A review of sulfur dioxide and particulate matter ($\text{PM}_{2.5}$ and $\text{PM}_{10}$) in greater Cairo, Egypt

Abstract

Greater Cairo is the largest metropolitan area in Egypt, with an estimated population density of 13107 people/km$^2$. The increased population and, thus, rapid urban growth in Greater Cairo has created a problem of overcrowded streets filled with cars and trucks which plays a big role in increased air pollution. This review aimed to showing concentrations of PM ($\text{PM}_{2.5}$, $\text{PM}_{10}$) and SO$_2$ in Greater Cairo during last years. Also, showing Sources of Air Pollutants, efforts of the Government of Egypt to Improve Air Quality, Egyptian Laws and guidelines, Regulations and Policies. In addition, showing role of the Egyptian Environmental Affairs Agency (EEAA) and national network to monitoring air pollutants. Finally, compare levels monitored in Greater Cairo with other cities at different countries around the world.

Keywords: sulfur dioxide, gaseous pollutants, particulate matter, $\text{PM}_{2.5}$, $\text{PM}_{10}$, Egypt

Introduction

The main component of atmosphere is ambient air; all humans, plants, living organisms and animals, which depends on it for survival on earth. The major challenges facing Egyptian government (Ministry of State for Environmental Affairs’ priorities) is protecting air from pollution. The ambient air is consisting of a mixture of solid and liquid particles and gases, which originate from natural sources while others are originate from human activities like: industry and agriculture activities, domestic activities, thermal power plants and vehicles emissions. Ambient air pollution take place when the air contains pollutants in quantities that could cause harm effects on human health, damage plants, animals and materials. The high rate of urbanization with rapid population growth together, increase in mobile vehicles, industrialization and increase fuel consumed in thermal power plants, would increase the levels of ambient air pollutants such as particulate matter ($\text{PM}_{2.5}$, $\text{PM}_{10}$) and sulphur dioxide (SO$_2$).

Air pollutants in ambient air of Greater Cairo - Egypt are divided into two major categories; particulate matter and gases. Fine particulates Matter ($\text{PM}_{10}$) resulted from the fuel burning of vehicles, power plant, factories and wood burning, while the coarse Particulates Matter with more than 2.5 micrometers in diameters resulted from wind ablation, volcanic eruptions and movement of vehicles on unpaved roads. PM and SO$_2$ Particles accumulate in air and reach to respiratory system lead to harmful healthy effect. The inhalation of these particles resulted in irritation of respiratory system as asthma case, while the fine particulates not only lead to increase heart and lung diseases. SO$_2$ is the most important ambient air pollutant, due to it is the most universally distributed and it is associated with acid rains, plant damage, high corrosion rates and general toxic effects. SO$_2$ is the classical ambient air pollutant related with Sulphur content in fossil fuels. It is the main inorganic gaseous pollutant in various flue and stack gases and industrial waste gases. Anthropogenic sources of SO$_2$ emissions are classified as:

(1) Combustions of fossil fuels in thermal power plants.
(2) Combustions of fossil fuels in industrial activities, commercial activities, petroleum refining, chemical production and residential heaters.
(3) Emissions from on-road vehicles such as cars, buses, trucks and motorcycles.
(4) Emissions from non-road vehicles such as construction and farm equipment, boats, ships, lawn mowers, snowmobiles, chainsaws and aircraft.

Greater Cairo description

The coordinates of Greater Cairo area are 30°08'N, 31°34'E (Figure 1). Greater Cairo is the most highly density region in Egypt - Africa with about more than 19 million. Geographically, Greater Cairo city is bordered from the east direction by El-Mokattam Hills to the Eastern Desert, and from the west by Abu-Rawash Hills and the Western desert. The climate is sunny and dry. Meteorologically, Greater Cairo is affected by desert weather; the annual precipitation range is 1–15 mm and the annual temperatures range is 14 – 34°C. The most predominant wind direction is from north for 9.8 months and from west for 2.2 months. The average wind speed during the winter season is above 9 m/s, which led to reduce the relative humidity in amient air of Greater Cairo than during summer season. These climate conditions enable particulate matter to be suspended in the air. If there is no rain and the wind speed is relatively low, the pollutants accumulate in higher concentrations. This leads to the smog phenomena. Industry is a major source of pollution in Cairo. In Egypt; 52% of the industries, 40% of thermal power stations and more than 2 million vehicles per day are found in Greater city. Vehicles running in Greater Cairo streets are old, 60% of which are over 10 years old. In addition, due to lack of rains and layout of tall buildings and narrow streets, Greater Cairo has very poor dispersion conditions, which create a bowl effect. Also, it is considered one of the highest polluted megacities in the world. Fuels used for vehicle in Greater Cairo are unleaded gasoline, diesel and natural gas. Finally, about...
50 – 55% of Greater Cairo houses of the national industrial activity, most of which are public sector. The most of these industrial activities are existed in two main zones: north (Shoubra El Kheima) and south (Helwan), which very close to the Nile and to thermal power plants.  

**National network for ambient air monitoring**  

Ministry of State for Environmental Affairs (EEAA) has started work in a network to monitor air pollutants at 1998 in the context of its responsibility for the protection of the Egyptian environment and it aims to identify the sources of pollutants, air quality, determine the level of control it and reduce the pollution of the air and recognize the state of air quality and focus on getting rid of the risk of air pollution reasons. A national monitoring network consists of 87 monitoring stations distributed all over the different regions of the Republic according to the following classification: Industrial areas (19) stations; Residential areas (11) stations; Traffic areas (11) stations; Urban areas (21) stations; Reference zones (9) stations; The areas with overlapping nature of the activities (16) stations. In addition, Environmental Monitoring Center (EMC) - Ministry of Health and Population have monitoring network distributed all over the different regions of the Republic, which consists of 77 monitoring stations for PM (PM_{10}, PM_{2.5}) and 74 monitoring stations for SO\(_2\). EEA several attempts are accomplished to decrease ambient air pollution in Greater Cairo city. One of these attempts is the Cairo Air Improvement Project (CAIP) with USAID. The Egyptian government was established national a network for ambient air pollutants in 36 sites in Greater Cairo. Another attempt is the Egyptian Environmental Policy Program (EEPP), which was helped decision makers to lay down environmental management agenda policy in Egypt. In addition, the governorate of Cairo in 2014 was decreased traffic emissions by: commenced a campaign to remove all street vendors by force from the streets of the city center, installed new traffic lights, opening of the Tahrir underground garage, which accommodates 1,700 vehicles and transformed some streets to pedestrian paths such as El Alfy Street.  

![Greater Cairo map](image)

**Figure 1 Greater Cairo map.**

**Literature review**

Greater Cairo is the largest urban area in Egypt. it consisting of Cairo governorate, Giza city, 6th of October City, Shubra El-Kheima and Obour City. Its population density is 13107 people/km\(^2\) The rapid urban growth and highly population density has created overcrowded streets, which contain high density of vehicles. Increase in vehicles density leads to increased ambient air pollution. Moreover, urban growth leads to increase industrial activities. Because of high density of vehicles and industrial activities in Greater Cairo, which are used by fossil fuels, emissions levels of PM (PM_{10} and PM_{2.5}) and SO\(_2\) are increased. Since 1999, The Black Cloud phenomenon has appeared during October and November months each year. This phenomenon is due to open burning of rice straw in the temperature inversion months leads to environmental and health problems. Between the period 2010 - 2020, the numbers of children suffering from hospital admission respiratory diseases are increased and the number of people suffering from cardiovascular disease and chronic pulmonary are increased. High concentration levels of PM (PM_{10} and PM_{2.5}) and SO\(_2\) could be occur due to poor ventilation in urban areas and low dispersion of ambient pollutant due to bulky building blocks and narrow streets. Petkova et al. mentioned that PM levels in Greater Cairo, Egypt were increased than the guidelines by several times. They were attributed high levels of PM to desert areas surrounding Cairo, large numbers of vehicles, industrial activities and Khamsin storms during spring and fall. Mostafa & Zakey found that the annual PM\(_{10}\) and PM\(_{2.5}\) levels at 17 sites during 2001 - 2002 were 85 and 170 g/m\(^3\), respectively. Wheida et al. reported that the temporal and spatial variability of PM\(_{10}\) concentrations during 2000-2004 and 2010-2015 at 18 stations in Greater Cairo. They found that the areas with low pollution levels were El-Abbaseya, Nasr City, and New Cairo, while areas with high pollution levels were El-Maasra, El-Maadi, El-Kolaly, and Abo-Zabaal. Pollutants are the major factors in disease of humans. PM and SO\(_2\) are penetrate the respiratory system via inhalation, causing hospital admission respiratory and cardiovascular diseases, central nervous system dysfunctions and finally cancer. In developing countries like Egypt, pollution is serious because high population density and uncontrolled industrialization and urbanization. SO\(_2\) is a harmful gas, which emitted mainly from combustion of fossil fuel. It affects human, plant and animal life. The mainly health problems of exposure to sulfur dioxide emissions are respiratory diseases, bronchitis and broncho-spasm, where SO\(_2\) is irritant and penetrates deep into the lung causing broncho-constriction. Moreover, it damage to the eyes and cause cardiovascular disease.  

Previous studies had reported a relationship between PM (PM\(_{10}\) and PM\(_{2.5}\)) and adverse health effects, when exposure was short-term (acute) or long-term (chronic) (Table 1). Size ranges of ambient air particles were showed in Figure 2. SO\(_2\) concentrations are often expressed in unit’s parts per billion (ppb), parts per million (ppm) and/or micrograms per cubic metre (\(\mu\text{g/m}^3\)). In previous studies,
Bates & Caton\textsuperscript{34} and the World Health Organization (WHO),\textsuperscript{33} concentrations in ppb were multiplied by a factor of 2.66 to convert into μg/m\textsuperscript{3}. While, PM concentrations are often expressed in units milligrams per cubic meter (mg/m\textsuperscript{3}) and/or micrograms per cubic meter (μg/m\textsuperscript{3}).\textsuperscript{33} In European countries, in urban areas anthropogenic sources like traffic density, industrial activities, thermal power plants, combustion sources, human-started forest fires, mining activities, building construction and quarrying are the most predominant sources for ambient air pollution.\textsuperscript{36} While the natural sources of ambient air pollution in Europe are forest fires, sea spray and soil re-suspension by the wind.\textsuperscript{36} In the UK, in most urban areas, emissions from traffic are pollutants such as SO\textsubscript{2} and PM.\textsuperscript{36} In India, SO\textsubscript{2} and PM formed due to anthropogenic activities such as burning fossil fuels, industrial processes and motor vehicles.\textsuperscript{37} Table 2 shows that the major sources of common air and other environmental pollutants.\textsuperscript{38}

### Table 1 Penetrability according to particle size\textsuperscript{27,31–32}

| Particle size | Penetration degree in human respiratory system |
|---------------|-----------------------------------------------|
| >11μm         | Passage into nostrils and upper respiratory tract |
| 7–11μm        | Passage into nasal cavity                     |
| 4.7–7μm       | Passage into larynx                           |
| 3.3–4.7μm     | Passage into trachea-bronchial area           |
| 2.1–3.3μm     | Secondary bronchial area passage              |
| 1.1–2.1μm     | Terminal bronchial area passage               |
| 0.65–1.1μm    | Bronchioles penetrability                     |
| 0.43–0.65μm   | Alveolar penetrability                        |

### Table 2 Major sources of common air and other environmental pollutants\textsuperscript{39}

| Pollutant | Source | References |
|-----------|--------|------------|
| PM        | Mostly traffic-related air pollution (mainly local emission) Other (domestic heating, industries, etc.) | 39–40 |
| SO\textsubscript{2} | Industrial production of sulfur-based products | 41 |
| NO\textsubscript{2} | Mainly derived from road traffic and the industrial burning of fuels Strongly related to diesel motor vehicles | 42–43 |
| O\textsubscript{3} | Industrial combustion and processes | 44 |
| CO        | Road traffic and industrial fuel burning     | 42 |
| Lead      | Gasoline, batteries, pipes and ammunition    | 45 |

![Figure 2 Size ranges of ambient air particles.\textsuperscript{31}](Image)
I. PM according to its diameter into:

- **Super Coarse**: its diameter are much higher than 10 µm, which is not vastly transported in ambient air because of the heaviness, therefore, they are falling quickly on the ground surface.

- **Coarse**: its diameter ranged from 2.5 - 10µm, these particulates could transport in ambient air for a long distances up to kilometers.

- **Fine**: its diameter ranged from 0.1 - 2.5µm, these particulates just seen by electronic microscope. It is inhaled to lungs through respiration which is harmful for the lungs.

- **Ultra-fine**: its diameters less than 0.1 µm, it is difficult to be precipitated, but it is gathered with each other, and its diameter amounts 1 µm, which is considered very harmful for human and animals.

II. **Gaseous pollutants**

- SO$_2$ is mainly produced from using of petroleum products including the element sulfur.

- Nitrogen dioxide gas is a product of the combustion of petroleum materials at high temperatures.

- Ozone gas is a product of the interaction in ambient air between nitrogen oxides and hydrocarbons at high temperatures.

- Carbon monoxide gas is formed through the process of incomplete combustion of fossil fuels.

**Egyptian Laws, Regulations and Policies**

The government of Egypt has various laws and regulations related to the environment. Egyptian Environmental Affairs Agency (EEAA) was established by presidential Decree No. 631/1982. The first modern and comprehensive law regulating the protection of the land, air and water environment from pollution in Egypt was law No. 4/1994. Some articles of Law No. 4/1994 were improved by Laws No. 9/2009 and 105/2015, and its Executive Regulations improved by Prime Minster Decrees No. 1095/2011, 710/2012, 964/2015, and 75/2017, which commonly known as the Environmental Protection Law.\textsuperscript{1,5,46} Ambient air quality guideline values in environmental law No. 4 of Egypt (1994) are presented in Table 2 & Table 3.\textsuperscript{46}

**Table 3 Ambient air quality limit values as given by law no.4 for Egypt\textsuperscript{1,5,46}**

| Pollutant                     | Zone   | Maximum limit (µg/m$^3$) | 1 hour | 8 hours | 24 hours | 1 year |
|-------------------------------|--------|--------------------------|--------|---------|----------|--------|
| Sulphur Dioxide               | Urban  | 350                      | 125    | 50      |
|                               | Industrial | 300                   | -      | -       | 150     | 60     |
| Carbon Monoxide               | Urban  | 30 000                   | 10 000 | -       | -       | -      |
|                               | Industrial | 30 000                | 10 000 | -       | -       | -      |
| Nitrogen Dioxide              | Urban  | 300                      | 150    | 60      |
|                               | Industrial | 300                   | -      | -       | 150     | 80     |
| Ozone                         | Urban  | 180                      | 120    | -       | -       | -      |
|                               | Industrial | 180                   | 120    | -       | -       | -      |
| Total Suspended Particles     | Urban  | -                        | -      | 230     | 125     |        |
|                               | Industrial | -                     | -      | 230     | 125     |        |
| Particulate Matter - PM$_{10}$| Urban  | -                        | -      | 150     | 70      |        |
|                               | Industrial | -                     | -      | 150     | 70      |        |
| Particulate Matter - PM$_{2.5}$| Urban | -                        | -      | 80      | 50      |        |
|                               | Industrial | -                     | -      | 80      | 50      |        |
| Suspended Particles measured as black smoke | Urban | -                        | -      | 150     | 60      |        |
|                               | Industrial | -                     | -      | 150     | 60      |        |
| Lead                          | Urban  | -                        | -      | 0.5     | -       | 1      |
|                               | Industrial | -                     | -      | -       | -       | -      |
| Ammonia                       | Urban  | -                        | -      | 120     | -       | -      |
|                               | Industrial | -                     | -      | 120     | -       | -      |

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Role of Egyptian government to improve ambient air quality

The Egyptian government is interested by reducing environmental impacts from ambient air pollution. The government was invested in infrastructure such as highways, bridges and ring roads around the Greater Cairo to decrease traffic density. Also, the Egyptian government was established eight towns to decrease population density in Greater Cairo. The government was facilitating natural gas use as the main fuel source in houses, industrial, power plants and transport sectors. Additionally, The government has been encouraged private cars and taxis to switch to natural gas as fuel. The Second Egypt Pollution Abatement Project (EPAP II) with the European Investment Bank (EIB), the Agency Francaise de Development (AFD), the World Bank and the Japan International Cooperation Agency (JICA) to achieve environmental subjection with the Egyptian environmental law. The Egyptian environmental protection Law #4 of 1994 was improved (by Law #9 of 2009), which forbid waste burning. EEEA has established continuous 24-hour monitoring for stacks emission in the cement industry. Also, regional EEEA offices are carrying out inspection monitoring in factories in Greater Cairo, Noncompliant factories are fined.5

Sources of air pollutants

Air pollutants may be either primary air pollutants, which emitted into the atmosphere directly (e.g.) sulfur dioxide (SO$_2$) and primary particulate matter (PM) or secondary air pollutants (e.g.) secondary PM, which formed by chemical reactions between primary pollutants in ambient air, mostly involving natural environment components such as water and oxygen.4 The local, urban, regional and global scale of air pollution can be distinguished, depending primarily on the atmospheric lifetime of specific air components.4 Sources also can be categorized on a geographical scale (point, line, area or volume sources). Sulphur dioxide (SO$_2$) is a prime pollutant (released directly to the atmosphere), which is released from fuel combustion of fossil fuels containing sulphur components. The major natural sources of SO$_2$ are volcanoes and oceans.45 In ambient air, SO$_2$ is oxidized by oxygen in air to sulfate ions (SO$_4^{2-}$) and sulfuric acid, which forming aerosol associated with other pollutants such as PM.$^{42–54}$ In addition, temperature has a significant effect on SO$_2$ levels in ambient air, while relative humidity and wind speed have insignificant effect.$^{35–37}$ Particulate matter (PM) are finely divided into solids or liquids that are dispersed throughout the air and are produced from combustion processes, domestic and industrial activities, as well from natural sources such as volcanoes, dust and forest fires.$^{35,38}$ Environmental Protection Agency$^{39}$ mentioned that ambient air particles with aerodynamic diameter less than 100μm are collectively. PM in ambient air is classified into two classes, PM$_{10}$ (air particles with aerodynamic diameter < 10μm) and PM$_{2.5}$ (air particles with aerodynamic diameter < 2.5μm). The ambient PM composition and size depends upon the source of pollution.$^{40}$ PM is usually divided into two types; primary PM which emitted directly from sources and secondary PM formed by the amalgamation with other compounds such as sulfate ions (SO$_4^{2-}$).41 The main sources of PM$_{2.5}$ and PM$_{10}$ in Greater Cairo are unpaved roads, vehicles, cement factors, industrial activities, construction activities, geological or weathering source contributions, thermal power plant and open burning.$^{15}$

Sampling and analysis

The methods of monitoring process in the national Network are as follows: The first method: through instantaneous automatic devices operated 24h/7day, where the data records and Statistical calculations done on hourly and daily basis. The second method: carried out through semi-automatic sampling devices (collection on filters), later these samples are analyzed in chemical laboratory to evaluate concentration levels.$^5$

Environmental human health effects of air pollutants

Epidemiological studies done with respect to the worsening ambient air quality at different places around the world have revealed the evidence of an increase in the rate of bronchitis, asthma, decreased lung function, pharyngitis, cough, eye irritation, fibrosis, emphysema, allergic rhinitis and low birth weight.$^{62,63}$ Lots of studies$^{44–50}$ reported that SO$_2$ causes headache, dizziness, fatigue, bronchitis, lung irritation, asthma, pulmonary edema and pneumonia. Skinder et al.$^{70}$ reported that SO$_2$ could be stay in the lungs for period time up to one week or more. Once SO$_2$ inhaled, it dissolves in the aqueous surfaces of the respiratory system and converted into sulphite and bisulphite, which is dispersed inside the cells of respiratory system.$^{70}$

Exposure to SO$_2$

Studies$^{33,35,71,72}$ reported the quantitative concentration levels that affected on human health from exposure to SO$_2$ (Table 4).

Table 4 Human Health Effects – Acute Exposure (<10min)$^{35}$

| Conc. (μg/m$^3$) | Exposure duration | Effects |
|------------------|-------------------|--------|
| 260              | 3 min             | Broncho-constriction |
| 500              | 5 min             | No effect |
| 600              | 10 min            | Increased airway resistance |
| 800              | 10 min            | Increased broncho-constriction |
| 1,048            | 5 - 10 min        | Decreased lung functions |
| 1,130            | 5 min             | Increased specific airway resistance |
| 1,300            | 3 min             |         |
| 1,300            | 1 - 5 min         | Dryness, irritation, burning of throat |
| 1,300            | 1 - 5 min         | Chest tightness, wheezing, dyspnea |
| 1,300            | 5 min             | Increased broncho-constriction |
| 1,600            | 10 min            |         |
| 1,600            | 5 min             |         |
| 2,000            | 10 min            | Increased specific airway resistance |
| < 2,600          | 1 - 5 min         | Chest tightness, wheezing, dyspnea |
| 2,600            | 0.5 - 1 min       | Increased airway resistance |
| 2,600            | 2 - 5 min         |         |
| 2,800            | 10 min            | Decreased respiratory function |
| 5,200            | 4 min             |         |
| 5,300            | 10 min            | Changes in airway resistance |
| 5.0 - 18.1       | 24 h              | Increased diastolic blood pressure |
| 5.9 - 19.7       | 24 h              | Asthma symptoms |

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Exposure to PM

Short-term effects due to exposure to PM are range from simple effects such as: irritation of the nose, eyes, throat, skin, coughing and breathing difficulties, to more serious effects like: bronchitis, asthma, pneumonia and lung diseases. Short-term exposure to PM can also cause dizziness, nausea and headaches. These symptoms could be aggravated by long-term exposure to PM, to cause serious problems for respiratory system, the neurological and might be cause cancer and/or deaths. Long-term exposure to PM and SO\textsubscript{2} cause: mortality due to respiratory disease (COPD and asthma), cardiovascular diseases and lung cancer. Health impact assessment (HIA) supply decision-makers with quantitative and qualitative information about pollutants levels and its effects on humans, to help them to put policy to safe people health.\textsuperscript{33} Mohammed et al.\textsuperscript{33} reported that a level of SO\textsubscript{2} was 92μg/m\textsuperscript{3} in Greater Cairo, Egypt during 2016. Also they used Air-Q\textsubscript{2.2.3}, model to predicted hospital admissions respiratory disease (HARD) cases due to SO\textsubscript{2} exposure, and they found the highest cases of HARD were 311 cases at 120-129μg/m\textsuperscript{3} of SO\textsubscript{2}.\textsuperscript{34,35} Shakour et al.\textsuperscript{36} mentioned that PM concentrations were 228-61μg/m\textsuperscript{3} at Greater Cairo. They studied the association between PM and hospital admissions respiratory diseases (HARD) by using Air-Q\textsubscript{2.2.3}, model, they found the highest cases of HARD due to PM exposure were 3780 – 4160 case.

Environmental effects

Plants

Plants are main indispensable parts of ecosystems and their sensitivity to air pollution is more considerable than standards of air pollution.\textsuperscript{37,38} Air pollution has become a serious environmental stress to crop plants due to increasing industrialization and urbanization during the last few decades.\textsuperscript{39} Plants are affected by exposure to pollutants levels such as conifers, which are more sensitive to SO\textsubscript{2}.\textsuperscript{40} The most injury indicator is tan to dark brown interveinal bifacial. Phaeophytin, carboxydrates, carotenoids, proteins and phenolic content decreased due to exposure to SO\textsubscript{2}.\textsuperscript{41,42} Pigment system in plants was damaged when plant exposed to SO\textsubscript{2} as short term.\textsuperscript{43} SO\textsubscript{2} cause direct injury to forests and crops by entering the leaves through the stomata and deposition to external surfaces, leading to negative effects on the growth.\textsuperscript{44} The crop species that are usually considered susceptible to SO\textsubscript{2} are barley, alfalfa, wheat, oats, clover, radish, lettuce, spinach, squash and beans, cabbage, onion. Corn and potato are resistant crop for SO\textsubscript{2}.\textsuperscript{45,46} Chauhan & Joshi\textsuperscript{47} opined that SO\textsubscript{2} and PM have harmful effects on mustard and wheat crops, where ambient air pollutants decreased chlorophyll, carotenoids contents and ascorbic acid. Then, it is very clear that industrial and urban ambient air pollution has become a serious problem to agricultural crops near to industrial and urban areas.\textsuperscript{48}
that used to run factories, power plants and vehicles, in addition to the decrease in consumption of diesel and oil fuel during 2012. In Greater Cairo which suffers from high population density that led to high traffic density and increasing in vehicles numbers compared to the capacity of roads. All of reasons led to increase air pollution with PM, especially PM$_{2.5}$. The main sources of PM$_{10}$ concentrations during 1999 – 2010 were mobile source emissions, open burning and soil dust. The main sources of PM$_{2.5}$ were mobile source emissions, open burning, soil dust and secondary species (ammonium nitrate and ammonium sulfate). During 1999–2010 The main sources of PM$_{10}$ and PM$_{2.5}$ were mobile source emissions, open burning, soil dust and secondary species. The pollutant levels between 2002 and 2010 are mostly attributable to natural sources such as khamasin storms from desert. The World Bank showed that in Greater Cairo the highest concentrations of PM$_{10}$ were found in Shobra area and Helwan area due to industrial activities. Where the highest concentrations of PM$_{2.5}$ were found in El-Quilaly and Shobra due to highest population density and thermal power plant. Furthermore, Zamalek area is a residential area for upper-middle-income households, which has PM$_{10}$ and PM$_{2.5}$ levels similar to those in El Quilaly and Helwan. Generally high levels of PM$_{10}$ and PM$_{2.5}$ were recorded in Greater Cairo was due to the arid climate and very low rainfall resulting from the area being surrounded by deserts. Figure 7 Showed the average percentage contribution of PM$_{10}$ source categories in Greater Cairo during different seasons. Figure 8 showed that the source-attribution of PM$_{10}$ air pollution in Greater Cairo dominated by vehicle emissions.
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Figure 6 The annual SO$_2$ Concentration in Greater Cairo.

Figure 7 Average percentage contribution of PM$_{10}$ source categories in Greater Cairo during different seasons.

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Different countries around the world have managed policy of air quality in megacities. The countries which have experiences in improving ambient air were Indonesia, India, Thailand, Philippines and United States in managing air quality in Jakarta, Mumbai, Bangkok, Manila and Los Angeles, respectively. Previous studies, find a number of variances between Greater Cairo and these cities. First, the air quality standards are the same in Greater Cairo and the other cities, but Cairo has a more policy for PM$_{2.5}$; Greater Cairo is still using diesel and heavy fuel oils. Second, these countries are have adopted vehicle emission standards in line with the Euro 4 and Euro 5 standards, while in Egypt is in line Euro 2 standard. Third, in the other countries vehicle emission testing (VET) is used, while in Egypt, it is used in Giza and Qalyoubieh Governorates. Fourth, in the other cities natural gas is widely used while, in Greater Cairo it is used in taxis. In the Greater Cairo, peoples will be exposed to higher levels of pollution. So it is expected that more than 4.6 million people will exposed to pollution during 2010 – 2020. Moreover, urban areas surrounding the Greater Cairo will also be exposed to higher levels of emissions. During 2010 - 2020, 137,000 persons will affect from chronic cardiovascular and pulmonary disease; respiratory diseases will affect about 11.1 million children. Vahlsing and Smith mentioned Ambient Air Quality Standards (AAQSs) for 75 countries found that the average 24-h monitoring during 2003–2005 for PM$_{10}$ and SO$_2$ is 95μg/m$^3$ (82–108μg/m$^3$) and 182μg/m$^3$ (158–205μg/m$^3$). The geographical distribution of PM$_{10}$ and SO$_2$ at selected demographics (ascertained for 96 countries, which represent 84% of the global population) of the survey was shown in Figure 9. Compared the annual average PM$_{10}$ concentrations in Greater Cairo with many cities of the world during 2006 Figure 10. They found in Asia, high PM$_{10}$ levels were monitored in Sarawak and Kuala Lumpur, respectively, while lower levels were founded in Singapore and Thailand. In Africa, a high PM$_{10}$ level was measured in Greater Cairo. WHO compared the annual average SO$_2$ concentrations in Greater Cairo with many cities of the world during 2006 Figure 11. In Greater Cairo the SO$_2$ levels were lower than 40μg/m$^3$. 

![Figure 8 Source-attribution of PM$_{10}$ air pollution in Greater Cairo dominated by vehicle emissions.](image)

![Figure 9 Map of Ambient Air Quality Standards (AAQS).](image)
Conclusion

This review aimed to showing concentrations of PM (PM$_{2.5}$, PM$_{10}$) and SO$_2$ in Greater Cairo during last years. Also, showing Sources of Air Pollutants, role of the Egyptian government to improve ambient air quality, Egyptian laws and guidelines, regulations and policies. In addition, showing role of the Egyptian Environmental Affairs Agency (EEAA) and national network to monitoring air pollutants. Finally, compare levels monitored in Greater Cairo with other cities at different countries around the world. Ambient PM$_{2.5}$, PM$_{10}$ and SO$_2$ samples were collected at Greater Cairo by EEAA and EMC monitoring stations. All samples were of 24-h duration (Daily average). Previous studies reported that PM and SO$_2$ levels were attributed due to: geological material, Mazut oil, mobile sources, industrial activities, construction activities and open burning. The Egyptian environmental affairs agency (EEAA), a pollutant monitoring program reports showed that the annual PM (PM$_{2.5}$ and PM$_{10}$) and SO$_2$ Concentration in Greater Cairo. In last years, levels of SO$_2$ decreased, which was attributed to replacement of other types of fuels by natural gas that used to run factories, power plants and vehicles, in addition to the decrease in consumption of diesel and oil fuel during 2012. In Greater Cairo higher population density will be led to increase vehicles.
numbers and traffic density in compared to the capacity of roads. All of reasons led to increase air pollution with PM, especially PM$_{2.5}$.

**Acknowledgments**

None.

**Conflicts of interest**

The authors declare that there is no conflict of interest.

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