Mausam, (1991), **42**, 4, 367-374

551.510.42 : 551.591 : 551.593.4

Atmospheric extinction related to aerosol mass concentration and meteorological conditions in the atmosphere of Qena (Egypt)

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(*Received 22 August 1989*)

सार--वायुविलय संहति सान्द्रता, तापमान और पवन गति पर वायुमंडलीय विलोप की निर्भरता को प्रदर्शित किया गया है। प्रकाश सेल संसूचक से 36 सें. मी. के पथ के पार प्रकाश स्रोत से विकिरण के प्रेषण की हानि के माप से वायुमंडलीय विलोप का पता लगाया गया था। निष्कर्षतः इसमें उच्च वायु विलय सान्द्रता, तापमान और पवन गति से उच्च विलोप का संबंध आ जाता है। किन्तु वहां कोई भी परस्पर (एक से एक) संबंध नहीं है। विलोप सहसंबंध और इसके प्रत्येक प्राचल के बीच सहसंबंध का अध्ययन किया गया है।

ABSTRACT. The dependence of the atmospheric extinction on aerosols concentration, temperature and wind speed is demonstrated. The atmospheric extinction was determined by measuring the transmission loss of radiation from a light source across 36 cm path with a photocell detector. Conclusions include a general association of high extinction with high aerosols concentration, temperature and wind speed, but there are no one-to-one relationships. A correlation study between the extinction coefficient and each of these parameters was performed.

Key words—Air pollution, Atmospheric extinction, Atmospheric visibility, Aerosol particles, Concentration, Meteorological conditions.

1. Introduction

The environmental impacts of air pollutants involve several effects on the earth's atmosphere and on atmospheric processes. One of the most important effects is the reduction of atmospheric visibility. Particulate emission of dusts, fumes, fly ash, and other solid particles, which is generally classed as aerosol particles, is the most common pollutants with potential visibility impacts (Robinson 1984). The need to measure the amount of particulate air pollutants has produced an increased interest in a possible relation between atmospheric extinction and the mass concentration of particulate matter in the atmosphere. The relationship between these two variables has primarily been studied in other works (*e.g.*, Charlson 1969, Noll *et al.* 1968, Pilat and Ensor 1970, 1971, Patterson and Gillete 1976 and Chylek *et al.* 1979). The results of many of these studies indicate that the existence of an unambiguous relation between the extinction and the mass concentration is limited. There are also a number of meteorological factors that are important in the determination of extinction coefficient owing to their effects on both the concentration of atmospheric particles and their size (Robinson 1984). The most important factors and relative humidity, mixing height, temperature, wind speed and direction.

This paper aims to study the relationships which exist between the atmospheric extinction and aerosol mass concentration, temperature and wind speed in the atmosphere of Qena city in upper Egypt.

2. Experiments

Simultaneous measurements of the extinction coefficient, concentration of the aerosol particles and some meteorological conditions (wind speed and temperature) were carried out seven times daily in the atmosphere of Qena city at the period from March 1988 to July 1988 and from August 1988 to January 1989 on the roofs of the faculties of science (site 1) and education (site 2) (about 25 m above the ground) respectively. Sites of measurements are marked on Fig. 1, which represents a location map of the study area. Site No. 1 locates in a desert area and far from the man activities while site No. 2 is urban area and lies in the centre of the city. In general, the atmosphere of the sampling area is mostly calm along the year (50% of the winds frequency is calm). The prevailing wind directions are SW, W and NW with percentage of occurrence equal to 16.2, 13.5 and 12.9 respectively (Met. Dept., A. R. Egypt 1988). Both the sites are located downwind related to the direction of the prevailing winds.

The extinction coefficient was determined by measuring the transmission loss of radiation from a light source caused by aerosol particles and gaseous constituents of the air through a 36 m path with a photocell detector using an optical device constructed by the authors. The device consists mainly of brass metal chamber connected to a tungsten light source and a photocell detector. Measurement procedure includes recording of readings of a digital electrometer in nA

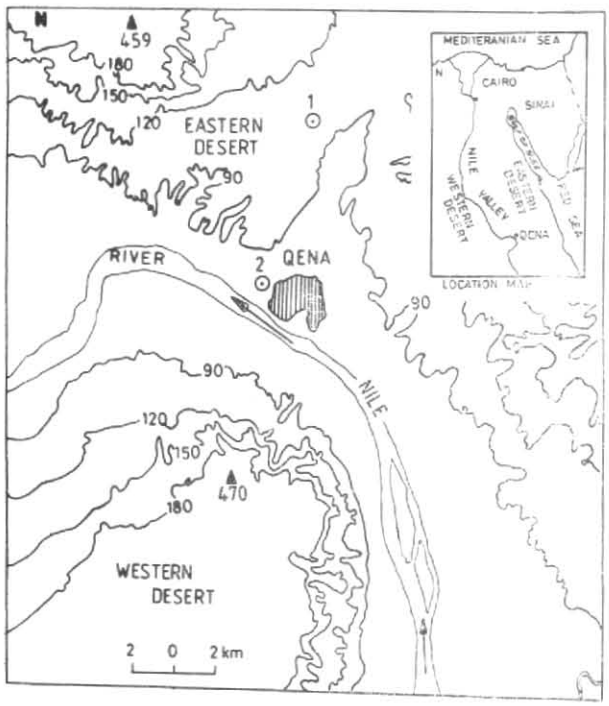

Fig. 1. A location map of the study area

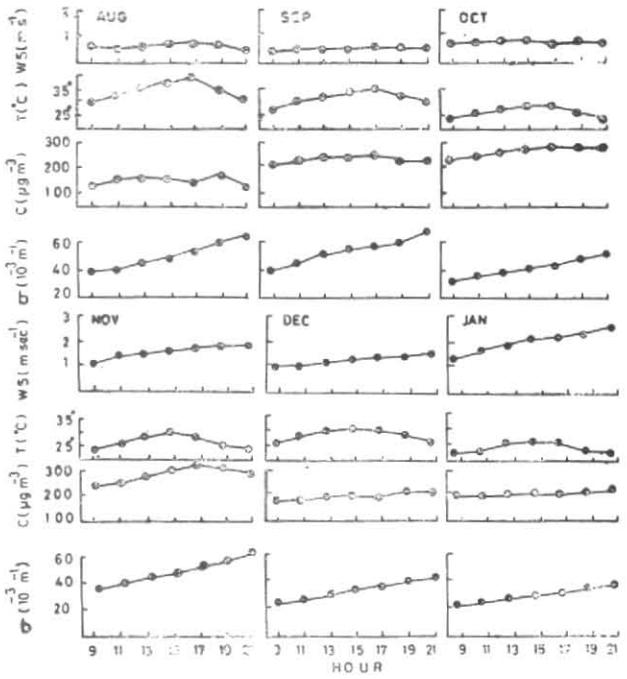

Fig. 2. Monthly average diurnal patterns for the extinction coefficient (σ), aerosol mass concentration (c), temperature (T) and wind speed (ws) at site 2

when the metal chamber is maximally evacuated from atmospheric air (I_o) and after its inlet (I). The measurements were carried out at a wavelength of 550 nm. The extinction coefficient (σ) is then calculated with the aid of the well known Lambert's equation :

$$I/I_0 = e^{-\sigma x} \qquad (1)$$

where, x denotes to the path length of the incident light, and σ is the summation of the extinction coefficients of aerosol particles (σ_p) and the gaseous constituents of the air (σ_{Rg}). For urban air pollution conditions, atmospheric extinction is caused primarily by fine particles and not by the gaseous constituents of the air (Robinson 1984). Also σ_{Rg} is less than 10% of the whole extinction σ and shows a negligible dependence on the meteorological parameters, so that it drops out as far as an important factor is concerned (Robinson 1984). In Eqn. (1), extinction coefficient is related to variations in aerosol particles concentration through its effect in the transmittance I/I_o.

More details about the construction and calibration of this device were given in a previous work (El-Shazly *et al.* 1989 b). Aerosol particles were collected from the atmosphere on cellulose nitrate membrane filter of 0.8 μm pore size and 50 mm diameter (Sartorius GmbH, West Germany Model 11304) using dust sampler of flow rate 1.5 m^3 hr^{-1} (Sartorius GmbH, West Germany Model 16711). The mass concentration of the aerosol particles is calculated in μg m^{-3} from weight difference between the membrane filter after and before sampling. The sampling period was 2 hr.

The measurements of the temperature were carried out using thermohygrograph (Model 34930, Gasela).

Wind speed measurements were made using air-meter of speed range 30-1000 metres per minute (Griffin & George, Model 1749, England).

3. Results and discussion

The results of the simultaneous measurements of extinction coefficient (σ), aerosol mass concentration (c), temperature (T) and wind speed (ws) recorded for the different months were averaged by hour of the day. The resultant diurnal patterns are shown in Figs. 2 and 3 for sites 1 and 2 respectively.

3.1. *Extinction and aerosol mass concentration*

From Figs. 2 and 3, it is immediately apparent the following :

(*i*) The extinction coefficient is, in general, closely related to the aerosols concentration (*e.g.*, hours from 9-15), *i.e.*, high extinction coefficient at high aerosols concentration and *vice versa*.

(*ii*) The obtained levels of σ are high at site 2 compared to site 1. They were found to be approximately 25% higher at site 2 than at site 1. This may be explained in terms of the high aerosol mass concentration, which measured at site 2. This can be explained in terms of the additional source of dust particles at station 2 compared to station 1 as shown clearly in the location map in Fig. 1. Beside the eastern desert, which is the main source of dust in the atmosphere of the whole study region with the aid of the NW-winds

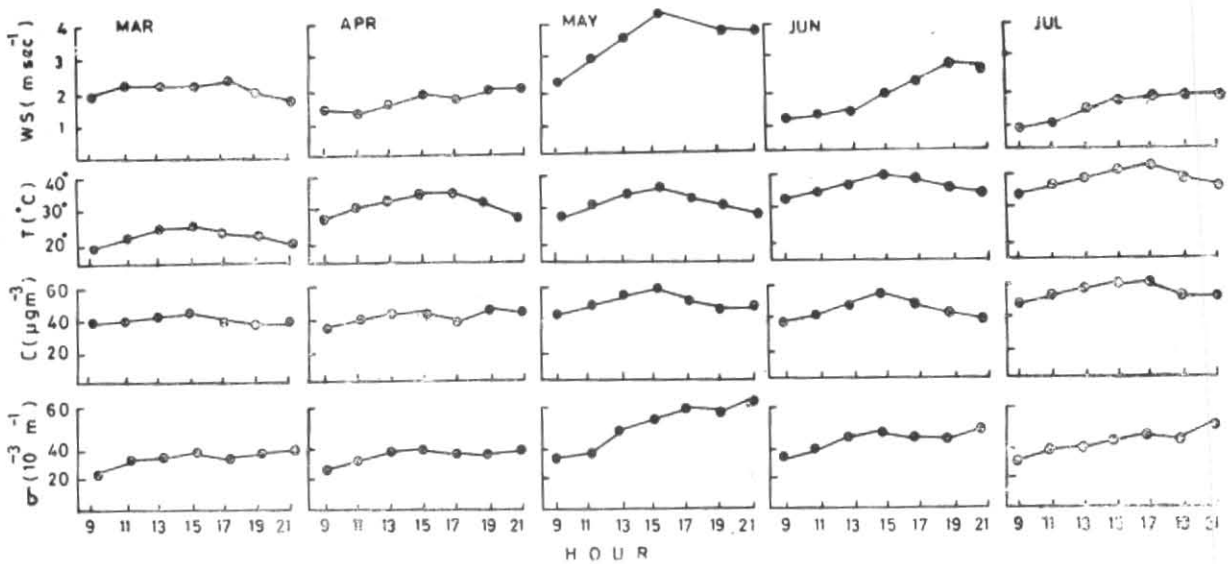

Fig. 3. Monthly average diurnal patterns for the extinction coefficient (σ), aerosol mass concentration (c), temperature (T) and wind speed (ws) at site 1

site 2 has the following additional sources :

(*i*) Anthropogenics, which represent an important sources due to the location of this site in the centre of the city.

(*ii*) Dusts dispersed from the western desert with the aid of SW-winds.

Consequently high mass concentration of aerosol particles at station 2 should be expected compared to its mass concentration at station 1.

Figs. 4 and 5 show the scatter plots of σ *vs* c for all measurements at sites 1 and 2, respectively. While there is a general association of high extinction with high aerosols concentration, there is no one-to-one relationship. This may be explained in terms of the strongly dependence of the relation between the extinction σ and the aerosol mass concentration c on the size distribution of the aerosol particles $n(r)$ even if we assume that the density and the refractive index of the particle do not change significantly with time (Ensor and Pilat 1971, Chylek *et al.* 1979).

A formal relation between σ and c can be written in the following form (Chylek *et al.* 1979, Jennings and Pennick 1980) :

$$c = \frac{4\rho}{3} \frac{\int r^3 n(r)\, dr}{\int r^2 Q_e(m, r, \lambda)\, n(r)\, dr} \sigma(\lambda) \quad (2)$$

where, Q_e (m, r, λ) is the Mie efficiency factor for extinction of a particle of density ρ, refractive index m and radius r. According to Eqn. (2), a simple linear relation between σ and c may be only obtained if one of the two following conditions is statisfied:

(*i*) The size distribution of aerosol particles does not change with time.

(*ii*) The extinction measurements are made at a wavelength satisfies the relation (Chylek *et al.* 1979, Jennings and Pennick 1980).

$$\int_0^\infty r^2 Q_e(m, r, \lambda)\, n(r)\, dr = h \int_0^\infty r^3 n(r)\, dr \quad (3)$$

where, h is a constant for the considered size distributions $n(r)$. This condition aims to eliminate the explicit dependence of relation (2) on the size distribution $n(r)$. Under this condition, Eqn. (2) takes the simple linear form

$$c = \sigma \frac{4\rho}{3h} \quad (4)$$

Chylek (1978) has found a sufficient condition for relation (3) to be satisfied is :

$$Q_e(m, r, \lambda) = hr \quad (5)$$

which says that the unambiguous linear relation (4) between c and σ will exist at such wavelength λ at which the extinction curve $Q_e(m,r,\lambda)$ can be reasonably well approximated by a linear function of the form of Eqn. (5). Furthermore, Chylek *et al.* (1979) have shown that for measurements made at λ=550 nm, the linearity

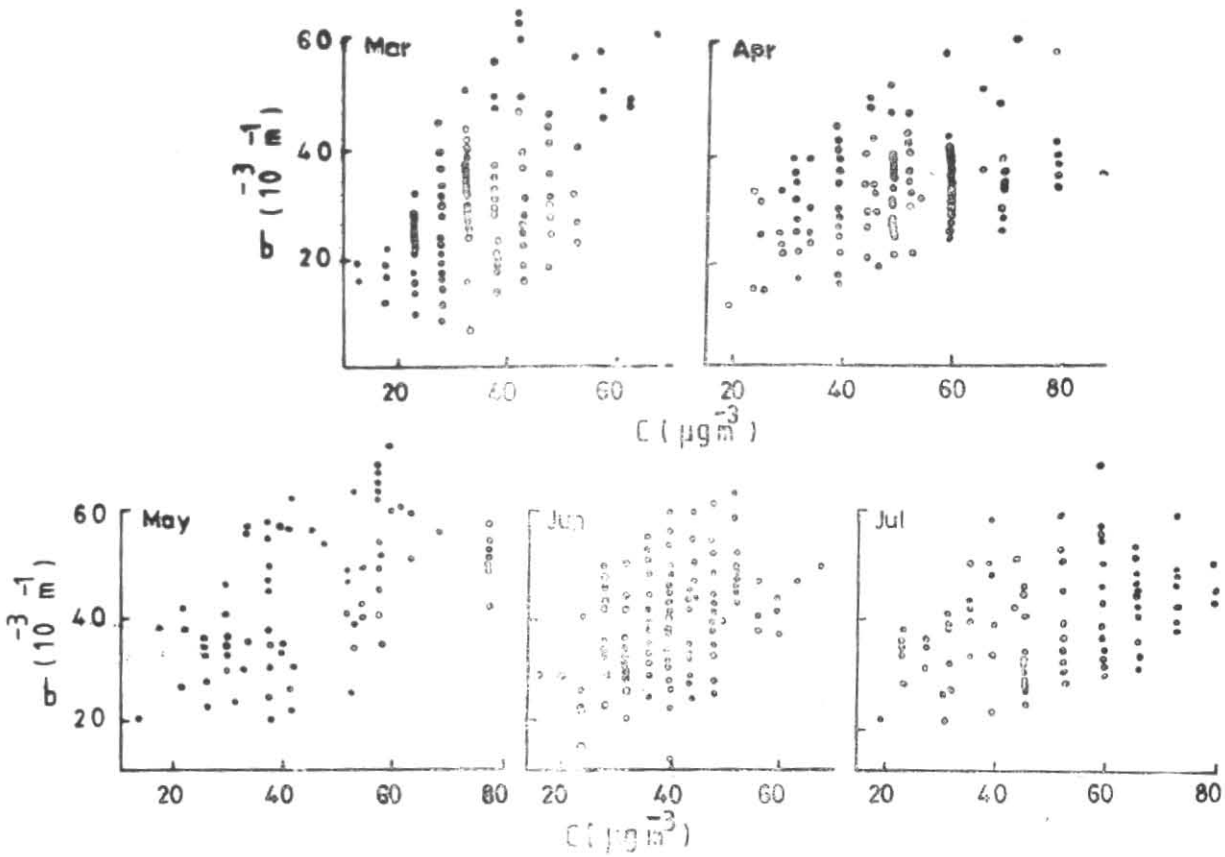

Fig. 4. Scatter plots of extinction coefficient (σ) *vs* aerosol mass concentration (c) for different measurement months at site 1

condition in Eqn. (5) is not satisfied at $r > 0.01$ μm, consequently one should not expect a linear, size independent relation between σ and c at $\lambda = 550$ nm unless most of the aerosol particles have $r < 0.01$ μm.

In the measurements program made in this work, it is noticeable that :

(*i*) The extinction measurements were made at $\lambda = 550$ nm.

(*ii*) The size distribution of the aerosol particles $n(r)$ changes with time at sites 1 and 2. This is clear in Figs. 6 and 7, which represent aerosol particle size distribution measured on two consecutive days at both sites during a measurement program conducted in Qena city in 1987 (El-Shazly 1989b). These Figures show clearly a change in $n(r)$ occurring between 21 and 22 September 1987 at site 1 and between 3 and 4 October 1987 at site 2. It is also shown in these figures that the change in $n(r)$ is high in the evening hours compared to the mornings especially at site 2.

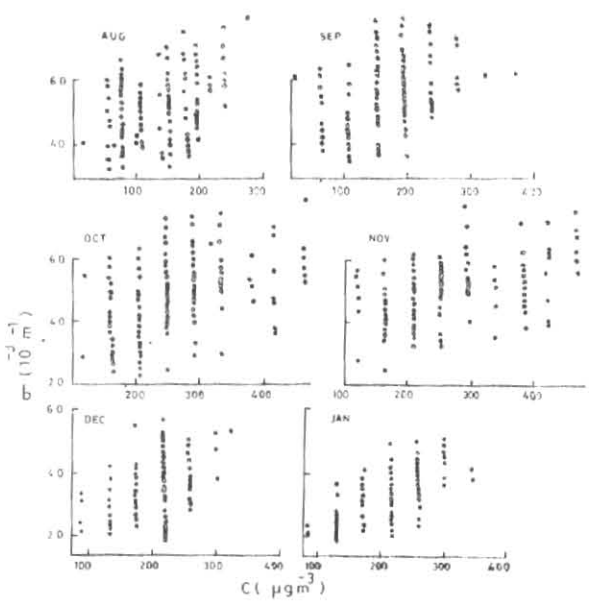

Fig. 5. Scatter plots of the extinction coefficient (σ) *vs* aerosol mass concentration (c) for different measurement months at site 2

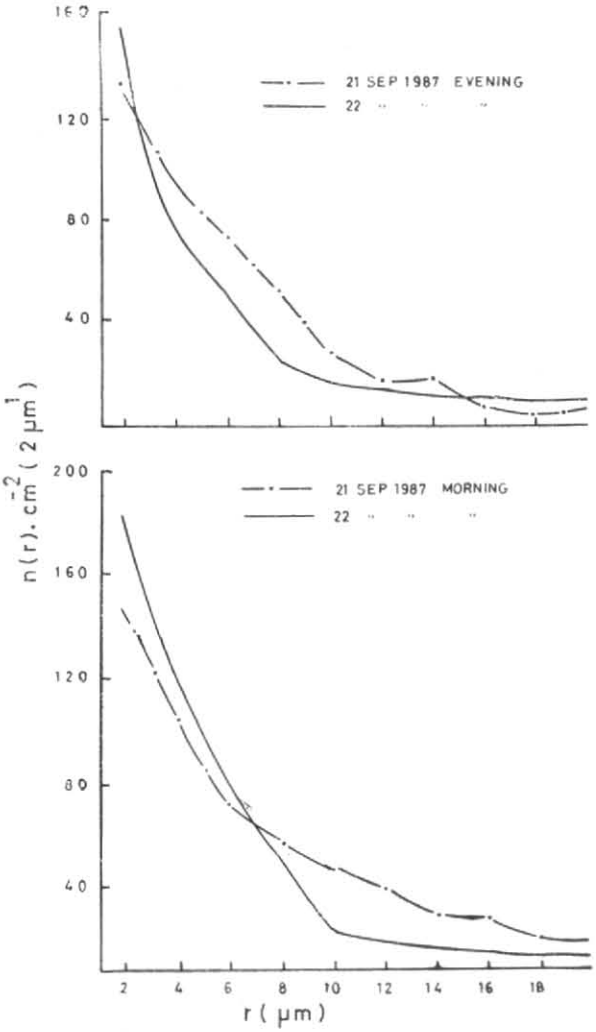

Fig. 6. Measured aerosol size distributions on two consecutive days at site 1

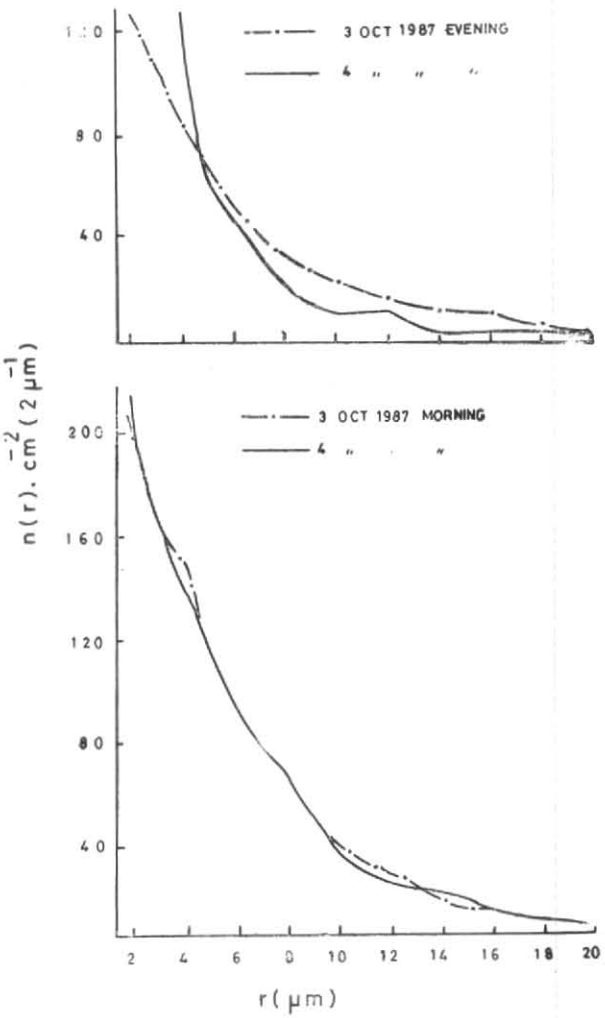

Fig. 7. Measured aerosol size distributions on two consecutive days at site 2

In view of the above discussions, an unambiguous linear relationship between σ and c should not be expected. In spite of this conclusion, a correlation study between these two variables show a significant correlation between them. The correlation coefficients calculated between the extinction σ and the aerosol mass concentration c are presented in Table 1 with their respective levels of significance for the two sampling sites. From this table, it can be observed that during the study period an acceptable correlation (0.36 at site 1 and 0.39 at site 2 and significance ($P<0.05$ at the two sites) were obtained. In addition, the most of the correlation cofficients were found to be higher for site 2 than for site 1. It ranges from 0.34 to 0.61 at site 2 while it ranges from 0.33 to 0.44 at site 1. This may be due to the slight change in $n(r)$ with time at site 2 compared to site 1, especially in the morning measurements (*see* Figs. 6 and 7). These correlations reveal an agreement with similar works (*e.g.*, Patterson and Gillete 1976, Pilat and Ensor 1971).

3.2. *Extinction and meteorological parameters*

Looking at Figs. 2 and 3, the following conclusions can be deduced :

(a) Clear diurnal patterns were observed for the temperature and wind speed with peaks and valleys which indicate a direct relationship between the meteorological parameters and σ. This may be acceptable in light of the following aspects :

(*i*) The high temperature on the earth's surface give rise to the vertical mixing of the pollutants causing an increase in the concentration of the aerosol particles and thus in the atmospheric extinction.

(*ii*) The sampling sites were chosen in the downwind direction related to the predominant NW-winds (Met. Dept., A. R.

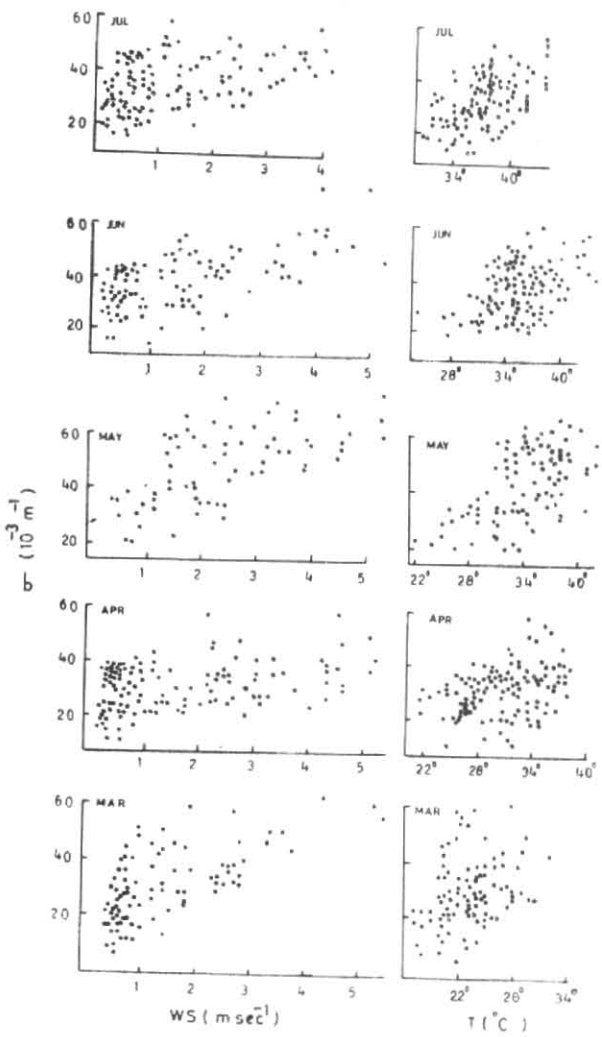

Fig. 8. Scatter plots of the extinction coefficient (σ) *vs* temperature (T) and wind speed (ws) for different measurement months at site 1

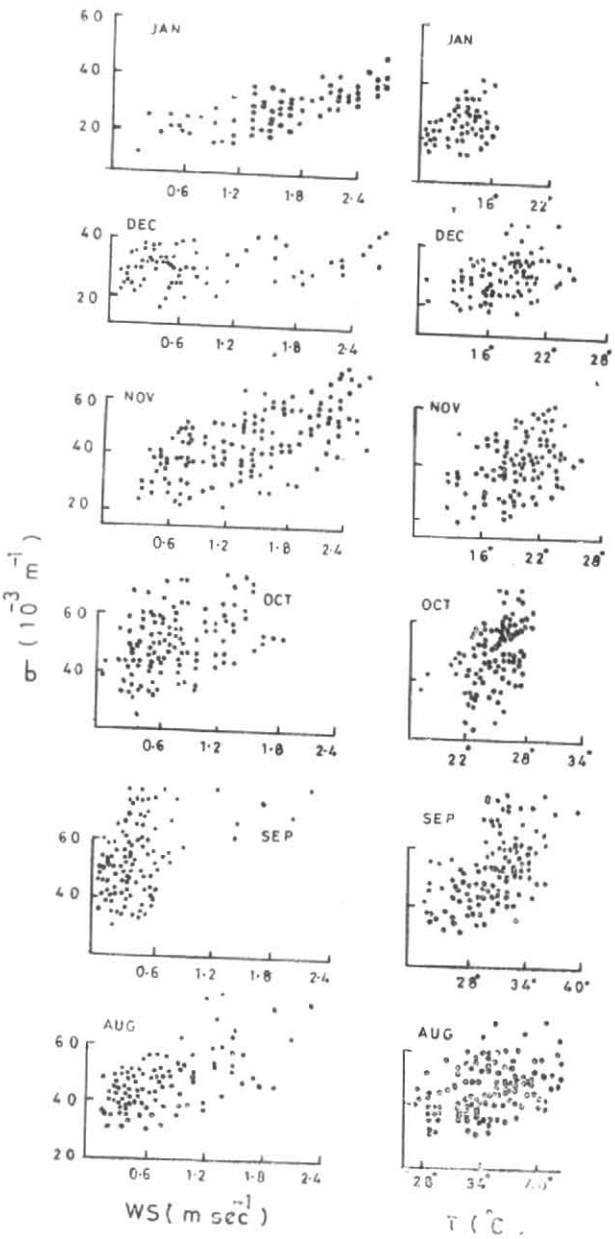

Fig. 9. Scatter plots of the extinction coefficient (σ) *vs* temperature (T) and wind speed (ws) for different measurement months at site 2

TABLE 1

Correlation coefficient of extinction coefficient with aerosol mass concentration and meteorological parameters at the two measurement sites

Site	Study period	No. of obsns.	Variables		
			c ($\mu g\ m^{-3}$)	T (°c)	ws (ms^{-1})
1	Mar	102	0.33*	0.24*	0.63**
	Apr	104	0.43*	0.31*	0.36*
	May	91	0.44*	0.58*	0.53*
	Jun	110	0.39*	0.49*	0.57*
	Jul	110	0.36*	0.47*	0.48*
	Whole period	516	0.36*	0.41*	0.52*
2	Aug	110	0.38*	0.41*	0.64*
	Sep	110	0.34*	0.62**	0.45*
	Oct	110	0.42*	0.48*	0.39*
	Nov	115	0.42*	0.37*	0. 64**
	Dec	97	0.45*	0.57*	0.53*
	Jan	85	0.61*	0.45*	0.73**
	Whole period	627	0.39*	0.60*	0.54*

*Level of significance $P<0.05$, **Level of significance $P<0.01$

Egypt 1988). High wind speed may thus cause high aerosol mass concentration and consequently high values of extinction coefficient σ may be obtained.

(b) It is noticeable in these figures, that in the evening measurements, there is somewhat deviation from the expected relations between σ and both T and ws as illustrated in conclusion (a). This may be explained in terms of :

(*i*) The relatively high values of relative humidity ($\simeq 70\%$) which may make its effect on the atmospheric particles and thus on the atmospheric extinction high in this time period compared to the effect of T and ws (El-Shazly *et al.* 1989a). As the relative humidity increases more aerosal particles being to absorb water molecules. This leads to effective changes in their size distribution and refractive index causing an increase in the extinction coefficient with increase in the relative humidity.

(*ii*) The possibility of deviation of the wind direction during the evening from the predominant wind direction (Met. Dept., A. R. Egypt 1988).

The scatter plots (Figs. 8 & 9) of σ *versus* T and ws for all measurements at sites 1 and 2 show general associations of high extinction with high temperature and wind speed. This is due to :

(*i*) The simultaneous effect of other meteorological parameters (*e.g.*, relative humidity and mixing height) in addition to these considered in this study on the atmospheric properties. Relative humidity is a more complex factor because its effect depends on the chemistry of the atmosphere. Also, there are many predictable relations explain its effect on the atmospheric extinction. Therefore, the dependence of the extinction coefficient on the relative humidity has been separately discussed in details in a previous work (El-Shazly *et al.* 1989a).

(*ii*) The change of the contribution rates of some sources (*e.g.*, man's various activities) to the concentration of the atmospheric particles.

Correlation coefficients between σ and both the temperature and wind speed are shown in Table 1. From this table it can be observed that :

(*i*) Variations in σ were found to be significantly related to variation in both temperature and wind speed ($P<0.05$ at the two sites). During the study period, a good correlation was observed.

Consequently, both the temperature and the wind speed have an important effect on σ in the atmosphere and none of them can be chosen individually as responsible for σ fluctuations. This conclusion seems to be logical, considering the significant role of both parameters in increasing the aerosal mass concentration and thus the atmospheric extinction, since the high wind speed urges the dispersion of the dusts from the eastern and western desert in the direction of the study region and the high temperature near the earth's surface give rise to the vertical mixing of the pollutants, which rises the particulate matters buoyancy in the atmosphere.

(*ii*) The most of correlation coefficients were higher for site 2 than for site 1. For the extinction-temperature – relations, it ranges from 0.37 to 0.62 at site 2, while it ranges from 0.24 to 0.58 at site 1. With respect to the extinction-wind speed-relations, the correlation coefficient ranges from 0.39 to 0.73 at site 2 and from 0.36 to 0.63 at site 1. This is consistent with the results of the correlation study of σ with c (sec. 3.1) where higher correlations were also observed at site 2 than at site 1.

4. Conclusions

Measurements of the atmospheric extinction σ in the atmosphere of Qena city have been carried out during the period from March 1988 to January 1989 at two sites. The results have been analysed with respect to their relation to aerosol mass concentration c and some meteorological variables (T and ws). From the analysis, the following findings have emerged:

(*i*) There are no unambiguous linear relations between σ and the aerosol mass concentration, temperature and wind speed, only general patterns show direct correlation between σ and each of these variables may exist.

(*ii*) Variations in σ were found to be significantly related to variations in each of c, T and ws ($P<0.55$). Also the correlation coefficients, in spite of its relatively low values, show acceptable correlations between σ and each of these variables considering the simultaneous effect of them on σ.

(*iii*) The high measured mass concentration at site 2 can account for increase in σ of up to about 25% above its value at site 1.

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