABLE I

RAINFALL RATE$R_{0.01}$FOR DIFFERENT LOCATIONS IN LIBYA

City	**Longitude (E)**	**Latitude (N)**	**Rate R0.01 form ITU maps(mm/h)**	**Rate R0.01 form local data (mm/h)**
Tripoli	13.19°	32.88°	30	62.1095
shahat	21.58°	32.80°	40	79.5155
Sabha	14.45°	29.02°	2	23.7737

b) Specific attenuation based on the variation of the operating frequency

Depending on locally data of the rain rate exceeded for 0.01% that taken from the Libyan meteorological organization, the specific attenuation is obtained based on the variation of the operating frequency for horizontal and vertical polarization, and listed in Table II.

From Table II, it can be noted that the rain has significant attenuation at the frequency greater than 10 GHz; and it can be observed that the specific attenuation for horizontal polarization in each city has the larger effect than the specific attenuation for vertical polarization.

TABLE IIIII

SPECIFIC ATTENUATION BASED ON LOCALLY MEASURED RAIN RATE IN LIBYA

f (GHz)	**Specific attenuation (dB/km)**					
	Vertical Polarization			**horizontal Polarization**		
	Shahat	Tripoli	Sabha	Shahat	Tripoli	Sabha
1	0.0017	0.0013	0.0006	0.0021	0.0017	0.0007
2	0.0078	0.0062	0.0026	0.0104	0.0082	0.0033
4	0.0652	0.0500	0.0178	0.0878	0.0665	0.0227
6	0.3930	0.2875	0.0853	0.5356	0.3877	0.1104
7	0.8254	0.5969	0.1693	1.0232	0.7363	0.2049
8	1.2195	0.8823	0.2508	1.5099	1.0879	0.3042
10	2.2392	1.6386	0.4868	2.6872	1.9606	0.5757
12	3.2052	2.3829	0.7527	3.8637	2.8604	0.8889
15	4.6640	3.5296	1.1948	5.7252	4.3050	1.4213
20	7.3023	5.6130	2.0185	9.2095	7.0197	2.4433
25	10.2458	7.9439	2.9543	12.8766	9.9075	3.5765
30	13.2791	10.3723	3.9702	16.3006	12.6665	4.7516
40	15.7576	12.4213	4.9265	19.0765	14.9781	5.8500
45	18.0668	14.3617	5.8851	21.3104	16.8983	6.8584
50	19.9112	15.9535	6.7414	22.9895	18.3926	7.7275
60	21.3761	17.2503	7.4953	24.4489	19.7057	8.5211
70	23.6324	19.2796	8.7385	26.2538	21.4076	9.6845
80	25.1985	20.7153	9.6730	27.3519	22.4856	10.500

Figures 1, 2, and 3 show the specific attenuation for horizontal polarization versus the operating frequency; based on local data of rain rate exceeded for 0.01% and that obtained from ITU-R P.837-5 model, in Sabha, Tripoli, and Shahat, respectively.

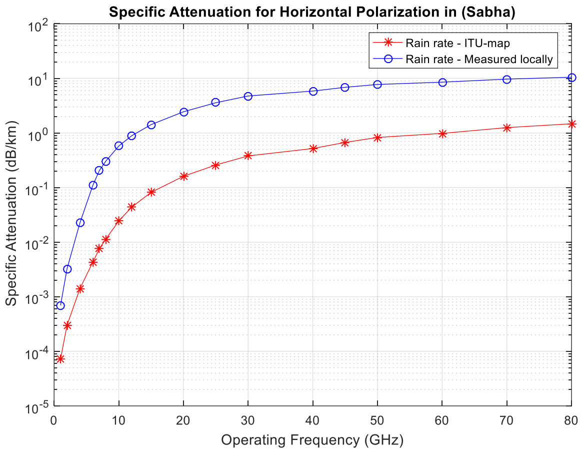

Fig. 1. Specific attenuation for 0.01%, time exceeded vs. frequency for horizontal polarization in Sabah

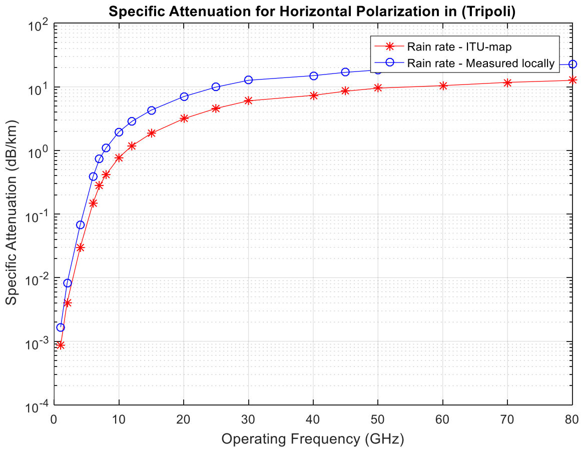

Fig. 2. Specific attenuation for 0.01%, time exceeded vs. frequency for horizontal polarization in Tripoli

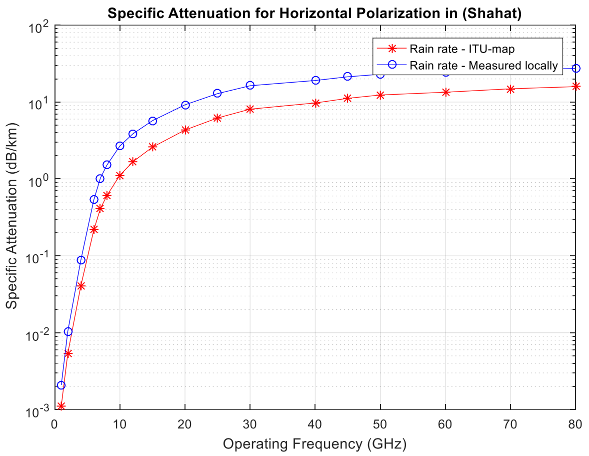

Fig. 3. Specific attenuation for 0.01%, time exceeded vs. frequency for horizontal polarization in Shahat

From Figures 1, 2, and 3, it can be seen that the specific attenuation due to the rain rate that measured locally is greater than the rain rate that obtained from the ITU-maps.

At 20 GHz, it can be noted that the specific attenuation that computed using the local rain rate date is larger than the specific attenuation that computed using the rain rate date from ITU-map by 2.2821 dB/km, 3.865 dB/km, and 4.882 dB/km, in Sabha, Tripoli, and Shahat, respectively.

c) Rain attenuation based on the variation of the path distance

Based on the horizontal polarization and the local data of the rain rate exceeded for 0.01%, Figure 4 show the variation of rain attenuation with changing the path distance, at the operating frequency is 15 GHz.

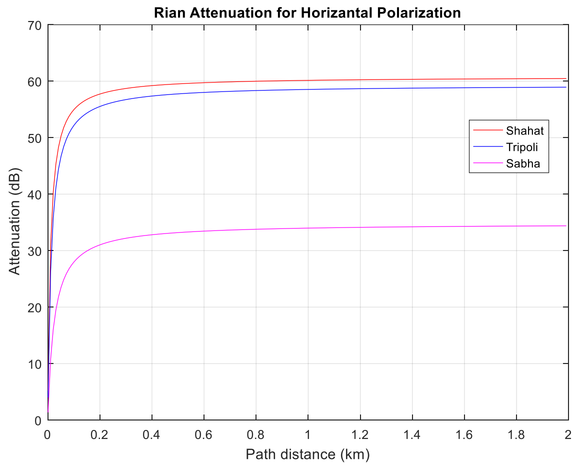

Fig. 4. Rain attenuation for 0.01%, time exceeded vs. path distance for horizontal polarization at 15 GHz

From Figure 4, it can be observed that, the rain attenuation is increase rapidly at path distance less than 0.2 km, from 0.2 km to 1 km the rain attenuation increase gradually, and the rain attenuation is almost constant at the path distance greater than 1 km.

Because the highest value of rainfall that found in Shahat city, form the, it can be noted that the rain attenuation in Shahat is larger than the rain attenuation in other cities.

d) Rain attenuation based on the variation of Percentages of time exceeded (%)

Figure 5gives the rain attenuation for different values of percentage of time exceeded in three cities under study at the operating frequency is 15 GHz, and 20 km path length.

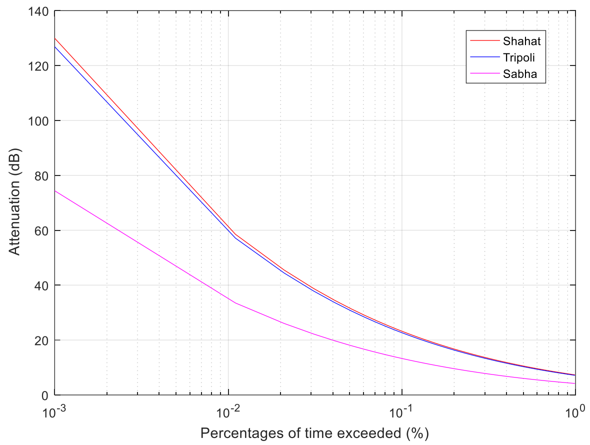

Fig. 5. Rain attenuation vs. Percentage of time exceeded for horizontal polarization at 15 GHz, and 20 km path length

From figure 5, it can be illustrated that the rain attenuation is increase with decrease the percentage of time exceeded, i.e. decrease of the availability of the microwave link. And from the Figure, it can be listed the rain attenuation for different values of percentage of time exceeded in Table III.

From Table III, it can be noted that the rain attenuation in increased by 39.27 dB, 66.94 dB, and 68.6 dB, when the percentage of time exceeded in decreased from 0.01% to 0.001%, in Sabha, Tripoli, and Shahat, respectively.

Table III. Rain attenuation for different values of system availability in Libya

Percentage of time exceeded (%)	**Rain attenuation (dB)**		
	Sabha	**Tripoli**	**Shahat**
0.001	74.39	126.9	130
0.01	35.12	59.96	61.4
0.1	13.29	22.65	23.22
1	4.194	7.152	7.152

IV. CONCLUSION

Based on the simulation results, it can be concluded that:

The specific attenuation based on the local data for horizontal polarization has more affected than the specific attenuation for vertical polarization; and the difference between these values was decreased with increase the operating frequency. Thus, in Shahat that has a high rain rate, using vertical polarization more economical.

The specific attenuation for horizontal polarization that calculated depending on the locally measured rain rate exceeded for 0.01% was a higher than the specific attenuation that computed based on the rain rate that obtained from ITU-R P.837-5.

The rain attenuation was increase with increase, at the path distance less than 1 km; and for path distance greater than 1 km, the rain attenuation nearly constant.

The rain attenuation values decrease as the degree of availability decreases. At low percentage of a system availability of terrestrial link, the link can be ensured in the lower rain rate city like Sabha, than the higher rain rate city like Shahat.

The simulation results in this paper give a helpful information for engineers to design a terrestrial microwave link in Libya.

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