Vol-5, Issue-6 PP. 207-214 ISSN: 2394-5788

GLOBAL JOURNAL OF ADVANCED RESEARCH
(Scholarly Peer Review Publishing System)

ANALYSIS OF THE SURFACE AIR QUALITY MEASUREMENTS IN THE GREATER CAIRO (EGYPT) METROPOLITAN

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ABSTRACT

Air pollution is considered one of the most severe issues facing developing countries. The Greater Cairo (GC) region has long been suffering from deteriorated air quality which is caused by high levels of anthropogenic activities, such as traffic, industries, and agricultural biomass burning events, as well as natural sources of particulate matter, such as dust and sand events. The present study aims at studying environmental pollution in GC area. The emission patterns of some major pollutants (sulfur dioxide, nitrogen dioxide, carbon monoxide, ozone, and particulate matter) measured by several pollution stations distributed around GC were analyzed, and areas of pollution hot spots were identified. The pollutants concentrations were found to exceed remarkably the Egyptian legal exposure limits during the period of measurement in some industrial areas. More actions need to be taken in order to lower the levels of air pollution and enhance the quality of life in the GC metropolitan.

General Terms: Air Quality; Air Pollution

Keywords: Air Quality; Air Pollution; Emission Pattern of Air Pollutants; Greater Cairo (Egypt)

1. INTRODUCTION

Air pollution is the introduction of particulates or harmful substances which are not part of the natural composition of air into the Earth's atmosphere, causing disease, death, damage, or disruption of the natural ecosystem. It has become a worldwide growing matter of concern, as it is thought to be a principal cause of several health issues, such as respiratory infections, cardiovascular disease, central nervous system (CNS) disorders, cancer, and mortality. As a result, data on air quality are becoming increasingly available and the scientific research concerning its associated health impacts is also evolving rapidly.

Greater Cairo (GC) is the largest metropolitan area in Egypt, consisting of Cairo Governorate, Giza city, Shubra El-Kheima, 6th of October City, and Obour City, with an estimated population density of 13107 people/km^2 (Central Agency for Public Mobilisation and

Statistics, 2017). The increased population and, thus, rapid urban growth in cities such as the GC has created a problem of overcrowded streets filled with cars and trucks which plays a big role in the cities' increased air pollution. Moreover, a growing urban community results in more industrial factories opening up in and around the city. Due to having a large number of vehicles and industrial factories, which are fuelled by fossil fuels, and emit large amounts of CO_2 and SO_2 emissions, the city's air pollution levels have risen substantially in recent years. Since 1999, The Black Cloud phenomenon has appeared in October and November, which added to the GC's poor air quality. The phenomenon is due to the burning of rice straw in the temperature inversion months - October and November – and it results in both environmental and health problems (World Bank Annual Report, 2013).

It has been estimated that there will be an increasing number of individuals that will suffer from health issues in Egypt due to the increasing air pollution. Between the years 2010 and 2020, it has been estimated that the number of children suffering from lower respiratory illness will increase up to 11.1 million and the number of people suffering from chronic pulmonary and cardiovascular disease will increase by 137,000 (World Bank Annual Report, 2013).

Kanakidou et al. (2011) reported that significant effort has been recently paid on understanding atmospheric composition change in the East Mediterranean due to human activities, supporting the role of the basin as the 'pressure-cooker' of transported air pollution from not only distant anthropogenic sources but also surrounding urban centers. They stated that air masses are mixed in the area under favourable meteorological conditions with high solar radiation, and particulate matters were shown to have a significant contribution by long-range transport of African dust or anthropogenic sources over the region. Petkova et al. (2013) provided an overview of PM air monitoring studies in Africa in order to assess how reported data compare to international air quality guidelines. They reported that PM levels in Cairo, Egypt were particularly worrisome as they exceeded the guidelines by several fold. The high levels of PM may be attributed to desert regions surrounding Cairo, frequent sand storms in spring and fall, and the large numbers of vehicles as well as industrial facilities. Zakey et al. (2008) reported that the annual PM2.5 and PM10 levels at 17 representative sites between 2001 and 2002 were 85±12 and 170±25 $\mu g/m^3$, respectively. Also, in a PM monitoring and source apportionment study during June and October, 2010 at five sites in GC, Lowenthal et al. (2014) demonstrated that the Egyptian 24-hour PM10 guidelines of 70 $\mu g/m^3$ (EEAA, 1994) was exceeded at all the sites between 91% and 96% of the sampling periods in June and October, respectively. Wheida et al. (2018) analyzed the temporal and spatial variability of PM10, NO_2, and O_3 concentrations for the periods 2000-2004 and 2010-2015 at 18 stations of the GC. They found that the less polluted areas were "El-Abbasseya, Nasr City, and New Cairo" stations, while the most polluted areas were "El-Maasra, El-Maadi, El-Kolaly, and Abo-Zabaal". The range of the concentrations of PM2.5, which is about 50% of the PM10, were well above the 75 $\mu g/m^3$ Egyptian Guidelines at all the studied stations.

2. MATERIALS AND METHODS

In this study, we consider air quality data for four gaseous pollutants, namely, sulfur dioxide (SO_2), Nitrogen dioxide (NO_2), carbon monoxide (CO), and ozone (O_3), and air-suspended particulate matter less than 10 µm in diameter (PM10). The concentrations of these pollutants are routinely measured on an hourly basis by the Egyptian Environmental Affairs Agency (EEAA) stations network. Also, the ozone gas is measured every hour by the Egyptian Meteorological Authority (EMA). The data available for this study consists of two datasets for the period 2010-2014: the first one contains the SO_2, NO_2, CO, and PM10 concentrations obtained from 17 stations of the EEAA network, and the second one corresponds to the O_3 measurements obtained from one station of the EMA network. Table 1 presents the names, coordinates, and type of each station for the period of study.

Table 1. Names of the measuring stations with their Coordinates and type available for the period of study.

Site no.	Name of station	Coordinates		Type
		lon	lat	
1	[a]El-Abbasseya	31°17'18.63"	30°04'39.75"	Urban/Residential.
2	El-Kolaly	31°14'37.23"	30°03'38.13"	Road side/Urban
3	Nasr City	31°19'34.28"	30°03'17.96"	Residential
4	El-Maadi	31°16'36.992"	29°57'45.706"	Residential
5	El-Tebeen	31°17'1.259"	30°9'9.55"	Industrial
6	Abo-Zabaal	31°24'26.39"	30°14'38.29"	Road side/Urban
7	Helioplis	31°20'75.37"	30°5'00.03"	Road side/Urban

8	Helwan	31°20'58.2"	29°50'01.57"	Road side/Urban
9	Nasser Institute	31°14'74.21"	30°5'71.40"	Road side/Urban
10	New Cairo	31°20'88.21"	30°2'01.34"	Residential
11	El-Maasra	31°17'43.58	29°54'86.22"	Residential
12	6-Oct	31°14'37.23"	30°03'38.13"	Road side/Urban
13	El-Mohandeseen	31°12'0.823"	30°4'5.021"	Residential
14	El-Salam	31°16'33.744"	30°6'8.936"	Residential
15	Giza Square	31°12'42.009"	30°01'39.256"	Residential
16	Fum El-Khalij	31°13'52.709"	30°1'22.743"	Residential
17	Shobra El-Kheima	31°14'32"	30°07'43"	Residential

[a]Note: the El-Abbasseya stations of the EMA and EEAA networks are the same.

3. RESULTS AND DISCUSSION

In order to assess the pollution level of SO_2, NO_2, CO, O_3, and PM10 during the period of the study, analysis of the concentrations and the spatial and temporal variability of theses pollutants was performed.

For simplicity, we are presenting the results of only four stations for each pollutant, except for CO and O_3 which have only three and one station, respectively. In order to choose the four stations, we divided the stations geographically into four sectors according to the basic four directions (north, south, east, and west). After dividing the stations into four sectors, we chose the most representing station for each sector, which has the least root-mean-square (R.M.S.) error with the spatial average of that sector. Note that the representative stations of each sector are not necessarily the same for the different species.

Moreover, areas of pollution hot spots were identified through assessment of the exposure limits exceedence in the considered sites according to the Egyptian Environmental Law 4/1994 (EEAA, 1994).

As the metrological conditions over a region are known to affect the concentration and distribution of air pollutants in this region, we also investigated the prevailing wind pattern in the four sectors and their relationship with the air pollution concentration and spatial distribution. EMA wind data measured over the 5-year period of study were used to produce the wind rose diagrams. Results showed that the prevailing wind direction is the north in all the sectors, whereas the prevailing wind speed is 6-10 KT in the northern and southern sectors and 10-16 KT in eastern and western ones (results not shown here).

3.1. Analysis of the Monthly Averaged Concentrations

Monthly averaged concentrations were extracted from the hourly observations to produce the 5-year monthly averaged mass concentrations. Figures 1-2 show the mass concentrations of SO_2, O_3, NO_2, CO, and PM10 at the selected sites. Figure 1a shows the five-year monthly averaged concentrations of SO_2 for the selected sites in the region. It is noticed that Site 09 (northern station) and Site 03 (eastern station) showed a maximum SO_2 concentration in the cold season, while southern and western stations showed maximum SO_2 concentration in the hot season. At a shorter (hourly) time scale, the SO_2 concentrations averaged over the entire study period ranged from 13.7 $\mu g/m^3$ (Site 11) to 29.1 $\mu g/m^3$ (Site 02), which are within the Egyptian legal limits for yearly SO_2 gas exposure (60 $\mu g/m^3$). Considering the obtained results, it is apparent that the cumulative sulfur dioxide concentrations at the selected locations were significantly within the annual mean set by the Egyptian law guidelines (EEAA, 1994).

Figure 1b shows the five-year monthly averaged concentrations of NO_2 for the selected sites in the region. The results indicated that there is a primary peak in late autumn and winter and a secondary peak in spring in all sites except Site 10. The minimum NO_2 concentrations were recorded in summer.

Figure 1c shows the five-year monthly averaged concentrations of carbon dioxide for the chosen sites. The CO seasonal cycle is mainly governed by the concentration of the hydroxyl radical (OH) in the troposphere and is expected to be lowest in the late summer when photochemistry is active and highest during late winter or spring. CO concentration in a specific location depends on several processes such as emissions, chemical production, chemical loss, transport and deposition, and these are associated with different spatial and temporal scales. From synoptic scale perspective, it is noticed that there is concerned matter with the question of how

synoptic scale processes influence the short-term CO variation and to what extent synoptic pressure systems can explain synoptic scale variation. As shown in Figure 1c, the CO pattern shows higher concentration in winter season and lower concentration in summer season with similar behavior to NO_2. The CO levels during the highest ozone days in the boundary layer over Cairo are just slightly higher than the average CO levels. Three main features of CO pattern are evident: (1) the CO seasonal cycle: high over winter months, decreasing sharply during April and increasing again from November, (2) lower CO concentrations increasing again from November, and (3) the minimum average CO is seen in July, August, and September with faster increase at Site 02. The very low ratio of sulfue dioxde to nitrogen oxide is clearly a good indicator showing that O_3 precursors such as NO_x, CO, and VOCs originate mainly from fossil fuel combustion from mobile sources in the region. These pollutants are subjected to chemical and photochemical transformations in the presence of solar radiation and atmospheric free radicals to form O_3.

The ozone precursors, NO_2 and CO, show monthly variations opposite to those of O_3 (Figures 1b and 1c). The higher values were recorded in late autumn and winter, while the lower values were recorded in summer. Moreover, a smaller peak was observed during spring in most stations. The higher values during late autumn and winter may be attributable to a combined effect of increased near-surface anthropogenic emissions (e.g., from heating processes), more intense biomass burning activities, and less photochemical reactions due to lower solar intensity and variation in temperature. On the other hand, the low values of NO_2 and CO in summer may be assigned to higher rate of photochemical reactions due to the higher solar radiation and the stronger vertical atmospheric mixing in summer. This seasonal variation pattern of NO_2 and CO is similar to the results of previous studies performed in many areas around the world (e.g., Al-Jeelani, 2014; Jallad & Espada-Jallad, 2010; Jun et al., 2007). Over the entire study period, the 24-hour averaged NO_2 concentrations ranged from 21.1 µg/m^3 (Site 05) to 61.6 µg/m^3 (Site 02), and the 8-hour averaged CO concentrations ranged from 3.3 mg/m^3 (Site 07) to 8.5 mg/m^3 (Site 16), both being lower than the Egyptian legal limits for 24-hour averaged NO_2 (150 µg/m^3) and 8-hour averaged CO (10 mg/m^3) exposure, respectively.

Figure 1d shows the five-year monthly averaged concentrations of PM10 for the chosen sites, the maximum concentrations were found in late autumn and winter due to unfavorable meteorological conditions for pollution dispersion along with biomass burning events in this time of the year. PM10 values are found to be high during late autumn and winter period, with low values occurring in summer. Meteorological conditions like high air pressure, atmospheric stability, and temperature inversion favor the enhancement of the PM10 concentration during the winter season. However, another peak can be observed in spring at some stations, which emphasizes the fact that besides seasonality there is also a spatial variability in the concentrations. Additionally, it is known (e.g., El-Metwally et al., 2008) that in GC the largest PM10 concentrations are due to an increased contribution of mineral dust from local sources or transported from the western and southern deserts-like regions of Egypt. Because dust storms are more frequent in spring, this season sometimes happens to be more polluted than winter.

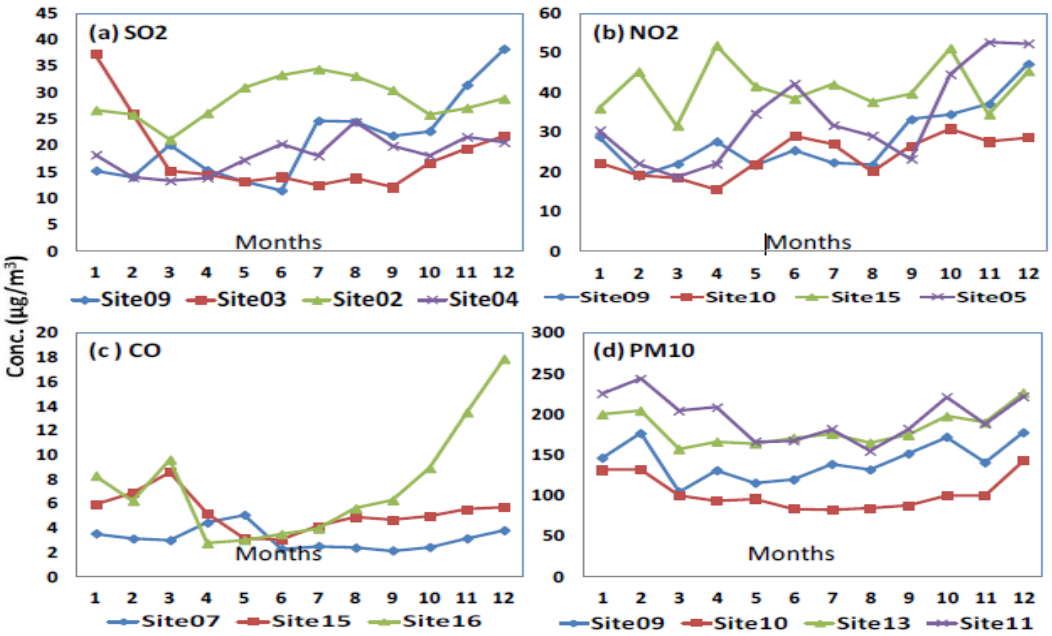

Figure 1. Five-year monthly averaged concentrations for the four representative stations for (a) SO_2, (b) NO_2, (c) CO and (d) PM10.

The autumn and wintertime maximum values are associated with increased anthropogenic emissions from fossil fuel combustion and open biomass burning during the agricultural harvest season together with unfavorable meteorological conditions for air pollution dispersion (i.e., more stable weather associated with temperature inversion during the cold periods) (Aboel Fetouh et al.,2013).

Oppositely, the lower concentrations of PM10 during summer may be attributed to the enhanced convection within a higher atmospheric mixing layer which could result in a strong dilution effect of the particulates. The 24-hour averaged PM10 concentrations over the entire study period ranged from 92.7 µg/m^3 (Site 10) to 221.1 µg/m^3 (Site 02), which indicates that PM10 concentrations exceeded the Egyptian legal limits for 24-hour averaged PM10 exposure (150 µg/m^3) in some stations according to the Egyptian Environmental Law4/1994, such as Site 02. The result indicated that the minimum concentrations of PM10 are likely found in eastern GC while the maximum PM10 mass concentrations found in western GC, despite the fact that the wind speed is comparable in east and west zones of GC. This result suggested that the difference in pollutants concentrations in these two zones could be attributed to intense local source emissions rather than to atmospheric conditions and pollutants transfer.

Figure 2 shows the five-year monthly averaged concentrations of ozone for the one available station (Site 01). The O_3 monthly variations in GC followed the globally familiar pattern over the five years of study, with the higher ozone mass concentration recorded in spring and late summer (warmer periods) and low values during late autumn and winter (colder periods), which was in agreement with other studies (Abdul-Wahab and Bouhamra, 2004; Al-Jeelani, 2014). The 8-hour averaged ozone concentration over the entire study period was 57.8 µg/m^3, which is within the Egyptian legal limits for yearly O_3 gas exposure level (120 µg/m^3), according to the Egyptian Environmental Law4/1994. The increased O_3 concentrations in summer and late summer are clearly due to its direct linear relationship with incoming solar radiation (i.e., temperature), which has a direct influence on chemical kinetic rates and the mechanism pathways for the O_3 production. On the other hand, the low concentrations of O_3 found in late autumn and winter could be a result of the long-range transport together with the fact that in early fall when temperature falls, the thermal decomposition of O_3 precursors decreases.

The origin of the atmospheric ozone entering the boundary layer during a deep subsidence event might be of upper tropospheric or stratospheric origin, but it could also come from the lower or the middle troposphere during stagnant regional conditions when important photochemical ozone production is observed over GC. It is not clear to which extend the regional models reproduce these events, which seem to be quite discontinuous and their effect might be quite significant during certain time periods usually lasting for several days.

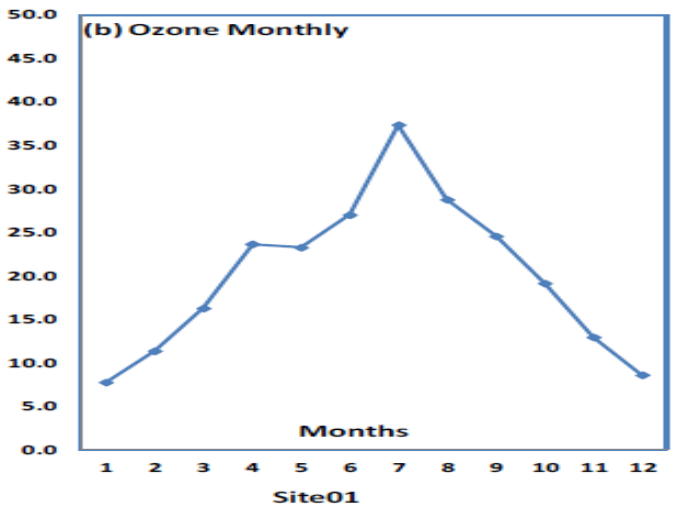

Figure 2. Five-year monthly variation of surface ozone over Site 01.

Due to the trans-boundary problem of surface ozone transfer, it seems that the GC is mostly and very frequently exceeded the ozone level during the warm period of the year and especially during July-August, when the atmospheric subsidence over the area is a quite common atmospheric feature and almost quasi-permanent as it comes out from the average climatology of the omega vertical velocity (Doche et al., 2014; Zanis et al., 2014). In general, in the GC during some high ozone events a large part of the measured ozone could not be attributed to the local or even regional emissions, which for the affected countries might be a reason of reconsideration of the procedures of compliance to air pollution standards.

As the SO_2, NO_2, and CO concentrations does not depend only on source emissions, but also on atmospheric diffusion, photochemical reactions, and weather conditions, especially temperature which can affect the chemical reactions in the atmosphere, these seasonal patterns could at least in part be explained by the seasonal evolution of the meteorological conditions. For instance, the relatively higher concentrations in winter may be due to the low boundary layer height (Abdul-Wahab & Bouhamra, 2004). Over GC the weather is characterizes and associated with important subsidence during summertime and cover the whole Egypt, and subsequently high ozone concentrations close to the surface (due to the high tropospheric ozone levels occurring at the same time. The geographic

areas with observed deep tropospheric subsidence seem to be the transition regions between a high-pressure system (to the west and northwest sector) and a low-pressure system (to the east sector) (not shown here). Over these areas, positive and negative geopotential height anomalies are observed (to the west and east, respectively). This behavior could be very useful for the study of the tropospheric influence to the boundary layer and the ground surface, especially for tracing large-scale deep subsidence events (downward movements of generally dry air masses) when analyzing surface measurements at sites where no vertical ozone measurements are available.

3.2. Analysis of the Pollution Hot Spots

The values of the permissible doses (exposure limits) for outdoor pollutants according to the Egyptian Environmental Law 4/1994 (EEAA, 1994) for the air pollutants considered in the study are as follows: for SO_2, 150 µg/m^3 for 24 hours and 60 µg/m^3 for a year of exposure, for NO_2, 150 µg/m^3 for 24 hours, for CO, 10 mg/m^3 (i.e., 10000 µg/m^3) for 8 hours, for O_3, 120 µg/m^3 for 8 hours, and for PM10, 150 µg/m^3 for 24 hours (note that WHO recommendations are much lower). Table 2 shows the frequency of exceedance of these permissible exposure limits for each pollutant in the concerned stations.

Table 2. The Frequency of Exceedance of Pollutants for Each Station.

Site no.	SO_2		NO_2		CO		O_3		PM10	
	N*	%	N	%	N	%	N	%	N	%
06	0.0	0.0	22.0	4.5	N/A**	N/A	N/A	N/A	525.0	68.4
02	9.0	0.7	3.0	0.4	N/A	N/A	N/A	N/A	803.0	68.0
11	0.0	0.0	0.0	0.0	N/A	N/A	N/A	N/A	726.0	64.8
04	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	559.0	64.3
13	10.0	0.6	0.0	0.0	N/A	N/A	N/A	N/A	899.0	58.3
17	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	720.0	55.1
07	N/A	N/A	N/A	N/A	24.0	1.1	N/A	N/A	345.0	50.8
08	4.0	0.3	1.0	0.2	N/A	N/A	N/A	N/A	476.0	45.6
05	0.0	0.0	0.0	0.0	N/A	N/A	N/A	N/A	637.0	40.9
15	6.0	0.5	0.0	0.0	361.0	9.9	N/A	N/A	457.0	35.7
09	1.0	0.1	0.0	0.0	N/A	N/A	N/A	N/A	398.0	33.0
12	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	398.0	31.9
14	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	269.0	23.5
01	4.0	0.4	6.0	1.1	N/A	N/A	0	0	168.0	19.1
03	1.0	0.1	8.0	0.9	N/A	N/A	N/A	N/A	238.0	15.6
10	N/A	N/A	0.0	0.0	N/A	N/A	N/A	N/A	48.0	8.5
16	N/A	N/A	N/A	N/A	313.0	26.1	N/A	N/A	N/A	N/A

*N: for SO_2, NO_2, and PM10 is the number of days exceeding the permissible limits, and for CO and $O_3$is the number of 8-hour averages exceeding the permissible limits;
**N/A: not applicable.

Figure 3 shows the yearly averages of SO_2 for each available station along with the 1-year permissible limit for it. From Table 2 and Figure 3, it is observed that SO_2 did exceed the 24-hour permissible limit on some occasions, but never the yearly limit. However, sulfur dioxide emissions stand out because these emissions are largely associated with the combustion of sulfur containing fuel whether as part of the human or development activities.

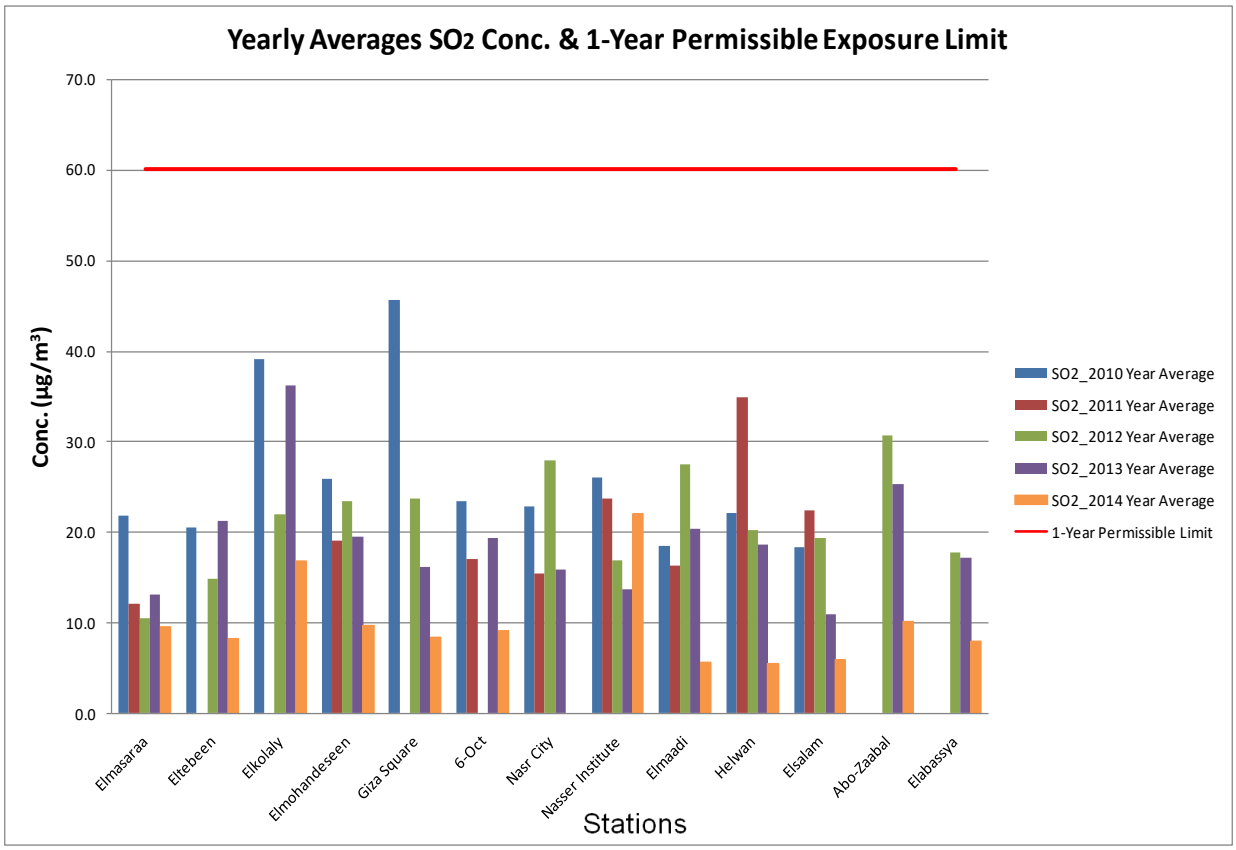

Figure 3. SO_2 yearly average for each available station. No station was shown to exceed the Egyptian yearly permissible limit of SO_2 during the 5 examined years.

Figure 4 shows the stations around GC region with those having concentrations exceeding the permissible limits (hot spots) marked with colored dashes for each specific corresponding pollutant.

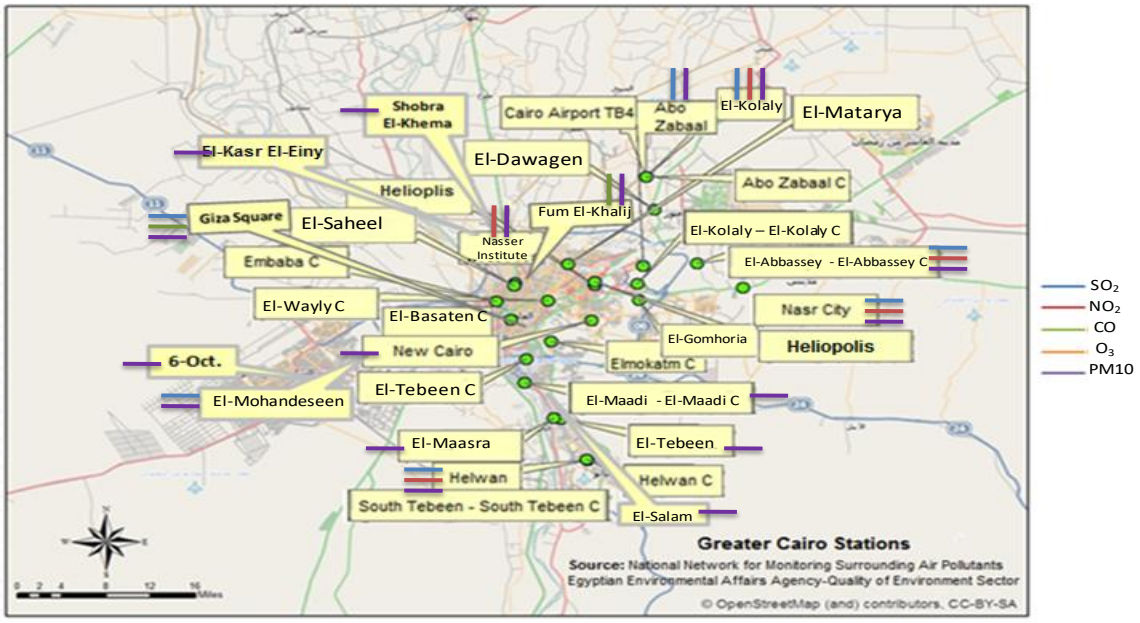

Figure 4. Location of all the EEAA air quality stations inside the GC region, showing areas of hot spots for each pollutant indicated graphically by corresponding colored dashes. Note that El-Abbasseya station comprises the instruments of both the EMA and EEAA networks. Only the stations listed in Table 1 were used in this analysis (Original map reproduced from an EEAA internal document.)

4. CONCLUSION

We presented the analysis of hourly measurements of five major air pollutants, namely, SO_2, NO_2, CO, O_3, and PM10, from 17 observation stations distributed around GC area for 5-year period (2010-2014). It was shown that the level of air pollution is affected by the local, regional, and topographic characteristics, highlighting the effect of potential sources and weather. It was observed that Site 2 can be considered the most polluted area in GC region, which can be explained by the increased urbanization effect in this region. Also, the analysis of the pollutants concentration levels showed that the Egyptian legal limits for the exposure to the concerned pollutants were exceed remarkably during the period of measurement in some industrial areas, which must be put into consideration in order to mitigate air pollution and enhance the quality of life in GC metropolitan.

5. ACKNOWLEDGEMENTS

The authors wish to acknowledge the Egyptian Meteorological Authority (EMA) and the Egyptian Environmental Affairs Agency (EEAA) for providing the data used in this study.

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