

Diurnal variation of atmospheric stability at Qena (Upper Egypt)

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सार – किसी भी स्थान पर वायु गुणवत्ता मॉडलों में प्रदूषकों के सांद्रण का पूर्वानुमान लगाने के लिए वायुमंडलीय स्थिरता का मॉनीटरन और प्रलेखन अपेक्षित है। इस कार्य का उद्देश्य साउथ वैली यूनीवर्सिटी (एस. वी. यू.) मौसम विज्ञानिक अनुसंधान केंद्र द्वारा 4 वर्षों के मौसम विज्ञानिक आँकड़ों (2001–2004) का उपयोग करके कवेना, इजिप्ट (26° 17', 32° 10', 96 मी. ए. एस. एल.) में दिन के घंटों के समय वायुमंडलीय स्थिरता में होने वाले परिवर्तन का मूल्यांकन करना है। परम्परागत एलगोरिथ्म आधारित वर्गीकरण विधियों से आरंभ करते हुए वायुमंडलीय स्थिरता का पास्कल-गिफॉर्ड (पी.-जी.) स्थिरता वर्गीकरण के अनुसार भूमंडलीय सौर विकिरण (जी. एस. आर.) के घंटेवार मान, सतही पवन गति (डब्ल्यू. एस.) और मेघ राशि (सी. ए.) से आकलन किया गया है। अध्ययन के क्षेत्र में भविष्य में वायुमंडलीय स्थिरता का मूल्यांकन करने के लिए अध्ययन की पूरी अवधि के दौरान प्राप्त हुए परिणामों का सांख्यिकीय विप्लेषण किया गया। वायुमंडलीय परिस्थितियों की प्रत्येक स्थिरता श्रेणी के लिए निश्चित अधोपवन दूरी (x) पर क्षैतिज (σ_y) और उर्ध्वाध्व (σ_z) दोनों प्रकीर्णन प्राचलों का भी आकलन किया गया। परिणाम दर्शाते हैं कि अध्ययन की अवधि में वायुमंडलीय परिस्थितियाँ दिन के घंटों में 46.5%, 24.3% और 29.2% तक क्रमशः अस्थिर, तटस्थ और स्थिर रहीं।

ABSTRACT. The monitoring and documentation of atmospheric stability are required for pollutants concentration prediction in air quality models at any location. The aim of this work is to assess how the atmospheric stability varies through the hours of the day at Qena, Egypt (26° 17', 32° 10', 96 m a.s.l.) using 4 years measured meteorological data (2001 - 2004) carried out by South Valley University (SVU)-meteorological research station. Starting from traditional algorithms based classifying methodologies, the atmospheric stability has been estimated from the hourly values of the global solar radiation (GSR), surface wind speed (WS) and cloud amounts (CA) according to Pasquill-Gifford (P-G) stability classification. Statistical analysis of these results through the whole period of this study was employed to evaluate the general future of the atmospheric stability in the region of the study. Dispersion parameters both horizontally (σ_y) and vertically (σ_z) were also calculated at a certain downwind distance (x) for each stability class of the atmospheric conditions. The results show that 46.5%, 24.3% and 29.2% of the day hours through the study period are characterized with unstable, neutral and stable atmospheric conditions respectively.

Key words – Air pollution, Atmospheric stability, P-G stability classes and dispersion coefficients.

1. Introduction

In many air pollution problems, it is essential to determine the concentration of pollutants downwind from a continuous source. The use of Gaussian dispersion algorithms require the estimation of horizontal and vertical growth of the plumes for predicting the ground level concentration. The horizontal and vertical growth of plumes are generally expressed in terms of standard deviations of concentrations in lateral and vertical directions (σ_y and σ_z respectively). These coefficients (σ_y and σ_z) could be parameterised and classified broadly

in the following two categories (Mohan and Siddiqui, 1996);

- (i) Empirical methods based on classification of atmospheric stability,
- (ii) Sophisticated methods based on the variance of wind velocity fluctuations.

Because the variance of wind velocity fluctuation is not available at the study area, an empirical method based

TABLE 1

Pasquill-Gifford stability classes (Stull, 2000)					
Surface wind speed (m/s)	For day time			For *night time	
	GSR			cloud	amount
	Strong	Moderate	Slight		
10-30 mW/cm ²	30-60 mW/cm ²	≥ 60mW/cm ²	≥ 4/8	≤ 3/8	
< 2	A	A to B	B	G	G
2 to 3	A to B	B	C	E	F
3 to 4	B	B to C	C	D	E
4 to 6	C	C to D	D	D	D
> 6	C	D	D	D	D

*Night was originally defined to include periods of 1 hour before sunset and after sunrise (Mohan and Siddiqui 1998).

-A (highly unstable or convective), B (moderately unstable), C (slightly unstable), D (neutral), E (moderately stable), and F (extremely stable). Later, stability G is also included to represent low wind night time stable conditions (Stull, 2000)

on classification of atmospheric stability uses to calculate σ_y and σ_z .

Atmospheric stability is the resistance of the atmosphere to vertical motion. It provides an indication of the turbulent state and dispersion capabilities of the atmosphere. This is of great importance in the field of air pollution control, which needs information about parameters of the atmospheric boundary layer (ABL), with reference to accumulation, dispersion and transport of air pollutants (Pekour and Kallistratova, 1993). Stability is a term applied qualitatively to the property of the atmosphere, which governs the accelerations of the vertical motion of an air parcel. In the popular Gaussian models, an index of atmospheric stability usually determines the functional form of the various algorithms, which in turn calculates the concentration of pollutants. The stability of the atmosphere is determined by comparing the adiabatic lapse rate of air parcel (Γ_d) with the environmental lapse rate (Γ_E) "as would be measured from instruments on arising balloon". By this approximation an unstable atmosphere occurs when $\Gamma_d > \Gamma_E$, however at $\Gamma_d < \Gamma_E$ the atmosphere tend to be stable. Neutral atmosphere is one in which $\Gamma_d = \Gamma_E$.

Because upper-air observations and observations from significantly different elevations are not always available, considerable efforts in the last three decades made to classify the atmospheric stability from several ground-based observations (Golder, 1972; Tombach *et al.*, 1973; USNRC, 1974; Smith, 1979; Sedefian and Bennet, 1980; Tagliazucca and Nanni, 1983; Thomas, 1986; Thomas, 1988; Singal *et al.*, 1997; Capanni *et al.*, 1999 and Adam, 2003).

The widely used method for evaluation of the atmospheric stability were proposed by Pasquill (1961)

TABLE 2

Urban dispersion parameters (for downwind distances between 100 and 10,000 m)		
P-G stability classes	σ_y	σ_z
A-B	$0.32 X (1+0.0004X)^{-0.5}$	$0.24X (1+0.001X)^{0.5}$
C	$0.22 X (1+0.0004X)^{-0.5}$	$0.20 X$
D	$0.16 X (1+0.0004X)^{-0.5}$	$0.14X (1+0.0003X)^{-0.5}$
E-F	$0.11 X (1+0.0004X)^{-0.5}$	$0.08X (1+0.00015X)^{-0.5}$

and improved by Gifford (1962) and Turner (1970). Not only is this classification system used to estimate plume characteristics; it is also used in many pollutants, atmospheric models as a proxy for atmospheric turbulence. These methods divide the atmospheric stability into six classes (A-F) in terms of different meteorological parameters such as (US-EPA, 1986; Ferenczi, 2001):

- (i) Global solar radiation, surface wind speed and cloud amounts,
- (ii) Standard deviation of the horizontal wind direction fluctuation,
- (iii) Surface wind speed and temperature gradient and
- (iv) Wind speed and net radiation.

The choice of a particular method may have a significant impact on final outcome from plume modeling studies on atmospheric dispersion since these methods generally do not lead to similar classification (Mohan and Siddiqui, 1998).

At Qena (26° 17', 32° 10', 96 m asl), the increase in air pollution level associated with the growing industries near the study area, dust and sand coming from the surrounding desert areas and sandy valleys (EL-Shazly, 1987), requires detailed on-site data of these parameters to study air quality related assimilative and carrying capacities. Accordingly, the main purpose of this study is to evaluate the atmospheric stability at Qena and study its diurnal variation, which defines the turbulent state of the atmosphere and also reflects its dispersion capabilities through the period of this study (2001 - 2004).

2. Methodology

Pasquill-Gifford stability classes were derived from the values of GSR, WS and CA according to Table 1. Measurement of these parameters was carried out at Qena (26° 17', 32° 10', 96 m asl) in Upper Egypt for 4 years (2001 - 2004) by SVU-meteorological research station.

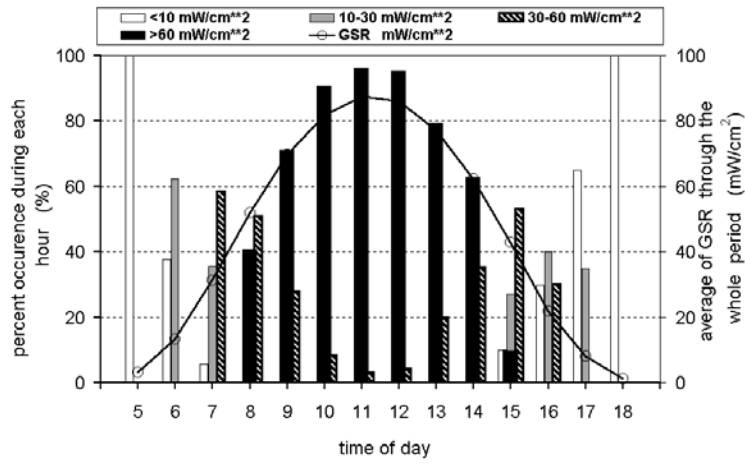


Fig. 1. Average and frequency distribution of global solar radiation, GSR (mW/cm^2) by time of day during the period of the study (2001-2004)

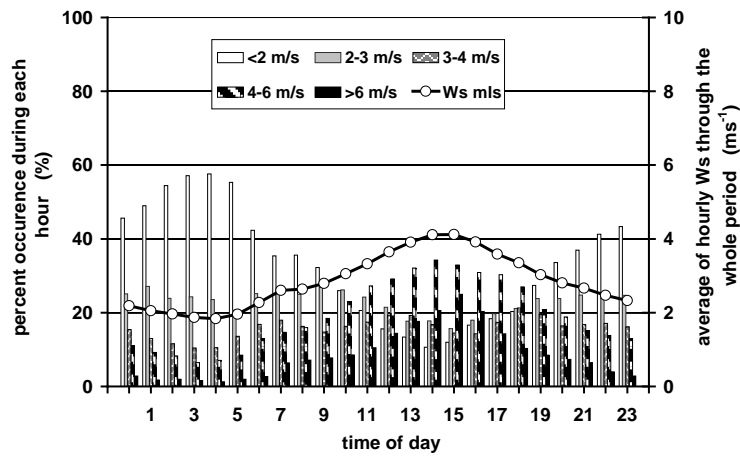


Fig. 2. Average and frequency distribution of wind speed, WS (ms^{-1}) by time of day during the period of the study (2001-2004)

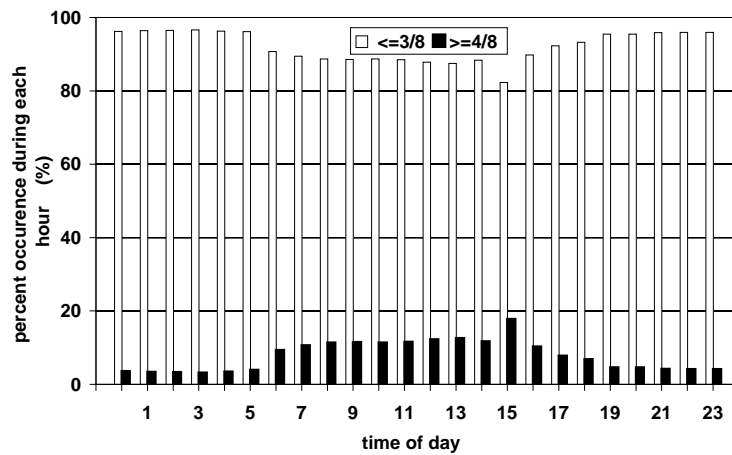


Fig. 3. Frequency distribution of cloud amounts, CA by time of day during the period of the study (2001-2004)

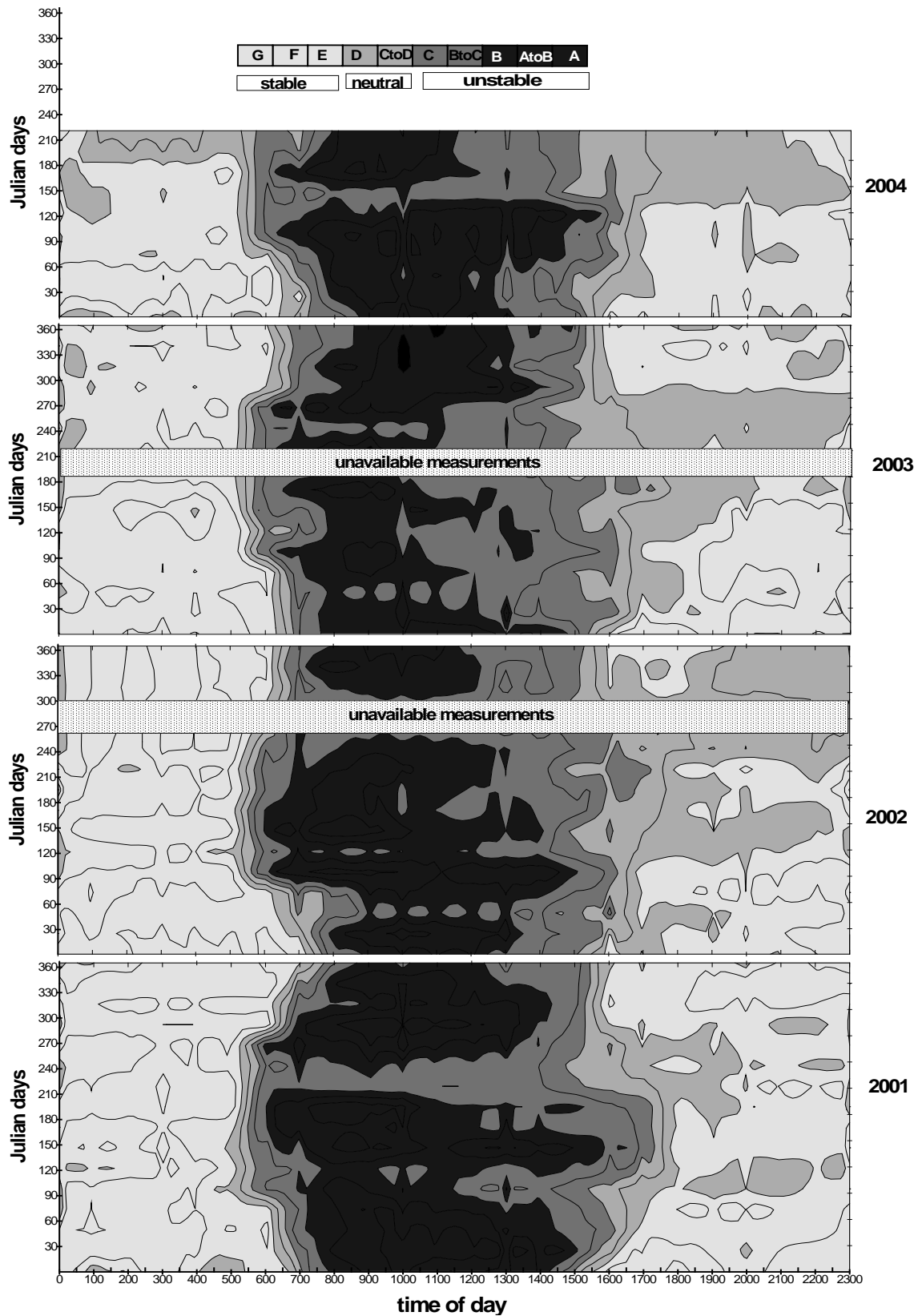


Fig. 4. Diurnal pattern of P-G stability classes as a function of the Julian days during the period of the study (2001-2004)

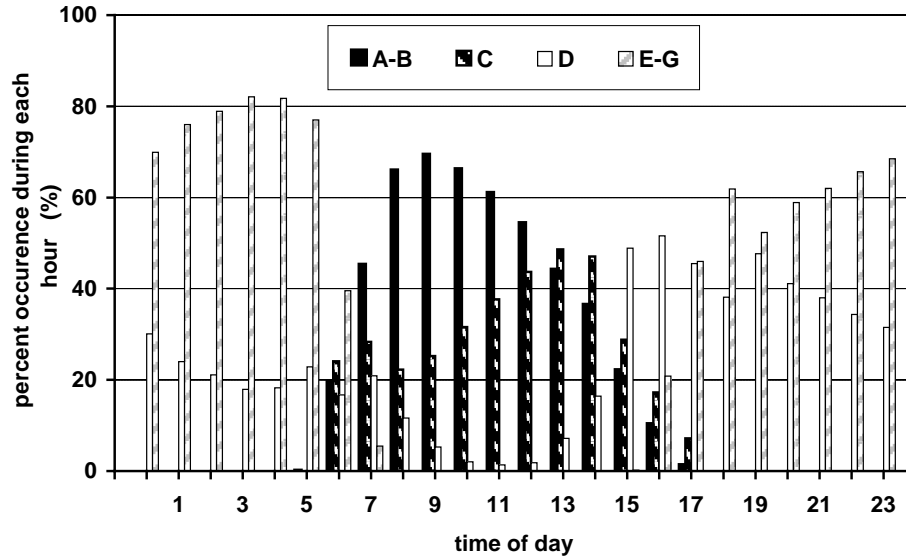


Fig. 5. Frequency distribution of P-G stability classes by time of day during the period of the study (2001-2004)

The horizontal (σ_y) and vertical (σ_z) dispersion parameters at certain downwind distance x were calculated for each stability class at each hour using Briggs formulae (Briggs, 1973) as discussed by Zannetti (1990). These formulae are also called McElroy-Pooler (1968) sigmas. They are suitable for urban and rural areas in the downwind range from 100 m to 10000 m (US- EPA, 1986). Table 2 gives these formulae in urban area.

3. Results and discussion

The frequency distribution of the values of GSR, WS and CA was employed to examine the collected data. The values of each parameter were classified according to P-G classes as mentioned above in Table 1. The analysis was calculated hourly to assess how these parameters varied through the hours of the day. The variation of P-G stability classes is mainly related to the corresponding variation of these parameters and time of day or night (Stull, 2000). Figs. 1, 2 and 3 show the percent occurrence (%) of GSR, WS and CA for different classes at each hour of the day, respectively. From these figures, the following aspects can be deduced:

(a) *With respect to GSR (Fig. 1)*

(i) It is clearly that the rise and fall of the GSR throughout the day hours is generally symmetrical with respect to the solar noon, following Gaussian distribution function. This conclusion is in a very good agreement with that concluded from the study of solar radiation

characteristics at Qena carried out in the period 1992-1993 (EL-Shazly *et al.*, 1996).

(ii) At daytime hours (9 a.m. to 2 p.m.), the dominant class is ≥ 60 mW/cm² ranging from 63% at 2 p.m. to 96% at 11 a.m.

(iii) At hours 7 a.m., 8 a.m. and 3 p.m., the dominant class is 30-60 mW/cm² (with percentage 59%, 51% and 53% respectively).

(iv) At hours 6 a.m. and 4 p.m., the dominated class is 10-30 mW/cm² (with percentage 62% and 40% respectively) and

(v) At hours 5 a.m., 5 p.m. and 6 p.m., the dominant class is <10 mW/cm² (with percentage 99.9%, 65% and 100%, respectively).

(b) *With respect to WS (Fig. 2)*

(i) It is clear that low values of the average of WS range from 1.83 ms⁻¹ at 4 a.m. to 4.12 ms⁻¹ at 3 p.m. These values also agree with that found in previous study at Qena (EL-Shazly, 1994).

(ii) At hours from 7 p.m. to 10 p.m., the percent occurrence of WS at the classes < 2 ms⁻¹ and 2-3 ms⁻¹ is higher than others classes. It ranges from 51% at 7 p.m. to 81% at 4 a.m. and

TABLE 3

Frequency distribution of P-G atmospheric stability classes, σ_y and σ_z for each class during the period from 2001 to 2004

P-G stability classes	Number of hours	Percentage (%)	σ_y (km)										σ_z (km)				
			for downwind distances, x, between 0.1 and 10.0 km after Briggs (1973)														
			0.1	2.5	5.0	7.5	10.0	0.1	2.5	5.0	7.5	10.0					
A	1094	4	0.031	0.6	0.9	1.2	1.4	0.03	1.1	2.9	5.2	8.0					
A to B	2139	9	0.031	0.6	0.9	1.2	1.4	0.03	1.1	2.9	5.2	8.0					
B	3136	13	0.031	0.6	0.9	1.2	1.4	0.03	1.1	2.9	5.2	8.0					
B to C	563	2	0.022	0.5	0.6	0.8	1.0	0.02	0.5	1.0	1.5	2.0					
C	4384	18	0.022	0.5	0.6	0.8	1.0	0.02	0.5	1.0	1.5	2.0					
C to D	819	3	0.016	0.3	0.5	0.6	0.7	0.014	0.3	0.4	0.6	0.7					
D	5098	21	0.016	0.3	0.5	0.6	0.7	0.014	0.3	0.4	0.6	0.7					
E	2451	10	0.011	0.2	0.3	0.4	0.5	0.008	0.2	0.3	0.4	0.5					
F	225	1	0.011	0.2	0.3	0.4	0.5	0.008	0.2	0.3	0.4	0.5					
G	4423	18	-	-	-	-	-	-	-	-	-	-					

(iii) However at the daytime (11 a.m. to 6 p.m.) the frequency class $4-6 \text{ ms}^{-1}$ is dominant. It ranges from 27% at 6 p.m. to 34% at 2 p.m.

(c) *With respect to CA (Fig. 3)*

(i) As shown in this figure, the CA is classified into two classes ($\leq 3/8$ and $\geq 4/8$). Generally the study region is characterized with semi cloudless weather throughout the year months.

(ii) The percent occurrence of class $\leq 3/8$ is higher than that of class $\geq 4/8$ at each hour.

(iii) It ranges from 3% at 3 a.m. to 12% at 3 p.m. for CA $\geq 4/8$, while it ranges from 88% at 3 p.m. to 97% at 3 a.m. for class $\leq 3/8$.

The above figures reflect the general pattern of these parameters at the study area. It has relatively high values of GSR and low amounts of cloud cover as well as relatively low values of wind speed. This is a general character of the most areas in Egypt except at the shores (Soliman, 1961 and Rizk, 1987).

Fig. 4 shows the diurnal pattern of P-G stability classes over the available days through the period of this study (2001-2004). Isolines of P-G stability classes are plotted as a function of the hour of the day and the available Julian days. This figure illustrates the type of P-G stability for each hour in this period. It offers qualitatively the diurnal variation of P-G stability classes in the study region. Also the percent occurrence of P-G stability classes for each hour of the day through the

whole study period was calculated as shown in Fig. 5. From this figure, one can conclude the following:

(i) During the daytime hours (8 a.m. to 3 p.m.) the atmosphere tends to be primarily unstable (A-C) with some neutral conditions (D). No occurrence of stable conditions (E-G) was found in this period of time.

(ii) During nighttime hours (6 p.m. to 5 a.m.) the atmosphere tends to be primarily stable (E-G) with some neutral conditions (D). No occurrence of unstable (A-C) was found in this period of time and

(iii) There are some transitional hours in which the stability conditions change from the unstable daytime period to stable nighttime (4 p.m. and 5 p.m.) and from the stable nighttime period to the unstable daytime hours (6 a.m. and 7 a.m.).

These results seem reliable if one considers the above-discussed nature of the atmosphere in the study region with respect to the behaviour of GSR, WS and CA, since the suggestion of Pasquill and Gifford for evaluation the atmospheric stability is based mainly on these parameters. Accordingly, it is concluded that Qena (Upper Egypt) is characterized to high extend with unstable atmosphere (46% of the hours of the day through the whole period). This deduction is very important for the future of the dispersion of the pollutants in this region, owing to the fact that unstable atmosphere strengths the dispersion of the pollutants both vertically and horizontally. Consequently Qena may be a suitable location for industrial projects. This conclusion is supported by Table 3, which summarizes the values of the

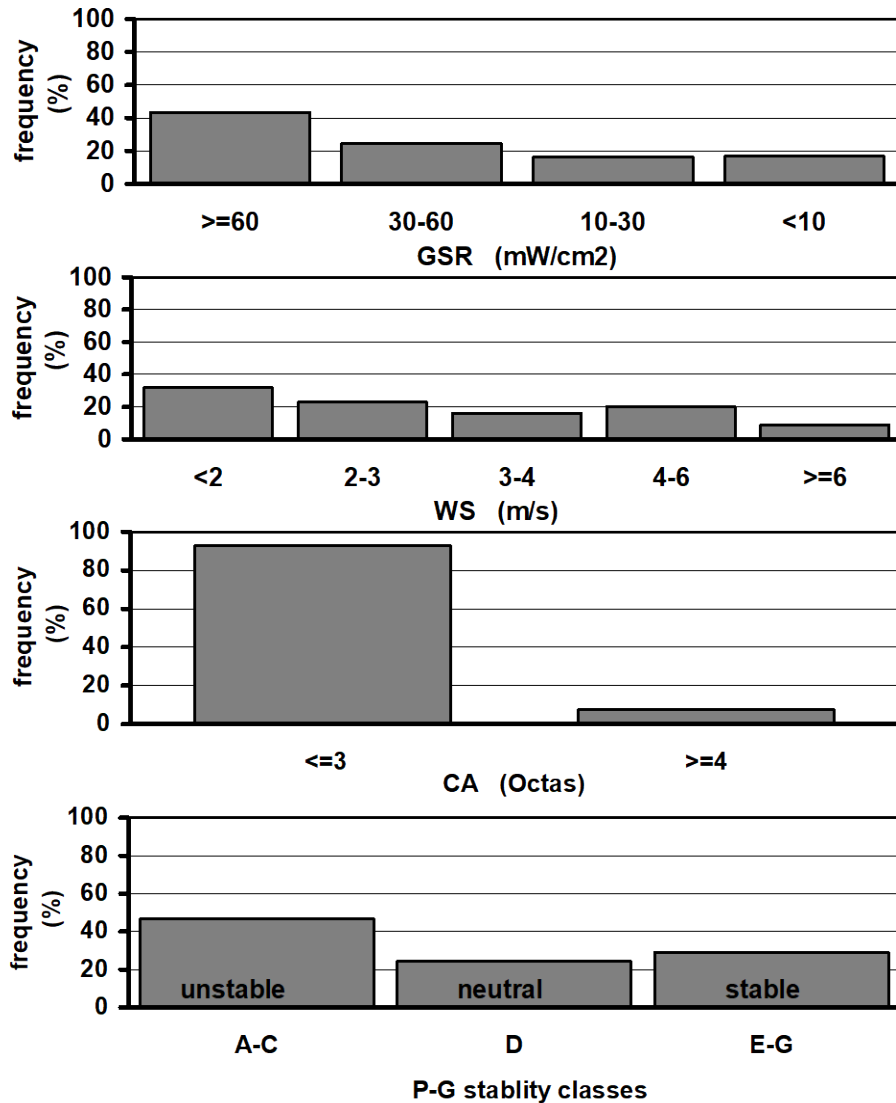


Fig. 6. Frequency distribution of GSR, WS, CA and P-G stability classes during the whole period of the study (2001-2004)

dispersion coefficients in horizontal (σ_y) and vertical (σ_z) directions, which were calculated by method based on a stability classification of the atmospheric conditions, after Briggs (1973). The table indicates the high values of σ_y and σ_z in the unstable atmospheric conditions in comparison with other ones.

5. Conclusions

This study leads to the following conclusions, which are also summarized in Fig. 6.

(i) The study region receives a considerable quantity of solar energy. 43 % of the hours during the days have

values of GSR in the range ≥ 60 mW/cm² and 67 % in the range ≥ 30 mW/cm².

(ii) The dominant classes of wind speed are < 2 ms⁻¹ and $2-3$ ms⁻¹ (32 % and 23 % respectively).

(iii) The cloud amount at Qena is very small. 93% of the hours during the days have values of CA in the range of $\leq 3/8$ and 7% in the range of $\geq 4/8$.

(iv) Statistical treatment of the results indicates that in approximately 46.5 %, 24.3% and 29.2% of the hours, the atmosphere at Qena was unstable, neutral and stable respectively.

(v) The majority of stable atmospheric conditions (E-G) occurs between the hours 6 p.m. and 6 a.m. However in the hours from 6 a.m. to 6 p.m. the atmospheric stability tends to be unstable (A-C) with a few occurrences of neutral atmospheric conditions (D) through the day and night time and

(vi) Qena is suggested to be preferable region for establishment different types of industrial projects in the future due to its suitable climate.

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