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Effects of humidity on sand and dust storm attenuation predictions based on 14 GHz measurement

Eltahir Idris Eltahir Mohamed[1], Elfatih A. A. Elsheikh[2], A. Awad Babiker[3], Islam Md. Rafiqul[4], Mohamad Hadi Habaebi[5], Aisha H. Abdulla[6], Elessaid Saad[7]
[1,4,5,6] Department of Electrical and Computer Engineering, International Islamic University Malaysia, Malaysia
[2]Department of Electrical and Electronic Engineering, King Khalid University, Abhaa, Saudi Arabia
[3,7]Department of Electrical and Electronic Engineering, Karary University, Omdurman, Sudan

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ABSTRACT

Several models were proposed to predict the attenuation of microwave signals due to sand and dust storms. Those models were developed based on theoretical assumptions like Rayleigh approximation, Mie equations or numerical methods. This paper presents a comparison between attenuation predicted by three different theoretical models with measured attenuation at 14 GHz. Dielectric constant of dust particles is one of the important parameter in prediction models. This constant is estimated from measured dust samples and is utilized for predictions. All models are found largely underestimating the measurement. Humidity is also monitored and has been observed higher during dust storm. Hence dielectric constants are re-estimated with relative humidity conditions using available conversion model. The prediction has a great impact of humidity and predicted attenuations are found much higher in humid than dry dust condition. However, all models underestimate the measurement even considering 100% of relative humidity. Hence it is recommended to investigate the models by considering humidity and other environmental factors that change during dust storm.

Corresponding Author:

Islam Md. Rafiqul
Department of Electrical and Computer Engineering
International Islamic University Malaysia (IIUM)
Gombak 53100 St. Kuala Lumpur, Malaysia
Email: rafiq@iium.edu.my

1. INTRODUCTION

The attenuation problem of microwave (MW) signals is caused by sand and dust storms is commonly discussed in the literature [1-27]. It seems to be there is a strong motivation for active researchers in this area to continue exerting more effort about the accurate measurements and predicting of sand and dust particle properties and their effect on the degradation of performance of communication systems. Scattering and absorption of microwave and millimeter wave signals causes signal attenuation and decrease the system performance. There for, studying of the propagation of microwave and millimeter-wave through dust storm is significant for reliable terrestrial, satellite, high altitude platform and 5th generation links [1-9].

Most of prediction models that predict attenuation of MW and millimetre wave (MMW) that propagates via dust storm are based on hypothetical concepts such as single particle scattering theory. In contrast, most of mathematical models are based on Rayleigh approximation or Mie scattering theory (single particle scattering theory) and do not include the multiple scattering effect or mutual interaction phenomena and depends only on approximations such as dust particle characteristics (shape, dielectric constants and size), visibility and frequency [10-12]. Furthermore, none of these models could provide reliable predictions compared to measured attenuation at different frequencies measured in desert areas. Actually, sand and dust storm is a complicated observable fact which is not easy to be illustrated by hypothetical models. From literature, it has been found that storms of dust is regularly accompanied by an obvious increase in the moisture content of air-born dust particles. Therefore, the electrical characteristics of dust particles can vary for that reason [1]. The previous studies on microwave propagation via sand and dust storms were centered on either a low level of dust moisture or dry dust particles [10-12]. A recent study shows the permittivity of dust and sand samples are dependent on chemical composition of the sample, frequency and moisture content [13].

Ghobrial, in 1980 discovered that hygroscopic water increase the complex permittivity of dust suspended particles, and the raise in the imaginary part is more noticeable [14]. However for a dust study in Khartoum, Sudan, when the relative humidity is 82%, the particle moisture content will be 5.1 percent by particle weight. Direct relation between the complex permittivity and relative humidity is created [15]. Some of studies show that at the dry-sand case, there is very small or negligibly changes in components of real part of complex permittivity However, clear change in the imaginary part of dielectric constant (loss factor) is observed when moisture content increases and frequency increases from 0.3 to 24 GHz. On the other hand, there is significant correlation between dust particle moisture content [1, 16, 17]. Observation of different size of soil samples (sand, silt, clay) reveals that primarily the dielectric constant increases gradually with the moisture content. After feat changeover of moisture value, the dielectric constant increases sharply. Additionally, the raise in the imaginary part of clay sample is superior to sand and silt samples [18].

In this paper, a comparison between attenuation predicted by three different theoretical models with measured attenuation at 14 GHz has been presented. Dielectric properties of dust particles is found very important parameter in prediction models. This constant has been estimated from measured dust samples and is utilized for predictions. All models are found largely underestimating the measurement. Dielectric constant has been re-estimated with relative humidity conditions and predicted attenuations are found much higher in humid than dry dust condition.

2. ATTENUATION PREDICTION

Dust storm can directly affect microwave signal propagation. This effect is very obvious at frequencies higher than 10 GHz. Few analytical and mathematical models were developed based on different backgrounds. In this part, selected prediction models were presented based on different backgrounds, such as rayleigh approximation, mie theorem and numerical methods,

2.1. Rayleigh approximation model

Ahmed et al in 1987 developed a model based on Rayleigh approximation and derived signal attenuation in regarding of dust storm parameters which can be measured easily. Considering that at optical wavelength the dust intensity is exponentially decays with distance and the dust caused attenuation can be expressed as [19]:

$$\alpha = 566.97\left(\frac{1}{v_0}\right)\left(\frac{r_e}{\lambda}\right)(G) \quad [\mathrm{dB/km}] \tag{1}$$

where:
α is the Attenuation
λ refers to the wavelength in meters
G is a constant which relies on the dielectric constants of the particles.
V_0 refers to the visibility in kilometers.
r_e the equivalent radius of the particles in meters.

$$G = \left[\frac{\varepsilon''}{(\varepsilon'+2)^2+\varepsilon''^2}\right] \tag{2}$$

where ε' is the phase constant and ε'' is the loss factor of dust particles. The visibility expression in this model is based on theoretical assumptions only and no validation has been done through measurements. In addition, this model loses its reliability as the frequency and dust concentration increases [19]. The parameter G is derived from complex permittivity of dust particles which has ignored the effects of humidity.

2.2. Mie scattering model

A model based on Mie scattering was proposed by S. M. Sharif in 2015, the variation of the dust particles dimensions and spherical particle shape were considered in this model as follows [1, 6, 20]:

$$A_P = \frac{1}{v^{1.07}}\left[c_1^{"} + c_2^{"} f^3 + c_3^{"} f^4\right] [\text{dB/km}] \tag{3}$$

where:
A_P is attenuation taking into account the size of the particle.
c''_1, c''_2 and c''_3 Constants that are dependent on the dielectric constant of the particle.

$$c_1^{"} = 5.757 \times 10^{-5} C1 \tag{4}$$

$$c_2^{"} = 3.255 \times 10^{-12} C2 \tag{5}$$

$$c_3^{"} = 3.853 \times 10^{-7} C3 \tag{6}$$

where

$$C1 = \frac{6\varepsilon"}{(\varepsilon' + 2)^2 + \varepsilon"^2} \tag{7}$$

$$C2 = \varepsilon" \left\{ \frac{6}{5} \frac{(7\varepsilon'^2 + 7\varepsilon"^2 + 4\varepsilon' - 20)}{((\varepsilon' + 2)^2 + \varepsilon"^2)^2} + \frac{1}{15} + \frac{5}{3((2\varepsilon' + 3)^2 + 4\varepsilon"^2)} \right\} \tag{8}$$

$$C3 = \frac{4}{3}\left\{ \frac{(\varepsilon' - 1)^2(\varepsilon' + 2) + [2(\varepsilon' - 1)(\varepsilon' + 2) - 9] + \varepsilon"^4}{((\varepsilon' + 2)^2 + \varepsilon"^2)^2} \right\} \tag{9}$$

Generally, the model has been based on single particle scattering theory and does not include the multiple scattering effect or mutual interaction phenomena [1, 6, 20]. It also considered the shape of dust particle as spherical which is not in reality [22]. This model is based on theoretical assumptions only and no validation has been done through measurements. The parameter C is derived from complex permittivity of dust particles which has ignored the effects of humidity.

2.3. Numerical model

The finite-difference time-domain (FDTD) and the turning band methods were used to calculate the wave attenuation in sand and dust storms at the frequencies of 10-100 GHz based on multiple scattering effects by Hsing-Yi et al. in 2012 to calculate attenuation due to dust storms as given below [21].

$$\alpha = 8.686 \times 10^3 \sum_{k=1}^{K} \sigma_{ext}(k\Delta r) N(k\Delta r) \Delta r \ [\text{dB/km}] \tag{10}$$

where:
K is an integer number of $r_{max}/\Delta r$
r_{max} is the maximum particle radius in the storm
Δr is the incremental radius
σ_{ext} is the extinction cross section and its depend on the dielectric constant.
N is the total particle density in number per m^3

$$\sigma_{ext} = \frac{8.05 \times 10^{-7}(f^{1.2} + 1)}{V^{0.3} r} \times \frac{\varepsilon"}{[(\varepsilon' + 2)^2 + \varepsilon"^2]} \quad [\text{m}^2] \tag{11}$$

This method assumed spherical dust particle shape and lognormal dust particle size distribution. These assumptions and approximations have restricted the use of this formula for limited prediction circumstances. Generally, multiple scattering theories try to determine the fluctuation characteristics of the wave. So that all the multiple scattering, diffraction and interference effects should be included. However, in practice, it is impossible to obtain a formulation which can include all these effects [1, 6, 21]. The parameter σ is calculated based on complex permittivity of dust particles which has ignored the effects of humidity.

3. MEASUREMENT

The climate conditions were monitored at Khartoum, Sudan for one-year period during June 2014 up to May 2015. Meteorology information of the study has been collected from weather stations of Khartoum Airport. The variations of signal levels for the microwave link of 2.7 km operating at 14.4 GHz was also monitored for the same period. Dust samples were collected and tested to evaluate dielectric characteristics. A location map of the microwave links and the Automatic Weather station is shown in Figure 1. During one year of measurement for the duration from June, 2014 to May, 2015 in Khartoum, a 22 dust storms were monitored. The cumulative distribution function of measured attenuation and visibility are shown Figures 2 and 3 respectively. In this section, it is explained the results of research and at the same time is given the comprehensive discussion. Results can be presented in figures, graphs, tables and others that make the reader understand easily [2, 5]. The discussion can be made in several sub-chapters.

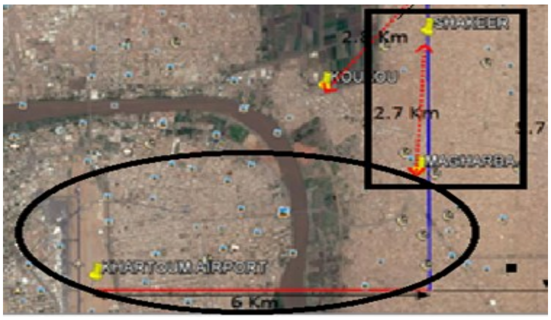

Figure 1. Location of 14.4 GHz microwave link and weather station [1, 6]

3.1. Measured dielectric characteristics of dust sample

Eight samples were collected during the dust storm to study the suspended particle characteristics. Chemical composition is carried out with Energy Dispersive X-ray Fluorescence Spectrometer which is used to investigate the chemical structure of samples solid, liquid, and powder with a range from C_6 to U_{92} with samples size of W300 x D 275 x H 100 mm and mass of 200g. SiO_2 is the major compound found in the samples. All compounds are listed in Table 1 with their percentages in total ingredients. Elsheikh *et al.* [1] and Ansari [16] shows a slight variation in the permittivity for the frequency range 3-20 GHz accordingly the values of permittivity in Table 2 were applied to 14 GHz [1, 16]. From the measured chemical composition and Looyenga equation for homogenous mixture calculation of complex permittivity is shown in Table 2 and the collected dust samples' complex permittivity is 4.271-j0.109, which is approximately agree with some published results [11, 14, 22, 25].

Table 1. Chemical composition of two samples

Sample 1	Ingredient	Sample 2	Ingredient
SiO_2	63.538	SiO_2	65.169
Al_2O_3	16.744	Al_2O_3	13.814
Fe_2O_3	9.214	Fe_2O_3	10.393
CaO	5.591	CaO	6.496
K_2O	1.824	K_2O	1.944
TiO_2	1.639	TiO_2	1.709
SO_3	1.079	MnO	0.177
MnO	0.146	V_2O_5	0.068
ZrO_2	0.062	ZrO_2	0.059
$V2O_5$	0.054	CuO	0.046
SrO	0.038	SrO	0.042
$Cr2O_3$	0.024	ZnO	0.034
ZnO	0.020	Cr_2O_3	0.030
CuO	0.013	NiO	0.008
NiO	0.007	NiO	0.007
Y_2O_3	0.007	Y_2O_3	

Table 2. The complex permittivity of some chemical compound [25]

Compound	Є'- j Є''
SiO_2	4.43-j0.04
$Al2O_3$	12.66-j1.31
Fe_2O_3	16.58-j0.93
$CaCO_3$	8.22-j0.12
$MgCO_3$	5.03j0.17
$CaSO_4$	5.01-j0.08

3.2. Measured visibility and attenuation

The measured system includes of radio link, meteorological sensors and data acquisition and processing hardware. The link under observation was operating at 14.4 GHz with 2.7 km length and it's located at North East Khartoum as shown in Figure 1. Meteorological information was obtained from a Weather Station at Khartoum International Airport and is about 6 Km from the link. Meteorological station was observing visibility (V), temperature (T), relative humidity (H), wind speed and direction.

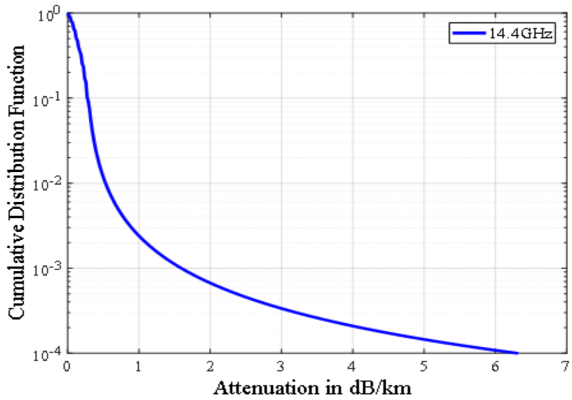

Figure 2. Cumulative distribution function of measured attenuation in Khartoum at 14.4 GHz link from June, 2014 to May, 2015 [1, 6]

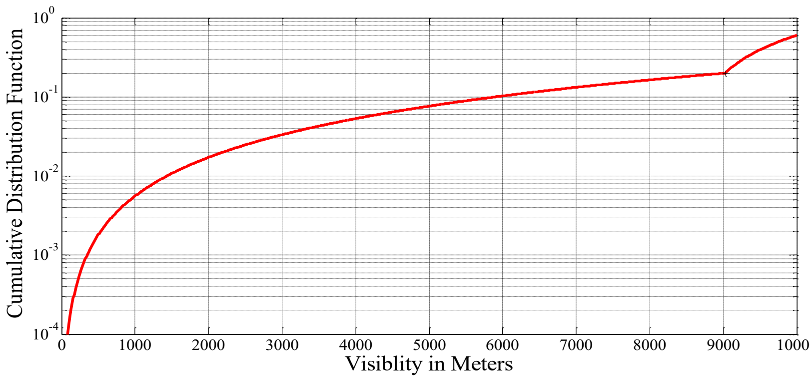

Figure 3. Cumulative distribution function of measured visibility from June, 2014 to May, 2015 in Khartoum [1, 6]

3.3. Effects of relative humidity on dielectric constant

The complex permittivity of the suspended particle relative to free space can be given as (12):

$$\varepsilon = \varepsilon' + j\varepsilon'' \tag{12}$$

where ε' and ε'' are the real and imaginary parts of dielectric constant respectively. Different techniques are used to measure dielectric constants of dust at different frequencies. When the relative humidity in the free space increases, the moisture content increases [26, 27]. S. M. Sharif in 2011 developed an empirical relationship to predict the dielectric constants versus relative humidity as follow [15]:

$$\varepsilon'_H = \varepsilon' + 0.04H - 7.78X10^{-4}H^2 5.56X10^{-6}H^3 \tag{13}$$

$$\varepsilon''_{\mathrm{H}} = \varepsilon'' + 0.02\mathrm{H} - 3.71\mathrm{X}10^{-4}\mathrm{H}^2 + 2.76\mathrm{X}10^{-6}\mathrm{H}^3 \tag{14}$$

where H is the relative humidity. From the study done in 2014 at Khartoum, Sudan, it was obvious that dust storms are accompanied with a severe increase of relative humidity as shown in Figure 4. Consequently, dust suspended particle is prone to capture moisture and as a result the electrical characteristics of the dust particle may change accordingly. In this section, new values of dust particle permittivity are proposed based on relative humidity. Maximum, average and minimum measured humidity were selected from dust storm events during June 2014 up to May 2015. Measured relative humidity values are used as shown in (13) and (14) to approximate the effect of relative humidity on suspended particle permittivity. Different values of dust particle dielectric constants corresponding to various levels of relative humidity are presented in Table 3. Results in Table (3) shows that by applying relative humidity values small changes can be observed in the real part of dielectric constant. On contrary, significant changes occur in the imaginary part (loss factor). At 100% humidity, ε''_H the value increases almost 10 times than dry value. Hence the humidity has great impact on signal attenuation during dust storms.

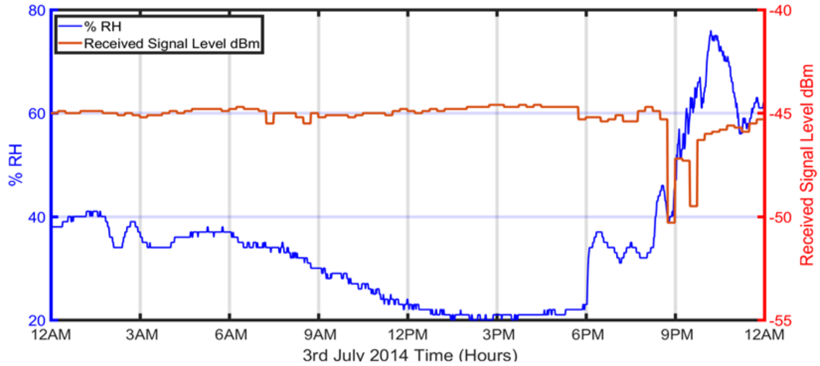

Figure 4. Relative humidity and received signal vs time during dust event at 3rd of July 2014

Table 3. The variations of relative permittivity with different humidity

Relative humidity%	ε'_H	ε''_H
Dry	4.271	0.109
20	4.804	0.383
45	5.002	0.509
70	5.169	0.638
100	6.051	1.150

4. RESULTS AND ANALYSIS

Models that predict microwave signal attenuation during propagation through a dust storm needs some information about characteristics of the dust storm such as visibility, particle shape, size, moisture, dielectric constant. Dust storm attenuation is predicted using as shown in (1-11) at 14 GHz using measured dielectric constants of 4.271-j0.109 and measured visibility as presented in Figures 3 and 5 shows the predicted attenuation using obtained dielectric constant value at dry case and compared with measured attenuation at 14 GHz and the small window in the right upper corner of Figure 5 shows magnification of the response of mathematical model at 14 GHz. It can be notice clearly that at the worst case of visibility of 0.08366 km, the corresponding predicted attenuation is 0.0938, 0.00428, and 0.002321 dB/km for using Rayleigh approximation, Mie scattering and Numerical method models, respectively while the measured attenuation is recorded as 6.312 dB/km at the same visibility.

The reasons of severe discrepancies in Figure 5 may be due to the visibility in Ahmed's model in 1987 was based on theoretical assumption and no validation has been done via measurements. S. M. Sharif model in 2015, was developed based on single particle scattering theory. However, the dust storm is a very complicated phenomenon, and single particle theory may not be applied. Hsing-Yi model in 2012, the method is not suitable, since it involves sets of arbitrarily oriented particles. Hence each orientation of the particle, it needs to do computations again with respect to the occurrence wave [19-21].

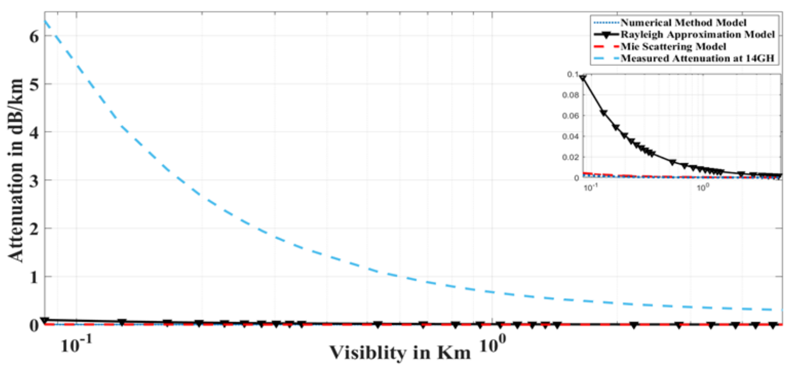

Figure 5. Comparison of predicted attenuation at 14 GHz and measured attenuation at the dry condition

Humidity is not considered in all three models, even though it has a great impact on dielectric constant and received signal level as shown in (1-11) are utilized to predict the dust storm attenuation at 14 GHz using measured dielectric constant with 100% relative humidity (possible worst scenario) and presented in Figure 6 and the small window in the right upper corner of Figure 6 shows magnification of the response of mathematical model at 14 GHz incorporation of worst case of humidity. However, it is obvious that the humidity has significant impact on predicted attenuation even though; predictions are still far below from the measured attenuation. At worst case of visibility 0.08366 km, the corresponding predicted attenuation is 0.6093, 0.03729, and 0.0146 dB/km for Rayleigh approximation, Mie scattering and Numerical method respectively. A significant improvement in the selected models' predictions at 14 GHz is noticed using wet particles rather than dry particles. The improvements in predictions using humidity and dry case are summarized in Table 4. The predicted attenuations are increased more than 5 times for all three methods.

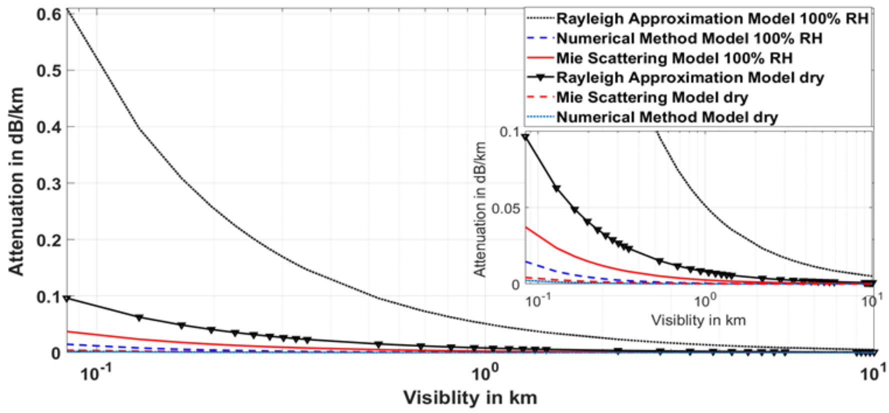

Figure 6. Comparison of predicted attenuation at 14 GHz at dry case and 100% percentage of relative humidity

Table 4. Comparison between predicted attenuation at the dry case and worst case of humidity for 0.08366 km of visibility

	Predicted Attenuation in dB/Km		
	Rayleigh	Mie	Numerical
Dry case	0.0938	0.00428	0.002321
100% Relative Humadity	0.6093	0.03729	0.01467
Improvement	6.4	8.7	6.3

5. CONCLUSION

Dust storm attenuation prediction based on Rayleigh approximation, Mie equations and numerical methods are investigated in this paper. Dielectric constants are estimated from measured dust samples and are utilized for predictions. All models largely underestimate the measurement at 14 GHz. Humidity is also monitored and has been observed higher during dust storm. Hence dielectric constants are re-estimated with relative humidity conditions using available conversion model. The predicted attenuations are increased more than 5 times for all three methods at the worst humidity level of (100%). Rayleigh approximation model predict the highest at both dry and humid conditions. Hence the humidity has significant impact on predicted attenuation even though; predictions are still far below from the measured attenuation. Therefore, it is highly recommended to investigate the models by considering humidity and other environmental conditions.

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REFERENCES

[1] Elfatih A. A. Elsheikh, Md. Rafiqul Islam,Mohamed H. Habaebi, Ahmad F. Ismail, Alhareth Zyoud, "Dust Storm Attenuation Modeling Based on Measurements in Sudan," *IEEE Transactions on Antennas and Propagation*, vol. 65, no. 8, pp. 4200-4208, 2017.

[2] Manhal Alhilali, Mustafa Ghanim, Jafri Din, Hong Yin Lam, "A methodology for precise estimation of rain attenuation on terrestrial millimetre wave links from raindrop size distribution measurements," *TELKOMNIKA Telecommunication Computing Electronics and Control*, vol. 17, no.5, pp. 2139-2146, October 2019.
[3] Musa, and S. O. Bashir and Aisha H. Abdalla, "Review and Assessment of Electromagnetic Wave Propagation in Sand and Dust Storms at Microwave and Millimeter Wave Bands Part I," *Progress In Electromagnetics Research M*, vol. 40, pp. 91-100, 2014.
[4] E. A. A. Elsheikh, M. R. Islam, J. Chebil, S. Bashir, and A. F. Ismail, "Preliminary analysis of dust storm effectson microwave links measured in khartoum," *In Proc. Malaysia International conference on communications*, pp. 181-185, Sep. 2015.
[5] M. R. Islam, E. A. A. Elsheikh, A. F. Ismail, S. O. Bashir, and J. Cheb, "Development of an empirical dust storm attenuation prediction model for microwave links in arid area-a proposed framework," *Proc. International Conference on Computer and Communication Engineering (ICCCE)*, pp. 224-227, 2014.
[6] E. A. A. Elsheikh, M. R. Islam, A. F. Ismail, M. H. Habaebi, "Dust storms attenuation measurements at 14 GHz and 21 GHz in Sudan," *Proc. International conference on Computing, Control, Networking, Electronics and Embedded Systems Engineering (ICCNEEE)*, pp. 11-16, 2015.
[7] M. R. Islam, E. A. A. Elsheikh, A. H. M. Z. Alam, and O. O. Khalifa, "Proposing a horizontal path adjustment factor for microwave link's attenuation prediction based on the analysis of dust storm behavior," *Proc. Malaysia International Conference on Communications (MICC), IEEE* , Sep. 2011, pp. 44-48.
[8] Z. E. O. Elshaikh, M. R. Islam, O. O. Khalifa, and H. E. Abd-El-Raouf, "Mathematical model for the prediction of microwave signal attenuation due to duststorm," *Progress In Electromagnetics Research M.*, vol. 6, pp. 139-153, 2009.
[9] Z. A. Shamsan, "Dust storm and diffraction modelling for 5G spectrum wireless fixed links in arid regions," *IEEE Access,* vol. 7, 2019.
[10] J. Goldhirsh, "Attenuation and backscatter from a derived two-dimensional duststorm model," *Antennas and Propagation, IEEE Transactions*, vol. 49, pp. 1703-1711, 2001.
[11] J. H. Thompson, "Dust cloud modeling and propagation effects for for radar and communication codes," *Center for Advanced Studies, Santa Barbara*, 1978.
[12] L. Y. Ahmed and L. J. Auchterlonie, "Microwave measurements on dust, using an open resonator," *Electron. Letter,* vol. 12, no. 17, pp. 445-446, Aug. 1976.
[13] Abdulwaheed Musa and Babu Sena Paul, "Dust particles' permittivity in microwave signal propagation: A Review" *Journal of Communications*, vol. 15, no. 1, January 2020.
[14] Ghobrial S. I, "Effect of hydroscopic water on dielectric constant of dust at X-band," *Electronics Letters* 8, vol. 16, no.10, May 1980.
[15] Sharif S. M, "Dust storms properties related to microwave signal propagation," *University of Khartoum Engineering Journal (UofKEJ)*, vol. 1, no. 1, pp. 1-9, 2011.
[16] Ansari A. J. and B. G. Evans, "Microwave propagation in sand and dust storm," *Proc. Inst. Electr. Eng*, vol. 129, 1982, pp. 315-322.
[17] Y. Lasne*, et al*., "Effect of salinity on the dielectric properties of geological materials: implication for soil moisture detection by means of radar remote sensing," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 46, pp. 1674-1688, 2008.
[18] Hafid Tahabal-Hafid, B R Vishvakarma, "Complex dielectric constant of sand and dust particeles at 11GHz as a function of moisture content," *Indian Journal of Radio &Space Physics*, vol. 14, pp. 21-24, 1985.
[19] Ahmed A. S., Ali, A. A., Alhaider, M. A., "Airborne dust size analysis for tropospheric propagation of millimetric waves into dust storms," *IEEE Transactions on Geoscience and Remote Sensing*, vol. GE-25, pp. 593-599, 1987.
[20] Sami M. Sharif, "Attenuation properties of dusty media using mie scattering solution," *Progress In Electromagnetics Research M*, vol. 43, pp. 9-18, Jul. 2015.
[21] H. Y. Chen and C. C. Ku, "Calculation of wave attenuation in sand and dust storms by the FDTD and turning bands methods at 10-100 GHz," *IEEE Transactions on Antennas and Propagation,* vol. 60, pp. 2951-2960, 2012.
[22] E. I. Eltahir, Elfatih A. A. Elsheikh, A. Awad Babiker and Khalid Hamid Bilal, "10 GHz Investigation of Sudanese Dust Event Particles Characteristics," *Proc. Int. Conf. Computer ,Communication and Electrical Engineering, (ICCCEEE) IEEE*, 2019.
[23] A. Musa and S. O. Bashir, "Electromagnetic waves propagation in dust storms at millimetre wave band," *J. Emerg. Trends Eng. Appl.Sci*., vol. 4, no. 2, pp. 162-167, 2013.
[24] Ghobrial, S. I. and S. M. Sharief, "Microwave attenuation and cross polarization in dust storms," *IEEE Transactions on Antennas and Propagation*, vol. 35, no. 4, pp. 418-425, 1987.
[25] Sharif, S. M., "Mineral and chemical composition of dust and its effect on dielectric constant," *IEEE Transactions on Geo Science and Remote Sensing*, vol. 33, no. 2, Mar. 1995.
[26] Singh H., Saxena K., Kumar V., Bonev B. and Prasad R., "An empirical model for prediction of environmental attenuation of millimeter waves," *Wireless Personal Communications, Springer*, pp.1-18, Jun. 2020.
[27] Sowden M., Blake D., Cohen D., Atanacio A. and Mueller U., "Development of an infrared pollution index to identify ground-level compositional, particle size, and humidity changes using Himawari-8," *Atmospheric Environment*, March 2020.