SUN-PHOTOMETRIC STUDY AND MULTIVARIATE ANALYSIS OFAEROSOL OPTICAL DEPTH VARIABILITY OVER SOME REPRESENTATIVE SITES OF THE KENYAN ATMOSPHERE

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ABSTRACT

The goal of this study was to explore the temporal-spatial characteristics of aerosol optical depth (τ)over the Kenyan urban (Nairobi-1°S, 36°E), rural (Mbita-0°S, 34°E) and maritime (Malindi-2°S, 40°E) atmospheres using sun spectrophotometric measurements obtained from Aerosol Robotic Network (AERONET).AERONET measurements have been taken in Kenya since 2006 and are aimed at assessing aerosol effects on climate and improving the aerosol data base in the region. The multivariate nature of environmental measurements however allows only a limited understanding of atmospheric aerosol characteristics when univariate analysis technique is used. Temporal-spatial characteristics of atmospheric aerosol optical depth can be understood comprehensively if it is appropriately retrieved from ground-based spectrophotometric measurements and then decoupled and analyzed using multivariate analysis techniques since they can explore groups of variables simultaneously, thus providing a more meaningful insight into the temporal-spatial variability of τ is inevitable. The influence of rain and dry spells and temperature on τ at wavelengths, λ = 440 nm and λ = 1020 nm as quantified by Principal Component Analysis (PCA) ranged between 76-83 % and 7-14 %and 4-7 % respectively for all the sites. It was found out that urban heat island (over Nairobi) and local air circulation effects (over Mbita and Malindi) modulate the characteristics of aerosol optical depth over the studied sites. Spatial variability in τ as shown by Hierarchical Cluster Analysis (HCA) is independent of measurement wavelength but dependent on aerosol burden in the atmosphere for each site. The individual and coupled influence of weather parameters on atmospheric aerosols has been isolated and quantified and found to be site dependent.

Keywords:*Aerosol optical properties; multivariate chemometric techniques; sun spectrophotometer; Kenyan atmosphere.*

INTRODUCTION

Aerosols constitute one of the most variable components of the Earth's atmospheric environment. They influence the Earth's atmospheric energy budget and climate through direct and indirect means [1, 2, 3]. Direct effects on radiation budget are via scattering and absorption of solar radiation while indirect effects are via modification of the properties of clouds through their action as Cloud Condensation Nuclei (CCN) [4]. Reliable information about the state of the environment through aerosol measurements canonly be acquired by use of techniques which adequately capture correlated trends and patterns in the measured aerosol optical properties [5]. Hence, application of univariate tests repeatedly are of little use; in any case, they increase the likelihood of an observation occurring by chance (the false-positive result) [6].

The East African region particularly Kenya has experienced rapid urbanization and industrialization as well as deforestation in the last 10-30 years which leads to a significant modulation of aerosol properties. This calls for the attention of the region's aerosol properties which in turn alter the radiative balance of the lower atmosphere. Hence, aerosol properties need to be quantified and modeled in order to fully understand their effects on the regional radiative budget and climate. Following aerosol variability in the atmosphere, ignoring their multivariate relationship with other meteorological parameters impedes their quantitative assessment and radiative modeling over Kenya.

Studies over Europe e.g. over Armilla, Granada in Spain show low τ (0.06) values in winter and high τ (0.43) values in summer [7]. The latter was attributed to several feedback processes such as photochemical conversions of gaseous pollutants to secondary aerosols; low rainfall rates that enhanced extreme soil aridity hence high mineral dust loading; reduction of particulate scavenging potential through wet deposition; and high frequency of Saharan dust incursions and vice versa for the winter case. It was also noted that τ at λ = 441 nm taken in South east Italy was larger than 0.20 from April to September 2003 and was lower than 0.20 from October 2003 to March 2004 [8]. This showed that continental pollution from Central and Eastern Europe, maritime and long-range transport of polluted air masses from Indian Ocean, mineral dust from North Africa, and sea spray from the Mediterranean Sea dominate the region during spring and summer. On the other hand, the average τ measured at λ = 750 nm for eight stations in China ranges widely from 0.32 (in Ejinaqi) to 0.68 (in Beijing): average coefficient of variation is 70 %; which is mostly due to dust events over western China [9, 10].

In Africa, the Saharan Mineral Dust Experiment at Quarzazate (Morocco) showed low τ values of about 0.28measured at λ = 500 nm. These low values were attributed to more frequent rains in winter and few occurrences of dust events [11]. Johnson *et al.* [12] noted that aircraft *in situ* measurements over West Africa showed a mixture of dust and biomass burning aerosol and indicated τ of 0.79 at λ = 550 nm. This compared well with τ from Bamzoumbou AERONET site (0.74) and a microtops sun photometer measurement (0.72), suggesting that both biomass burning and mineral dust were important contributors to τ at this wavelength. At the same site, τ at λ = 500 nm was observed to remain high (>0.2) throughout the year (average of 0.48). In Mongu, Zambia, τ at λ = 500 nm was found to be as high as 0.80. Thedifferences in τ over Bamzoumbou (Niger) and Mongu (Zambia) were due to the variations in the mixture proportions of biomass burning aerosol and mineral dust. The two dominating aerosol types areimportant contributors to τ at λ = 500 nm [13].

The observed τ values could be as a result of coupled influences of rainfall, temperature, relative humidity among other meteorological variables. Thus, there is a need to decouple them before analysis. Such an end calls for the use of multivariate analysis techniques that reduce the dimensionality of the data structure and also allow for handling a group of variables simultaneously. This captures information about their evolution in time and space, correlated trends and patterns in the measured aerosol optical depthsover each study site. This study entails temporal and spatial monitoring of aerosol optical depths and their comparative study over urban, rural and maritime sites in Kenya.

METHODS

1. THEORETICAL BASIS OF AEROSOL MEASUREMENTS AND UTILITY OF MULTIVARIATE TECHNIQUES

A spectrophotometric measurement of aerosol optical depth is achieved via the Aerosol Robotic Network (AERONET) using the Beer-Lambert-Bouguer relation as detailed in Holben *et al*., [14]. AERONET is a federated network of ground based instruments and data archive for aerosol characterization of spectrophotometric measurements. The AERONET measurements are taken at λ = 340 nm, 380 nm, 440 nm, 500 nm, 675 nm, 870 nm, 940 nm (for water vapor correction) and 1020 nm with a 1.2^o full field of view made every 15 minutes [14, 15].

The three sites at which the measurements were taken are: Malindi (2°S, 40°E) representing a maritime site since it is close to the Indian Ocean (elevation 12 m); Mbita (0°S, 34°E) representing a rural site dominated by agricultural and biomass burning and lying on the shores of Lake Victoria (elevation 1125 m) and Nairobi (an industrial city site) (1°S, 36°E) (elevation 1650 m) (Fig. 1). Nairobi's AERONET sun photometer proximity to the industrial area of the city allows for systematic monitoring of aerosols in relation to anthropogenic input into the atmosphere.

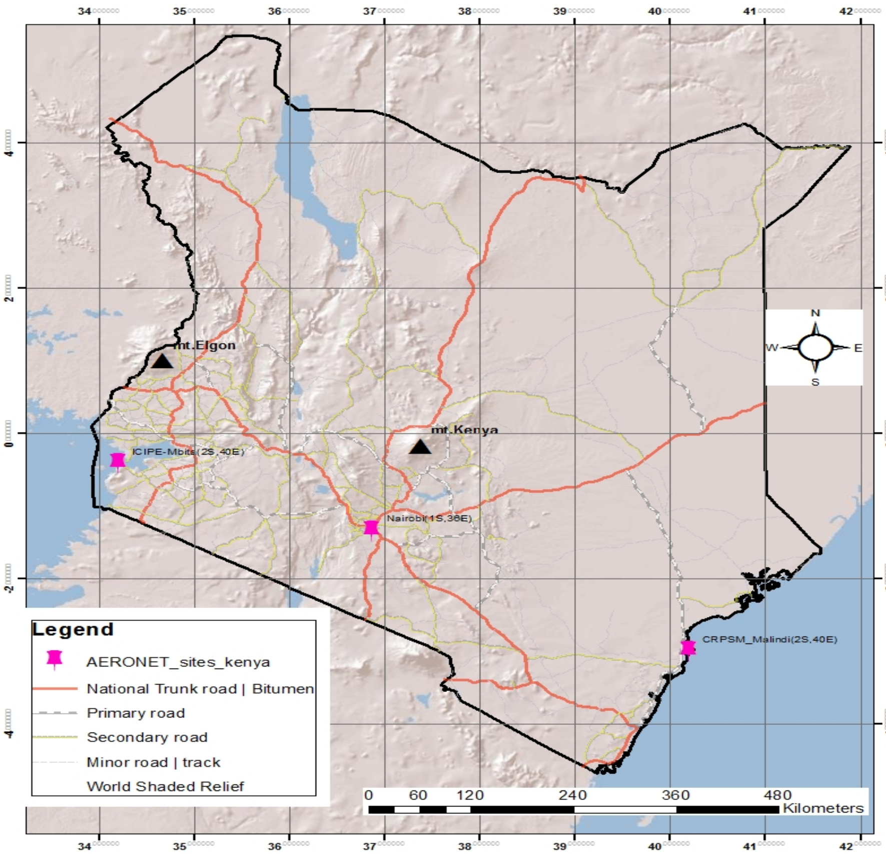

Figure 1: Map indicating the three AERONET study sites in Kenya.

AERONET level 1.5 data was used in the study between 2006-2008 period for Nairobi, 2007 for Mbita and 2008 for Malindi. The selection of the years over each site was limited to the availability of the data considering the requirement of large datasets by multivariate analysis techniques. Some of the study sites e.g. Nairobi had started as early as in the year 2004 but had one month of measurement, in 2005, the site had only three months of measurements i.e. August, October and December. Additionally, Malindi started in 2007 but had one month of measurement (September), in 2008, the measurements were between February and December. Furthermore, Mbita started in 2005 with measurements in December only, in 2006, the site had measurements in March, April, November and December.

The complex nature of the environment as a result of the inherent variability, correlations as well as latent patterns among its measurable components limits the understanding of the characteristics of atmospheric aerosols as obtained from univariate analysis.This calls for the use of techniques that are capable of handling a group of variables and data structures simultaneously, enabling exploratory analysis. We used Principal Component Analysis (PCA) [16, 17, 18] and Hierarchical Cluster Analysis (HCA) [17]for exploring the temporal and spatial characteristics in τ respectively.

PCA builds linear multivariate models of complex data sets [16], using orthogonal basis vectors (eigenvectors) called Principal Components (PC). The PC reduces the dimensionality of complex data and also minimizing the effects of measurement error. PCA mathematical model is described in Equation 1, where T_k is a nxk matrix of PC scores and V_K^T is the mxk matrix of eigenvectors.

$$A = T_k V_k^T + \varepsilon \text{..........................} \quad (1)$$

Eigen vectors in V_K^T forms a set of orthonormal raw basis vectors for A (the data matrix of τ) while ε is the residual. The columns of T_k are called scores and are mutually orthogonal but not normalized. Each independent source of variation in τ data yields a single PC (eigenvector) is expected in the model [17].

HCA finds sample/object clusters within data using criteria developed from the data itself hence the term cluster analysis. The HCA technique is based on distances between pairs of points in the measurement space are inversely related to the degree of similarity as in Equation 2.

$$S_{ik} = 1 - \frac{d_{ik}}{d_{max}} \text{....................................} (2)$$

Where S_{ik} is the measure of similarity between samples i and k, d_{ik} is the distance between samples i and k, and d_{max} is the distance between the most dissimilar samples which is also the maximum distance in the data set [17].

2. RETRIEVAL OF AEROSOL OPTICAL DEPTH AND MULTIVARIATE ANALYSIS

Table 1: Annual and spatial variation in τ at zero SZA over the study sites for the 2006-2008 period

Site	Year	Wavelength in nanometers (nm)			
		440	675	870	1020
		Aerosol optical depth (τ)			
Nairobi	2006	0.17±0.03	0.12±0.02	0.12±0.02	0.11±0.01
	2007	0.03±0.01	0.07±0.01	0.06±0.01	0.09±0.01
	2008	0.15±0.02	0.12±0.03	0.12±0.02	0.11±0.01
Mbita	2007	0.15±0.02	0.10±0.03	0.08±0.01	0.07±0.01
Malindi	2008	0.17±0.03	0.13±0.02	0.12±0.02	0.15±0.01

The data (aerosol optical depth) was then grouped into Early Morning (7-9 AM), Late Morning (9-11AM), Early

Afternoon (11 AM-1 PM) and Late Afternoon (1-3:30 PM) time intervals for each wavelength and site. The grouping was necessary to aid in appropriate structuring of the data for multivariate analysis and also for studying the temporal characteristics in τ using Unscrambler 9.7 (CAMO As. Oslo) using PCA.In order to reduce the dimensionality of the data for analysis in terms of temporal variability, the data (τ) was re-formatted to have weekly averages representing the sample space (rows), while the time intervals were treated as the variable space (columns). HCA was realized by using weekly τ of common time interval into a custom written algorithm in MATLAB 7.1.

Mean centering was performed on τ dataset and before PCA was applied. This not only improved the precision of estimates from ill-conditioned and collinear data but also enhanced the interpretive process of visualizing the data (graphical interface).

RESULTS AND DISCUSSION

To start with, we would like to give a brief overview of the regions' picture in terms of the variations in the aerosol optical depth (τ). The annual averages of τ at zero Solar Zenith Angle (SZA) for the three sites of study are as detailed in Table 1. The variation in τ over Nairobi is attributed to the influence of annual rainfall received. The 14.4 % increase in the annual rainfall received over Nairobi in the 2006-2007 period translates to an observable drop in τ for all wavelengths.

1. EXPLORATORY ANALYSIS OF TEMPORALCHARACTERISTICS OF AEROSOL OPTICAL DEPTH (τ)

PCA score plots of τ for selected observation wavelengths (λ = 440 nm and λ = 1020 nm) are shown in Fig. 2a-b for Nairobi, Fig. 3a-b and Fig. 4a-b for Mbita and Malindi respectively. Three Principal Components (PCs)were obtained over Nairobi:PC1 (76 %) was found to correspond to the rainy period (long and short rains which appear in Eastern Africa between March-May and October-November respectively);PC2 (14 %) corresponds to dry spell weeks while PC3 (7 %) represents the temperature at the time of measurement. The remaining 3 % corresponds to noise in the data which could be due to uncertainties in aerosol measurements. This conclusion was drawn by observing the rainfall and temperature data for Nairobi in the study period. Aerosol optical depths values vary during rainy and dry spells due to wet and dry deposition of atmospheric aerosols respectively

Thus τ has temporal variability with respect to rainy (blue) and dry (green) spells. Rainy (both long and short) spells were characterized by low τ values (0.08-0.31) caused by wet removal of aerosols from the atmosphere e.g. Weeks 9-20 (long rains) and Weeks 44-47 (short rains). Nairobi experiences low temperature of 10.5 °C (against an annual average of 18.9°C) for Weeks 21-31 from June-August which limits photochemical production of aerosols and dust loading, hence, low τ values. Furthermore, Nairobi is an urban heat island with elevated night temperatures than those of the surrounding rural areas; this allows for the transportation of cold air accompanied by aerosols from surrounding regions hence the high τ values particularly for weeks with no rainfall at all (Weeks 42, 43 and 48).

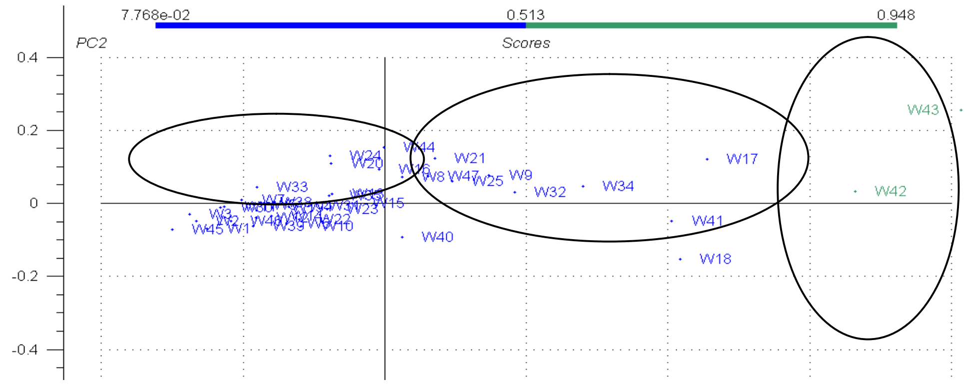

Figure 2a: Plot of PCA scores for 48 samples (weeks) in four variables (time interval) dataset measured at λ=440 nm for Nairobi (2006).

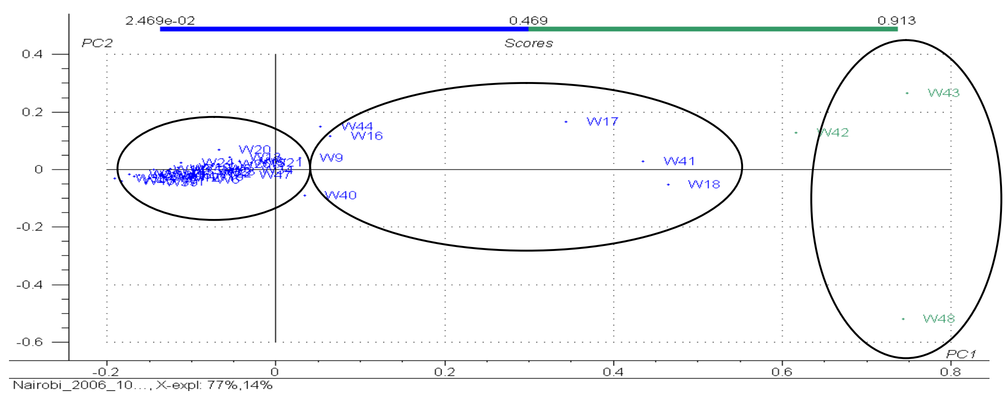

Figure 2b: Plot of PCA scores for 48 samples (weeks) in four variables (time interval) data set measured at λ=1020 nm for Nairobi (2006).

The score plot in Fig. 2b corresponds to λ = 1020 nm and shows similar patterns in τ to those seen at λ = 440 nm. However, there is a much clearer clustering probably due to the reduction in uncertainty effects in aerosol measurements at this wavelength [19].

As noted in Fig. 3a-b, temporal modulation of τ is wavelength independent as the suggested clusters in τ for both rainy and dry spells at the two observation wavelengths. The rainy spell (blue) in Fig. 3a is characterized by lower τ (0.07-0.34) values attributable to wet removal of aerosols from the atmosphere. Dry spell (green) comprises of τ for weeks 8, 24, 25, 26, 28, 29, 30, 33 and 34. These weeks had no rainfall received and are characterized by heavy biomass burning (as a source of energy for cooking). The high τ values (0.34-0.61) (during the dry period) and hazy nature of clustering in the score plot for Fig. 3a is due to the local air circulation effect from Lake Victoria along which Mbita lies. The clarity in the PCA score plots in Fig. 3a and b depends on the measurement wavelength (as also earlier noted over Nairobi). The influence of temperature (PC3) on aerosol optical depth in the λ = 440 nm over Mbita is less by 3 % when compared to that of Nairobi. This is because Mbita is a rural site that is relatively free from anthropogenic influences i.e. industrial emissions that promote aerosols in this wavelength; hence the low explained variance.

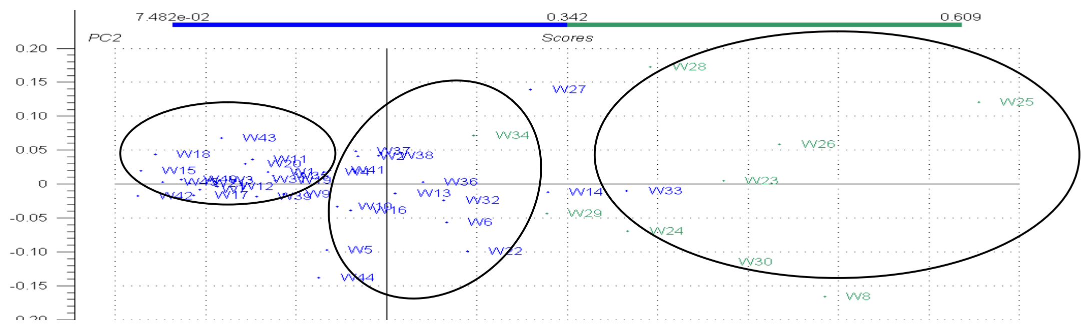

Figure 3a: Plot of PCA scores for 48 samples (weeks) in four variables (time interval) data set measured at λ=440 nm for Mbita (2007).

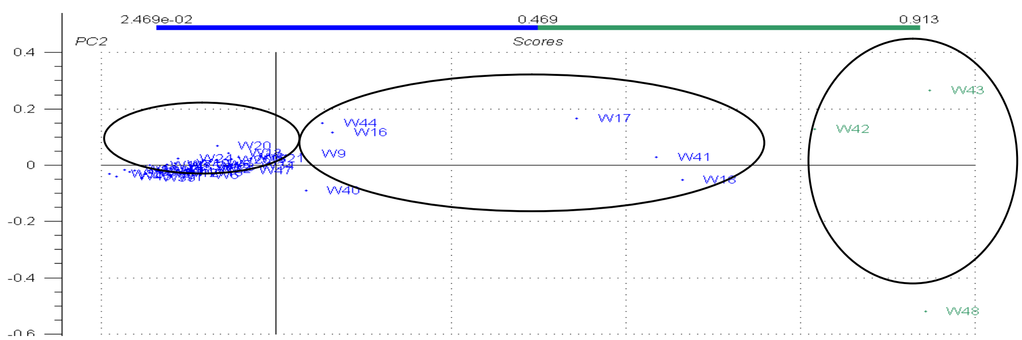

Figure 3b: Plot of PCA scores for 48 samples (weeks) in four variables (time interval) data set measured at λ=1020 nm for Mbita (2007).

Local air circulation effect as impacted on by high temperature (annual average of 23.3℃) over Malindi explains the existence of a single cluster at the two wavelengths. During long and short rain, Malindi is characterized by lower τ values (0.04-0.24) while dry spells (Weeks 20, 21, 22, 23, 25, 26, 27, 29, 30 and 31) have high τ values (0.24-0.45) (Figure 4a). This is as a result of wet deposition of aerosols and enhanced soil aridity due to dry spells respectively. Elevated temperature over Malindi (23.3°C) when compared to that of Nairobi (18.9°C) in 2008 enhances soil aridity which accelerates dust loading and local air circulation effect on the previous site. This modulates aerosol loading in the atmosphere for the λ = 1020 nm wavelength with an explained variance of 6 %. The clarity in the score plots (Fig. 4a, b) also depends on wavelength of measurement which is attributable to uncertainties in aerosol measurements [19].

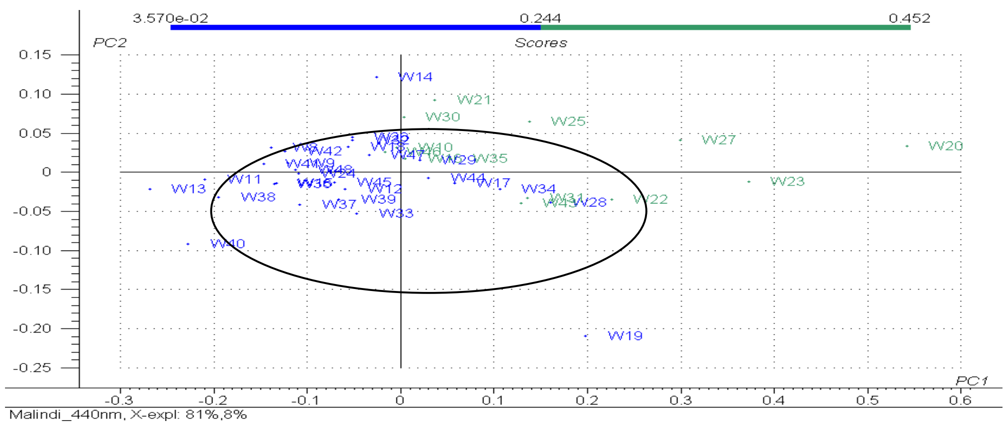

Figure 4a: Plot of PCA scores for 48 samples (weeks) in four variables (time interval) data set measured at λ=440 nm for Malindi (2008).

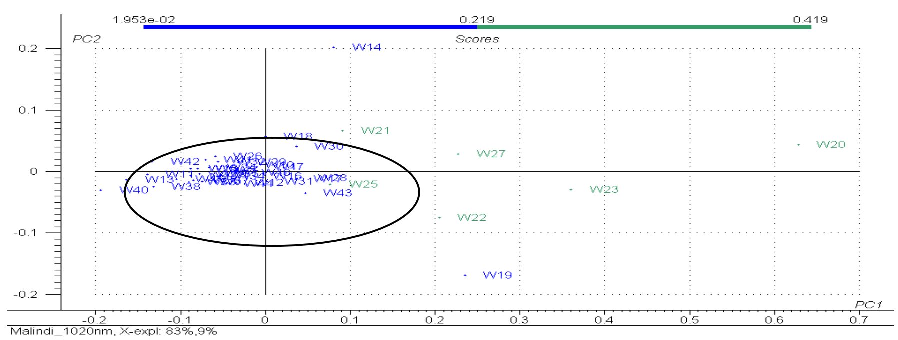

Figure 4b: Plot of PCA scores for 48 samples (weeks) in four variables (time interval) data set measured at λ=1020 nm for Malindi (2008).

It is noted that the PCA score plots for Mbita and Malindi are hazy particularly in the λ = 440 nm wavelength. This was due to local air circulation effect from Lake Victoria and the Indian Ocean that facilitated aerosol transport between the land and the adjacent water body respectively. On the contrary the

PCA score plots for Nairobi are clearer compared to those of Mbita and Malindi attributable to the absence of any water body near it. Table 2 summarizes the influence of rain and dry spells and temperature on temporal variability in aerosol optical depth

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Table 2: Percentage influence of rain and dry spells and temperature on aerosol optical depth

AERONET site and year	Rain spell (PC1 in %)	Dry spell (PC2 in %)	Temperature (PC3 in %)	Wavelength of measurement (λ) in nm
Nairobi (2006)	76±1	14±1	7±1	440
	77±1	14±1	7±1	1020
Mbita (2007)	87±1	7±1	4±1	440
	77±1	14±1	6±1	1020
Malindi (2008)	81±1	8±1	7±1	440
	83±1	9±1	7±1	1020

Even though the data is given for different years, it was notable that the influence of rain on aerosol optical depth dominates over Malindi followed by Mbita and then Nairobi. This is as a result of efficiency in wet removal of aerosols from the atmosphere since the previous two sites i.e. Malindi and Mbita received higher rainfall rates as compared to Nairobi. Other than elevated vehicular and industrial emissions that promote photochemical processes (over Nairobi) as documented earlier [20, 21, 22], dust loading is a significant contributor to aerosol generation process and hence variability for all sites. The influence of dry spell and temperature significantly drops to between 7-14 % and 4-7 % respectively, this is because during the dry spell, removal of aerosols from the atmosphere via dry deposition is not as efficient as wet deposition.

2. EXPLORATORY ANALYSIS OF THE SPATIAL CHARACTERISTICS OF AEROSOL OPTICAL DEPTH

The spatial characteristics of aerosol optical depth (τ) in the sampled atmospheres were probed using HCA for Nairobi and Mbita (October-December 2007) and Nairobi and Malindi (March-May 2008) at λ = 675 nm. It was not possible to probe the spatial characteristics for all the three sites simultaneously since there was no common time interval in which the data was obtained. The τ was observed to have a spatial variability from which two clear clusters were assigned to each site as shown in Fig. 5a.

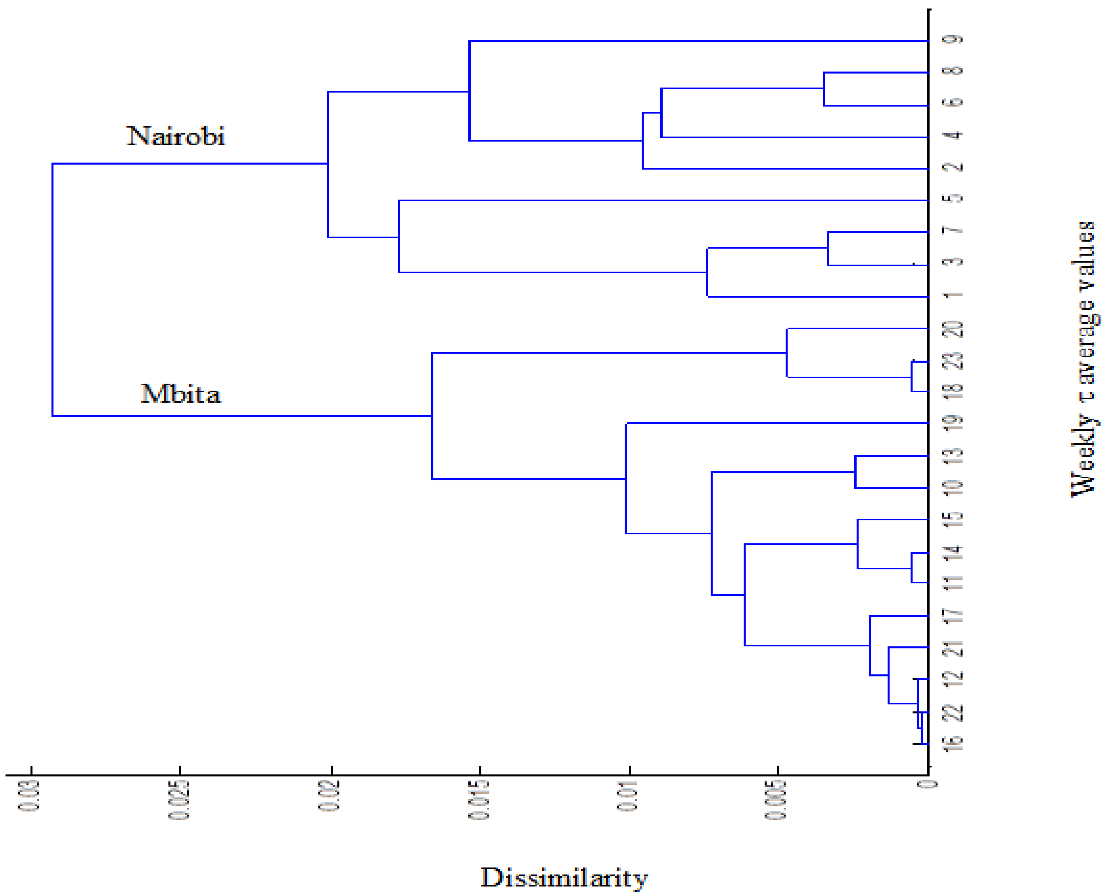

Figure 5a: Dendrogram of 23 weekly average τ from Nairobi and Mbita for 675 nm wavelength channel (October-December 2007).

Cluster one is characterized by indices 1-3-7-5-2-4-6-8-9 (corresponding to Nairobi) while the other group comprises of indices 16-22-12-21-17-11-14-15-10-13-19-18-23-20 (corresponding to Mbita). The division was attributed to the difference in area specific atmospheric aerosol burden (concentration) for the wavelength of measurement. τ values were constrained to the stated time interval to remove the seasonal influence. Urban heat island effect on aerosol transportation over Nairobi explains the two sub-clusters i.e. 1-3-7-5 and 2-4-6-8-9. From Fig. 5a, Mbita had also two main sub clusters: 18-23-20 and 16-22-12-21-17-11-14-15-10-13-19 that may be attributed to local air circulation effects which alter the aerosol burden in the atmosphere.

The results in Fig. 5b for λ = 1020 nm demonstrate that the observed geographical variability of τ is independent of wavelength. This is because the two major clusters suggested are similar to the ones for λ = 675 nm. There are however variations in the sub-clusters in each major cluster for each wavelength. This may be attributed to other aerosols characteristics e.g. aerosol mode of generation which affect aerosol burden in the atmosphere differently for the two sites.

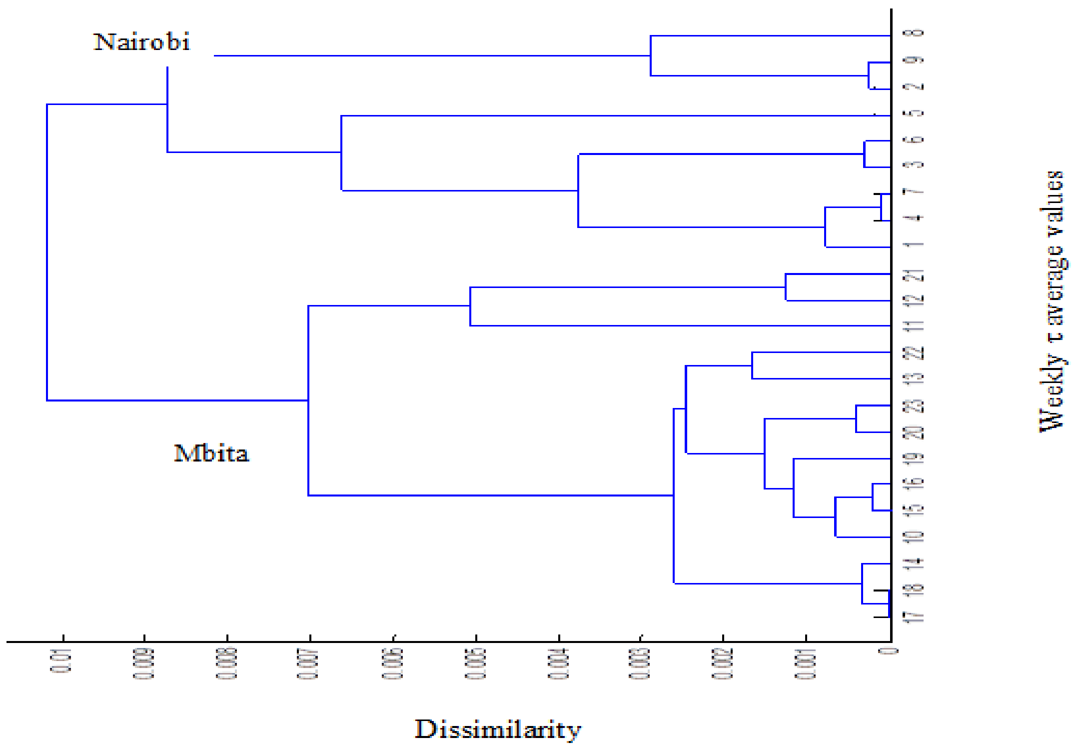

Figure 5b: Dendrogram of 23 weekly average τ from Nairobi and Mbita for 1020 nm wavelength channel (October-December 2007).

The high τ values for λ = 1020 nm over Mbita is attributed to both pollen grains from maturing plants of different types and prevalent dust lifting. Various sub-clusters in the main cluster (17-18-14-10-15-16-19-20-23-13-22-11-12-21) may be attributed to variation in relative humidity. Sub-cluster 11-12-21 corresponds to week number 37 and 38 that are known to be dominated by biogenic aerosols from maturing plants and harvest time over the site. Sub-clusters 10-15-16-19-20-23, 13-22 and 17-18-14 can be attributed to dust loading as modulated by temperature. Specifically, sub-cluster 17-18-14 corresponds to week number 40, 43 and 44 that is characterized by high temperature (23.6℃) that accelerates dust loading.

On the other hand, construction activities prevalent over Nairobi that enhance dust loading can be the reason for the sub-cluster 2-9. Coagulation and condensation processes attributed to significant relative humidity over Nairobi (of about 77.7 %) during the time interval under study might be the reason for sub-clusters 1-4-7, 3-6 and 5 for accumulation mode aerosols originating from vehicular and industrial emissions dominating the site.

Weekly τ averages for Nairobi and Malindi (March-May 2008) are displayed in Fig. 6 for λ = 675 nm.The τ values are also clustered into two main groups i.e. cluster 5-10-3-4-8-7-9-1-6-2 and cluster 11-12-13-16-20-15-18-19-14-17 corresponding to Nairobi and Malindi respectively. Local air circulation effect over Malindi modulates aerosol burden hence the sub-clusters 14-17, 18-19, 13-16-20-15, 12 and 11. On the other hand, Nairobi is characterized by sub-clusters 5-10, 3-4-8 and 7-9 that are as a result of urban heat island effects, which alters aerosol burden in the atmosphere hence τ through aerosol transportation.

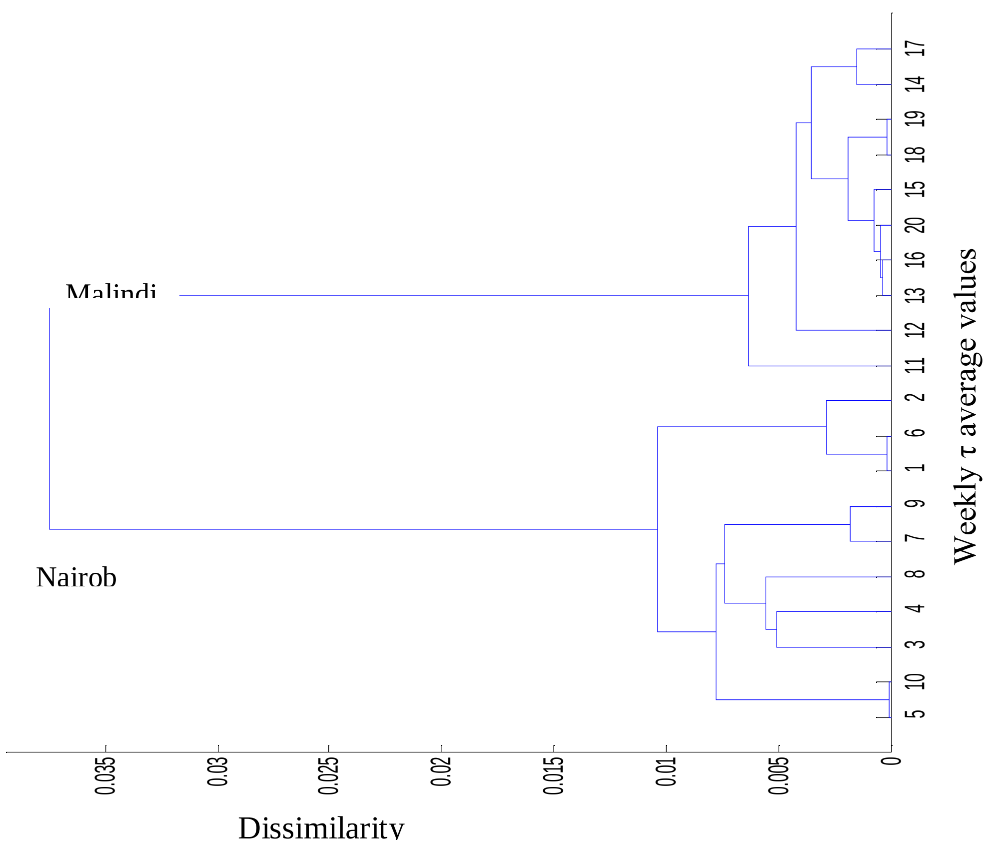

Figure 6: Dendrogram of 20 weekly average τ from Nairobi and Malindi for 675 nm wavelength channel (March-May 2008).

CONCLUSIONS

This paper presents a sun photometric study and multivariate analysis of aerosol optical depths in some representative sites of the Kenyan atmosphere, namely, Malindi, Mbita and Nairobi. Variations in the annual averages of τ were mainly attributed to annual rainfall received plus biomass burning activities (Mbita) and anthropogenic input (Nairobi). PCA investigations quantified the influence of rainy and dry spells and temperature on aerosol optical depths over each site. In addition to vehicular and industrial emissions over Nairobi, urban heat island effects were observed to aid in the modulation of aerosol optical depth over the site. The contribution of local air circulation effects (Mbita and Malindi) and the efficiency in wet and dry deposition of aerosols (for all sites) from the atmosphere also modulates aerosol burden in the atmosphere. Variations in spatial characteristics of τ were attributed to aerosol burden over the study sites while at each site; the variability depends on aerosol characteristics e.g. hygroscopicity and mode of generation in a given wavelength of measurement in the atmosphere under study.

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REFERENCES

1. IIntergovernmental Panel on Climate Change (IPCC). Climate Change 2001: *The specific basis. Contribution of working group 1 for the third assessment report.* Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. Van der Linden, X. Dac, K. Maskell, C.A. Johnson (eds.). Cambridge University Press: UK (2001).

2. Intergovernmental Panel on Climate Change (IPCC). Climate Change: *The Physical Science Basis, Contribution of the working group I to the fourth Assessment Report of the IPCC*. S. Solomon, D.H. Qin, M. Manning, M. Marquis, K. Averyt, M. Tignor, H.L. Miller, Z.L. Chen. Cambridge University Press: Cambridge (2007).

3. CR.J. Charlson, S.E. Schwartz, J.M. Hales, R.D. Cess, J.A. Coakley, J.E. Hansen and D. J. Hofmann. Climate forcing by anthropogenic aerosols. Science. 255: 423-430 (1992).

4. AP. Alpert, Y.J. Kaufman, Y. Shay-el, D. Tanre, A. Da Silva and Y.H. Joseph. Dust forcing of climate inferred from correlation between dust data and model errors, Nature, 395: 367-370 (1998).

5. LV. Lovchinov and S. Tsakovski. Multivariate statistical approaches as applied to environmental physics studies, CEJP, 4(2):277-298 (2006).

6. KA. N. Karp, J.L. Griffin and S.L. Kathryn. Application of partial least squares discriminant analysis to two-dimensional difference gel studies in expression proteomics, Proteomics., 5: 81-90 (2005).

7. AL. Alados-Arboledas, H. Lyamani and F.J. Olmo. Aerosol size properties at Armilla, Granada (Spain), Q. J. R. Meteorol. Soc., 129:1395-1413 (2003).

8. PM.R. Perrone, M. Santese, A.M. Tafuro, B.N. Holbenand A. Smirnov. Aerosol load characterization over south-east Italy for one year of AERONET sun photometer measurements, J. Atmos. Res.,75:111-133W (2005).

9. Xia Xiang-ao, Chen Hong-Bin, Wang Pu-Cai, Zong Xue-Mei, Qiu Jin-Huan and Philippe Gouloub, Lageo. Aerosol properties and their spatial and temporal variations over north China in spring 2001, Tellus., 57B: 28-39 (2005).

10. LZ. Li, Xia Xiangao, C. Maureen, Mi Wen, B. Holben, W. Pucai, C. Hongbin, Si-Chee, Tsay, T.F. Eck, Z. fengsheng and E,G, Dutton. Aerosol optical Properties and their radiative effects in northern china. J. Geophys. Res., 112, D22501, doi: 10291 2006JD007382 (2007).

11. TC. Toledano, M. Wiegner M. Garitammer, M., Seefeldner, J. Gasteiger, D. Műller and P. Koepke. Spectral aerosol optical depth characterization of desert dust during SAMUM 2006, Tellus.,61B: 216-228 (2009).

12. JB.T. Johnson, S. Christopher, J.M. Haywood, S.R. Osborne S. McFarlane, C. Hsu, C. Salustro and R. Kahn. Measurements of aerosol properties from aircraft, satellite and ground-based remote sensing: A case study from the Dust and Biomass-burning Experiment (DABEX). Q.J.R. Meteorol. Soc., D01: 10.1002.qj.420 (2009).

13. LC. Liousse and H. Cachier. Measurement of black carbon aerosol in the atmosphere of two different source regions – Real time data for Paris region and Savanna site of the Ivory Coast, Environ. Technol., 13: 959-967 (1995).

14. HB.N. Holben, T.F. Eck, I. Slutsker, D. Tanre, J.P. Buis, A. Setzer E. Vermote, J.A. Reagan, Y.J. Kaufman, T. Nakajima, F. Lavenu, I. Jankowiakand A. Smirnov. AERONET-A federated instrument network and data archive for aerosol characterization, Remote Sens. Environ., 66:1-16 (1998).

15. HB.N. Holben, , T.F. Eck, I. Slutsker, D. Tanre, J.P. Buis, A. Setzer, E. Vermote, J.A. Reagan, Y.J. Kaufman, T. Nakajima, F. Lavenu, I. Jankowiak and A. Smirnov**.** An emerging ground based aerosol climatology: Aerosol optical depth of AERONET, J. Geophys. Res., 106:12067-12097 (2001).

16. GP. Gemperline. Practical Guide to Chemometrics, Taylor and Francis Group (2006).

17. HD. Hedwig and W. Maenhaut. Application of principal component and cluster analysis to the study of the distribution of minor and trace elements in normal human brain, Chemometrics and Intelligent Laboratory Systems., 9:273-286 (1990).

18. AA. Alexandridis, S. Haralambos and G. Bafas. Modeling and control of continous digesters using the PLS methodology, Chem. Eng. Comm., 191:1271-1284 (2004).

19. K.D. Knobelspiesse, C. Pietras, G.S. Fargion, M. Wang, R. Frouin, M.A. Miller, A. Subramaniam and W.M. Balch. Maritime aerosol optical thickness measured by handheld sunphotometer. Remote Sensing of Environment, 93 (1-2):87-106 (2004).

20. GM.J. Gatari, J. Boman and W. Annemarie Characterization of aerosol particles at an industrial background site in Nairobi, Kenya. X-ray Spectrom., 38:37-44 (2009).

21. E.D.S. Van Vliet and P.L. KinneyImpacts of roadway emissions on urban particulate matter concentrations in sub-Saharan Africa: New evidence from Nairobi, Kenya. Environ Res. Lett., Doi:10.1088/1748-9326/2/4/045028 (2007).

22. AD. C. Adukpo: Characterization of MAX-DOAS instrument and application to satellite validation. M. Phil. (Physics), University of Bremen., (2002).