Research Article

Suspended Particulates Concentration (PM_{10}) under Unstable Atmospheric Conditions over Subtropical Urban Area (Qena, Egypt)

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The main purpose of this study is to evaluate the suspended particulates (PM_{10}) in the atmosphere under unstable atmospheric conditions. The variation of PM_{10} was investigated and primary statistics were employed. The results show that, the PM_{10} concentrations values ranged from 6.00 to $646.74 \mu\text{g m}^{-3}$. The average value of PM_{10} is equal to $114.32 \mu\text{g m}^{-3}$. The high values were recorded in April and May ($155.17 \mu\text{g m}^{-3}$ and $171.82 \mu\text{g m}^{-3}$, respectively) and the low values were noted in February and December ($73.86 \mu\text{g m}^{-3}$ and $74.05 \mu\text{g m}^{-3}$, respectively). The average value of PM_{10} of the hot season ($125.35 \times 10^{-6} \text{ g m}^{-3}$) was higher than its value for the cold season ($89.27 \mu\text{g m}^{-3}$). In addition, the effect of weather elements (air temperature, humidity and wind) on the concentration of PM_{10} was determined. The multiple R between PM_{10} and these elements ranged from 0.05 to 0.47 and its value increased to reach 0.73 for the monthly average of the database used. Finally, the PM_{10} concentrations were grouped depending on their associated atmospheric stability class. These average values were equal to $122.80 \pm 9 \mu\text{g m}^{-3}$ (highly unstable or convective), $109.37 \pm 12 \mu\text{g m}^{-3}$ (moderately unstable) and $104.42 \pm 15 \mu\text{g m}^{-3}$ (slightly unstable).

1. Introduction

Adam [1] reviewed that the diurnal variation of temperature near the ground is one of the key characteristics of the atmospheric boundary layer (ABL) over land. The convective atmosphere constitutes the daytime unstable ABL. It consists of thermal plumes, that is, updrafts surrounded by large downdrafts. They grow in the morning with the solar heating of the surface of the earth. In the ABL, the air flow is turbulent because of two different mechanisms: friction with the surface and surface heating by the sun. Adam and El Shazly [2] evaluated the atmospheric stability at Qena and studied its diurnal variation which define the turbulent state of the atmosphere and also reflect its dispersion capabilities through the period from 2001 to 2004. They found that there are transitional hours in which the stability conditions change from the stable nighttime period to the unstable daytime hours (6:00 and 7:00 LST). During the daytime hours (8:00–15:00 LST), the atmosphere tends to be primarily unstable

with some neutral condition. In addition, no occurrences of stable conditions were found in this period of time. This study is to assess the level of air pollution under unstable conditions after the transitional hours at midmorning hours (9:00–11:00 LST). This time is chosen because it is usually a period of a high traffic and increase of the human activities. Moreover, earlier studies of the diurnal cycle PM_{10} concentrations observed elsewhere around the world show two peaks: one at midlate evening, 19:00–01:00 LST, and the other one at midmorning, 8:00–11:00 LST (e.g., [3–9]). However, Corsmeier et al. [10] explained that at the midlate evening, peak in PM_{10} concentrations is associated with wood burning emissions during evenings. During this period domestic emissions are at a maximum and, especially during anticyclonic weather patterns, are emitted into very shallow boundary layers, resulting in the accumulation of pollutants near the surface. In addition, Trompetter et al. [11] mentioned that the peaks observed during the morning period were traffic related sources alone and were unlikely to be a significant

FIGURE 1: (a) Map of Egypt, location of studied area at Qena. (b) Wind rose for midmorning hours (9:00–11:00 LST) through the period from 2002 to 2003. (c) * refers to South Valley University (SVU) meteorological research station.

source of pollution. It has therefore been hypothesized that vertical mixing of elevated layers of pollution stored aloft down to the surface may account for the increased morning concentrations at the surface.

According to the World Health Organization (WHO) assessment of the burden of disease due to air pollution, more than 2 million premature deaths can be attributed to the effects of urban outdoor air pollution and indoor air pollution every year. More than half of this disease burden is founded by the populations of developing countries [12]. Several published scientific studies indicate that there is an association between air pollutants to which people are routinely exposed and a wide range of adverse health outcomes: Krupnick and Portney, [13]; Hall et al. [14]; Sommer et al., [15]; Martuzzi et al., [16]; Hall et al., [17]; Scammell, [18]. In addition, Egyptian Environmental Affairs Agency (EEAA) reported that air pollution is one of the most important challenges and obstacles facing Egypt which have a major impact on increasing rate of development in all fields. However, the problem had emerged with the significant increase in various manufacturing processes and its accompanied emissions in air. Moreover, the terrible increase of vehicles number operated with fossil fuel (as results of the increase of population number) which is considered the worst cause of air pollution despite the fact of their necessity to modern life emits large quantities of gases [19]. The main legal instrument

dealing with environmental issues in Egypt is Law 4/1994 which is commonly known as the law on protection of the environment. The law deals mostly with the protection of the environment against pollution. Law 4/1994 also stipulates the role of the EEAA as the main regulatory agency for environmental matters. Article 35 of the environmental law 4/1994 and article 34 of its executive regulations define the maximum permissible levels of pollutants in ambient air. The national standard of the concentration of suspended particulate matters (PM_{10}), in terms of maximum permissible limits and exposure period, is $70 \mu g m^{-3}$ (24-hrs) [20, 21].

At Qena ($26.2^{\circ}N$, $32.7^{\circ}E$, and 96 m above mean sea level), there are several reasons for suspended particulate matters in the atmosphere. The main sources are sand and soil from the western and eastern hills which overlook the city, dusty roads with incomplete garbage removal, and the man-made processes such as agriculture, vehicles, and industry [22]. Qena is a place of many factories such as aluminum factory, two factories of sugar, and a factory of cement [23]. Furthermore, through the period of this study, there are emissions from mechanical scrapings such as construction work in new Qena city, reclamation of desert land for agriculture, and continuous drilling and building to complete the camp of South Valley University (see Figure 1). So, this work focuses on the study of suspended particulate matters (PM_{10}) at Qena. Many sources offer good descriptions of

PM₁₀ concentrations in Egypt such as Sivertsen and El Seoud [24], Elminir et al. [25], Elminir [26], and Zakey et al. [21]. However, Sivertsen and El Seoud [24] reported that the annual average concentrations of PM₁₀ range between 100 $\mu\text{g m}^{-3}$ and 200 $\mu\text{g m}^{-3}$ in urban and residential areas and between 200 $\mu\text{g m}^{-3}$ and 500 $\mu\text{g m}^{-3}$ near industrial areas. In addition, Zakey et al. [21] have evaluated the PM₁₀ concentrations at 17 sites representing different activities (industrial, urban, and residential) in Greater Cairo area. They found that the PM₁₀ concentrations were generally high with yearly average values of $170 \pm 25 \mu\text{g m}^{-3}$. Moreover, at the region of this study, Adam [27] mentioned that the turbidity diurnal variations were very limited during the most hours of the day except for sunrise and sunset hours. He studied the Ångström turbidity coefficient (β) through the period from 2001 to 2004, and the maximum hourly values of β were 0.208 (at 07:00 LST). This behavior may be due to the frequent occurrence of inversions, allowing for the dispersion of aerosols [28, 29].

The main aim is restricted to assess the level of particulate matters with an aerodynamic diameter $\leq 10 \mu\text{m}$ (PM₁₀) at midmorning hours (9:00–11:00 LST). In addition, the effect of weather elements on the concentration of suspended particulates (PM₁₀) was investigated. Moreover, the atmospheric stability at the midmorning hours (9:00–11:00 LST) was determined, and the PM₁₀ concentrations were grouped depending on their associated atmospheric stability class.

2. Site and Data Set

The site of this study is located at South Valley University at Qena (26.20°N, 32.70°E, and 96.00 m above mean sea level). Figures 1(a) and 1(c) illustrate the map of Egypt and the location of studied area at Qena (*refers to SVU—meteorological research station). Qena is a city in the southern part of Egypt with 220,000 inhabitants (2009 estimate), capital of Qena governorate with 3.0 million inhabitants (2006 estimate) and an area of 1,800 km², situated on the east bank of the Nile between the western and eastern desert (Figure 1(a)). It lies within the subtropical region, and its terrain is semidesert. The climate of Egypt is characterized by small-scale depressions moving across the Great Sahara. This is due to khamsin depressions (March to May) and Sudan monsoon trough (September to December). The weather associated with these depressions is generally hot, dry, and dusty. From March to May, dry and strong southwesterly winds tend to occur over northern Africa when a desert depression develops and passes over strong baroclinic zone extending from west to east parallel to the southern Mediterranean coast [30]. Accordingly, the climate of Qena is characterized by a hot season from March to October and a cold season from November to February. In addition, a phenomenon of Qena climate is the hot spring wind that blows across all Egypt. This wind usually arrives in April, but occasionally occurs in March and May [31]. Additional detail about particular cases of a Sahara cyclones and subsynoptic phenomenon can be found in the work by Hassan [32].

The South Valley University (SVU) meteorological research station (Figure 1(c)) measured the particulate matters from 9:00 to 11:00 LST (2 hours). As a result, this study deals with 288 data of PM₁₀ samples which represent the PM₁₀ concentrations for midmorning hours (9:00–11:00 LST) during the period 2002–2003. Ten months (Jul. 02 to May 03) PM₁₀ samples were collected during the period of this study. The number of samples represents more than 80% of the days for the all months in this study (except 57% for Feb. 02). The shortage of the samples in February and the unavailable data in March are due to technical reasons which were related to the sampler. Approximately, these months represent the different two seasons: hot season period (173 samples) and cold season period (115 samples).

Graseby-Anderson (GMW) PM₁₀ Sampler (Model 1200 and serial no. 715) was used to collect atmospheric PM₁₀ in this meteorological research station. This sampler is used to sample particulate matters with an aerodynamic diameter of 10.00 micron and less. The inlet head is symmetrical and therefore insensitive to wind direction and relatively insensitive to wind speed. The PM₁₀ sampler draws air into a specially shaped inlet at a flow rate of 40 ± 4 cubic feet per minute. PM₁₀ particulate matters are collected on an 8 × 10 inch matted quartz fiber filter surface. The concentration of PM₁₀ particulate matters (in micron grams per cubic meter, $\mu\text{g m}^{-3}$) is calculated by weighing (Sartorius balance, TE 214S, max. 210 g, d = 0.1 mg) the particulates collected on the filter and dividing by the measured air sample volume. Complete operational details are contained in instruction and operation manual High Volume PM₁₀ Sampler [33]. The Egyptian meteorology authority is responsible for the scientific advice and calibration of the Egyptian Monitoring Network. The PM₁₀ sampler is calibrated according to a quality assurance plan for air monitoring.

In the current study, the used data of atmospheric stability during the midmorning hours (9:00–11:00 LST) was provided by Adam and El Shazly [2]. However, Pasquill-Gifford stability classes were derived from the average values of global solar radiation (GSR), wind speed (Ws), and cloud amount (CA) during the interval from 9:00 to 11:00 LST. Measurement of these parameters was carried out at Qena by SVU-meteorological research station. However, the atmospheric stability was classified, according to Pasquill-Gifford, as 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 nighttime stable conditions [34].

3. Results and Discussion

3.1. Primary Statistics Analysis of PM₁₀. In this study the variation of PM₁₀ concentrations was investigated to assess the collected data. Figure 2(a) refers to the fluctuations of PM₁₀ values ($\mu\text{g m}^{-3}$) during the period of this study. In addition, primary statistics of these data were estimated. These statistics include the average (Ave.), maximum (Max.), minimum (Min.), coefficient of variance (CV), and a number of available samples (n) for each month, hot season, cold

FIGURE 2: Variation of (a) PM_{10} concentration ($g\ m^{-3}$), (b) air temperature (T , $^{\circ}C$), (c) relative humidity (Rh , %), (d) wind speed (W_s , $m\ s^{-1}$), and (e) atmospheric stability, for midmorning hours (9:00–11:00 LST) at Qena through the period 2002–03.

season, and all period of measurements. Table 1 summarized the descriptive statistics of PM_{10} . Both table and figures reflect that, for the whole samples, PM_{10} concentrations values ranged from $6.00\ \mu g\ m^{-3}$ to $646.74\ \mu g\ m^{-3}$ (the maximum was in 19 April 2003, includes a dust and phenomenon of sand raised) and showed average of $114.32\ \mu g\ m^{-3}$. The average values of PM_{10} through the hot season period and cold season period were $125.35\ \mu g\ m^{-3}$ and $89.27\ \mu g\ m^{-3}$, respectively. The monthly mean of PM_{10} reflects a remarkable variation from month to month. This behavior may be due to the change of the atmospheric conditions such as wind speed, wind direction, humidity, and solar insulation levels (the effect of these atmospheric conditions on PM_{10} will be studied in the next section). It can be seen that the high concentrations were recorded in April and May ($155.17\ \mu g\ m^{-3}$

and $171.82\ \mu g\ m^{-3}$, resp.). This behavior may be due to dry southwesterly winds that tends to occur over northern Africa when a desert depression develops and passes over strong baroclinic zone extending from west to east parallel to the southern Mediterranean coast. The features which specify the khamsin weather conditions (causes rising sand, sand storm, and temperature) have attracted the attention of many meteorologists in Egypt and was considered by their studies (e.g., [30, 32, 35, 36]). Wind direction data were recorded in the mentioned interval (9:00 to 11:00 LST). Approximately, the wind direction is from the southwesterly direction in Qena area during the time of the measurements (wind from sector $225\text{--}285^{\circ}$ occurred during 66% of the time of these measurements, see Figure 1(b)). Both, the wind direction and wind speed are crucial parameters for these severe conditions. In addition, the low PM_{10} concentrations were noted in February and December ($73.86\ \mu g\ m^{-2}$ and $74.05\ \mu g\ m^{-2}$, resp.). Low winter-time temperature ($22^{\circ}C$) often results in stable weather conditions that aggravate the effects of particle emissions from the urban traffic [21]. The coefficient of variation (CV) which is defined as the ratio of the standard deviation to the mean values gives an indication of the dispersion of the values [37]. CV values are equal to 72.30%, 68.34%, and 64.87% for all period, hot season, and cold season, respectively. These values are relatively high and may be due to the variability of meteorological conditions (see the next section). The highest values of CV were recorded in April (87.90%). In April, it is expected due to the relatively high instability of the local climate during this time interval, that is, there is a high variation in climatic conditions from one day to another [38]. This variation in climatic conditions may be due to the hot desert cyclones known as the khamsin. The atmospheric stability (in April) was identified as A (11.90%), A to B (35.71%), B (16.67%), B to C (9.52%), C (16.67%), C to D (4.76%), and D (4.76%).

Moreover, the distribution of the samples at different PM_{10} concentration classes was employed to illustrate the difference between the levels of PM_{10} in both seasons. These classes are ≤ 50 , 51–70, 71–100, 101–200, 201–300, 301–400, 401–500, 501–600, and 601–700 ($\mu g\ m^{-3}$). The percentage of samples for each class to the total samples (288) in the hot season period (P_h), cold season period (P_c), and all measurement period (P_t) was estimated and illustrated in Table 2. From this table, one can conclude that the maximum values of P_t occur at the class 101–200 $\mu g\ m^{-3}$ (42.10%). At PM_{10} classes $\leq 70\ \mu g\ m^{-3}$, PM_{10} levels for cold season was higher than PM_{10} levels for hot season, while the opposite happens at classes $> 70\ \mu g\ m^{-3}$. The high values of PM_{10} levels in the hot season may be connected with the high insulation levels and strong convective processes characteristic of arid regions. Accordingly, the fine dust particles are easily lifted to high altitudes and horizontally transported by synoptic-scale atmospheric disturbances to the areas thousands of kilometers away from their source regions [39]. Adam and EL Shazly [2] have studied the atmospheric stability during the period from 2001 to 2004 to explain the convective processes characteristic of the area of this study. They found that during the daytime hours (8:00–15:00 LST), the atmosphere tends

TABLE 1: Average, maximum, and minimum of PM_{10} concentration ($\mu\text{g m}^{-3}$), coefficient of variation, and number of sampling during the period 2002-03.

Period	Ave.	Min.	Max.	CV	<i>n</i>
Jan.	97.91	9.97	263.53	0.64	31
Feb.	73.86	25.27	219.97	0.68	16
Mar.			No available data		
Apr.	155.17	27.70	646.74	0.86	43
May	171.82	44.02	318.17	0.41	25
Jun.			No available data		
Jul.	99.38	10.53	175.83	0.47	28
Aug.	103.17	14.30	201.02	0.40	37
Sep.	116.34	8.22	259.76	0.45	34
Oct.	107.47	29.55	283.41	0.47	33
Nov.	95.57	6.49	317.74	0.68	28
Dec.	74.05	16.35	118.95	0.42	13
Cold season	89.27	6.49	317.74	0.70	88
Hot season	125.35	8.22	646.74	0.71	200
All samples	114.32	6.49	646.74	0.72	288

TABLE 2: Percentage of samples to the total samples for each PM_{10} class for hot season (P_h), cold season (P_c), and all measurement period (P_t).

PM_{10} ($\mu\text{g m}^{-3}$)	All period	Hot season	Cold season
≤ 50	18.6	12.7	28.0
51–70	8.9	7.5	11.2
71–100	18.6	17.9	19.6
101–200	42.9	47.4	35.5
201–300	8.6	11.6	3.7
301–400	1.4	1.2	1.9
401–500	0.4	0.6	0.0
501–600	0.4	0.6	0.0
601–700	0.4	0.6	0.0

to be primarily unstable with some neutral conditions. They concluded that these results seem reliable if one considers the nature of the atmosphere in the study region with respect to the behavior of global solar radiation, wind speed, and clouds amount. They illustrated that the average hourly values (9:00–11:00 LST) of global solar radiation vary from 91.00 mW cm^{-2} through the hot season period to 60.00 mW cm^{-2} through cold season period with annual average equal to 81 mW cm^{-2} . In addition, the winds are light at most of the year. The average hourly value (9:00–11:00 LST) of wind speed was 2.65 m s^{-1} (hot season period) and 1.96 m s^{-1} (cold season period) with an annual average value equal to 2.31 m s^{-1} .

3.2. The Effect of Meteorological Factors in PM_{10} Level. Earlier studies (e.g., [40–43]) reviewed that the meteorology plays an important role in ambient distributions of air pollution. The importance of meteorological factors in the transport and diffusion stage of air pollution cycle is well recognized. The entering of pollutants from the ground surface, their

residence in the atmosphere, and the formation of secondary pollutants is controlled not only by the rate of emission of the reactants into the air from the source, but also by wind speed, turbulence level, air temperature, and precipitation. Thus, it is often important to understand the physical processes leading to an observed concentration of pollutants at a given point. The variation of meteorological variables (T , R_h , and W_s) is shown in Figures 2(b), 2(c), and 2(d) for the intervals of the measurement samples (9:00–11:00 LST) through the period under study. Although [44] mentioned that the rainfall is one of the reasons for low particulate pollutants as the pollutants are washed out by rain, this factor is not important at Qena (it lies within the subtropical region characterized by hot and dry weather). Wet deposition by precipitation or wet removal is one of the main mechanisms for removal of aerosols from the atmosphere. In addition, this particulate pollutant changes the precipitation pattern and spins down the hydrological cycle.

First, statistics of meteorological variables for the intervals of the measurement samples (9:00–11:00 LST) through 2002–03 are listed in Table 3. This table includes average (Ave.), maximum (Max.), minimum (Min.), and coefficient of variance (CV). The number of observations (n) for each month, hot season, and cold season and within the whole period of this study is reported in this table. Air temperature (T) ranged between 14.20°C (19/1/2003) and 37.40°C (16/5/2003). The minimum of monthly average temperature was recorded in February 2003 (17.08°C), and the maximum temperature was recorded in May 2003 (33.27°C). The seasonal average temperature varied from 22.46°C (in cold season) to 29.45°C (in hot season). Wind speed (W_s) varied from 1.00 m s^{-1} to 7.50 m s^{-1} with average value during the study period equal to 2.74 m s^{-1} . The lowest of monthly average wind speed was recorded in February 2003 (1.81 m s^{-1}) and highest of monthly average wind speed was recorded in April 2003 (3.08 m s^{-1}). Through the study period, the average

TABLE 3: Average, maximum, minimum of T , Rh , and Ws , coefficient of variation, and number of observation for each month, cold season, hot season, and all observation during the period (2002-03).

Period	Weather elements	Ave.	Min.	Max.	CV	n
Jan.	T	17.23	14.20	22.40	0.11	31
	Rh	47.81	27.00	67.00	0.23	
	WS	2.50	0.50	6.50	0.42	
Feb.	T	17.08	14.80	24.40	0.15	16
	Rh	44.06	22.00	60.00	0.20	
	WS	1.81	1.00	6.50	0.81	
Apr.	T	27.53	22.00	35.80	0.13	43
	Rh	23.37	10.00	42.00	0.31	
	WS	3.08	0.50	8.00	0.58	
May	T	33.27	24.20	37.40	0.09	25
	Rh	29.36	21.00	49.00	0.25	
	WS	2.60	1.50	5.00	0.38	
Jul.	T	29.02	22.70	36.10	0.15	28
	Rh	18.89	5.00	39.00	0.45	
	WS	2.77	1.00	7.50	0.61	
Aug.	T	28.77	21.80	36.10	0.16	37
	Rh	19.43	5.00	39.00	0.39	
	WS	2.81	1.00	7.50	0.57	
Sep.	T	30.08	21.80	36.40	0.13	34
	Rh	29.38	15.00	49.00	0.32	
	WS	3.01	1.00	6.50	0.46	
Oct.	T	28.34	23.60	32.80	0.10	33
	Rh	29.79	12.00	48.00	0.31	
	WS	2.63	1.00	8.00	0.60	
Nov.	T	27.95	21.80	36.10	0.15	28
	Rh	18.36	5.00	39.00	0.45	
	WS	2.75	1.00	7.50	0.61	
Dec.	T	29.73	23.60	36.10	0.15	13
	Rh	16.54	5.00	29.00	0.49	
	WS	2.88	1.00	7.50	0.59	
Cold season	T	22.46	36.10	14.20	0.30	88
	Rh	33.75	88.00	5.00	0.56	
	WS	2.51	7.50	0.50	0.62	
Hot season	T	29.25	37.40	21.80	0.14	200
	Rh	24.85	49.00	5.00	0.38	
	WS	2.84	8.00	0.50	0.56	
All samples	T	27.18	37.40	14.20	0.22	288
	Rh	27.38	67.00	5.00	0.48	
	WS	2.74	8.00	0.50	0.57	

value of wind speed was equal to 2.74 m s^{-1} . The seasonal average wind speed varied from 2.81 m s^{-1} (in cold season) to 2.86 m s^{-1} (in hot season). The humidity ranged between 5% and 67% during the study period. The maximum humidity was noted in January, and minimum humidity was recorded in July, August, November, and December. The seasonal averages of humidity varied from 24.85% (in hot season) to 33.75% (in cold season).

In addition, atmospheric stability was identified as A (14.04%), A to B (33.68%), B (25.61%), B to C (6.67%),

C (15.09%), C to D (3.16%), and D (1.75%). During this interval, the atmosphere tends to be primarily unstable (A–C) with some neutral condition (D). No occurrences of stable conditions (E–G) were found in this period of time. These results seem reliable if one considers the atmosphere of the study region that is related to the behavior of GSR, Ws , and CA. As mentioned above, the suggestion of Pasquill and Gifford for determining the nature of convection is based on the variation of these parameters. These results reflect clearly that Qena is characterized to high extent with unstable

TABLE 4: Correlation coefficients (R) between PM_{10} and weather elements for each month, cold season, hot season, and all observations during the period (2002-03). Multiple correlation and F -statistics values.

Period	R			Multiple R	F -statistics
	T	Rh	WS		
Jan.	-0.11	0.24	0.13	0.32	1.05
Feb.	0.23	0.32	-0.21	0.44	0.95
Apr.	0.37	0.12	-0.02	0.47	3.62*
May	-0.31	0.32	0.10	0.34	0.92
Jul.	-0.03	-0.18	-0.14	0.21	0.37
Aug.	-0.14	0.07	0.00	0.15	0.24
Sep.	-0.27	0.02	-0.16	0.33	1.19
Oct.	-0.03	0.32	-0.24	0.40	1.85
Nov.	-0.01	0.05	0.01	0.05	0.02
Dec.	-0.11	0.15	-0.26	0.32	0.34
cold season	-0.02	0.12	0.07	0.21	1.28
hot season	0.09	0.14	-0.05	0.19	2.55*
all data	0.16	0.04	0.00	0.33	8.94**

*Significance level (significance F at confidence level 99%).

atmosphere. This deduction is very important for the future of the dispersion of the pollutants in this region, owing to the fact that unstable atmosphere strengthens the dispersion of the pollutants both vertically and horizontally [2]. Figure 2(e) shows the atmospheric stability classes for the midmorning hours through the period of this study.

Correlation analyses were carried out to quantify the relationship, if any, between the meteorological variables (T , Rh, and Ws) and PM_{10} for each month, hot season, cold season, and all the samples. These correlation coefficients (R) have been done to assess the relationship between PM_{10} and these meteorological variables. Table 4 summarized these results. For all cases, the results showed that there is no significant correlation between PM_{10} and these meteorological parameters. The values of R were weak ($R < 0.5$). In contrast, a significant correlation was found between the monthly average of PM_{10} and temperature ($R = 0.5$). Figure 3 illustrated the variation of the monthly average of PM_{10} and the weather variables (T , Rh, and Ws). This Figure reflects a weak correlation between PM_{10} and Ws ($R = 0.3$) and a very weak correlation with Rh ($R = -0.1$). Similar results were obtained by [5] in Northern Sweden. They found low correlations ($R < 0.5$) between PM_{10} and the weather parameters (T and Ws). They explained that this is associated with the large variability of wind direction (Wd) that was very frequently observed in connection with low Ws. In this study, PM_{10} concentrations at midmorning with respect to wind directions for whole measuring period are presented in Figure 4. The PM_{10} concentrations were at higher values when prevailing wind direction was in the sector 225–285° (see Figure 1(b)). Wind from sector 225–285° occurred during 66% of the time of these measurements. One of the possible explanations might be that the most polluted location, the main road to South Valley University, is opened from S-SW direction where the big crossroad with a highway. Another reason could be the influence of the great source of air pollution from mechanical scrapings and

other human activities to complete the camp of South Valley University.

Multiple correlation coefficients have been employed to assess the relationship between PM_{10} and these meteorological variables, and the results were presented in Table 4. From this table it was noted that particulate pollutants PM_{10} showed a significant correlation with these parameters in April (multiple $R \approx 0.50$). In addition, multiple R is statistically significance (F -statistics = 3.62*). As mentioned previously, in April, it is expected due to the relatively high instability of the local climate during this time interval [38]. This variation in climatic conditions may be due to the hot desert cyclones known as the khamsin. Highest PM_{10} concentrations were also affected because of wind speed. Wind affects turbulence near the ground, thus affecting the dispersion of pollutants released into the air. Turbulence (largely the up and down motion of air) is generated in part by airflow over rough ground. The greater the wind speed, the greater the turbulence and hence the greater the dispersion of pollutants that are near the ground [45]. The value of multiple R increased ($R = 0.73$) for the case of the monthly average of PM_{10} and the weather variables (T , Rh, and Ws).

In order to see a clearer effect of the air temperature (T) on PM_{10} , further analysis was employed. The PM_{10} values were classified according to the corresponding air temperature in 1°C intervals. Then, the averages of PM_{10} values per each interval were estimated. Figure 5(a) shows the relationship between T (°C) and the average values of PM_{10} for each interval. The value of R between them is equal to 0.54. Although, the correlation between PM_{10} and T for each case is a weak (see Table 4), there is a correlation between the average of PM_{10} for each interval and T ($R = 0.54$). However, the value of R does not guarantee that the regression line can fit the data well [46]. A statistical analysis to determine if R is statistically significant was applied. The relation between the residuals of the average of PM_{10} for each interval and T as independent variable was implemented. The residual plot

FIGURE 3: Monthly average variation of PM_{10} concentration ($g\ m^{-3}$), and air temperature (a), relative humidity (b), and wind speed (c) at Qena during the period from 2002 to 2003.

is shown in Figure 5(b). This figure shows a random pattern for the values of these residuals. Accordingly, the linear relationship between the average of PM_{10} for each interval, and T provides a good fit to the data. In addition, the value of F -statistics was equal to 2.00* (* refers to significance of F at confidence level 99%). Therefore, the value of R is statistically significant. This indicates that the values of average PM_{10} for each intervals increase linearly with increased T . Krecl et al. [5] have classified PM_{10} according to the corresponding air temperature in $5\ ^{\circ}C$ intervals. A trend between the average values of PM_{10} for each interval and the corresponding air temperature (-30 to $10^{\circ}C$) was evident. For the positive range of T , they found that the PM_{10} increased with increasing T . In addition, El Shazly [47] mentioned that the high dust content in the lower atmospheric layers arising from the

FIGURE 4: PM_{10} concentrations ($g\ m^{-3}$) for difference wind direction at Qena during the period from 2002 to 2003.

FIGURE 5: (a) Variation of the average PM_{10} concentration for each interval of T and (b) the residual plot.

well-developed vertical mixing of dust particles owing to the high temperature.

Finally, the PM_{10} concentrations were grouped depending on their associated atmospheric stability class (A, A to B, B to C, and C). Then, the average concentration values of PM_{10} per each class were estimated. The values were 122.80 ± 9 , 117.41 ± 7 , 109.36 ± 12 , 104.57 ± 8 , and 104.42 ± 15 ($\mu g\ m^{-2}$), respectively. Concerning the atmospheric stability classes C to D and D, the average PM_{10} concentrations are not considered statistically relevant. This is due to the fact that

both classes showed a low frequency of occurrence during the study period (4.76%). The variability of PM_{10} according to the change of atmospheric stability classes is expected. This may be due to the variability of the dispersion coefficients in horizontal (σ_y) and vertical (σ_z) directions. However, Adam and El Shazly [2] estimated σ_y and σ_z , by a method based on a stability classification of the atmospheric conditions (after [48]), at Qena during the period from 2001 to 2004. They found that the values of σ_y and σ_z decreased with increasing instability conditions.

4. Conclusions

The present study is to assess the levels of PM_{10} at subtropical urban area. The database used values of PM_{10} under unstable atmospheric conditions. By making use of the available information, the following conclusions are drawn to the best of our knowledge about the PM_{10} and its relationship with the weather elements at the study region. The results could be summarized in the following outcomes.

- (i) For the midmorning hours (9:00–11:00 LST), PM_{10} concentrations showed average of $114.32 \mu g m^{-3}$. This average was equal to $89.27 \mu g m^{-3}$ at the cold season and $125.35 \mu g m^{-3}$ at the hot season. The high values of PM_{10} levels in the hot season may be connected with the high insulation levels and strong convective processes characteristic of arid regions.
- (ii) During the period of dust storm (the khamsin weather conditions), the PM_{10} levels at Qena increase to reach a relatively high values ($646.74 \mu g m^{-3}$ at 19 April 03).
- (iii) PM_{10} was shown a poor correlation with both Rh (R ranged from -0.12 to 0.32) and Ws (R ranged from -0.26 to 0.16). Although a weak correlation between PM_{10} and T was found (R ranged from -0.27 to 0.37), the values of R between the averages of PM_{10} for each interval values of temperature ($1^\circ C$) and T was equal to 0.54 . In additions, for the monthly average values there is a significant correlation that was found between the PM_{10} and temperature ($R = 0.5$). The monthly average of the PM_{10} and the weather elements showed a significant correlation. The multiple R was equal to 0.73 .
- (iv) Under unstable atmospheric conditions, the PM_{10} concentrations decrease with decreasing instability of the atmosphere. The average values of PM_{10} were equal to $122.80 \pm 9 \mu g m^{-3}$ (highly unstable or convective), $109.37 \pm 12 \mu g m^{-3}$ (moderately unstable), and $104.42 \pm 15 \mu g m^{-3}$ (slightly unstable).

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References

- [1] M. E.-N. Adam, *A sodar-based investigation of the atmospheric boundary layer [Ph.D. thesis]*, Meteorological Institute, University of Freiburg, Freiburg, Germany, 2003.
- [2] M. E.-N. Adam and S. M. El Shazly, "Diurnal variation of atmospheric stability at Qena (Upper Egypt)," *Mausam*, vol. 59, no. 1, pp. 69–76, 2008.
- [3] M. D. Keywood, G. P. Ayers, J. L. Gras, R. W. Gillett, and D. D. Cohen, "Relationships between size segregated mass concentration data and ultrafine particle number concentrations in urban areas," *Atmospheric Environment*, vol. 33, no. 18, pp. 2907–2913, 1999.
- [4] J. G. Watson, J. C. Chow, D. H. Lowenthal, M. R. Stolzenburg, N. M. Kreisberg, and S. V. Hering, "Particle size relationships at the Fresno Supersite," *Journal of the Air and Waste Management Association*, vol. 52, no. 7, pp. 822–827, 2002.
- [5] P. Krecl, J. Ström, and C. Johansson, "Diurnal variation of atmospheric aerosol during the wood combustion season in Northern Sweden," *Atmospheric Environment*, vol. 42, no. 18, pp. 4113–4125, 2008.
- [6] A. Tate and R. A. Spronken-Smith, "A preliminary investigation of the air pollution meteorology of Alexandra, Central Otago, New Zealand," *Clean Air and Environmental Quality*, vol. 42, pp. 15–21, 2008.
- [7] M. Arkouli, A. G. Ulke, W. Endlicher et al., "Distribution and temporal behavior of particulate matter over the urban area of Buenos Aires," *Atmospheric Pollution Research*, vol. 1, pp. 1–8, 2010.
- [8] T. Ancelet, P. K. Davy, T. Mitchell, W. J. Trompetter, A. Markwitz, and D. C. Weatherburn, "Identification of particulate matter sources on an hourly time-scale in a wood burning community," *Environmental Science and Technology*, vol. 46, no. 9, pp. 4767–4774, 2012.
- [9] S. K. Grange, J. A. Salmond, W. J. Trompetter, P. K. Davy, and T. Ancelet, "Effect of atmospheric stability on the impact of domestic wood combustion to air quality of a small urban township in winter," *Atmospheric Environment*, vol. 70, pp. 28–38, 2013.
- [10] U. Corsmeier, M. Kossmann, N. Kalthoff, and A. Sturman, "Temporal evolution of winter smog within a nocturnal boundary layer at Christchurch, New Zealand," *Meteorology and Atmospheric Physics*, vol. 91, no. 1–4, pp. 129–148, 2006.
- [11] W. J. Trompetter, P. K. Davy, and A. Markwitz, "Influence of environmental conditions on carbonaceous particle concentrations within New Zealand," *Journal of Aerosol Science*, vol. 41, no. 1, pp. 134–142, 2010.
- [12] World Health Organization, "World Health Organization air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide," Summary of risk Assessment, 2005, http://whqlibdoc.who.int/hq/2006/WHO_SDE_PHE_OEH_06.02_eng.pdf.
- [13] A. J. Krupnick and P. R. Portney, "Controlling urban air pollution: a benefit-cost assessment," *Science*, vol. 252, no. 5005, pp. 522–528, 1991.
- [14] J. V. Hall, A. M. Winer, M. T. Kleinman, F. W. Lurmann, V. Brajer, and S. D. Colome, "Valuing the health benefits of clean air," *Science*, vol. 255, no. 5046, pp. 812–817, 1992.

- [15] H. O. Sommer, J. C. Chanel, H. Vergnaud, M. Herry, N. Sedlak, and R. Seethaler, "Monetary valuation of road traffic related air pollution: health costs due to road traffic-related air pollution: an impact assessment project of Austria, France and Switzerland," in *Proceedings of the 3rd WHO Ministerial Conference*, 1999.
- [16] M. Martuzzi, F. Mitis, A. Biggeri, and R. Bertollini, "Health impact assessment of air pollution in the eight major Italian cities," WHO Regional Office for Europe, Copenhagen, Denmark, EURO/02/5040650, http://www.euro.who.int/_data/assets/pdf_file/0013/91111/E75492.pdf.
- [17] J. V. Hall, V. Brajer, and F. W. Lurmann, "Air pollution, health and economic benefits-Lessons from 20 years of analysis," *Ecological Economics*, vol. 69, no. 12, pp. 2590–2597, 2010.
- [18] M. K. Scammell, "Qualitative environmental health research: an analysis of the literature, 1991–2008," *Environmental Health Perspectives*, vol. 118, no. 8, pp. 1146–1154, 2010.
- [19] EEAA, Egypt State of Environment, and Egyptian Environmental Affairs Agency, 2011, <http://www.eeaa.gov.eg/eimp/mainair-problem.html>.
- [20] M. A. Mosalam Shaltout, A. H. Hassan, and A. M. Fathy, "Total suspended particles and solar radiation over Cairo and Aswan," *Renewable Energy*, vol. 23, no. 3–4, pp. 605–619, 2001.
- [21] A. S. Zakey, M. M. Abdel-Wahab, J. B. C. Pettersson, M. J. Gatari, and M. Hallquist, "Seasonal and spatial variation of atmospheric particulate matter in a developing megacity, the Greater Cairo, Egypt," *Atmosfera*, vol. 21, no. 2, pp. 171–189, 2008.
- [22] A. Mohamed, F. M. Abdelkel Kerim, A. B. Bassily, E. Armia, and M. Nassary, "Heavy metals determination in the atmosphere of Qena using spectroscopic technique," *Bulletin of the Faculty of Science, Qena, Assiut University*, vol. 1, no. 1, 1987.
- [23] S. M. El Shazly, Kh. O. Kassem, A. A. Hassan, and E. A. Hala, "Assessment of mixing height at Qena/upper Egypt based on radiosonde data," *Resources and Environment*, vol. 2, pp. 275–280, 2012.
- [24] B. Sivertsen and A. A. El Seoud, "The air pollution monitoring network for Egypt," in *Proceedings of the Dubai International Conference on Atmospheric Pollution*, Dubai, UAE, February 2004.
- [25] H. K. Elminir, R. H. Hamid, F. El-Hussainy, A. E. Ghitas, M. M. Beheary, and K. M. Abdel-Moneim, "The relative influence of the anthropogenic air pollutants on the atmospheric turbidity factors measured at an urban monitoring station," *Science of the Total Environment*, vol. 368, no. 2–3, pp. 732–743, 2006.
- [26] H. K. Elminir, "Relative influence of air pollutants and weather conditions on solar radiation—part I: relationship of air pollutants with weather conditions," *Meteorology and Atmospheric Physics*, vol. 96, no. 3–4, pp. 245–256, 2007.
- [27] M. E.-N. Adam, "Sensitivity analysis of aerosol effect in UVB transmission to solar zenith angle at subtropical location (Qena, Egypt)," *Atmospheric Environment*, vol. 71, pp. 311–318, 2013.
- [28] H. F. S. Rizk, S. A. Farag, A. Ateia, and A. El-Bialy, "Effect of pollutant aerosols on spectral atmospheric transmissivity in Cairo," *Environment International*, vol. 11, no. 6, pp. 487–492, 1985.
- [29] H. F. S. Rizk, S. H. Soliman, A. B. El Beialy, and A. A. Ateia, "Aerosol optical thickness in Cairo atmosphere," *Journal of the Institution of Engineers*, vol. 66, pp. 45–51, 1986.
- [30] A. I. El-Tantawy, "On the cyclogenesis and structure of spring desert depressions in subtropical Africa. Egyptian Meteorological Authority (EMA)," *Meteorological Research Bulletin*, vol. 69, pp. 68–107, 1969.
- [31] S. M. Robaa, "On the estimation of UV-B radiation over Egypt," *Idojaras*, vol. 112, no. 1, pp. 45–60, 2008.
- [32] A. A. Hassan, *A diagnostic study of a North African depression [Ph.D. thesis]*, University of Reading, West Berkshire, UK, 1974.
- [33] Graseby-Anderson, *Instruction and Operation Manual High Volume PM10 Sampler*, Atlanta, Ga, USA, 1988.
- [34] R. B. Stull, *Meteorology For Scientists and Engineers*, Brooks Cole, 2000.
- [35] M. G. El-Fandy, "The formation of depression of the Khamsin type," *Quarterly Journal of the Royal Meteorological Society*, vol. 66, pp. 323–335, 1940.
- [36] A. I. El-Tantawy, "The role of jet stream in the formation of desert depression in the Middle East," *World Meteorological Organization*, vol. 64, pp. 159–171, 1964.
- [37] C.-K. Lee, "Multifractal characteristics in air pollutant concentration time series," *Water, Air, and Soil Pollution*, vol. 135, no. 1–4, pp. 389–409, 2002.
- [38] M. E.-N. Adam, "Effect of the atmosphere on UVB radiation reaching the earth's surface: dependence on solar zenith angle," *Atmospheric and Oceanic Science Letter*, vol. 4, pp. 139–145, 2011.
- [39] T. N. Carlson and J. M. Prospero, "The large-scale movement of Saharan air outbreaks over the North equatorial Atlantic," *Journal of Applied Meteorology*, vol. 11, pp. 283–297, 1972.
- [40] A. J. Fernández Espinosa, M. Ternero Rodríguez, and F. Fernández Álvarez, "Source characterisation of fine urban particles by multivariate analysis of trace metals speciation," *Atmospheric Environment*, vol. 38, no. 6, pp. 873–886, 2004.
- [41] C. E. Chung, V. Ramanathan, D. Kim, and I. A. Podgorny, "Global anthropogenic aerosol direct forcing derived from satellite and ground-based observations," *Journal of Geophysical Research*, vol. 110, no. 24, 2005.
- [42] K. Karar, A. K. Gupta, A. Kumar, A. K. Biswas, and S. Devotta, "Statistical interpretation of weekday/weekend differences of ambient gaseous pollutants, vehicular traffic and meteorological parameters in urban region of Kolkata," *Journal of Environmental Science and Engineering*, vol. 47, no. 3, pp. 164–175, 2005.
- [43] B. V. Bhaskar and V. M. Mehta, "Atmospheric particulate pollutants and their relationship with meteorology in Ahmedabad," *Aerosol and Air Quality Research*, vol. 10, no. 4, pp. 301–315, 2010.
- [44] R. Jaenicke, "Tropospheric aerosols," *International Journal of Geosciences*, vol. 54, pp. 1–31, 1993.
- [45] C. N. Oren, *Air Pollution*, Access Science, McGraw-Hill, 2001, <http://www.accessscience.com/>.
- [46] C. J. Willmott, "On the validation of models," *Physical Geography*, vol. 2, pp. 184–194, 1981.
- [47] S. M. El Shazly, "A study of linke turbidity factor over Qena / Egypt," *Advances in Atmospheric Sciences*, vol. 13, no. 4, pp. 519–532, 1996.
- [48] G. A. Briggs, *Diffusion Estimates For Small Emissions*, Atmospheric Turbulence and Diffusion Laboratory, Oak Ridge, Tenn, USA, 1973.