

# Dependence of raindrop size and shape parameters on rain attenuation prediction over a tropical location

Temitope Y Kolade-Oje<sup>1\*</sup>, M. O. Ajewole<sup>2</sup>, J. S. Ojo<sup>2</sup> and A. T. Adediji<sup>2</sup>

<sup>1</sup>Department of Physics and Electronics, Adekunle Ajasin University, Akungba-Akoko, Ondo State, Nigeria.

<sup>2</sup>Department of Physics, Federal University of Technology, Akure, Ondo State, Nigeria.

\*Corresponding author. Email: temitopekoladeoje@gmail.com

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Received 1st March 2022; Accepted 4th April 2022

**ABSTRACT:** Rain attenuation is a phenomenon that weakens signal propagation, particularly in high frequency bands and in areas with significant rainfall rates, one of which is the tropical area. Falling raindrops undergo changes in shapes as they grow in sizes. The goal of this research is to use a theoretical method to examine the impact of drop shapes and sizes on rain attenuation prediction. The extinction cross section of spherical and non-spherical raindrops was calculated using the Mie theory and T-matrix respectively. The specific rain attenuation for spherical and non-spherical raindrops was computed at various frequencies in the microwave band and compared with the ITU-R838 model. It was observed that the non-spherical drops model has higher values for rain attenuation, and thus is best suitable for predicting rain attenuation.

**Keywords:** Extinction cross section, Mie Theory, non-spherical raindrops, specific rain attenuation, T-matrix.

## INTRODUCTION

The millimetre and microwave wave spectrum offers bandwidth for future 5G communication; however, it is significantly influenced by atmospheric conditions like rain, temperature, oxygen, fog, and other factors. Rain, as one of these factors causes wave propagation at this frequency band to be substantially hindered (Narekar and Bhalerao, 2015). The amount of signal loss caused by rain is determined by the rain's structure. Thus, the typical raindrop morphologies and size distributions is important for evaluating the impacts of rainfall on point to point and earth– space communication linkages operating at millimeter and microwave frequencies (Ayo *et al.*, 2021). Other rainfall parameters such as the canting angle, rain rate and liquid water content have intense effects on waves propagating at these astronomically high frequencies (Alao and Musiliyu, 2013). Signal instability is caused by rain-induced propagation defects such as attenuation, and this has various deteriorating impacts on millimeter wave transmissions. Frequency, rain rate, and polarization are three variables that are usually utilized to forecast specific rainfall attenuation. (Adetan and Obiyemi, 2016; Shrestha and Choi, 2017).

Rain attenuation has a far greater impact on wireless communication in tropical places with high rainfall throughout the year (Kolade-Oje *et al.*, 2021). Therefore, it is critical to develop a model that can precisely anticipate the amount of attenuation induced by rain in order to ensure stable and consistent network performance (Okamura and Oguchi, 2010; Tan *et al.*, 2021). The drop size distribution (DSD) and shapes is crucial in determining rainfall attenuation at high radio frequency bands, and its modeling varies depending on the climate. A large number of theoretical studies on the shape-size dependence of raindrops have been reported in literature. Pruppacher and Pitter (1971) published the first work on drop shapes and sizes, the research introduced a numerical solution for the pressure balance equation to describe drop shapes of 13 raindrops of sizes ranges from 0.25 to 3.25 mm with 0.25 mm steps and the raindrop shapes were observed to have change from spherical to asymmetric oblate spheroid and to an oblate with a concave depression as the drops sizes increases. Beard and Chuang (1987) used the Laplace equation to develop a model for raindrop shapes, resulting in raindrops with a

flattened base, as opposed to the concave depression obtained by the Pruppacher and Pitter (1971). The more realistic drop shape model proposed by Kolade-Oje *et al.* (2021) is used in this study; this model computed the shape of raindrops with sizes ranging from 0.25 to 4 mm in 0.25 mm steps. The model improves on both the Pruppacher and Beard models in that it computes the shapes of larger raindrops and obtains spherical shapes for drops with radius less than 0.5 mm, oblate with flattened base for drops with radius 0.5 mm ≤ 2.5 mm, and oblate shape with concave depression for raindrops with radius 2.5 mm ≤ 4 mm. The T-matrix model was used to calculate the extinction cross section for the non-spherical raindrops and the specific attenuation for by these raindrops were computed, the dependence of the specific attenuation on the raindrop shapes was observed by comparing the results obtained with those obtained using the Mie theory for spherical drops and the ITU 898 model. Thus, the objective of this study is to use a theoretical method to examine the impact of drop shapes and sizes on rain attenuation prediction.

**METHODOLOGY**

The extinction cross-section of spherical and non-spherical raindrops with radius 0.5 to 4 mm were calculated using Mie theory and T-matrix respectively. The Mie theory has been applied to compute the extinction cross section with the assumption that the drops are spherical in shape. It is obtained as:

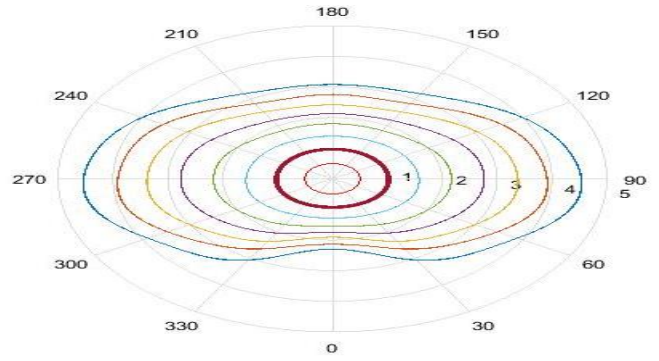
$$\sigma_{ext} = \frac{\pi D^2}{2x^2} \sum_{n=1}^{\infty} (2n+1)(a_n + b_n) \tag{1}$$

To determine the extinction cross section for realistic non-spherical drops, numerical approximations such as the T-matrix approach, Fredholm integral equation, spheroidal function expansion, and moment method are required. In this work, the T-matrix approach (Somerville *et al.*, 2016) is adopted to compute the extinction cross sections of non-spherical raindrops. Axial ratio obtained for realistic raindrops by Kolade-Oje *et al.* (2021) which reveals that larger raindrops have a distorted shape, comparable to an oblate spheroid with a concave base, as seen in Figure 1, were placed into the T matrix algorithm to compute the extinction cross section for non-spherical droplets.

The extinction cross section  $\sigma_{ext}$  defined as the total power removed from the incident wave is expressed as for the T matrix method as:

$$\sigma_{ext} = \frac{2\pi}{k_1^2} (p_{nm} a_{nm} + q_{nm} b_{nm}) \tag{2}$$

Where  $a_{mn}$  and  $b_{mn}$  are the expansion coefficient of the incident wave while  $p_{nm}$  and  $q_{nm}$  are the expansion coefficient of the scattered field.



**Figure 1.** Simulated Raindrop shapes (Kolade- oje *et al* 2021).

**Drop size distribution**

Drop size distribution is distinctive to a region's environment, hence a single model may not be sufficient to reflect the physical reality of DSD in all regions (Ajayi and Ofoche, 1984; Ajayi and Olsen, 1985). Comparative investigations of various DSD models have revealed that log-normal models provide the best fit to observed DSD in tropical climates. As a result, the log-normal distribution proposed by Adimula and Ajayi (1996) is used in this study as:

$$N(D) = \frac{N_T}{\sigma D \sqrt{2\pi}} \exp \left[ -\frac{1}{2} \left\{ \frac{\ln(D) - \mu}{\sigma} \right\}^2 \right] \tag{3}$$

Where: Where:  $N_T = 45.325R^{0.6703}$ ,  $\mu = -0.39141 + 0.1873\ln(R)$  and  $\sigma = 0.40723 - 0.05862\ln(R)$

**Computation of specific rain attenuation**

The extinction cross-section obtained from the T-matrix and Mie theory, as well as the lognormal distribution, are used to determine specific attenuation. The specific attenuation is given as:

$$\gamma = 10 \log(e) * 10^3 \sum_{r_{max}}^{r_{min}} \sigma_{ext} N(D) \tag{4}$$

Where the  $\sigma_{ext}$  is the extinction cross section,  $N(D)$  is the drop size distribution  $e$  is the exponential constant and  $r_{min}$  and  $r_{max}$  generally have values of 0.5 to 4 mm respectively.

**RESULTS AND DISCUSSION**

The extinction cross section  $\sigma_{ext}$  which is a significant parameter in the calculation of rain attenuation is

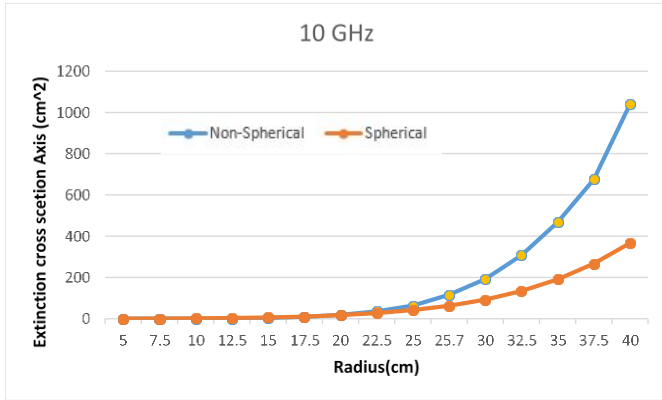


Figure 2. Extinction cross section against Radius at 10GHz.

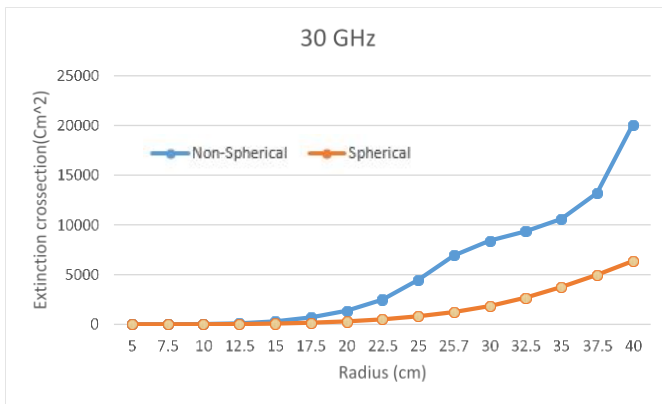


Figure 3. Extinction cross section against radius at 30GHz

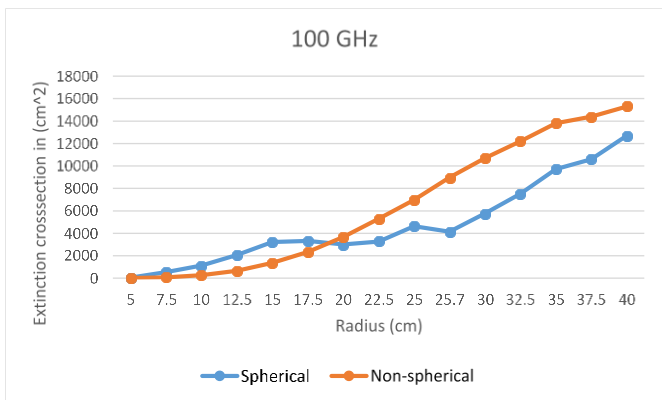


Figure 4. Extinction cross section against radius at 100GHz.

computed and plotted against radius for frequencies 10, 30 and 100 GHz as shown in Figures 2 to 4. Results shows that realistic non-spherical raindrops has higher extinction cross section than spherical drops, this is due to the asymmetric shape of the oblate raindrops. More so, it was

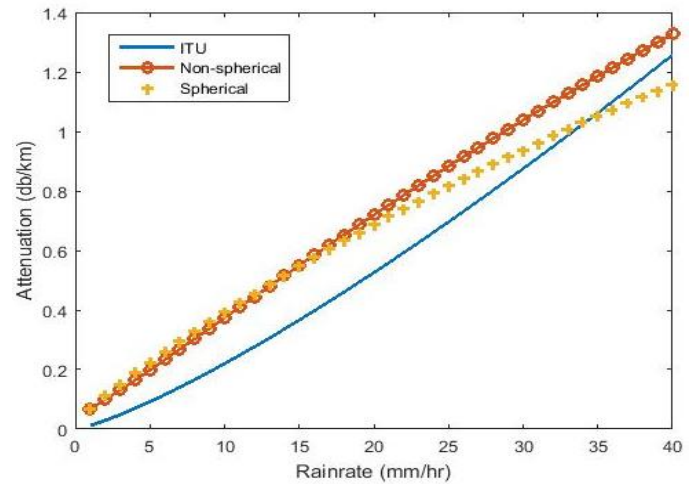


Figure 5. Attenuation vs Rainrate at 10GHz.

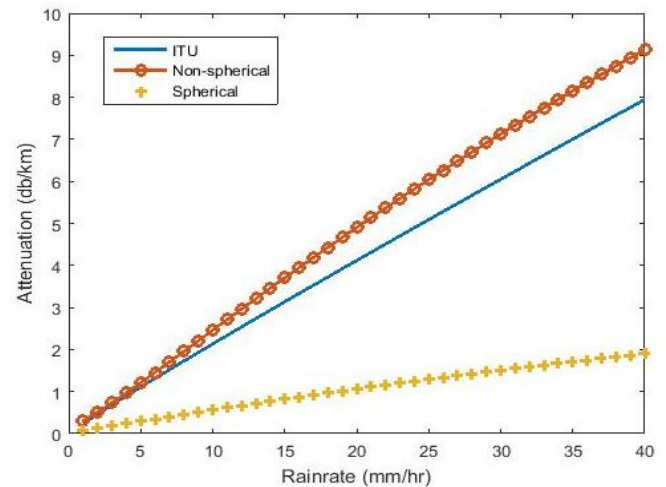
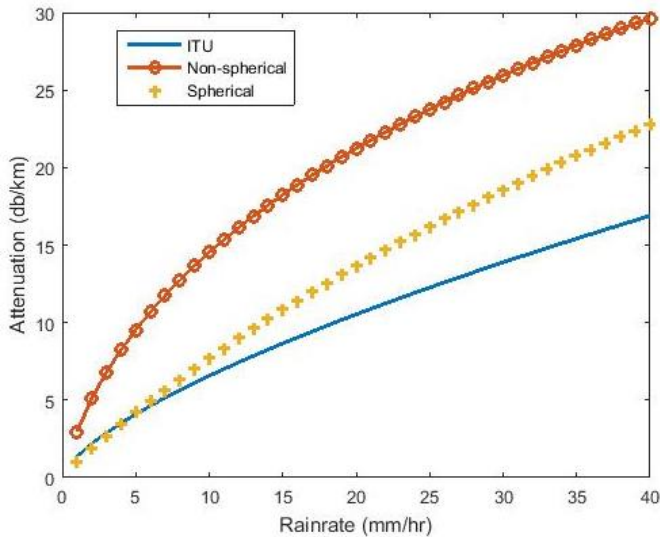


Figure 6. Attenuation vs Rainrate at 30GHz.

observed that the differences in values increase with increase in the drop size and became conspicuous at about 2.5 mm because at this point the aspect ratio of the non-spherical drop is much less than one, in addition, an increase irregularity is observed with increase in frequencies. The extinction cross section pattern observed agrees with that observed by Biswas *et al.* (2016).

### Specific rain attenuation

The specific rain attenuation for spherical and non-spherical raindrop has being computed and plotted against rain rate for frequencies 10, 30 and 100 GHz. Comparison is done by plotting against the ITU-R838 as shown in Figures 5 to 7. The comparison obviously shows that the ITU-R model underestimates the attenuation at the three frequencies, more so a significantly increases in



**Figure 7.** Attenuation vs Rain rate at 100 GHz.

attenuation is observed with increase in frequency. This result is consistent with result obtained by Tan *et al.* (2021). The comparison with the ITU model clearly shows that the ITU-R model underestimates the attenuation at the two frequencies studied, which is also evident from the plots in this study.

## Conclusion

The Mie theory and the T- matrix approach has been adopted to compute the extinction cross section for spherical and non-spherical raindrops using theoretical methods. The specific attenuation of drops ranging from 0.5 to 4 mm radius were computed at different rain rate. The comparison with the ITU\_R838 model shows that the non-spherical model gives higher values for specific rain attenuation than ITU and the spherical model. This research has shown that the non-spherical model should be applied for rain attenuation prediction because it gives better values for rain attenuation, which will help engineers and communication system designer to design systems that will be less susceptible to rain attenuation effect.

## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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