Determination of Aerosol Mass Loading in Ilorin Using Remote Sensing Technique.

P.E. Okpani

Department of Industrial Physics and Electronics, Ebonyi State University,
P.O. Box 1037, Abakaliki, Ebonyi State, Nigeria.

E-mail: pszlkpn@yahoo.com

ABSTRACT

This study was undertaken to employ a passive remote sensing technique to obtain the daily variation of aerosol mass loading and aerosol size distribution in Ilorin, Nigeria, a sub Saharan site, for the months of October, 1987 through June 1988. The value of the scaling factor, K, ranges from 0.2246 to 4.0266 with an average of 0.8540, while that of the shaping constant, V*, ranges from 1.7109 to 2.6969 with an average of 2.1788.

(Keywords: passive remote sensing, aerosol mass loading, aerosol size distribution)

INTRODUCTION

An atmospheric aerosol is a small solid or liquid particle that remains suspended in the air within certain limits. Aerosol particles are divided into three size categories namely Aitken particles (radii less than 0.1 μm), large particles (radii between 0.1 μm and 1.0 μm), and giant particles (radii greater than 1.0 μm). The number concentration of aerosol particles varies widely with time and location ranging from 10^3 to 10^5 per cm^3 (Ludwig et al, 1971; Pruppacher and Klett, 1978).

The presence of aerosols in the atmosphere can be quantified by either by atmospheric visibility - measured in km - or atmospheric turbidity (i.e., aerosol mass loading -a dimensionless quantity) (Maduekwe and Chendo, 1997).

The measurement of the physical and chemical properties of aerosols has been a central theme since the beginning of aerosol science. The variety of devices and methods adopted for such purposes represent a diverse collection of instrumentation designed for specific application. The reason for this diversity is that no single technique or group of techniques provides a means of characterizing the extremely wide range of particle size shape and chemical composition found in nature (Liou, 1980).

The basic principle associated with remote sensing involves the interpretation of radiometric measurements of electromagnetic radiation characterized by a specific spectral interval which is sensitive to some physical aspects of the medium. This is because electromagnetic waves interacting with a medium will leave a signature, which may be used to identify the composition and structure of that medium. When solar radiation transverses the atmosphere, a part of the incident energy is removed by scattering and absorption by atmospheric aerosols as well as other atmospheric constituents. But by purposely selecting wavelengths in which attenuation due to selective absorption by the other atmospheric constituents do not occur their effects can be eliminated (Igbal, 1983).

MATERIALS AND METHODS

The data analyzed in this work were obtained in Ilorin (Lat 8.53˚N, Long 4.57˚ E) during the period from October 1987 to June 1988 using a radiometer - EKO sun photometer MS 120. Only the 500 nm and 675 nm channels were used because at these wavelengths there is practically no water vapor absorption and absorptions by ozone and uniformly mixed gases are negligible. The reading of the instrument is in volts but this reading is proportional to the monochromatic radiant flux density in Wm^{-2} at the observing point. The readings were taken at 30 - minute intervals each day starting from 8.000 hours and ending at 18.00 hours whenever the solar disk is visible.

Each channel of the instrument has its calibration voltages which vary with time because of the depreciation of the interference filters. The ratio of the measured voltage, V , to the corresponding calibration voltage, V_o, for each day is exactly equal to the ratio of the monochromatic radiant flux density, $I(\lambda)$ to the extraterrestrial monochromatic radiant flux density, $I_o(\lambda)$.

To determine the aerosol shaping constant, V*, which is proportional to the size distribution of the aerosol particles and the scaling factor, K, which is proportional to the number concentration of the particles from the measured and calibration voltages for each channel, the following steps were taken.

The hour angle, ω, was computed from the formula (Tiwari, 2006):

$$\omega = 15^{\circ}(12 - T_a) \quad \textbf{(1)}$$

where T_a is the true solar time or local apparent time (LAT). The day angle, Γ, was computed from the formula (Igbal, 1983):

$$\Gamma = \frac{2\pi(\sigma - 1)}{365} \quad \textbf{(2)}$$

where σ is the day number of the year ranging from 1 on January 1 to 365 on December 31. The solar declination, δ, was computed from the formula (Walraven, 1978):

$$\delta = \begin{pmatrix} 0.006918 - 0.399912\cos\Gamma \\ +0.070257\sin\Gamma \\ -0.006758\cos 2\Gamma \\ +0.000907\sin 2\Gamma \\ -0.002697\cos 3\Gamma \\ +0.00148\sin 3\Gamma \end{pmatrix} \left(\frac{180}{\pi}\right) \quad \textbf{(3)}$$

The relative optical mass, M_r was computed from the formula (Igbal, 1983):

$$M_r = \left(\sin\phi\sin\delta + \cos\phi\cos\delta\cos\omega\right)^{-1} \quad \textbf{(4)}$$

where ϕ is the geographic latitude. The values of the overall extinction coefficients τ_1 and τ_2 at wavelengths λ_1 = 500nm and λ_2 = 675nm were computed from the formulas (Goody, 1964):

$$\tau_1 = \frac{-1}{M_r}\ln\left(\frac{V(\lambda_1)}{V_o(\lambda_1)}\right) \quad \textbf{(5)}$$

$$\tau_2 = \frac{-1}{M_r}\ln\left(\frac{V(\lambda_2)}{V_o(\lambda_2)}\right) \quad \textbf{(6)}$$

where $V(\lambda)$ is the voltage reading for the channel of wavelength λ and $V_o(\lambda)$ is the corresponding calibration voltage. The Rayleigh optical depths, τ_{R1} and τ_{R2} at wavelengths λ_1 = 500nm and λ_2 = 675nm which are due to scattering by air molecules are computed from the formulas (Liou, 1980):

$$\tau_{R1} = 0.008569\lambda_1^{-4}\begin{pmatrix} 1 + 0.01113\lambda_1^{-2} \\ +0.0003\lambda_1^{-4} \end{pmatrix} \quad \textbf{(7)}$$

$$\tau_{R2} = 0.008569\lambda_2^{-4}\begin{pmatrix} 1 + 0.01113\lambda_2^{-2} \\ +0.0003\lambda_2^{-4} \end{pmatrix} \quad \textbf{(8)}$$

The aerosol optical depths τ_{A1} and τ_{A2} at the employed wavelengths were computed from the formulas (Igbal, 1983):

$$\tau_{A1} = \tau_1 - \tau_{R1} \quad \textbf{(9)}$$

$$\tau_{A2} = \tau_2 - \tau_{R2} \quad \textbf{(10)}$$

Finally the aerosol shaping constant, V*, and the scaling factor, K, were obtained from a rearrangement Junge's distribution law (Liou, 1980):

$$V^* = 2 + \frac{\ln\left(\tau_{A1}/\tau_{A2}\right)}{\ln\left(\lambda_1/\lambda_2\right)} \quad \textbf{(11)}$$

$$K = \tau_{A1}\lambda_1^{V*-2} \quad \textbf{(12)}$$

RESULTS AND DISCUSSION

The average daily values of the scaling factor, K, which is proportional to the number concentration of the particles and the shaping constant, V*, which is proportional to the size distribution of the particles for the months of October, 1987 to June 1988 are presented in Tables 1 to 8.

Figures 1 and 2 show the monthly mean daily values of the Scaling factor, K, and the Shaping Constant, V*, respectively, for the whole period of observation - October, 1987 to June, 1988.

A careful examination of Tables 1 to 8 as well as Figure 1 reveals that the values of the scaling factor, K, are much higher in the months of October to February than in the months of May and June.

The reason for the significant increase in the value of K during the period from October to February is that Ilorin is inundated with the low – level continental North-Easterly winds commonly known as Harmattan (Adeyefa and Adedokun, 1991). This wind transports large quantities of dust particles from the Sahara Desert to the site. In addition, during the non-Harmattan months the West African Sub region is washed by the humid SW Monsoon winds from the Atlantic Ocean. These winds greatly increase the moisture content of the atmosphere.

Table 1: Average Daily Values of the Scaling Factor, K, and the Shaping Constant, V*, for the Month of October, 1987.

Date	Values of K	Values of V*
01-10-87	0.68251	2.2212
04-10-87	1.10691	2.1593
05-10-87	1.1479	2.0584
09-10-87	1.0845	2.2207
12-10-87	0.6423	2.1957
14-10-87	0.7394	1.9939
17-10-87	1.1689	2.0584
20-10-87	1.1054	2.1517
22-10-87	0.8496	2.2208
25-10-87	0.9397	2.2159
26-10-87	1.0468	2.2082
28-10-87	0.8505	2.2174
29-10-87	0.6817	2.2215
31-10-87	1.1713	1.9888

Table 2: Average Daily Values of the Scaling Factor, K, and the Shaping Constant, V*, for the Month of November, 1987.

Date	Values of K	Values of V*
02-11-87	1.5180	1.9995
03-11-87	1.1435	2.0148
04-11-87	0.5522	2.1927
05-11-87	0.8190	2.1802
12-11-87	0.6924	2.0563
13-11-87	0.5429	1.9202
16-11-87	1.1184	2.1256
17-11-87	1.0440	1.9930
18-11-87	0.5271	2.2676
20-11-87	0.9647	2.0926
21-11-87	1.2745	2.1833
22-11-87	1.0966	2.1429
27-11-87	0.4004	1.7109
29-11-87	0.4096	1.9400
30-11-87	0.4083	2.0026

Table 3: Average Daily Values of the Scaling Factor, K, and the Shaping Constant, V*, for the Month of December, 1987.

Date	Values of K	Values of V*
12-12-87	0.7156	2.1485
06-12-87	1.1294	2.1971
10-12-87	0.5626	2.1973
11-12-87	0.5764	2.3720
12-12-87	0.5357	2.2405
13-12-87	0.5564	2.5302
14-12-87	0.6333	2.3321
15-12-87	0.6521	2.1793
16-12-87	1.0780	2.2133
17-12-87	0.6442	2.4892
18-12-87	0.5382	2.2567
19-12-87	0.5830	2.6656
20-12-87	1.0092	2.4077
21-12-87	0.7097	2.6479
22-12-87	0.4700	2.4905
23-12-87	0.6727	2.5470
24-12-87	0.8299	2.3561
26-12-87	0.9547	2.4235
28-12-87	0.6314	2.3958
29-12-87	0.8041	2.6675
30-12-87	0.8099	2.6969
31-12-87	0.9882	2.3767

Table 4: Average Daily Values of the Scaling Factor, K, and the Shaping Constant, V*, for the Month of January, 1988.

Date	Values of K	Values of V*
01-01-88	1.6029	2.2600
03-01-88	1.7131	2.2008
05-01-88	0.6649	2.1619
06-01-88	0.8844	2.2988
07-01-88	1.4505	2.1924
08-01-88	3.0487	2.1360
09-01-88	4.0266	2.1714
10-01-88	2.9601	2.1159
11-01-88	1.8013	2.0843
12-01-88	1.0071	2.1246
13-01-88	1.2846	2.5763
14-01-88	1.6495	2.3343
15-01-88	1.7587	2.3678
16-01-88	1.4578	2.3164
17-01-88	1.3939	2.3885
18-01-88	1.2787	2.3772
19-01-88	1.1264	2.2277
23-01-88	0.8268	2.0541
26-01-88	0.7031	2.2064
27-01-88	0.7065	2.2887
28-01-88	1.0186	2.1457
30-01-88	1.2751	2.1786
31-01-88	1.8073	2.3004

Table 5: Average Daily Values of the Scaling Factor, K, and the Shaping Constant, V*, for the Month of February, 1988.

Date	Values of K	Values of V*
01-02-88	0.7731	2.0850
05-02-88	1.2451	2.2859
06-02-88	0.8366	2.1657
07-02-88	0.9995	2.2387
17-02-88	1.5758	2.1267
18-02-88	0.9087	2.1564
19-02-88	0.5527	2.1329
20-02-88	0.6811	2.2451
21-02-88	0.5625	2.4463
22-02-88	0.4661	2.2165
23-02-88	1.0972	2.1415
24-02-88	0.7492	2.2329
25-02-88	0.7681	2.5397
26-02-88	0.4895	2.1491
27-02-88	0.9941	2.2654
28-02-88	1.4826	2.4387

Table 6: Average Daily Values of the Scaling Factor, K, and the Shaping Constant, V*, for the Month of April, 1988.

Date	Values of K	Values of V*
01-04-88	0.6378	2.1255
02-04-88	0.7182	2.1487
03-04-88	1.2938	2.1667
04-04-88	0.8445	2.2497
05-04-88	0.8221	2.3073
06-04-88	0.6951	2.3027
08-04-88	1.2051	2.1431
10-04-88	1.0285	2.2651
12-04-88	0.7895	2.1596
13-04-88	0.9406	2.2851
14-04-88	0.8561	2.2681
16-04-88	1.0458	2.1856
18-04-88	1.0951	2.2071
19-04-88	0.7486	2.3008
20-04-88	1.1549	2.2481

Table 7: Average Daily Values of the Scaling Factor, K, and the Shaping Constant, V*, for the Month of May, 1988.

Date	Values of K	Values of V*
01-05-88	0.3041	2.2418
02-05-88	0.4872	2.1089
04-05-88	0.5681	2.1856
06-05-88	0.6092	2.2651
07-05-88	0.4136	2.2841
10-05-88	0.3947	2.0657
12-05-88	0.5831	2.1485
14-05-88	0.3486	1.9982
15-05-88	0.4195	2.1461
16-05-88	0.4480	2.1205
20-05-88	0.4231	2.1266
21-05-88	0.4338	2.1703
24-05-88	0.2943	2.2973
25-05-88	0.6170	2.1583
28-05-88	0.6077	1.9849
29-05-88	0.4737	2.1208

Table 8: Average Daily Values of the Scaling Factor, K, and the Shaping Constant, V*, for the Month of June, 1988.

Date	Values of K	Values of V*
01-06-88	0.4032	1.9281
02-06-88	0.5292	2.0833
04-06-88	0.3451	2.0591
06-06-88	0.5873	1.9523
08-06-88	0.2856	2.1281
09-06-88	0.6468	1.8833
10-06-88	0.2663	2.2434
11-06-88	0.8260	1.9824
13-06-88	0.6345	1.9103
15-06-88	0.4129	1.8750
16-06-88	1.1090	1.9278
18-06-88	0.2246	1.8768
19-06-88	0.3643	2.4191
21-06-88	0.5706	1.8667
22-06-88	0.6477	1.9672
23-06-88	0.2384	1.9352
27-06-88	0.8729	1.8682
30-06-88	0.3816	1.7528
14-06-88	0.5106	2.0667

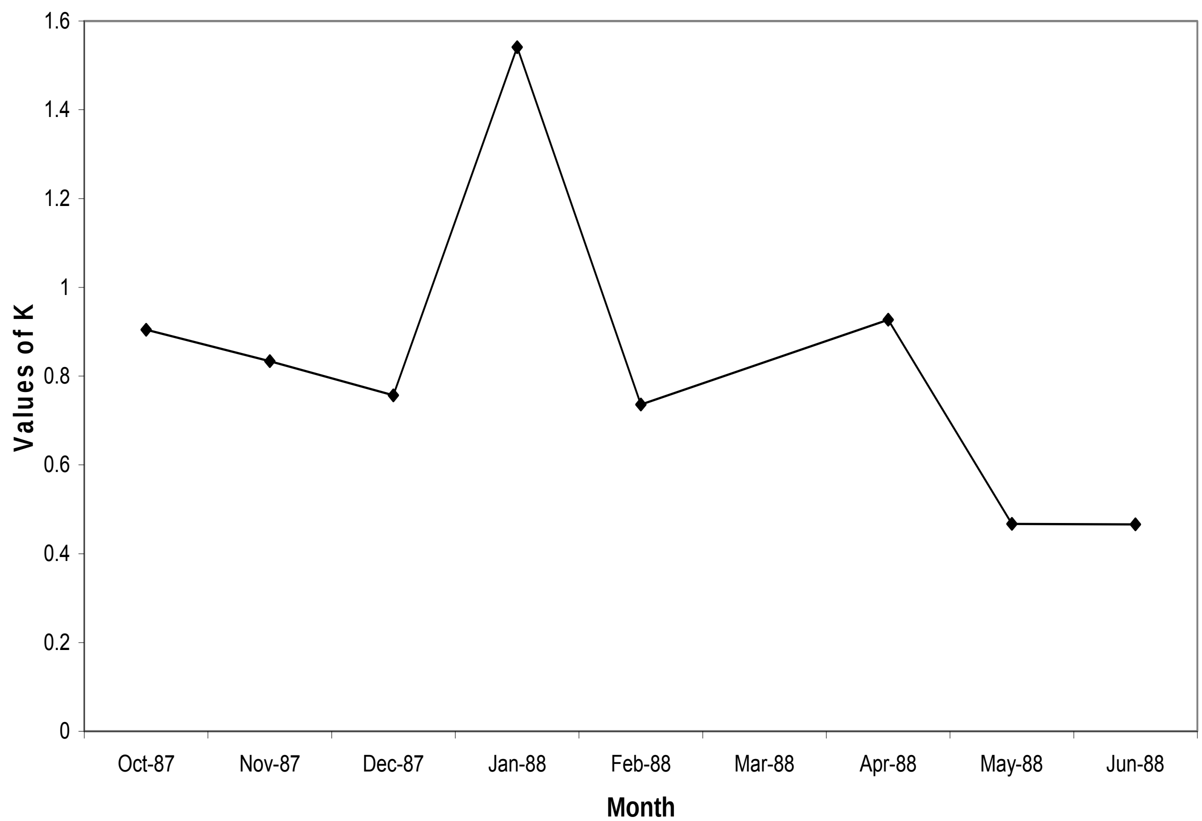

Figure 1: Monthly Mean Daily Values of the Scaling Factor, K, for October, 1987 to June, 1988.

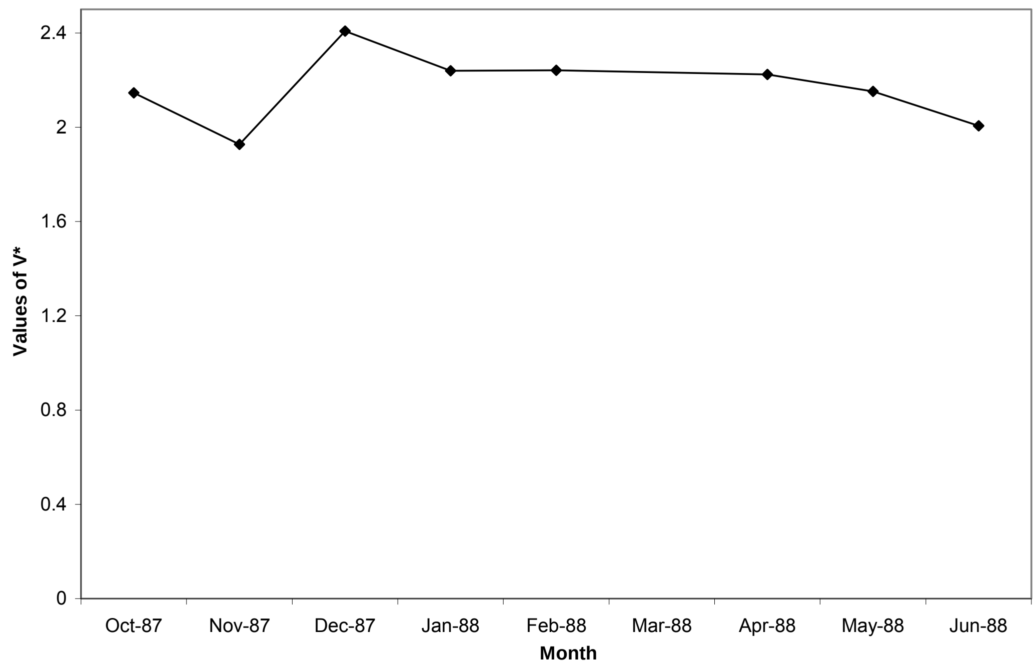

Figure 2: Monthly Mean Daily Values of the Scaling Constant, V*, for October, 1987 to June, 1988.

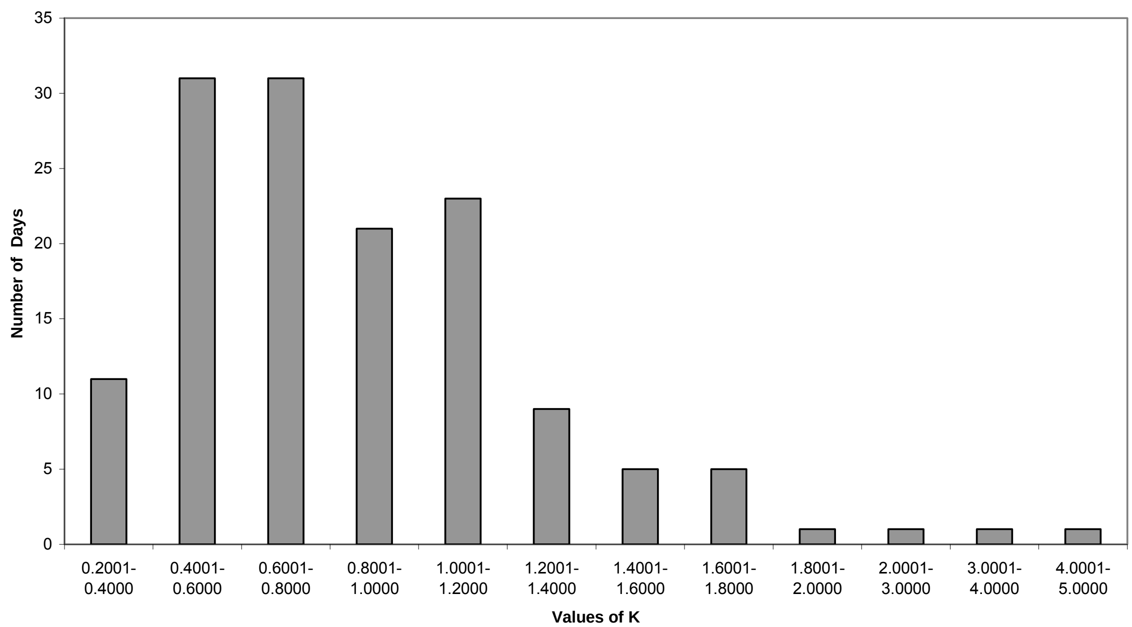

Figure 3: Frequency Distribution of the Scaling Factor, K, for October, 1987 to June, 1988.

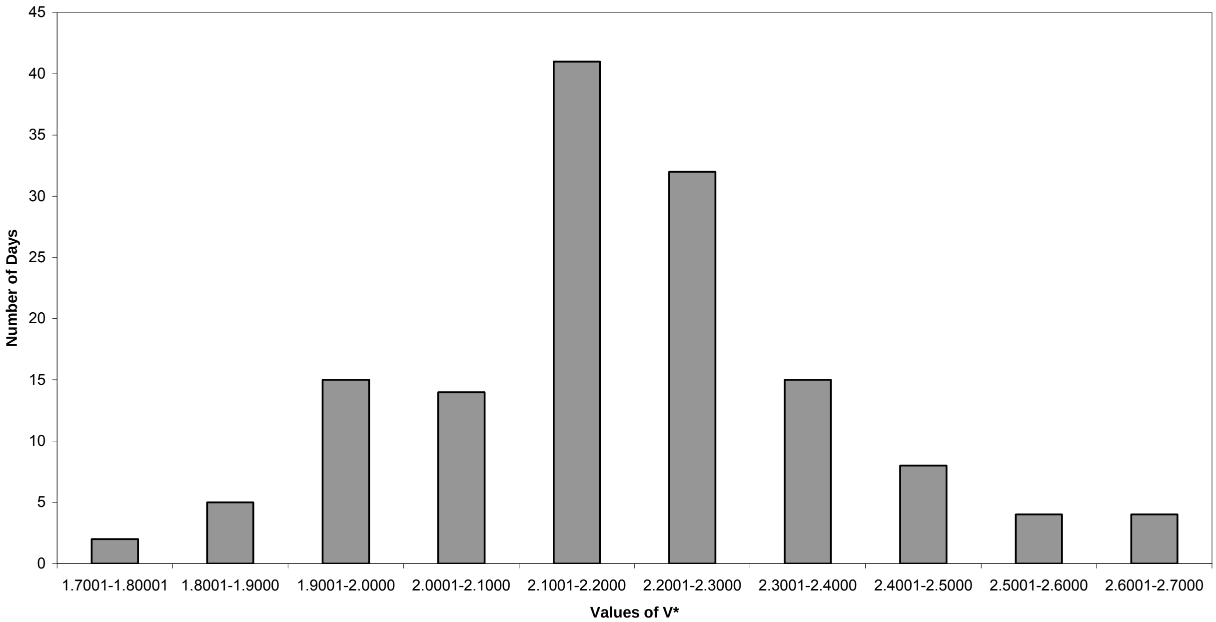

Figure 4: Frequency Distribution of the Scaling Constant, V*, for October, 1987 to June, 1988.

Consequently, a large amount of the aerosol particles present will sediment out of the atmosphere since they serve as condensation nuclei (Pruppacher and Klett, 1978).

From Tables 1 to 8 and Figure 2, it can also be observed that the values of V* are relatively constant during the whole period from October, 1987 to June,1988. This means that the size distribution of the aerosol particles is maintained even though the number concentration changes. The values of V* are also observed to be consistently close to two. The implication of this is that a large proportion of the aerosol particles in Ilorin atmosphere is dust from the Sahara Desert even during the non-Harmattan season. This conclusion is based on the report of Prospero et al (1978).

The total number of observation days was 140. Figures 3 and 4 show the frequency distribution of the scaling factor, K, and the shaping constant, V*, respectively for the whole period of observation - October, 1987 to June, 1988.

A close examination of Figure 3 shows that the frequency distribution of the scaling factor, K, is skewed towards the lower values. This shows that the concentration of aerosol particles in the atmosphere is such that the higher the concentration the smaller the frequency of occurrence.

The frequency distribution of the shaping factor (Figure 4) is near log normal with a peak at the 2.1001 – 2.2000 range. This implies that the size distribution of aerosol particles in the atmosphere follows a log normal distribution law with large particles (size between 0.1 μm and 1.0 μm) predominating (Goody, 1964).

CONCLUSION

Results obtained from measurements and calculations show that aerosol mass loading scaling factor, K, for Ilorin had the lowest value of 0.2246 on June 18, 1988 and the highest value of 4.0266 on January 9, 1988. This shows an increase of 1693% indicating a very high fluctuation. The results also show that the shaping factor, V*, ranges from 1.7528 on June 30 to 2.6969 on December 16. This represents an increase of only 54%.

The average values of K and V* were 0.8540 and 2.1788 respectively. The conclusion that can be drawn from these result is that the contribution of Saharan dust to the total burden of atmospheric aerosols in Ilorin is very high. This is so since there is a great increase in aerosol mass loading when the dust-laden Harmattan is blowing. Also even when the prevailing winds are the rain-bearing SW monsoon winds which cause a significant reduction in the atmospheric aerosol mass loading scaling factor, a large proportion of the aerosol particles is Saharan dust as shown by the value of the shaping factor being consistently close to two. In view of this changes in the dust output from the Sahara Desert (be they man-made or natural) is of potential significance for the climate of Ilorin town (Ludwig et al, 1971)

ACKNOWLEDGEMENT

The author wishes to express his gratitude to Dr. G.O. Idemudia, former HOD, Physics Department, Usmanu Danfodiyo University, Sokoto, Nogeria, for graciously supplying him the 230-page data he laboriously obtained while in Ilorin during this period.

REFERENCES

1. Adeyefa, Z.D. and Adedokun, J.A. 1991. "Pyrheliometric Determination of Atmospheric Turbidity in Harmattan Over Ile-Ife, Nigeria". *Renewable Energy*. 1(3): 555 - 566.

2. Goody, R.M. 1964. *Atmospheric Radiation I: Theoretical Basis*. Oxford University Press: London, UK.

3. Igbal, M. 1983. *An Introduction to Solar Radiation*. Academy Press: New York, NY.

4. Liou, K.N. 1980. *Introduction to Atmospheric Radiation.* Academy Press: New York, NY.

5. Ludwig, J.H., Morgan, G.B., and McMullen, T.B. 1971. *Man's Impact on Climate*. MIT Press: Cambridge, MA.

6. Maduekwe, A.A.L. and Chendo, M.A.C. 1997. "Atmospheric Turbidity and the Diffuse Irradiance in Lagos, Nigeria". *Solar Energy*. 61(4): 241-249.

7. Prospero, J.M., Savoie, D.L., Carson, T.N., and Nes, R.T. 1978. "Monitoring Saharan Aerosol Transport by Means of Turbidity Measurements". In: *SCOPE 14 :Saharan Dust – Mobilization, Transport and Deposition*. 172 – 186.

8. Pruppacher, H.R. and Klett, J.D. 1978. *Microphysics of Clouds and Precipitation*. D. Reidel Publishing Company: London, UK.

9. Tiwari, G.N. 2006. *Solar Energy - Fundamentals, Design, Modelling and Applications*. Narosa Publishing House: New Delhi, India.

10. Walraven, R. 1978. "Calculating the Position of the Sun". *Solar Energy*. 20(5): 393-397.

SUGGESTED CITATION

Okpani, P.E. 2009. "Determination of Aerosol Mass Loading in Ilorin Using Remote Sensing Technique". *Pacific Journal of Science and Technology.* 10(2):5-13.

Pacific Journal of Science and Technology