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A review of sulfur dioxide and particulate matter ($PM_{2.5}$ and 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 (PM_{10}, $PM_{2.5}$) 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, $PM_{2.5}$, PM_{10}, Egypt

Volume 6 Issue 3 - 2020

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Received: August 13, 2020 | **Published:** August 31, 2020

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.[1] 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.[2,3] The high rate of urbanization with rapid population growth together, increase in mobile vehicls, industrialization and increase fuel consumed in thermal power plants, would increase the levels of ambient air pollutants such as particulate matter (PM_{10}, $PM_{2.5}$) and sulphur dioxide (SO_2).[4]

Air pollutants in ambient air of Greater Cairo - Egypt are divided into two major categories; particulate matter and gases. Fine particulates Matter ($PM_{2.5}$) 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.[5] 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.[5] 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:[6,7]

(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, lawnmowers, snowmobiles, chainsaws and aircraft.[8]

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.[5] 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 1–15mm 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.[9] 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.[10] 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.[11] 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.[12]

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.[5,13,14] 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.[13,14] EEAA 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 laying down environmental management agenda policy in Egypt.[15–17] 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.[17,18]

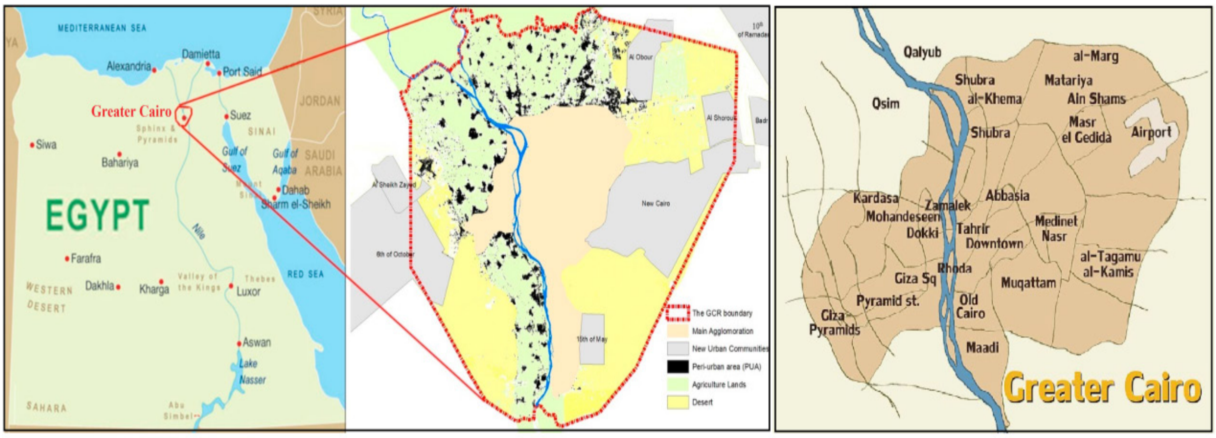

Figure 1 Greater Cairo map.[19]

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.[19,20] 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.[21] 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.[22] 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.[23] Petkova et al.[24] 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 Khamasin storms during spring and fall. Mostafa & Zakey[25] founded that the annual $PM_{2.5}$ and PM_{10} levels at 17 sites during 2001 - 2002 were 85 and 170 g/m^3, respectively. Wheida et al.[26] 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-Abbasseya, 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 admision respiratory and cardiovascular diseases, central nervous system dysfunctions and finally cancer.[27,28] In developing countries like Egypt, pollution is serious because high population density and uncontrolled industrialization and urbanization.[29] SO_2 is a harmful gas, which emitted mainly from combustion of fossil fuel.[27] 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.[30]

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).[31,32] Size ranges of ambient air particles were showed in Figure 2.[33] SO_2 concentrations are often expressed in unit's parts per billion (ppb), parts per million (ppm) and/or micrograms per cubic metre (µg/m^3). in previous studies,

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Bates & Caton[34] and the World Health Organization (WHO),[33] concentrations in ppb were multiplied by a factor of 2.66 to convert into μg/m³. While, PM concentrations are often expressed in units milligrams per cubic meter (mg/m³) and/or micrograms per cubic meter (μg/m³).[35] 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 predominat sources for ambient air pollution.[36] While the natural sources of ambient air pollution in Europe are forest fires, sea spray and soil re-suspension by the wind.[36] In the UK, in most urban areas, emissions from traffic are pollutants such as SO_2 and PM.[36] In India, SO_2 and PM formed due to anthropogenic activities such as burning fossil fuels, industrial processes and motor vehicles.[37] Table 2 shows that the major sources of common air and other environmental pollutants.[38]

Table 1 Penetrability according to particle size[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[38]

Pollutant	Source	References
PM	Mostly traffic-related air pollution (mainly local emission) Other (domestic heating, industries, etc.)	39–40
SO_2	Industrial production of sulfur-based products	41
NO_2	Mainly derived from road traffic and the industrial burning of fuels Strongly related to diesel motor vehicles	42–43
O_3	Industrial combustion and processes	44
CO	Road traffic and industrial fuel burning	42
Lead	Gasoline, batteries, pipes and ammunition	45

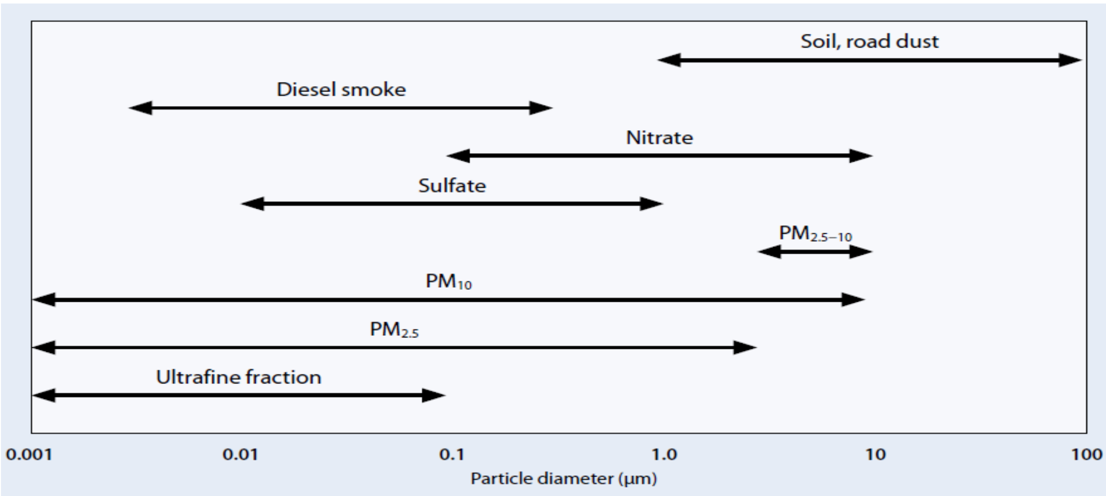

Figure 2 Size ranges of ambient air particles.[33]

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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.[1,5,46] Ambient air quality guideline values in environmental law no. 4 of Egypt (1994) are presented in Table 2 & Table 3.[46]

Table 3 Ambient air quality limit values as given by law no.4 for Egypt[1,5,46]

Pollutant	Zone	Maximum limit (µg/m³)			
		1 hour	8 hours	24 hours	1 year
Sulphur Dioxide	Urban	300	-	125	50
	Industrial	350	-	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
	Industrial	-	-	-	1
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 to 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 Française 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. EEAA has established continuous 24-hour monitoring for stacks emission in the cement industry. Also, regional EEAA offices are carrying out inspection monitoring in factories in Greater Cairo, Noncompliant factories are fined.[21]

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.[47] The local, urban, regional and global scale of air pollution can be distinguished, depending primarily on the atmospheric lifetime of specific air components.[47] 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.[48–51] 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.[52–54] In addition, temperature has a significant effect on SO_2 levels in ambient air, while relative humidity and wind speed have insignificant effect.[55–57] 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.[55,58] Environmental Protection Agency[59] 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.[60] 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-}).[61] 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[64–69] 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/m³)	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
1,300	10 min	
1,600	5 min	
1,600	10 min	
2,000	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	Changes in airway resistance
5,300	10 min	
5.0 - 18.1	24 h	Increased diastolic blood pressure
5.9 -19.7	24 h	Asthma symptoms

Table Continued...

Conc. (µg/m³)	Exposure duration	Effects
75	24 h	Wheeze
6.3 - 72.6	10 year	increase in respiratory disease and lung cancer mortality
10 - 15 50	Annual 3 year	allergic rhinitis

Environmental Protection Agency - United States (EPA) classified pollutants:[5]

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.[27,73–75] In addition, when pollutants were penetrate through the skin cause damage, mutagenic and carcinogenic.[75] Long-term exposure to PM and SO_2 cause: mortality due to respiratory disease (COPD and asthma), cardiovascular diseases and lung cancer.[33,76] 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.[33] Mohammed et al.[77] reported that a level of SO_2 was 92µg/m³ in Greater Cairo, Egypt during 2016. Also they using Air-$Q_{2.2.3}$ model to predicted hospital admissions respiratory disease (HARD) cases due to SO_2 exposure, and they found the highest cases of HARD were 311 cases at 120-129µg/m³ of SO_2. Shakour et al.[78] mentioned that PM concentrations were 228-61µg/m³ at Greater Cairo. They studied the association between PM and hospital admissions respiratory diseases (HARD) by using Air-$Q_{2.2.3}$ 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.[79] Air pollution has become a serious environmental stress to crop plants due to increasing industrialization and urbanization during the last few decades.[80] Plants are affected by exposure to pollutants levels such as conifers, which are more sensitive to SO_2.[81] The most injury indicator is tan to dark brown interveinal bifacial.[82,83] Phaeophytin, carbohydrates, carotenoids, proteins and phenolic content decreased due to exposure to SO_2.[84–87] Pigment system in plants was damaged when plant exposed to SO_2 as short term.[88] SO_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.[89] The crop species that are usually considered susceptible to SO_2 are barley, alfalfa, wheat, oats, clover, radish, lettuce, spinach, squash and beans, cabbage, onion. Corn and potato are resistant crop for SO_2.[70,90] Chauhan & Joshi[91] opined that SO_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.[92]

Materials

Damage of materials and cultural heritage are process which occurs by exposure to ambient air pollutants and meteorological parameters such as temperature, relative humidity and precipitation. Among the anthropogenic ambient air pollutants, SO_2 which is considered as the most important air pollutant in damage of several materials.[48] Many materials are affected such as stones used in historic and cultural monuments.[48] SO_2 emissions were deposited on surfaces of materials and then converted into sulfates particles. In ambient air, SO_2 might be converted into sulfate particulates which associated with PM and then deposited on surfaces of materials and can cause corrosion. Both sulfate particles and SO_2 may be dissolve in rain droplets and then increase the acidity and corrosion. Previous studies are recommended by using the following: Zinc, weathering steel (when annual mean of SO_2 levels was 15 µg/m³) and Bronze, limestone, sandstone (when annual mean of SO_2 levels was 10 µg/m³).[48]

Results and discussion

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). Abu-Allaban et al.[15] monitored PM (PM_{10} and $PM_{2.5}$) in different sites in Greater Cairo, they reported PM levels were attributed due to: geological material, Mazut oil, mobile sources, and open burning (in Al El-Zamalek); mobile sources (in El-Qualaly); geological material, marine contribution, mobile sources, mazut, and open burning (in Helwan); open burning, geological dust and mobile sources (in Kaha); geological material, cement, mobile sources, open burning and lead and copper smelter (in El-Maasara) and geological material, mobile sources, mazut, and open burning (in Shobra) (Figure 3). Nasralla[93] reported annual average SO_2 concentration of 105µg/m³ in Helwan, the industrial area south of Cairo. The annual mean concentration of SO_2 reported by the Environmental Information & Monitoring Program (EIMP) in implementation with the Egyptian Environmental Affairs Agency (EEAA) was found to be 49ug/m³, 39 ug/m³ and 28ug/m³ during the years 2007, 2008 and 2009, respectively.[94] Mohammed[95] mentioned that annual mean concentrations of SO_2 in ambient atmosphere during (2007 – 2008) were (27.5 - 38.7 µg/m³) at shoubra El-Kheima and (59.1 - 70.1µg/m³) at Helwan. These concentrations are less than the value of 60µg/m³ set by the US Ambient Air Quality Standard,[96] and also the Egyptian limit for the annual concentration of SO_2[97] for shoubra El-Kheima, While higer than Egyptian limitation for Helwan. The maximum seasonal concentrations of SO_2 were 85.9µg/m³ over Helwan (industrial area) during winter seasons and 42.8 µg/m³ over shoubra El-Kheima (industrial area) during winter seasons. He attributed higher seasonal levels to climatic conditions, topography and photochemical reaction. Mohammed et al.[77] reported that the daily mean concentration SO_2 at Shoubra El-Khaima in Greater Cairo during 2016 were 60–116µg/m³, which lower than the Egyptian Permissible Daily (125 µg/m³ in urban and 150µg/m³ in industrial) average limit in Annex No. 5 of the Executive Regulations of Law No. 4/1994 improved by Law 9/2009.[94,97] They reported the annual mean were 92µg/m³ for SO_2, which are lower than the Egyptian limit of 125µg/m³ in urban and 150µg/m³ in industrial for SO_2.[94,97] 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 Figure 4–6.[1,5,25,98–100] The decrease of SO_2 concentration showed in Figure 6 was attributed to replacement of other types of fuels by natural gas

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that used to run factories, power plants and vehicles, in addition to the decrease in consumption of diesel and oil fuel during 2012.[5] 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 $PM_{2.5}$.[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.[21] The World Bank[21] 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-Qulaly 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 Qulaly and Helwan.[21] Generally high levels of $PM_{2.5}$ and PM_{10} were recorded in Greater Cairo was due to the arid climate and very low rainfall resulting from the area being surrounded by deserts.[98] Figure 7 Showed the average percentage contribution of PM_{10} source catagories in Greater Cairo during different seasons.[98] Figure 8 showed that the source-attribution of PM_{10} air pollution in Greater Cairo dominated by vehicle emissions.[101]

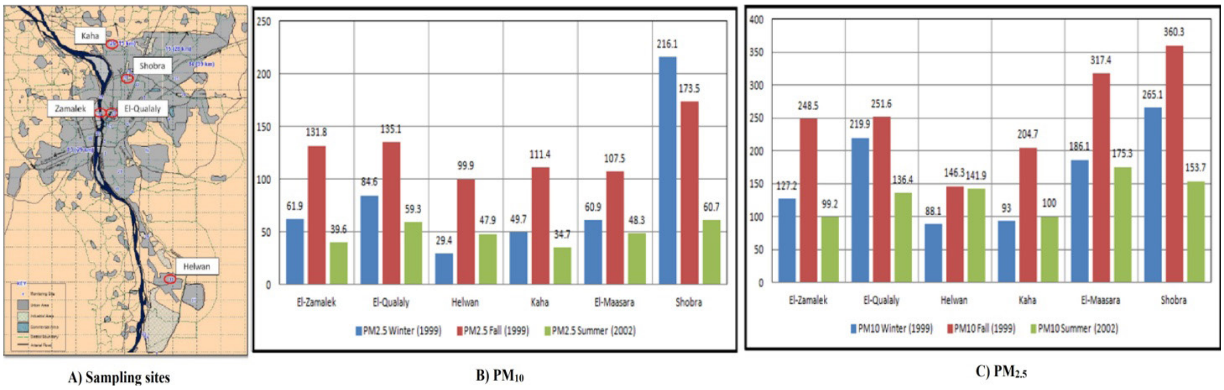

Figure 3 Summary of PM (µg/m³) at different sites in Greater Cairto.[15]

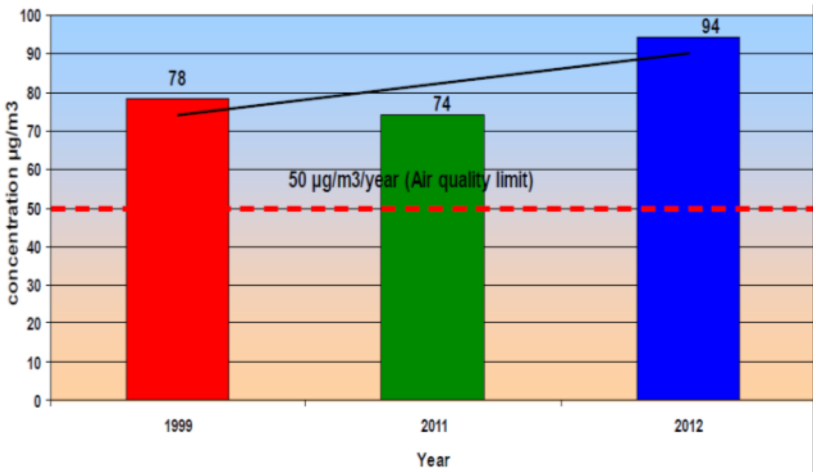

Figure 4 The annual $PM_{2.5}$ Concentration in Greater Cairo (1999 – 2012).

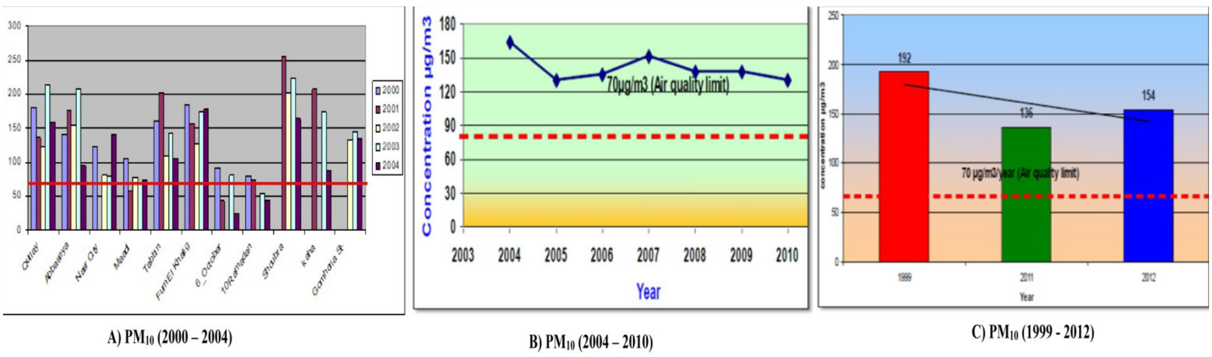

Figure 5 The annual PM_{10} Concentration in Greater Cairo.

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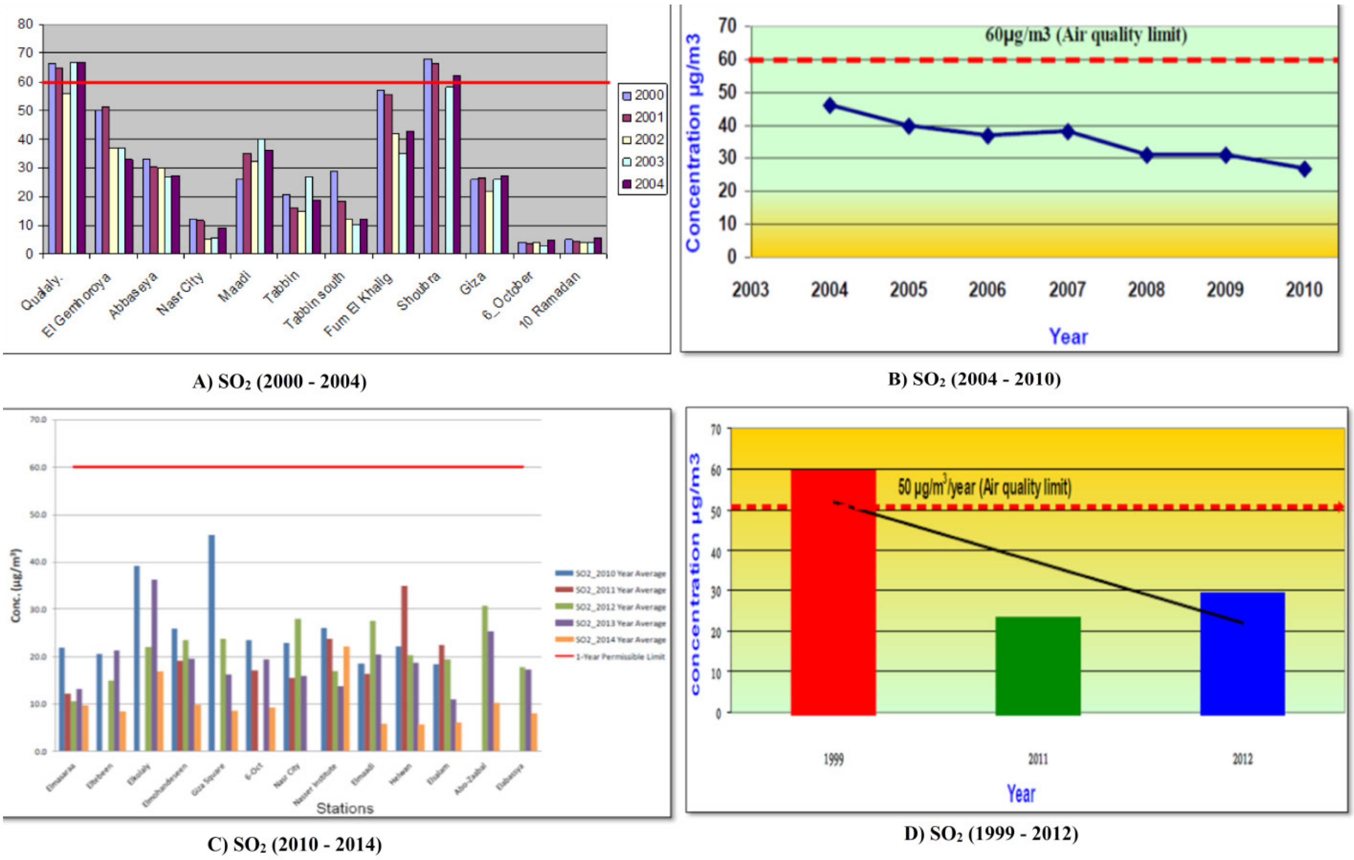

Figure 6 The annual SO_2 Concentration in Greater Cairo.

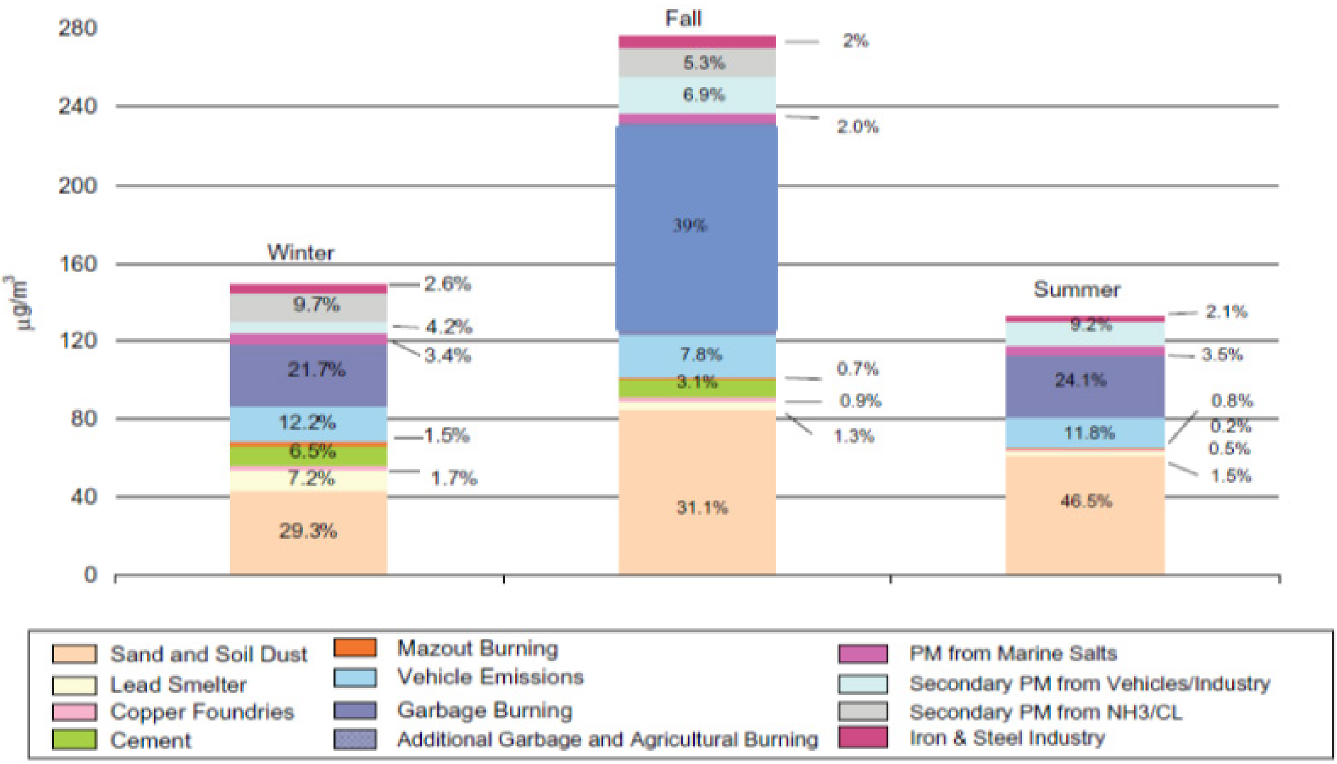

Figure 7 Average percentage contribution of PM_{10} source catagories in Greater Cairo during different seasons.

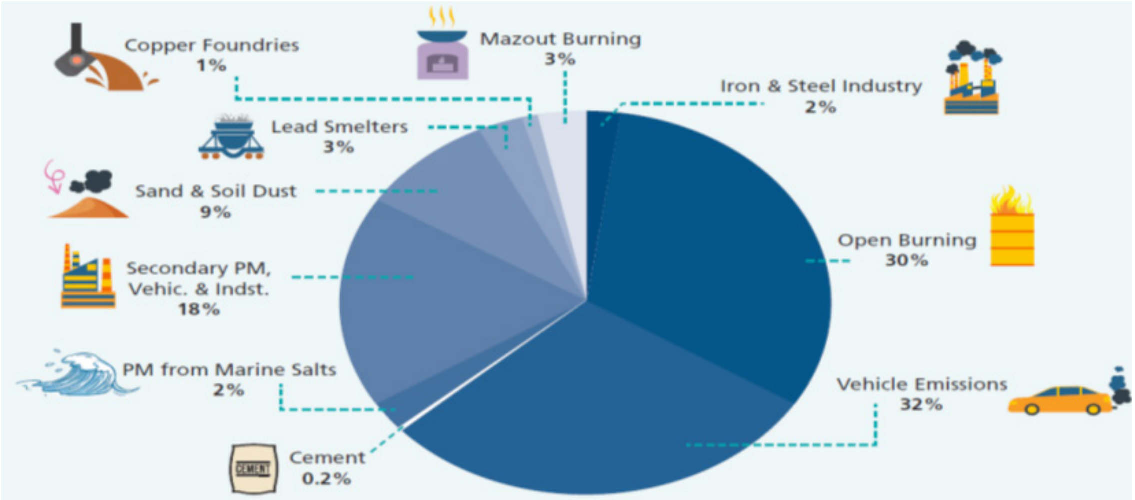

Figure 8 Source-attribution of PM_{10} air pollution in Greater Cairo dominated by vehicle emissions.[99]

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.[21] 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.[21] 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.[21] 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.[102–104] Vahlsing and Smith[105] 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.[33] 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[33] 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.

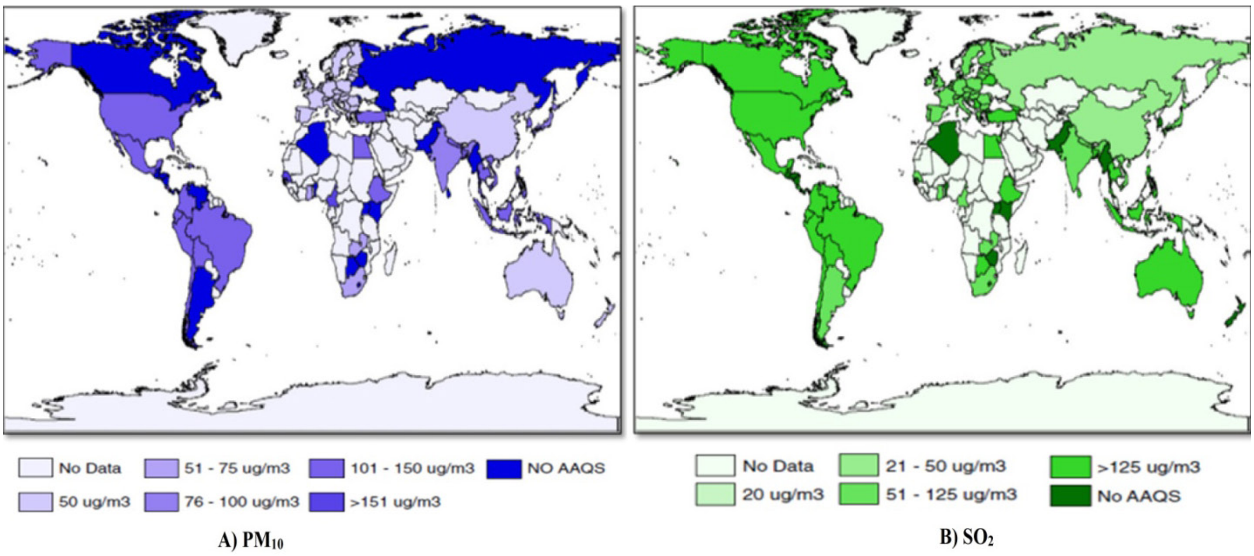

Figure 9 Map of Ambient Air Quality Standards (AAQS).

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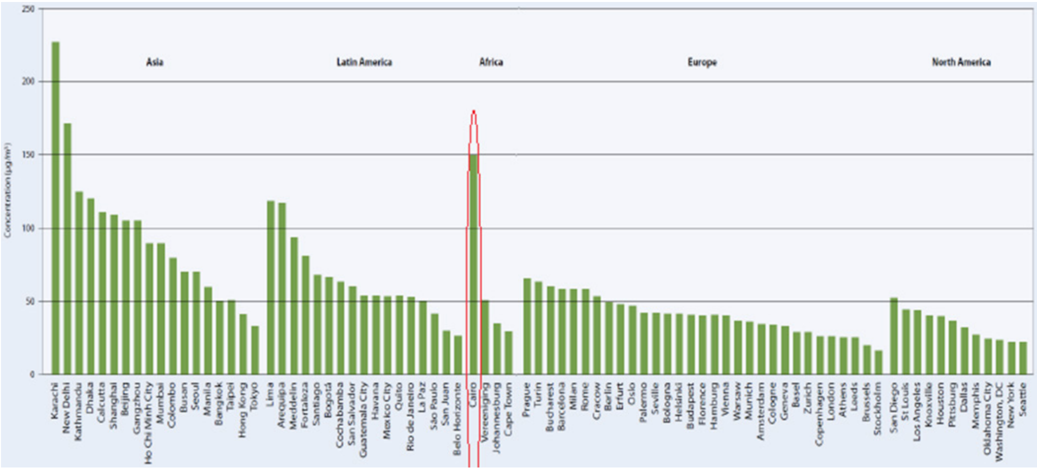

Figure 10 Annual average PM_{10} concentrations in different cities worldwide.

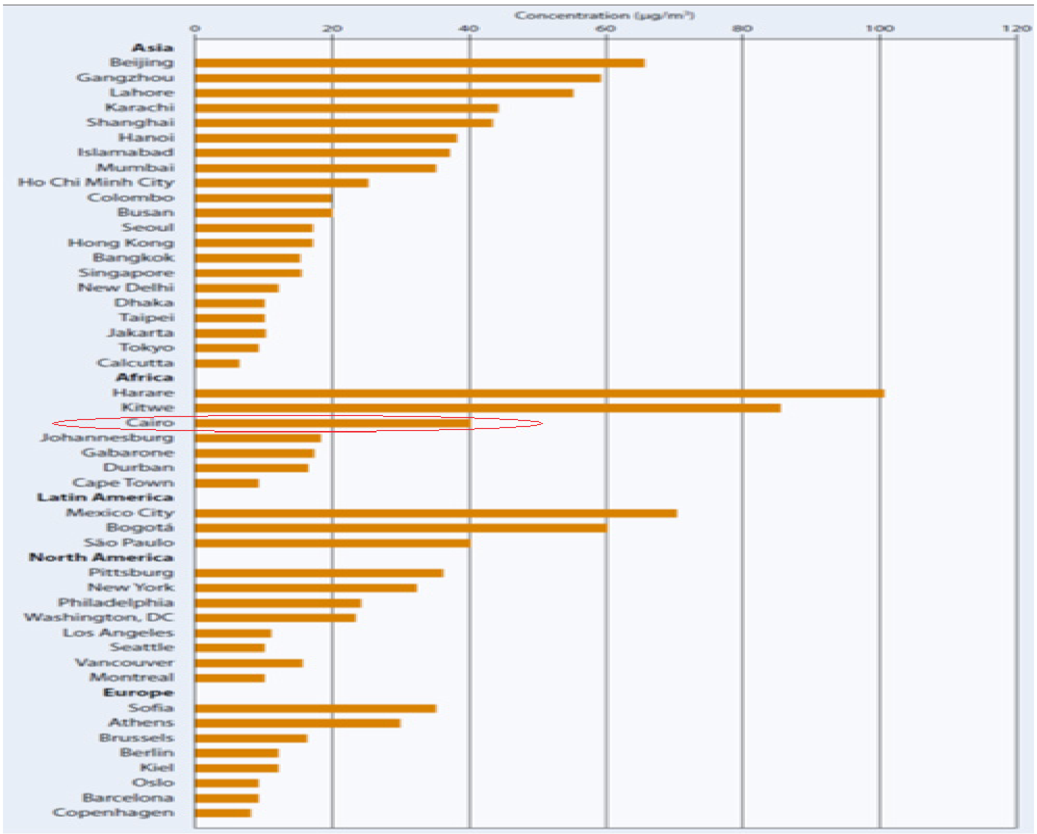

Figure 11 Annual average SO_2 concentrations in 2000–2005 in different cities worldwide.[33]

Conclusion

This review aimed to showing concentrations of PM (PM_{10}, $PM_{2.5}$) 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

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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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