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Air Quality Indices, Sources and Impact on Human Health of PM_{10} and $PM_{2.5}$ in Alexandria Governorate, Egypt

Ashraf A. Zahran[1], M. Ismail Ibrahim[2], Alaa El-Din Ramadan[3], M. M. Ibrahim[4*]

[1]Department of Natural Resources and Planning to Development, Environmental Studies and Research Institute, El Sadat University, Sadat City, Egypt
[2]Matroh Branch Affairs, Alexandria University, Alexandria, Egypt
[3]Faculty of Science, Alexandria University, Alexandria, Egypt
[4]Environmental Sciences, Faculty of Science, Alexandria University, Alexandria, Egypt
Email: ashraf_zahran@amatec-az.com, *m.sobky87@gmail.com

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Abstract

In this study, PM_{10} and $PM_{2.5}$ were measured in seven sites representing different activities (the same sites of EEAA monitoring stations) in addition to eighth site that used as a background. All results were higher than AQLs of EEAA, US/EPA, and EC although PM_{10} and $PM_{2.5}$ are considered to be a direct cause of cardiovascular diseases as well as lead to death and it may be a reason for a number of chest diseases in short-term as well as long-term. Results were compared to the Air Quality Forecast system which developed by EEAA and AQI which created by US/EPA was calculated for some PM_{10} and $PM_{2.5}$. Probable potential anthropogenic sources for such high concentrations of PM included unpaved roads, indiscriminate demolition and construction work, industrial activities, and solid wastes. This study resulted in a number of suggestions and recommendations include: 1) Implementation of integrated ISO 26000 and ISO 14001, 2) EIMP/EEAA monitoring stations need restructuring plan to cover all areas in Alexandria, 3) EIMP/EEAA must be supported with $PM_{2.5}$ monitors, 4) PM control systems must be used in all industrial activities to reduce PM pollution from the source, 5) AQL of $PM_{2.5}$ in the ambient environment must be reduced and it must be included in the working environment parameters, 6) Environmental law must be applied strictly, and 7) Multidisciplinary co-operation especially between environment and public health specialists must be increased.

Keywords

Air Pollution, PM, PM_{10}, $PM_{2.5}$, Air Quality Forecast, Air Quality Index, Human Health

1. Introduction

1.1. Particulate Matters

Particulate Matters (PM) are a complex mixture of particles that can be solid, liquid or both vary in size, composition, and origin. The specific composition and size distribution of PM varies by region, time of year, time of day, weather conditions and other factors (WHO, 2001) [1].

1.1.1. PM Categories

PM can be divided into four categories:

- **TSP:** (Total Suspended Particulates): particulate matter with an upper size limit of approximately 100 μm.
- **PM_{10}:** particles with a diameter less than 10 micrometers (course particles), such as those found near roadways and dusty industries, and pose a health concern because they can be inhaled into and accumulate in the respiratory system.
- **$PM_{2.5}$:** particles with a diameter less than 2.5 micrometers (fine particulates) such as those found in smoke and haze, and are believed to pose the largest health risks. $PM_{2.5}$ has very small size less than one-seventh the average width of a human hair and can lodge deeply into the lungs and reach terminal bronchioles and alveoli.
- **UFPs** (Ultrafine Particulates): particles with a diameter less than 0.1 micrometer ($PM_{0.1}$) (WHO, 2001) [1].

1.1.2. PM Sources

It is imperative to survey sources to solve the problem of PM high concentrations. PM sources may be natural or anthropogenic: 1) Natural sources that include dust storms, pollen grains and spores, volcanic eruptions, forest and grassland fires and sea spray. 2) Anthropogenic sources that include industrial processes, combustion of fossil fuel, either by stationary sources or by transportation, construction and demolition activities, exciting of road dust in the atmosphere (especially in unpaved roads), domestic solid waste, smoking, and agricultural operations (US EPA, Dec. 2009) [2].

1.1.3. Health Effects

Exposure to PM_{10} and $PM_{2.5}$ has adverse effects on human health whether in the short or long terms. US/EPA published a reference about Integrated Science Assessment for Particulate Matter (ISA PM) in December 2009, which included inventory of different health effects of PM_{10} and $PM_{2.5}$ which scientific studies had shown that there was an explicit correlation between PM concentrations and these diseases. (US EPA, Dec.2009) [2].

1) Exposure to $PM_{2.5}$

$PM_{2.5}$ considered more influential than PM_{10} on human health because of its ability to penetrate the respiratory system and access to trachea and primary bronchi. Research studies have shown that exposure to large concentrations of

$PM_{2.5}$ leads to different health problems in respiratory and circulatory systems and cause mortality as shown in Table 1 (US EPA, Dec.2009) [2].

2) Exposure to $PM_{10\text{-}2.5}$

Different epidemiologic studies have done to find correlation between PM_{10} concentrations and different health diseases as shown in Table 2 (US EPA, Dec.2009) [2].

1.2. Air Quality Index

The AQI is an index for reporting daily air quality. As the AQI increases, an increasingly large percentage of the population is likely to experience increasingly severe adverse health effects. Different countries have their own air quality indices that are not all consistent. Different countries also use different names for their indices such as Air Pollution Index and Pollutant Standards Index (PSI). Computing AQI requires an air pollutant concentration from a monitor or model. The function used to convert from air pollutant concentration to AQI varies by pollutant, and is different in different countries. AQI values are divided into ranges, and each range is assigned a descriptor and a color code. Standardized public health advisories are associated with each AQI range (David Mintz, Sept. 2012) [3].

Table 1. Summary of causal determinations for short-term exposure to $PM_{2.5}$.

Size fraction	Exposure	Outcome	Causality determination
$PM_{2.5}$	Short-term	Cardiovascular Effects	Causal
		Respiratory Effects	Likely To Be Causal
		Central Nervous System	Inadequate
		Mortality	Causal
$PM_{2.5}$	Long-term	Cardiovascular Effects	Causal
		Respiratory Effects	Likely To Be Causal
		Mortality	Causal
		Reproductive And Developmental	Suggestive
		Cancer, Mutagenicity, And Genotoxicity	Suggestive

Table 2. Summary of causal determinations for short and long-term exposure to $PM_{10\text{-}2.5}$.

Size Fraction	Exposure	Outcome	Causality Determination
$PM_{10\text{-}2.5}$	Short-term	Cardiovascular effects	Suggestive
		Respiratory effects	Suggestive
		Central nervous system	Inadequate
		Mortality	Suggestive
	Long-term	Cardiovascular effects	Inadequate
		Respiratory effects	Inadequate
		Mortality	Inadequate
		Reproductive and developmental	Inadequate
		Cancer, mutagenicity, genotoxicity	Inadequate

1.3. Study Area

The study area is Alexandria governorate, the second largest industrial city in Egypt. It has the latitude and longitude of 31˚13'N and 29˚58'E, with a population more than 4.6 million according to the latest report of CAPMAS, 2012 [4]. Measurements and survey carried out in the seven sites of EEAA monitoring stations and eighth site as background as shown in **Table 3** and **Figure 1** (IDSC, Dec 2011) [5].

1.4. Environmental Problem

This thesis was prepared to study the environmental problem of the very high concentrations of PM_{10} and $PM_{2.5}$ that have serious health effects. Available data as in WHO report about polluted cities classified Egypt as one of the most polluted countries all over the world (WHO, 2001) [7], CAPMAS Annual reports from 2003 to 2011 recorded that the annual average concentrations of PM_{10} in Alexandria city were higher than AQLs (IDSC, Dec 2011) [5], as shown in **Table 4** and **Figure 2**. In addition, there is lacking of data about $PM_{2.5}$ although it has highly risk impact than PM_{10}.

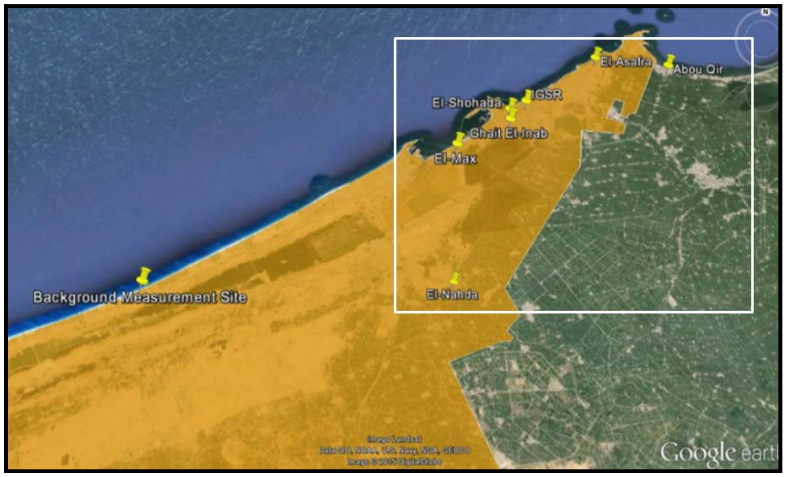


Figure 1. Showing the background site and other measurement sites.

Table 3. Sites of EEAA monitoring stations in Alexandria. (http://www.eeaa.gov.eg/eimp/Sites&indicators.html (Last visit: 03/07/2015)) [6].

ID (*)	Site	Area Type	Latitude (N)	Longitude (E)
28	Abu Qir	Industrial	31˚16'08.88"	30˚05'47.44"
42	El-Shouhada	Traffic	31˚11'27.49"	29˚54'07.57"
29	El-Max	Industrial	31˚08'29.73"	29˚50'34.11"
30	IGSR	Traffic	31˚12'09.66"	29˚55'07.39"
31	El-Asafra	Residential	31˚16'18.07"	30˚00'24.74"
32	Gheat El-Inab	Residential	31˚10'41.93"	29˚54'10.28"
41	El-Nahda	Industrial	30˚59'43.00"	29˚50'58.36"
	North Coast	Background	30˚57'55.28"	29˚32'04.07"

(*)according to EIMP/EEAA.

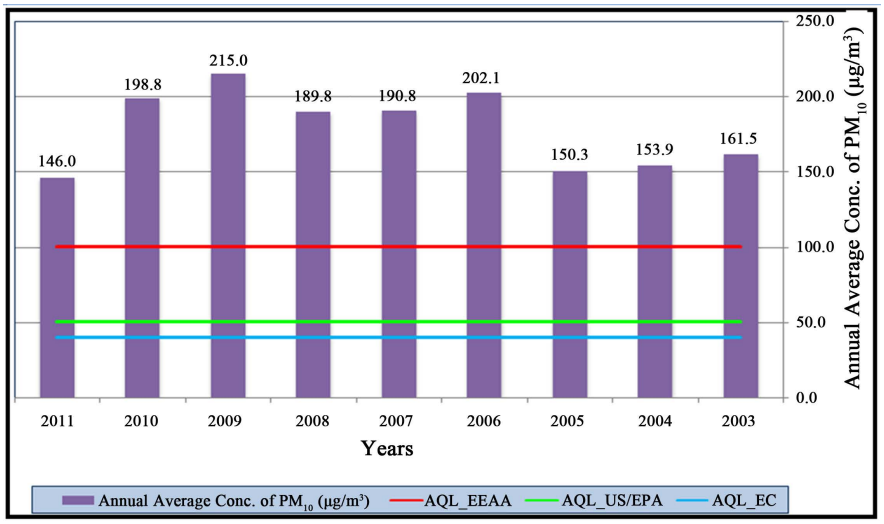


Figure 2. Annual average concentrations of PM_{10} in Alexandria (μg/m^3).

Table 4. Annual Average Concentrations of PM_{10} (μg/m^3) (IDSC, Dec 2011) [5].

Year	Annual Average Conc. of PM_{10} (μg/m^3)	AQLs		
		EEAA	US/EPA	EC
2003	161.5	100	50 (*)	40
2004	153.9			
2005	150.3			
2006	202.1			
2007	190.8			
2008	189.8			
2009	215			
2010	198.8			
2011	146			
Average	179			

(*)US/EPA revoked the annual PM_{10} NAAQS in 2006.

2. Material and Methods

2.1. Monitoring Instruments

To complete this research, multiple devices have been used such as, CEL-712 MICRO DUST PRO to measure PM_{10} and $PM_{2.5,}$ GPS to determine locations of measurement points on the map, and digital camera to document different activities of the ambient measurement locations which would help us in the interpretation of the figures and results.

2.2. Previous Data Sources

Previous data collected from different sources such as (EEAA) and (CAPMAS), Table 4.

2.3. Metrological Data

Climatic variables are considered as one of the very important factors in understanding and analyzing any results of all air pollutants and significantly affect the concentration of pollutants in the air and help in identifying places which highly affected by any contaminant.

2.4. Legislations

Results of PM_{10} and $PM_{2.5}$ measurements compared to AQLs in:

1) The local legislations that issued by the ministry of state for environmental affairs represented by EEAA as shown in Table 5.

2) AQLs of US/EPA as shown in Table 6.

3) AQLs of EC as shown in Table 7.

Table 5. AQLs for PM, EEAA (EEAA, 2011) [8].

The recent amendment	Parameter	Averaging Time	AQL (μg/m^3)
2011 Decision of the prime minister in 1095 for 2011 amending some provisions of regulations of environmental law no. 4 of 1994	TSP	24-hour	230
		annual	125
	PM_{10}	24-hour	150
		annual	100
	$PM_{2.5}$	24-hour	100
		annual	70

Table 6. NAAQS for PM, US/EPA. (http://www.epa.gov/ttn/naaqs/standards/pm/s_pm_history.html) (Last visit: 05/ 07/ 2015) [9].

The recent rule	Primary/ Secondary	Indicator	Averaging Time	Level (μg/m^3)	Form
2012	primary and secondary	$PM_{2.5}$	annual	12	annual arithmetic mean, averaged over 3 years
			annual	15	annual arithmetic mean, averaged over 3 years
			24-hour	35	98th percentile, averaged over 3 years
		PM_{10}	24-hour	150	not to be exceeded more than once per year on average over a 3-year period

Table 7. AQLs of air pollutants for EC (http://ec.europa.eu/environment/air/quality/standards.htm) (Last visit: 05/07/2015) [10].

Pollutant	Conc.	Averaging period	Legal nature	Permitted exceedances each year
Fine particles ($PM_{2.5}$)	25 μg/m^3	1 year	target value entered into force 1.1.2010 limit value enters into force 1.1.2015	n/a
PM_{10}	50 μg/m^3	24 hours	limit value entered into force 1.1.2005	35
	40 μg/m^3	1 year	limit value entered into force 1.1.2005	n/a

2.5. Air Quality Index (AQI)

AQI is a number used by government agencies to communicate to the public how polluted the air is currently or how polluted it is forecast to become as mentioned above. In this study, AQI of PM in United States (US/EPA, Dec 2011) [11]—**Table 8**—and Air Quality Forecast in Egypt (EEAA)—**Table 9**—used for assessment of results.

The equation that's used to calculate the AQI is: [3]

$$I = \frac{I_{high} - I_{low}}{C_{high} - C_{low}}\left(C - C_{low}\right) + I_{low}$$

where:

I = the (Air Quality) index,

C = the pollutant concentration,

C_{low} = the concentration breakpoint that is $\leq C$,

C_{high} = the concentration breakpoint that is $\geq C$,

I_{low} = the index breakpoint corresponding to C_{low},

I_{high} = the index breakpoint corresponding to C_{high}.

PM_{10} Air Quality Forecast used in this research to create another one for $PM_{2.5}$. Both AQFs consist of the same categories and the same color icons. The only difference was decreasing of ranges according to AQLs. PM_{10} has AQL of 150 μg/m^3 for 24-hrs and $PM_{2.5}$ has AQL of 100 μg/m^3 for 24-hrs and hence all values of PM_{10} Pollution Index was multiplied by correction factor 0.67 to create a new Air Quality Forecast for $PM_{2.5}$ as shown in **Table 10**.

Table 8. AQI Ranges, Colors and Descriptors in US/EPA (US/EPA, Dec 2011) [11].

AQI Levels of Health Concern	Numerical Value	Meaning
Good	0 - 50	Air quality is considered satisfactory, and air pollution poses little or no risk.
Moderate	51 - 100	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
Unhealthy, sensitive groups	101 - 150	Members of sensitive groups may experience health effects. The general public is not likely to be affected.
Unhealthy	151 - 200	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.
Very Unhealthy	201 - 300	Health warnings of emergency conditions. The entire population is more likely to be affected.
Hazardous	301 - 500	Everyone may experience more serious health effects.

Table 9. Air Quality Forecast of PM_{10}_EEAA (http://www.eeaa.gov.eg/English/main/env_air_aqi.asp (Last visit: 03/07/2015)) [12].

Air Quality	Good		Moderate	High		Very High	
Classification	Clean	Normal	Moderate	Attention	Alert	Warning	Emergency
PM_{10} (μg/m^3)	0 - 99	100 - 199	200 - 349	350 - 419	420 - 549	550 - 649	>650

Table 10. New Air Quality Forecast of $PM_{2.5}$.

Air Quality	Good		Moderate	High		Very High	
Classification	Clean	Normal	Moderate	Attention	Alert	Warning	Emergency
$PM_{2.5}$ (μg/m^3)	0 - 66	67 - 133	134 - 233	234 - 279	280 - 366	367 - 433	> 434

2.6. Study Area; Alexandria Governorate

The study area was Alexandria Governorate; major industrial center in Egypt. Alexandria lies on the Mediterranean Sea at the western edge of the Nile River delta as shown in **Figure 3**. It has the latitude and longitude of 31˚13'N and 29˚58'E. On 01 January 2013, population in Alexandria has reached to 4,616,625 citizens that represent approximately 5% of the population of Egypt (CAPMAS, 2012) [4].

Alexandria is considered a moderate climate to great extent compared to other governorates. Temperatures range between 4˚C in the winter season, 39˚C in the summer season and average annual temperature reach to 21˚C. Total rainfall has reached 150.64 mm during 12 months (from 01 July 2014 to 30 June 2015). As for the wind, the average wind speed over the past year did not exceed 12 km/hr and the prevailing wind in Alexandria always has been from the northwest. PM measurements were conducted during the last month of spring season (from May 21, 2015 to June 20, 2015). These period recorded readings were very close to the annual average temperature and wind speed as shown in **Table 11**, as well as this period did not record rainfall at all and hence there no wet deposition of PM occurred (http://www.wunderground.com) [13].

3. Results and Discussion

PM_{10} and $PM_{2.5}$ were measured in seven sites in Alexandria which representing different activities as shown in **Figure 4**. These sites include Abu Keir, El-shouhada Square, El-Max, IGSR, El-Asafra, Ghait El-Inab, and El-Nahda.

For PM_{10} Results, El-Nahda site recorded the highest average concentration (1805 μg/m^3), while Ghait El-Inab site recorded the lower average concentration (170 μg/m^3). When comparing concentrations to AQLs of EEAA and US/EPA (150 μg/m^3); All sites were higher than AQLs except Ghait El-Inab. When comparing concentrations to AQL of EC (50 μg/m^3); All sites were higher than AQLs as shown in **Table 12** and **Figure 5**.

For $PM_{2.5}$ Results, El-Nahda site also recorded the highest average concentration (1368 μg/m^3), while Ghait El-Inab site recorded the lower average concentration (70 μg/m^3). When comparing concentrations to AQL of EEAA (100 μg/m^3); All sites were higher than AQL except Ghait El-Inab. When you compare results up to AQL of US/EPA (35 μg/m^3); All sites were higher than AQL without any exceptions as is shown in **Table 13** and **Figure 6**.

PM_{10} and $PM_{2.5}$ were compared to the Air Quality Forecast which created by EEAA. For PM_{10} Results, three sites were classified as "Emergency" (>650 μg/m^3) while two sites were classified as "Alert" (420 to 549 μg/m^3) while one site was

Figure 3. Alexandria governorate.

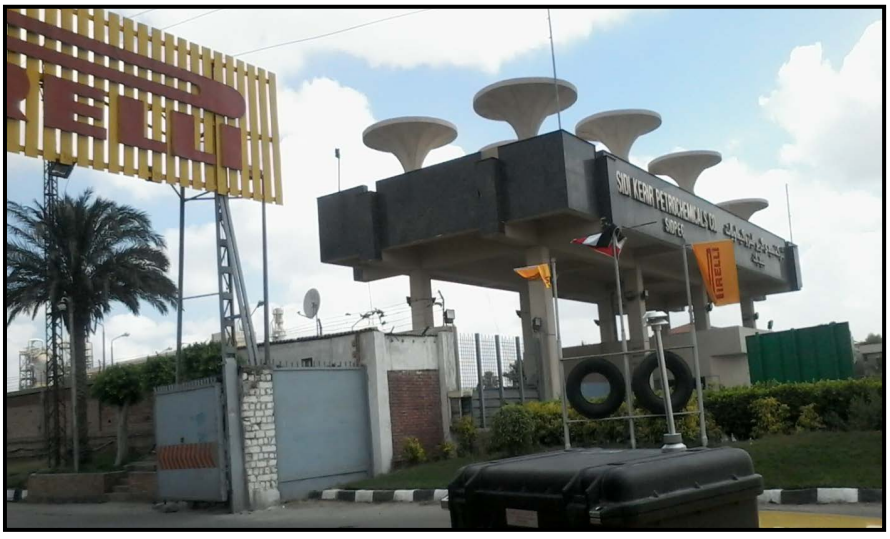


Figure 4. PM_{10} and $PM_{2.5}$ measurements using Casella Dust Detective (Created in: 31 May 2015).

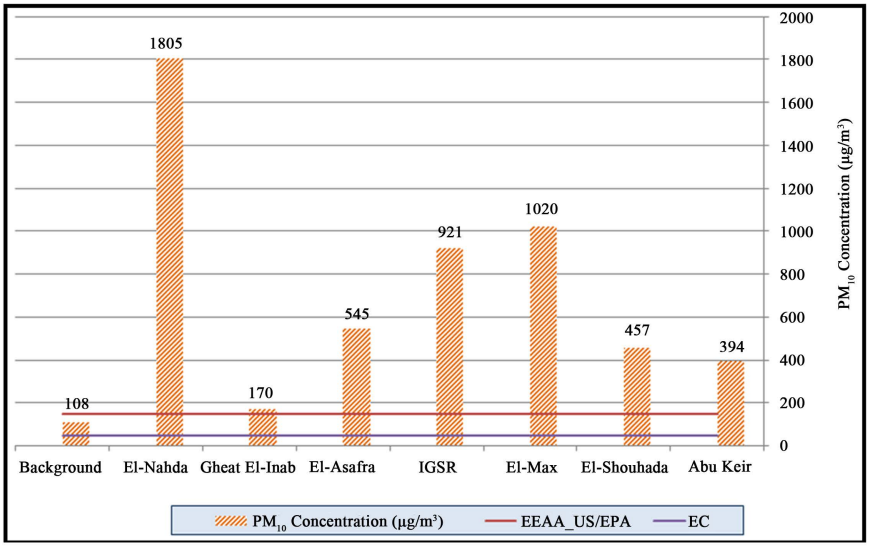


Figure 5. Comparison between PM_{10} conc. ($\mu g/m^3$) and air quality forecasts.

Table 11. Metrological data, El-Nouzha station, Alexandria (21 May: 20 June 2015). (http://www.wunderground.com) [13].

	Max	Avg	Min	Sum
Temperature				
Max Temperature (˚C)	39	29	25	
Mean Temperature (˚C)	31	24	22	
Min Temperature (˚C)	23	20	17	
Degree Days				
Heating Degree Days (base 65)	0	0	0	0
Cooling Degree Days (base 65)	22	11	6	335
Growing Degree Days (base 50)	37	26	21	805
Dew Point				
Dew Point (˚C)	22	16	0	
Precipitation				
Precipitation (mm)	0.0	0.0	0.0	0.0
Snow depth	-	-	-	-
Wind				
Wind (km/h)	34	13	0	
Gust Wind	-	-	-	
Sea Level Pressure				
Sea Level Pressure (hPa)	1017	1012	1004	

Table 12. Summary of results for PM_{10} measurements in all sites.

ID	Area	Area Type	Site Coordinates		Parameter	Concentration (μg/m³)	AQL (μg/m³) for 24-hrs		
			Latitudes (N)	Longitudes (E)			EEAA	US/EPA	EC
28	Abu Keir	Industrial	31˚16'8.88"	30˚05'47.44"	PM_{10}	**394**	150	150	50
42	EL-Shohada	Traffic	31˚11'27.49"	29˚54'7.57"		**457**			
29	EL-Max	Industrial	31˚8'29.73"	29˚50'34.11"		**1020**			
30	IGSR	Traffic	31˚12'09.66"	29˚55'07.39"		**921**			
31	EL-Asafra	Residential	31˚16'18.07"	30˚00'24.74"		**545**			
32	Ghait El-Inab	Residential	31˚10'41.93"	29˚54'10.28"		**170**			
41	El-Nahda	Industrial	30˚59'43.00"	29˚50'58.36"		**1805**			
	North Coast	Background	30˚57'55.28"	29˚32'04.07"		**108**			

Table 13. Summary of PM_{10} Air quality forecasts according to EEAA limits.

Classification	**Clean**	**Normal**	**Moderate**	**Attention**	**Alert**	**Warning**	**Emergency**
PM_{10} (μg/m³)	0 - 99	100 - 199	200 - 349	350 - 419	420 - 549	550 - 649	>650

Sites	-	Ghait El-Inab Background Site	-	Abu Keir	EL-Shouhada EL-Asafra	-	EL-Max El-Nahda IGSR
No. of Sites	0	2	0	1	2	0	3

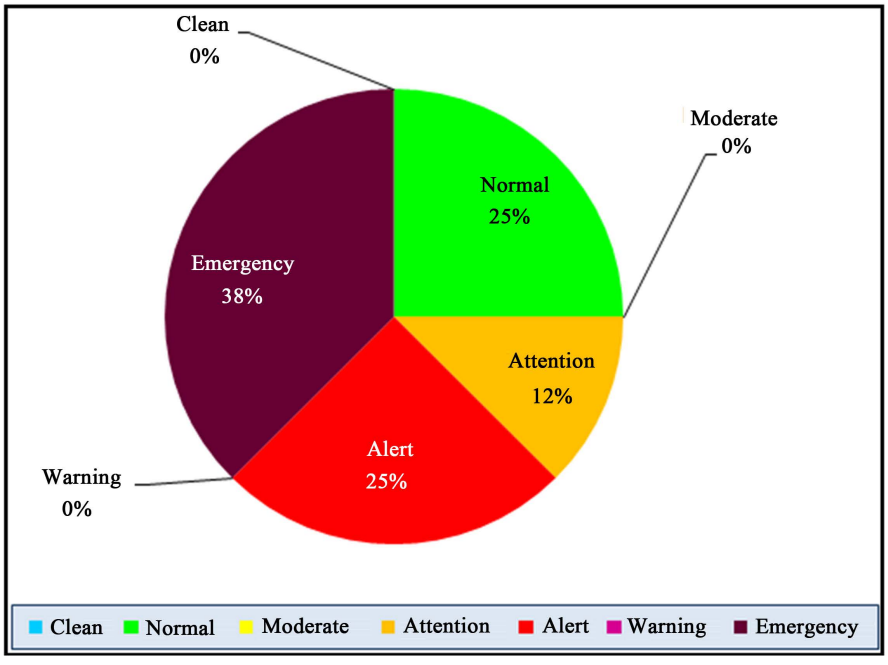


Figure 6. Pie chart for air quality forecast of PM_{10} conc. in all sites.

classified as "Attention" (350 to 419 μg/m³) and another site was classified as "Normal" (100 to 199 μg/m³) as shown in **Table 14** and **Figure 7**. For $PM_{2.5}$ Results, five sites were classified as "Emergency" (>434 μg/m³) while one site was

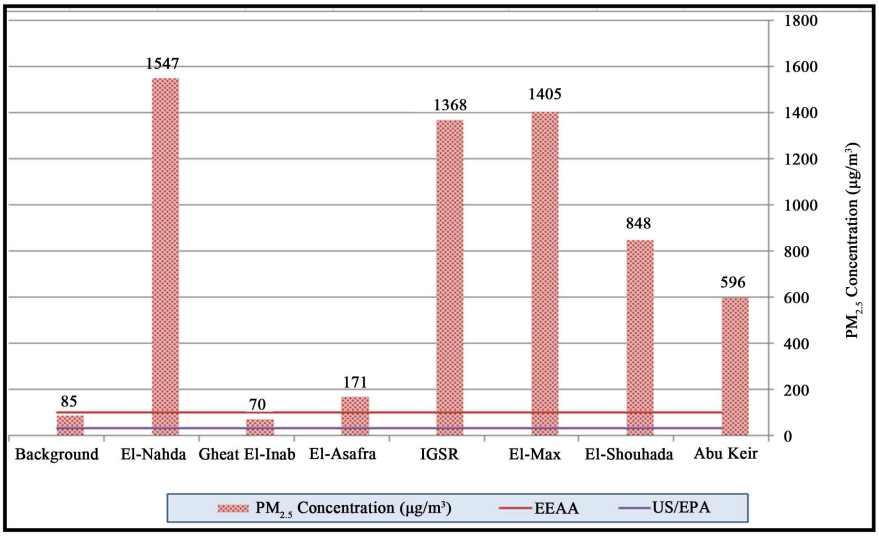


Figure 7. Comparison between $PM_{2.5}$ conc. (µg/m^3) and Air Quality Forecasts.

Table 14. Summary of PM_{10} AQIs according to US/EPA limits.

Category	I_{low} - I_{high}	PM_{10} (µg/m^3)		AQI	Sites
		C_{low} - C_{high}	C (measured)		
Good	0 - 50	0 - 54			
Moderate	51 - 100	55 - 154	**108**	**77**	**Background Site**
Unhealthy for Sensitive Groups	101 - 150	155 - 254	**170**	**108**	**Ghait El-Inab**
Unhealthy	151 - 200	255 - 354			
Very Unhealthy	201 - 300	355 - 424	**394**	**257**	**Abu Keir**
Hazardous	301 - 400	425 - 504	**457**	**341**	**EL-Shohada**
	401 - 500	505 - 604	**545**	**441**	**EL-Asafra**
N/A	N/A	>604 µg/m^3	**921**	**N/A**	**IGSR**
			1020	**N/A**	**EL-Max**

classified as "Moderate" (134 to: 233 µg/m^3) and another site was classified as "Normal" (133 to 67 µg/m^3) as shown in Table 15 and Figure 8.

In addition, PM_{10} and $PM_{2.5}$ concentrations were compared to the AQI which created by US/EPA. These AQIs calculated according to the previous equation that mentioned in 3.5.2. AQIs were not applicable for three sites that have PM_{10} concentrations higher than 604 µg/m^3 as shown in Table 16 and for five sites that have $PM_{2.5}$ concentrations higher than 500.4 µg/m^3 as shown in Table 17.

The background measurement site in the north coast recorded 108 µg/m^3 for PM_{10} while $PM_{2.5}$ recorded 85 µg/m^3 and both were below than AQLs of EEAA and classified as "Normal" in the EEAA Air Quality Forecast.

3.1. Expected Sources of PM

There are several potential sources of PM pollution which was noticed during

Table 15. Summary of results for $PM_{2.5}$ measurements in all sites.

ID	Area	Area Type	Site Coordinates		Parameter	Concentration (μg/m³)	AQL (μg/m³) for 24-hrs		
			Latitudes (N)	Longitudes (E)			EEAA	US/EPA	EC
28	Abu Keir	Industrial	31˚16'8.88"	30˚05'47.44"	$PM_{2.5}$	**596**	100	35	-
42	EL-Shohada	Traffic	31˚11'27.49"	29˚54'7.57"		**848**			
29	EL-Max	Industrial	31˚8'29.73"	29˚50'34.11"		**1405**			
30	IGSR	Traffic	31˚12'09.66"	29˚55'07.39"		**1368**			
31	EL-Asafra	Residential	31˚16'18.07"	30˚00'24.74"		**171**			
32	Ghait El-Inab	Residential	31˚10'41.93"	29˚54'10.28"		**70**			
41	El-Nahda	Industrial	30˚59'43.00"	29˚50'58.36"		**1547**			
	North Coast	Background	30˚57'55.28"	29˚32'04.07"		**85**			

Table 16. Summary of $PM_{2.5}$ Air Quality Forecast according to EEAA limits.

Classification	**Clean**	**Normal**	**Moderate**	**Attention**	**Alert**	**Warning**	**Emergency**
$PM_{2.5}$ (μg/m³)	0 - 66	67 - 133	134 - 233	234 - 279	280 - 366	367 - 433	>434
Sites	-	Ghait El-Einab Background Site	EL-Asafra	-	-	-	EL-Max, IGSR, EL-Shohada, Abu Keir, El-Nahda
No. of sites	-	2	1	-	-	-	5

Table 17. Summary of $PM_{2.5}$ AQI according to US/EPA limits.

Category	I_{low} - I_{high}	**$PM_{2.5}$ (μg/m³)**		**AQI**	**Sites**
		C_{low} - C_{high}	$C_{measured}$		
Good	0 - 50	0.0 - 12.0			
Moderate	51 - 100	12.1 - 35.4			
Unhealthy for Sensitive Groups	101 - 150	35.5 - 55.4			
Unhealthy	151 - 200	55.5 - 150.4	**70**	**158**	**Ghait El-Inab**
			85	**166**	**Background**
Very Unhealthy	201 - 300	150.5 - 250.4	**171**	**221**	**EL-Asafra**
Hazardous	301 - 400	250.5 - 350.4			
	401 - 500	350.5 - 500.4			
N/A	N/A	>500.4 μg/m³	N/A	**596**	**Abu Keir**
			N/A	**848**	**EL-Shohada**
			N/A	**1368**	**IGSR**
			N/A	**1405**	**EL-Max**
			N/A	**1547**	**El-Nahda**

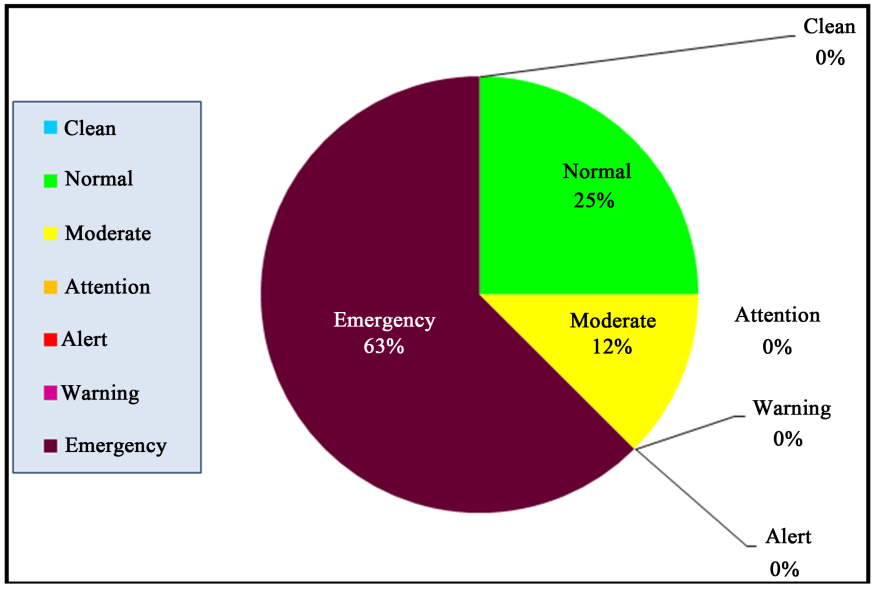


Figure 8. Pie chart for air quality forecast of $PM_{2.5}$ conc. in all sites.

measurements in different sites. Those sources may be natural (such as dust storms and pollens) or may be anthropogenic sources.

Major anthropogenic probable sources which noticed were industrial Activities, Demolition and construction, unpaved streets, solid wastes, and fuel Combustion.

3.1.1. Industrial Activities

Alexandria is the largest industrial city (with ≈40% of the total Egyptian industry). There are 280,000 registered industrial firms and 1,837,000 registered handicraft workshops. It has 10 industrial zones with total area 22,687 Acre as shown in **Table 18**. Many industries are considered to be major sources of PM pollution such as cement, fertilizers, ceramic, chemical, and timber industries (http://www.alexandria.gov.eg (Last visit: 24/07/2015)) [14].

3.1.2. Demolition and Construction

Construction and demolition wastes are considered to be one of the major anthropogenic sources of PM pollution. Its adverse effects increase with wind movement especially when it leaved without disposal in designated places. In 2010, demolition wastes in Egypt have reached 41.7 million tons (IDSC, Dec 2011) [5].

3.1.3. Unpaved Streets

According to CAPMAS reports, 1035 km approximately of roads in Alexandria unpaved (equivalent to 21% of roads in the governorate)—**Table 19**—while the number of licensed vehicles up to 622,542 vehicles at the end of December 2012.

83221 of them are Lorries and 10,208 trucks as well as others that entering and leaving daily from the governorate (IDSC, Dec 2011) [5].

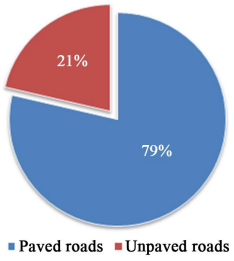
This huge number of cars with the presence of nearly a quarter of the streets

Table 18. Industrial zones in Alexandria governorate (http://www.alexandria.gov.eg (Last visit: 24/07/2015)) [14].

Industrial Zones	Dependency	Construction decision		Issuer	Total Area (Acre)
		No.	Year		
El-Manshia El-Gdeda Ind. Zone	Governorates	523	1990	Ministerial Decision	843.5
El-Nasryah Ind. Zone	Governorates	972	1999	Ministerial Decision	168
Merghem Ind. Zone	Governorates	523	1990	Ministerial Decision	3576
Seven Up (31 km) Ind. Zone	Governorates	1123	1998	Ministerial Decision	814
SIPCO Ind. Zone	Governorates	240	2002	Prime Minister	160
El-Agamy Ind. Complex	Governorates	1827	2002	Council of Ministers	3
El-Nahda Ind. Zone	New Cities	2244	2000	Council of Ministers	4611
Om Zghew Ind. Zone	Governorates	1906	1997	Ministerial Decision	2851
New Borg El-Arab Ind. City	New Cities	506	1979	Presidential Decree	5465
Free Ind. Zone	Free Zone	207	1973	Presidential Decree	1357.14

Table 19. Paved and Unpaved roads, Alexandria, 2012.

Alexandria roads	Length (km)	%
Paved roads	3814	78.7
Unpaved roads	1035	21.3



of Alexandria unpaved inevitably lead to raise dust and the high concentrations of PM_{10} and $PM_{2.5}$ in ambient air significantly.

3.1.4. Solid Wastes

Agricultural residues in Alexandria became 212.7 thousand tons in 2010 while household wastes reached to 969.3 thousand tons and hence Alexandria became the third governorate (after Cairo and Giza) in terms of waste generation (CAPMAS, 2012) [4]. Garbage companies cannot collect all these quantities of wastes on a regular basis and keep part of it in streets that causes dust creation in the ambient air with any slight increase in winds movement.

3.2. Adverse Effects on Human Health

We start searching for statistics on the prevalence of respiratory and cardiovascular diseases rates in Alexandria to compare them to what has been accessed from the concentrations of PM_{10} and $PM_{2.5}$ in order to demonstrate the relationship that was recognized in epidemiologic studies that mentioned above. However, we did not find any data except limited statistics of respiratory diseases in Egypt as shown in **Table 20** (CAPMAS, 2012) [4].

Table 20. Cases of admissions and deaths in central and general hospitals, Egypt (2010:2012). (CAPMAS, 2012) [4].

Disease	2010			2011			2012		
	Admission	Death	% Deaths to admission cases	Admission	Death	% Deaths to admission cases	Admission	Death	% Deaths to admission cases
Chest	59,322	644	1.1%	56,041	442	0.8%	80,597	931	1.2%
Severe respiratory diseases	467	3	0.6%	614	3	0.5%	1,079	5	0.5%

We cannot say for sure that the $PM_{2.5}$ was the only cause of those rates of patients and deaths as there is interference with other reasons that may be other air pollutants. It may be also because of genetic factors or otherwise. However, $PM_{2.5}$ remains one of reasons that led to the occurrence of these diseases and deaths, but we cannot accurately determine the percentage of its impact.

3.3. Management Options

There are several management options for mitigating these high concentrations of PM_{10} and $PM_{2.5}$ and hence protect human health from adverse effects that mentioned above. These options include,

1) Increasing awareness about ISO2600 (CSR) and ISO 14001,

2) Restructuring EIMP/EEAA monitoring stations and supporting them with $PM_{2.5}$ monitors,

3) Using different PM collection devices in industrial activities,

4) Reducing AQL of $PM_{2.5}$, and

5) Increasing Environmental law enforcement firmly.

3.3.1. Implementation of Integrated ISO 26000 and ISO 14001

CSR is the traditional way to refer to the role of a business in contributing positively to the larger community in which it operates. ISO 26000 uses the term Social Responsibility (SR) to refer to this concept, to show that its guidance can be used by all kinds of organizations (ECOLOGIA, May 2011) [15].

However, since this handbook is designed especially for the needs of small and medium size businesses, we have used CSR the more familiar term throughout. ISO 26000 identifies seven core subjects that socially responsible businesses should address. Implementers of ISO 26000 should evaluate their actions in each of the core subjects, to identify what they are doing in their current practices, and to set priorities for improvements (ECOLOGIA, May 2011) [15]. ISO 26000 has seven core subjects which are

1) Organizational governance: Practicing accountability and transparency at all levels of your organization; using leadership to create an organizational culture which uses core values of social responsibility when making business decisions.

2) Human rights: Treating all individuals with respect; making special efforts to help people from vulnerable groups.

3) Labor practices: Providing just, safe and healthy conditions for workers;

engaging in two way discussions to address workers' concerns.

4) Environment: Identifying and improving environmental impacts of your operations, including resource use and waste disposal.

5) Fair operating practices: Respecting the law; practicing accountability and fairness in your dealings with other businesses, including your suppliers.

6) Consumer issues: Providing healthy and safe products, giving accurate information, and promoting sustainable consumption.

7) **Community involvement and development**: Getting involved in the betterment of the local communities that your organization operates in; being a good neighbor (ECOLOGIA, May 2011) [15].

ISO 14001 is an internationally agreed standard that sets out the requirements for an environmental management system. It helps organizations improve their environmental performance through efficient use of resources and reduction of waste, gaining a competitive advantage and the trust of stakeholders (ISO Central Secretariat, 2015) [16].

ISO 14001 helps:

- Demonstrate compliance with current and future statutory and regulatory requirements.
- Increase leadership involvement and engagement of employees.
- Improve company reputation and the confidence of stakeholders through strategic communication.
- Achieve strategic business aims by incorporating environmental issues into business management.
- Provide a competitive and financial advantage through improved efficiencies and reduced costs.
- Encourage better environmental performance of suppliers by integrating them into the organization's business systems.

Implementation of integrated ISO 2600 and ISO 14001 will solve many environmental problems. For example, Wadi El-Qamar Street can be paved as Social responsibility of surrounding companies in this area according to 7th ISO 26000 core subject or as Improvement of their environmental performance by decreasing PM emitted because of transporting raw materials and products according to ISO 14001 (ISO Central Secretariat, 2015) [16].

3.3.2. Restructuring of EIMP/EEAA Monitoring Stations

Quick review of the administrative border of the Alexandria governorate—**Figure 3** shows that the monitoring stations need to restructure as:

1) Nearly western half of the Alexandria does not have monitoring stations, although it includes the New Borg El-Arab city, which includes several industrial zones.

2) Total area of cultivated land in Alexandria governorate is 18,120,000 Acre according to IDSC in 2010 (8,427,000 old land + 9,642,000 new land) with total cropped area of 31,612,000. Most of those agricultural areas are located in the southern part of Alexandria and there is no monitoring stations represent agri-

culture areas, although it is considered downwind for all industrial areas.

3) There are 6 stations of the seven which include instruments to monitor PM_{10} and none of them include any device for measuring $PM_{2.5}$ although it is the most dangerous to human health.

3.3.3. Reducing Pollution from the Source

PM collection occurs when the particle leaves the entraining air and contact a collecting surface. There are different applicable techniques such as elutriators, cyclones, electrostatic precipitator, etc.

1) Elutriators for PM collection

Elutriators used for PM collection can have either vertical or horizontal orientation. A simplified horizontal elutriators design shown in **Figure 9** (Robert F. Phalen, and Robert N. Phalen, 2013) [17].

2) Cyclones:

Cyclones (and aerosol centrifuges) impart a rotational velocity to the particle-containing air stream that produced an increased artificial g-force (gravitational acceleration), sometimes called a "centrifugal" force, to the particles. The increased g-force increases the collection efficiency, especially for small particles that normally settle slowly. A common cyclone design used for PM collection is shown in **Figure 10** (Robert F. Phalen, and Robert N. Phalen, 2013) [17].

3) Electrostatic precipitator

Charged particles in an electrical field can encounter electrostatic forces that greatly exceed resistive drag and gravitational forces. Charged particles are attracted to oppositely-charged and grounded bodies. The velocity with charged particle move toward a collecting surface can be more than 1000 times greater than the particle's terminal settling velocity. The movement of an electrically-charged particle toward a collector is the mechanism by which an electrostatic precipitator (ESP) operates. Particles that are to be collected need not carry an initial electrical charge; **Figure 11** (Robert F. Phalen, and Robert N. Phalen, 2013) [17].

4) Spray towers

Spray towers typically introduce a water spray that falls downward through an upward-flowing "dirty" air stream. Contaminant particles are collected on the

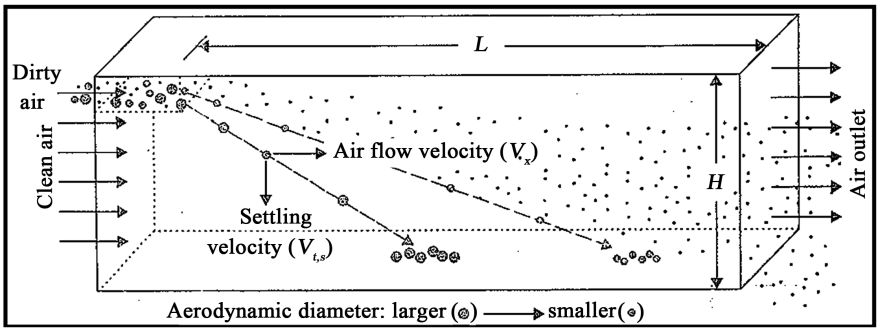


Figure 9. Cross sectional view of a simplified horizontal elutriator (Robert F. Phalen, and Robert N. Phalen, 2013) [17].

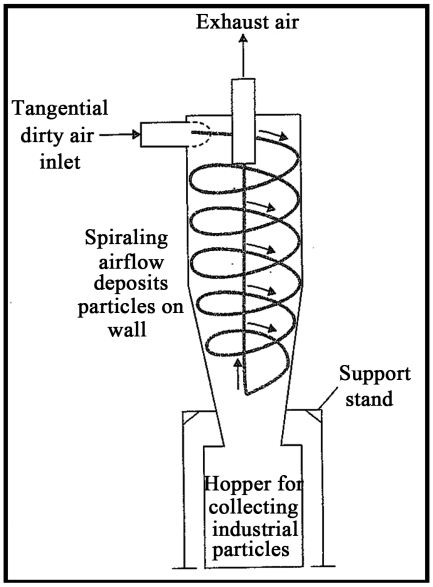


Figure 10. Simplified aerosol cyclone (Robert F. Phalen, and Robert N. Phalen, 2013) [17].

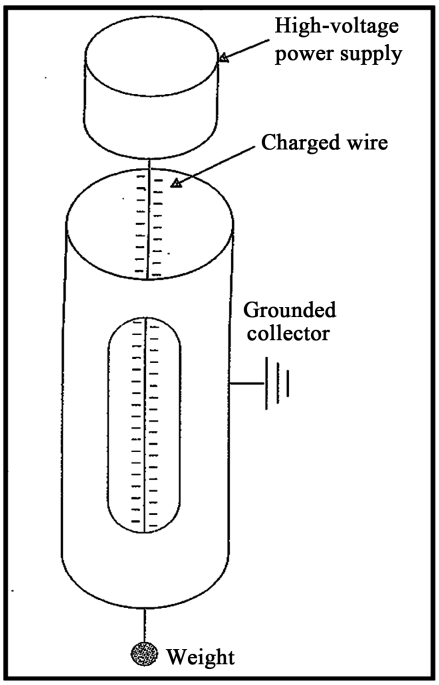


Figure 11. Electrostatic precipitator (Robert F. Phalen, and Robert N. Phalen, 2013) [17].

falling water droplets by impaction and diffusion. Gases are collected by diffusion to the water droplets where they are absorbed. A demister (e.g., wire screens) above the sprayer section collets contaminated water droplets before they exit at the top of the tower. Cleaned air exits above the demister at the top of the tower. Water droplets and condensed water (from the demister) fall into a sump or drain at the bottom of the tower, **Figure 12** (Robert F. Phalen, and Robert N. Phalen, 2013) [17].

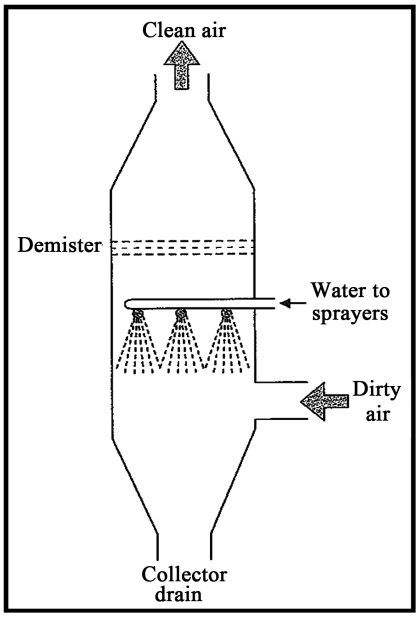


Figure 12. Spray tower (Robert F. Phalen, and Robert N. Phalen, 2013) [17].

5) Venturi Scrubbers

Venturi Scrubbers operate on the principles similar to spray towers. They differ in that the contaminated air usually flows downward toward a converging "throat" where it is rapidly accelerated. Liquid is introduced along the wall above the converging section, where it is aerosolized upon encountering the reduced pressure in the throat. The aerosolized and falling collection liquids contacts and collects the downward flowing particles and gases in a diverging lower section of the scrubber, **Figure 13** (Robert F. Phalen, and Robert N. Phalen, 2013) [17].

6) Bag filters

Bag filters are specialized filters that are preferable to simple flat filters because they can be repeatedly cleaned and reuse. Thus, they do not require frequent replacement. Bag filters are widely used for the collection of PM in high-throughput applications, such as coal-fired power plants, or for other industrial processes that require efficient dust emission controls, **Figure 14** (Robert F. Phalen, and Robert N. Phalen, 2013) [17].

7) Packed beds

Packed beds, such as those containing activated charcoal or collections of glass, metal, or plastic beads, are used for efficiently collecting particles and gases, including caustic substances. The beads can be coated with various substances to improve their performance (Robert F. Phalen, and Robert N. Phalen, 2013) [17].

3.3.4. Reducing $PM_{2.5}$ AQL

$PM_{2.5}$ not included in the Egyptian environmental law till 2011, and also its AQLs in the new amendment (for 24-hr and annual average) is noticed to be higher than all international AQLs as shown in **Figure 15**. It must be reduced to be compatible with international AQLs.

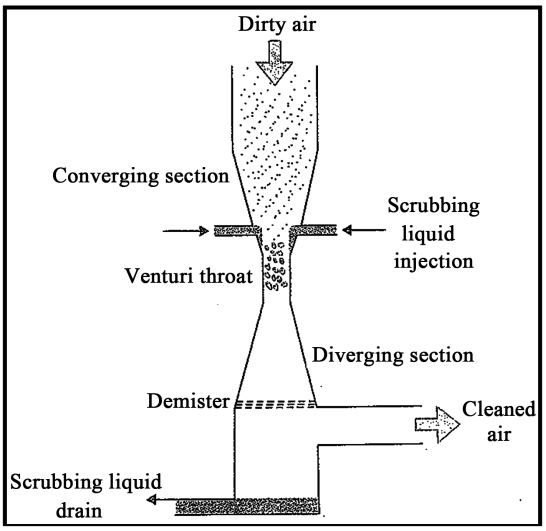


Figure 13. Schematic diagram of Venturi Scrubbers (Robert F. Phalen, and Robert N. Phalen, 2013) [17].

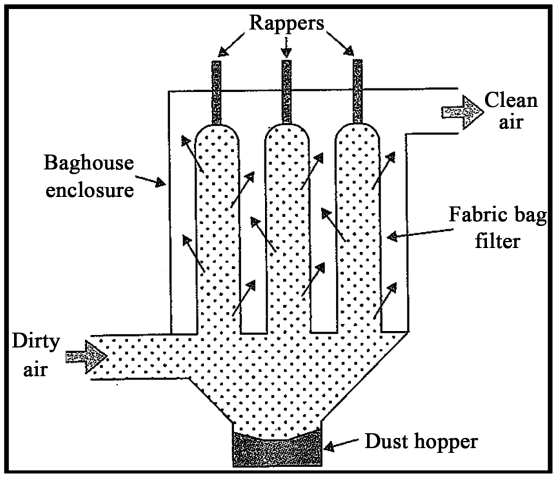


Figure 14. Example of bag-house dust collector design (Robert F. Phalen, and Robert N. Phalen, 2013) [17].

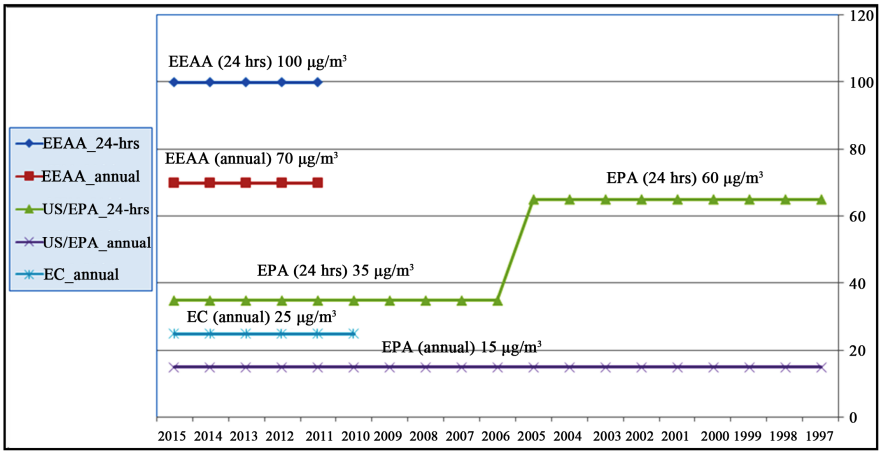


Figure 15. Comparison between $PM_{2.5}$ AQLs (Local and International).

3.3.5. Environmental Law Enforcement Firmly

One of the most serious problems that lead to increasing of PM pollution is "soft" enforcement of environmental regulations. The response of industry to current environmental regulations in Alexandria, Egypt was investigated. Environmental officers in 55 industrial firms completed a questionnaire examining their opinions about current environmental regulations, the statuses of their companies' compliance with those regulations, and the environmental management progress and problems in their companies. Although Egyptian industrialists had positive opinions about environmental regulations, their companies were not in satisfactory compliance with those regulations. The context in which environmental concern started in Egypt and the economic environment of Egyptian industry had led to "soft" enforcement and implementation of environmental regulations. The response of Alexandria's industrial firms to the issued environmental regulations was limited to adopting symbolic "end-of-pipe" environmental protection measures. Progress in environmental management and problems in industries of Alexandria were also investigated (Hisham El-Zayat, Gihan Ibraheem, and Sherif Kandil, April 2006) [18].

4. Conclusions and Recommendations

4.1. Conclusions

1) El-Nahda site recorded the highest concentration of PM_{10} and $PM_{2.5}$ while Ghait El-Inab site recorded the lower concentration.

2) For PM_{10} Results; three sites were classified as "Emergency"—Air pollution is (Very High)—according to Air Quality Forecast of EEAA, two sites were classified as "Alert", one site was classified as "Attention"—Air pollution in both sites is (High), and another site was classified as "Normal"—Air quality is (Good).

3) For $PM_{2.5}$ Results; five sites were classified as "Emergency" according to Air Quality Forecast of EEAA—Air pollution is (Very High), one site was classified as "Moderate"—Air quality is (Moderate), and another site was classified as "Normal"—Air quality is (Good).

4) Most probable anthropogenic sources of these high concentrations of PM_{10} and $PM_{2.5}$ include industrial activities as Alexandria governorate has more than 40% of industries in Egypt, unpaved roads which represent 21% of roads in Alexandria, randomized demolition and construction work, and solid wastes.

5) All previous research studies confirm that $PM_{2.5}$ is more serious than PM_{10} on both the short term and long term. $PM_{2.5}$ has high ability to penetrate respiratory system as well as it remains suspended in the air for longer time than PM_{10}. $PM_{2.5}$ is causal of some cardiovascular diseases and mortality, likely to be Causal of Respiratory Effects, and Suggestive to be causal of some Reproductive and Developmental diseases, Cancer, Mutagenicity, and Genotoxicity.

6) AQLs of $PM_{2.5}$ in the Egyptian Environmental Law according to last amendment (for 24-hr and annual average) are noticed to be higher than all in-

ternational AQLs for the ambient environment. On the other hand, $PM_{2.5}$ hasn't AQL in the Egyptian Environmental Law for the working environment till now.

7) Nearly western half of the Alexandria does not have monitoring stations, although it includes the New Borg El-Arab city that includes several industrial zones.

4.2. Recommendations

1) Implementation of integrated ISO 26000 and ISO 14001 can help in solving many environmental problems.

2) EIMP/EEAA monitoring stations need restructuring plan to cover all areas and all activities in Alexandria.

3) EIMP/EEAA must be supported with $PM_{2.5}$ monitors as it's more serious than PM_{10} and there are lacking of data about this pollutant and hence.

4) Particulate Matters control systems such as bag filters, Packed beds, wet and dry Scrubbers must be used in all industrial activities to reduce PM pollution from the source not to adopt "end-of-pipe" environmental protection measures.

5) AQL of $PM_{2.5}$ in the ambient environment must be reduced to meet international limits. It must be included in the working environment parameters also.

6) Environmental law must be applied strictly.

7) Increase the multidisciplinary co-operation especially between environment and public health specialists.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Abbreviations

AQHI	Air Quality Health Index
AQI	Air Quality Index
AQL	Air Quality Limits
CAPMAS	Central Agency for Public Mobilization and Statistics
CSR	Corporate Social Responsibility
EC	European Commission
EEAA	Egyptian Environmental Affairs Agency
GPS	Global Positioning System
IDSA	Information and Decision Support Center
IGSR	Institute for Governmental Service and Research
ISA	Integrated Science Assessment
NAAQS	National Ambient Air Quality Standards
PI	Pollution Index
PM	Particulate Matters
PM_{10}	Particulate Matters with a diameter less than 10 μm
$PM_{2.5}$	Particulate Matters with a diameter less than 2.5 μm
PSI	Pollutant Standards Index
PUF	Polyurethane Foam
SAS	Static Air Sampling
TSP	Total Suspended Particulates
UFPs	Ultrafine Particulates
US/EPA	United States/Environmental Protection Agency
WHO	World Health Organization