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Prediction of inhalation health risk of mercury emissions from stacks of cement plant employing coal as an alternative fuel

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***Abstract*---**Due to the Egyptian shortage of energy sources, especially for energy-intensive industries, the Egyptian President decree No 105-2015, and the Egyptian Prime Minister's Decisions No. 964 - 2015, No 544-2017, and No 618-2017 setting standards for the exportation, using, handling, and storage of coal as an alternative fuel in mega industries within the Arab Republic of Egypt. Fossil fuels, with their different types, are materials that produce different amounts of air pollutants, especially coal, which, when burned, produces quantities of sulfur oxides, carbon oxides, and some heavy metals that have environmental and health effects in the short and long term alike. The objective of the present study is to identify the distance from each stack of approximately zero mercury concentration as compared to the distance of the external plant fences to ensure that the community air is free from mercury of the cement production source by using an air pollutants dispersion model. This study was a descriptive cross-sectional survey that was conducted in Cement Production plant in the Helwan area that use coal as an energy source. Stack sampling of both vapor and particulates' Hg was conducted according to the standard isokinetic method. The Dispersion of mercury particles was

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according to the concentration of mercury, which was released from the cement plant stack as a product of coal-burning and according to the meteorological conditions (wind speed, wind direction, humidity, and temperature) in the Helwan Zone at the time of sampling. The dispersion modeling is done by using the AERMOD air pollutant dispersion modeling program, which was issued by American Environmental Protection Agency (USEPA). In this study, we can see the difference between the release of mercury particles and their movement in the air. The results of the study show that the moving of mercury particles in the air in not go very long due to the low concentrations of mercury, which were found in the stack emission samples, and due to the wind direction and speed.

***Keywords*---**AERMOD, cement industry, coal, energy source, mercury emissions, dispersion model, Hazard Quotient.

Introduction

Coal is a combustible rock, and about 50% of its carbonaceous material is derived from the compaction and alteration of ancient plants. It has different kinds of plants and a wide range of impurities. It is one of the global alternative fuels that is widely used instead of petroleum and natural gas in different Egyptian industrial sectors, including cement production and power generation (Li, 2022). If combusted, it releases huge quantities of air pollutants, including carbon oxides (CO_x) and particulate matter that usually contains heavy metals (chromium (Cr), copper (Cu), manganese (Mn), mercury (Hg), nickel (Ni), and zinc (Zn)), which liberate as metal vapours or compounds when coal is burned (Vassilev et al., 2015).

All forms of mercury are toxic to humans. Exposure to elemental mercury or its compounds is harmful to human health, especially for foetuses and children at the early stages of development. Mercury is persistent in the environment, highly bio-accumulative, and can cause a variety of toxic effects, including nephrotoxicity, teratogenicity, and damage to the cardiovascular system. Endocrine-disrupting and immune-toxicological properties are under scientific discussion (Holoubek, 2016). To be tolerable, the annual concentration of Hg in the air should not exceed 300 ng/m^3 annually according to the US EPA integrated risk information system (IRIS), and 200 ng/m^3 based on the WHO. (Nakazawa, 2016)

There are many cement production technologies, of which the most efficient energy-saving one is the dry process, which is most famous for clinker manufacture in new bond plants and significant overhauls of the best accessible technology (BAT) for the creation of concrete. Clinker is a dry-process furnace that uses a multistage preheating and pre-calcination process. Portland concrete is created by first co-crushing a blend of around 80% limestone and 20% dirt. This is then calcined and, in this manner, consumed at temperatures achieving 1,450°C. Amid the high-temperature handling, the furnace passes on knobs of calcium and silicon oxides held together by calcium aluminates (Li, 2018). In

Egypt, the Egyptian Environmental Law No. 4/1994, as amended by Law No. 9/2009, and its executive rule, which was issued by Prime Minister's Decree No. 1963/2017-Annex No. 6 Table No. 6. mentioned the maximum emission limits of some heavy metals (Pb and Hg) from point sources that use coal as an alternative fuel. In addition, the previous regulations set standards for the exportation, use, handling, and storage of coal as an alternative fuel in mega industries within the Arab Republic of Egypt (P.E.Minister, 2017).

Many factors affect the diffusion and traveling distance of air pollutants emitted from a point source, including the source's strength, the chemical and physical characteristics of the pollutants, the meteorological factors (wind speed and direction, temperature, and pressure variations), and the topography of the area. The net spatial effect of this emission is the outcome of these interacting factors (Zhou, 2007) .

In Egypt, the prevailing wind direction is northwest (NW) to north (N). Sometimes, the wind direction is reversed to southeast (SE) to south (S), especially in winter. The wind direction is a very important parameter in the dispersion of air pollutants. The urban areas downwind of the coal-using industrial facilities may suffer from high ambient concentrations of heavy metals (Hereher, 2018).

The AERMOD program is a steady-state Gaussian plume air dispersion model that is a product of a working group between the American Meteorological Society (AMS) and the US Environmental Protection Agency (EPA). It represents the current state of science and promulgates a dispersion model from the U.S. EPA. BREEZE AERMOD is an enhanced version of the EPA-approved AERMOD that provides modellers with the tools and functionality required to perform air quality analyses that help to address permitting, regulatory, and nuisance issues, as well as perform academic research. Breeze AERMOD/ISC offers the most complete air quality modeling system available on the market today. (EPA, 2017).

Mercury (Hg) exists in various forms: elemental (or metallic), inorganic, and organic. These forms of mercury differ in their degree of toxicity and their effects on the nervous, digestive, and immune systems, as well as the lungs, kidneys, skin, and eyes. Most people are exposed to low levels of mercury over a long period of time (chronic exposure). However, others are exposed to high levels of mercury for short periods (acute exposures). An example of acute exposure would be mercury exposure due to an industrial accident. Many factors affect the health outcome of Hg exposure, including the form of Hg, dose, developmental stage of the exposed person, duration of exposure, and route of exposure (WHO, 31 March 2017).

Health risk assessment (HRA) is the process of evaluating the nature and likelihood of unfavourable health consequences among people exposed to chemicals in polluted environment. HRA has four main stages, including hazard identification, dose-response assessment, exposure assessment, and risk characterization. The two types of HRA are carcinogenic and non-carcinogenic health risk assessments. The advantages of HRA are that it provides: (1) a snapshot of current health status; (2) data to support the decision-making of new programs or plans; and (3) data necessary to follow up with at-risk populations. (Gyamfi, 2020)

The present study aims to predict the ambient mercury concentrations using the AERMOD dispersion model, assess their inhalation health risks at different distances from a coal-fired cement plant employing anthracene coal as an alternative fuel in Helwan, and identify the safe ambient downwind distances from the stacks.

Material and Methods

This case study was conducted during the period from September 2019 to August 2020 (during the four seasons) within a cement production plant in the Helwan zone, Cairo, Egypt. The coordinates of the plant are 29° 49' 20.38" N and 31° 18' 28.28" E. The cement plant is using anthracene coal as an alternative fuel. The concentrations of Hg emitted from the stacks were obtained through sampling and analysis of stack mercury emissions in both particulate and vapor phases. Company data were collected using a company data sheet, including stack height, diameter, and emission rate. Meteorological data were obtained from Trinity Consultants, Inc., including wind speed and direction, temperature, humidity, and rainfall. Topographic characteristics of the area, including altitude, steepness, and topographic type, were obtained from the USGS Science for a Changing World (EPA, 2017).

Mercury emissions were sampled using an Apex isokinetic sampler, Model X5000, Apex-USA. The total sampling time was 120 minutes for each run, which was divided equally between the two sampling stages. The first 60 minutes were for the sampling of particulate mercury (P-Hg) at six points from two ports in the stack according to the standard methods of EPA ISO-Kinetic Method No. 5 using filtration techniques (EPA, 2020). The second 60 minutes were for the sampling of vaporized mercury (V-Hg) at six points from two stack ports based on the EPA isokinetic method 29 (SRI-Atmosphere, 2017) (EPA, 2016). The absorbing solution of mercury vapor was 4% potassium permanganate (Sigma Aldrich-Merck grade), which was set up in an impinger that was preceded by a10% hydrogen peroxide (Sigma Aldrich-Merck grade) impinger to absorb SO_2 from the air (SO_2 may cause interference). The two sampling stages were conducted at a rate of 25 l/min (SRI-Atmosphere, 2017).

Atomic Absorption Spectrometer–2015 - USA model PerkinElmer PinAAcle 900T was used for analysis of V-Hg, and P-Hg samples after digestion using 5% nitric acid of Fisher Grade and filtration (Yuan, 2014). After analysis, the P-Hg and V-Hg emission loads were calculated using equations (7) and(8) (EPA, 2016, 2020) and (EPA, 2017). Stack volumetric gas flow can be calculated from the next equation:

$$f = v \times \pi r^2 \qquad (1)$$

where f is the flow rate of air released from the stack in cubic meters per hour (m^3/h), v is the air velocity in the stack in meters per second (m/sec), π is a constant equal to 3.14, and r is the radius of the inner stack (m).

$$L = C \times f \qquad (2)$$

where L is the load of mercury in the air released from the stack in milligrams per hour (mg/h), C is the articulate or vapor mercury concentration in the sample in milligrams per cubic meter (mg/m^3), and f is the flow rate of air released from the stack in cubic meters per hour (m^3/h).

$$final\ L\ (g/sec) = \frac{L\ (mg/hour)}{36 \times 10^5} \qquad (3)$$

Where *final L* is the input data in the model in grams per second (g/sec), and L is the calculated load in milligrams per hour (mg/h) divided by 1000 to convert milligrams to grams and divided by 3600 to convert hours to seconds. All previous equations were used to calculate the P-Hg and V-Hg loads to enable the calculation of the hazard quotient HQ of each separately.

The American Meteorological Society-Environmental Protection Agency Regulatory Model (AERMOD) was applied as a Gaussian Plume Air Dispersion Model. It was fed by the input data, which include the meteorological AERMOD form files, a terrain file for the Helwan, characteristics of the point source emission data, and the total mercury load in grams per second (EPA, 2017). The US-EPA AERMOD Dispersion Modelling Program was applied to predict the ambient concentrations of P-Hg and V-Hg at many distances from the specified source (AERMOD program doesn't calculate in the area where program expects the emission load to be zero) (EPA, 2017).

To predict inhalation health risks of ambient P-Hg and V-Hg at different distances from the source; equations (4) and (5) were used to calculate the mercury hazard quotient as a non-carcinogenic hazard that may be inhaled by adults and children in the areas around the point source of mercury emissions (EPA, 2011).

$$\text{Average Daily intake of Hg via inhalation } (ADI_{inh}) = C_s \times \frac{Inh_g \times EF \times ED}{PEF \times BW \times AT} \qquad (4)$$

Where Inh_g = the inhalation rate (m^3/day), for adults = 20 m^3/day, for children = 7.5 m^3/day, EF (exposure factor) = 350 days/year, ED is the exposure duration, for adults = 30 years, for children = 6 years, PEF (person exposure factor) = 1.36×10^9 m^3/Kg, BW= Body Weight in Kg = 70 Kg for adults, 15 Kg for children, AT = Averaging time in days = For adults 30*365 = 10950 days, and children 6*365=2190 days.

The Non-carcinogenic inhalation hazard quotient of V-Hg and P-Hg were calculated using equation (5):

$$\text{Non-Carcinogenic Inhalation Hazard Quotient} = HQ_{inh} = \frac{ADI_{inh}}{RFD} \qquad (5)$$

Where: RFD = the reference dose in mg/kg/day = 2.86×10^6 for inhalation.
The Non-carcinogenic inhalation health index of mercury was calculated using equation (6):

$$HI = P\text{-}HQ + V\text{-}HQ \qquad (6)$$

Results

The stack mercury concentrations (mg/m^3) and loads (grams/sec) from line 1 were higher than those from line 2. Moreover, the concentrations of the total mercury emissions were higher than the Egyptian maximum emission limits stated in Annex 6 Table 6 of the Egyptian Prime Minister Decree No. 1963-2017 (Table (1)). Then, the air modeling program (AERMOD) was operated to identify the pathway of the movement of the mercury load within the wind direction and wind speed in the area around the plants.

Regarding line 1 stack, , the autumn stack sample indicated that the most effective wind speed and direction were from 3.60 to 5.70 m/sec (a gentle to moderate breeze) and the prevailing wind direction was northwest (NW) to north (N) (Figure (1a). Moreover, the estimated safe distance free from ambient Hg was higher than 4500 m from the stack (Figures (1b, 1c). The two winter samples showed higher effective wind speeds ranging from 5.7 to more than 11.10 m/sec (Figure 3a, 5a) with a prevailing wind direction of west-southwest (WSW) and northeast (NE) (Figures 3a, 5a), and safe distances of more than 4500 and 5200 m respectively (Figures (3b-3c), (5b-5c)). The spring sample exhibited a wind speed range of 2.1-5.7 m/sec that represent calm to gentle to moderate breeze (Figure 7a), with prevailing wind direction of north-northwest-west (N-NW-W), and safe distance of higher than 4700 m (Figures (7b, 7c)). The summer samples displayed wind speed ranged from 2.10 to 11.10 m/sec that represent gentle to strong breeze, with prevailing wind directions south southwest (SSW) to northwest (NW) and north northwest (NNW) (Figure (9a, 11a), and safe distances of 3200 and 3800 m respectively (Figures (9b-9c), (11b-11c)).

Concerning line 2, the autumn sample, the autumn stack sample indicated that the most effective wind speed and direction were from 3.60 to 5.70 m/sec (a gentle to moderate breeze) and the prevailing wind direction was northwest (NW) to north (N) (Figure (2a). Moreover, the estimated safe distance free from ambient Hg was higher than 4500 m from the stack (Figures (2b, 2c). The two winter samples showed higher effective wind speeds ranging from 5.70 to 8.80 m/sec (Figures 4a, 6a) with a prevailing wind direction of southwest (SW) to north (N) and northeast (NE), and safe distances of more than 5200 and 4500 m respectively (Figures (4b-4c), (6b-6c)). The spring sample exhibited a wind speed range of 3.60 -5.70 m/sec that represent calm to gentle to moderate breeze (Figure 8a), with prevailing wind direction of northwest (NW) to north (N), and safe distance of higher than 3500 m (Figures (8b – 8c)). The summer samples displayed wind speed ranged from 5.70 to 8.80 m/sec that represent moderate breeze to fresh breeze, with prevailing wind direction northwest (NW) to north (N) (Figures 10a, 12a), and safe distances of 4200 and 4500 m respectively (Figures (10b-10c), (12b-12c)).

Table (1): Concentrations and Load of mercury emissions from the two lines of the Cement Plant using anthracene coal as alternative fuels (2019-2020)

Month	Sampling Season	Line-1				Line-2			
		Vapor Mercury		Particulate Mercury		Vapor Mercury		Particulate Mercury	
		C (mg/ m^3)	L (gram/ sec)	C (mg/ m^3)	L (gram/ sec)	C (mg/ m^3)	L (gram/ sec)	C (mg/ m^3)	L (gram/ sec)
October 2019	Autumn	0.004	0.000	0.085	0.001	0.062	0.001	0.227	0.002
December 2019	Winter	0.148	0.001	0.427	0.004	0.079	0.001	0.276	0.003
February 2020	Winter	0.115	0.001	0.508	0.005	0.094	0.001	0.413	0.004
April 2020	Spring	0.074	0.001	0.428	0.004	0.085	0.001	0.220	0.002
June 2020	Summer	0.097	0.001	0.350	0.003	0.059	0.003	0.295	0.001
August 2020	Summer	0.076	0.001	0.247	0.002	0.021	0.000	0.308	0.002
Egyptian Maximum Emission Limit (mg/m^3)		0.05	-	0.05	-	0.05	-	0.05	-

C Concentration in mg/m^3

L Load in gram/sec

Egyptian Maximum Emission Limit according to Annex 6 table 6 the Egyptian Prime Minister Decree No 1963-2017

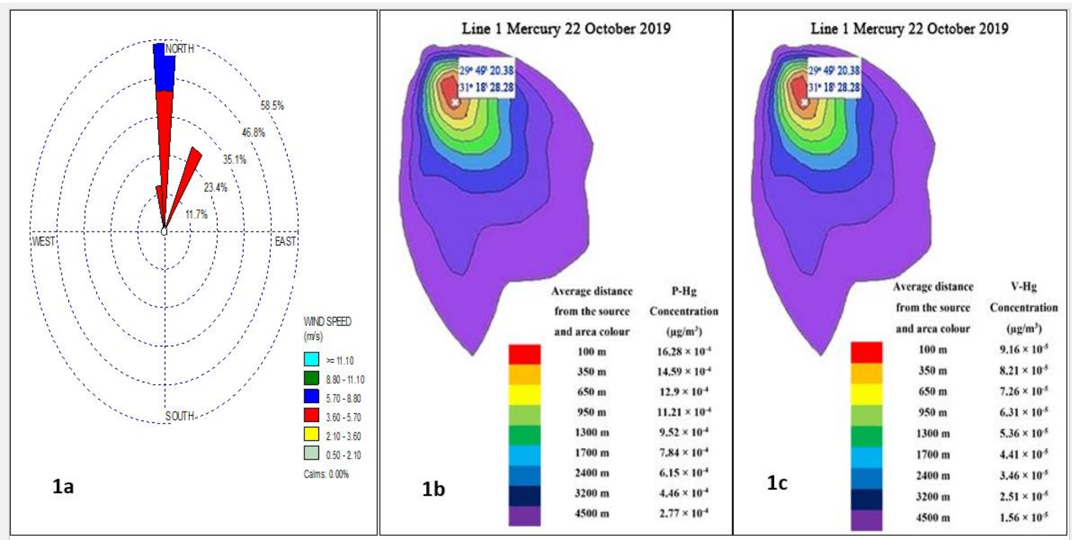

Figure (1): Output of the AERMOD model of line 1 in Helwan area during the day of sampling (October 22nd , 2019) 1a (Wind speed (m/sec) and direction), 1b (Dispersion model of Particulate Mercury emission load in line 1), and 1c (Dispersion model of Vapour Mercury emission load)

Table (2): Non-Carcinogenic Inhalation Hazard Quotient and inhalation Health Index of the predicted ambient mercury around line 1 stack – October 22, 2019 (Autumn)

Mercury HQ	100 m	350 m	650 m	950 m	1300 m	1700 m	2400 m	3200 m	4500 m
Mercury Vapour - Adults	4.52E-8	4.05E-8	3.58E-8	3.11E-8	2.64E-8	2.18E-8	1.71E-8	1.24E-8	7.69E-9
Mercury Particulate - Adults	8.03E-7	7.19E-7	6.36E-7	5.53E-7	4.70E-7	3.87E-7	3.03E-7	2.20E-7	1.37E-7
HI of adults	8.48E-07	7.60E-07	6.72E-07	5.84E-07	4.96E-07	4.09E-07	3.20E-07	2.32E-07	1.45E-07
Mercury Vapor - Children	3.01E-9	2.70E-9	2.39E-9	2.08E-9	1.76E-9	1.45E-9	1.14E-9	8.25E-10	5.13E-10
Mercury Particulate - Children	5.35E-8	4.80E-8	4.24E-8	3.69E-8	3.13E-8	2.58E-8	2.02E-8	1.47E-8	9.12E-9
HI of children	5.65E-08	5.07E-08	4.48E-08	3.90E-08	3.31E-08	2.73E-08	2.13E-08	1.55E-08	9.63E-09

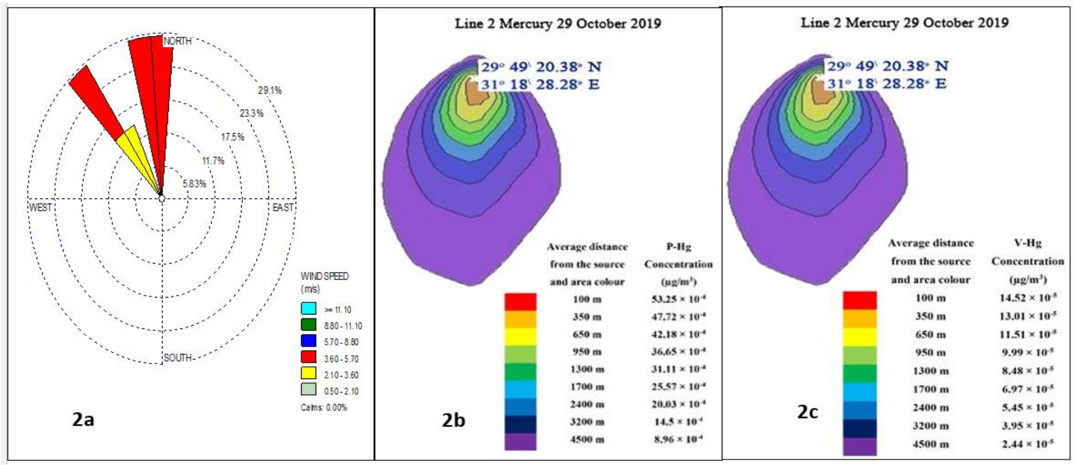

Figure (2): Output of the AERMOD model of line 2 in Helwan area during the day of sampling (October 29th, 2019)2a (Wind speed (m/sec) and direction), 2b (Dispersion model of Particulate Mercury emission load in line 2), and2c (Dispersion model of Vapour Mercury emission load)

Table (3): Non-Carcinogenic Inhalation Hazard Quotient and Inhalation Health Index of the predicted ambient mercury around line 2 stack – October 29, 2019 (Autumn)

Mercury HQ	100 m	350 m	650 m	950 m	1300 m	1700 m	2400 m	3200 m	4500 m
Mercury Vapour - Adults	7.16E-7	6.42E-7	5.67E-7	4.93E-7	4.18E-7	3.44E-7	2.69E-7	1.95E-7	1.21E-7

Mercury Particulate - Adults	2.63E-6	2.35E-6	2.08E-6	1.81E-6	1.53E-6	1.26E-6	9.88E-7	7.15E-7	4.42E-7
HI of adults	3.35E-06	2.99E-06	2.65E-06	2.30E-06	1.95E-06	1.60E-06	1.26E-06	9.10E-07	5.63E-07
Mercury Vapour - Children	4.77E-8	4.28E-8	3.78E-8	3.29E-8	2.79E-8	2.29E-8	1.80E-8	1.30E-8	8.04E-9
Mercury Particulate - Children	1.75E-7	1.57E-7	1.39E-7	1.20E-7	1.02E-7	8.41E-8	6.59E-8	4.77E-8	2.95E-8
HI of children	2.23E-07	2.00E-07	1.77E-07	1.53E-07	1.30E-07	1.07E-07	8.39E-08	6.07E-08	3.75E-08

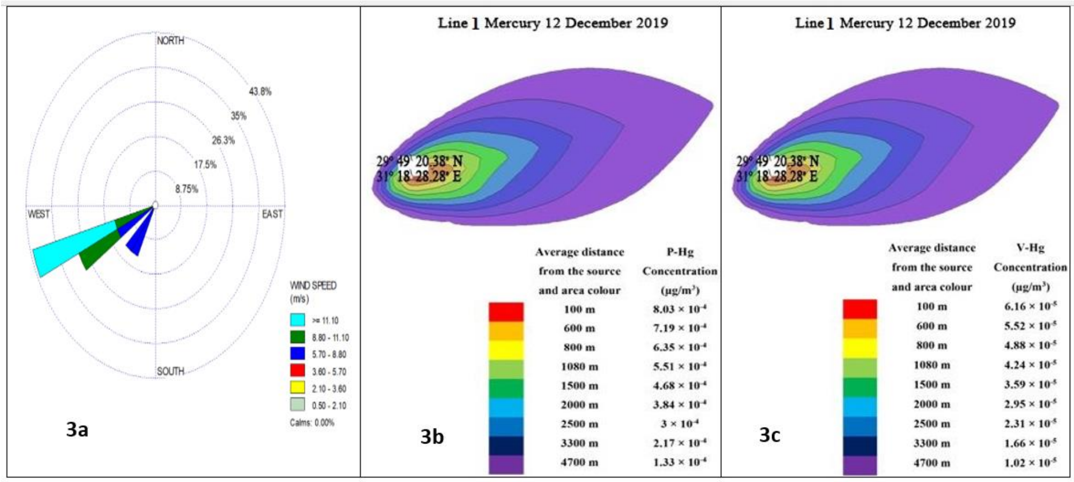

Figure (3): Output of the AERMOD model of line 1 in Helwan area during the day of sampling (December 12th ,2019) 3a (Wind speed (m/sec) and direction), 3b (Dispersion model of Particulate Mercury emission load in line 1), and 3c (Dispersion model of Vapour Mercury emission load)

Table (4): Non-Carcinogenic Inhalation Hazard Quotient and inhalation Health Index of the predicted ambient mercury around line 1 stack – December 2019 (Winter)

Mercury HQ	100 m	600 m	800 m	1080 m	1500 m	2000 m	2500 m	3300 m	4700 m
Mercury Vapour - Adults	3.04E-7	2.72E-7	2.41E-7	2.09E-7	1.77E-7	1.45E-7	1.14E-7	8.21E-8	5.04E-8
Mercury Particulate - Adults	3.96E-6	3.55E-6	3.13E-6	2.72E-6	2.31E-6	1.89E-6	1.48E-6	1.07E-6	6.56E-7
HI of adults	4.26E-06	3.82E-06	3.37E-06	2.93E-06	2.49E-06	2.04E-06	1.59E-06	1.15E-06	7.06E-07
Mercury vapor -	2.03E-8	1.82E-8	1.60E-8	1.39E-8	1.18E-8	9.70E-9	7.58E-9	5.47E-9	3.36E-9

Children									
Mercury Particulate - Children	2.64E-7	2.36E-7	2.09E-7	1.81E-7	1.54E-7	1.26E-7	9.88E-8	7.12E-8	4.37E-8
HI of children	2.84E-07	2.54E-07	2.25E-07	1.95E-07	1.66E-07	1.36E-07	1.06E-07	7.67E-08	4.71E-08

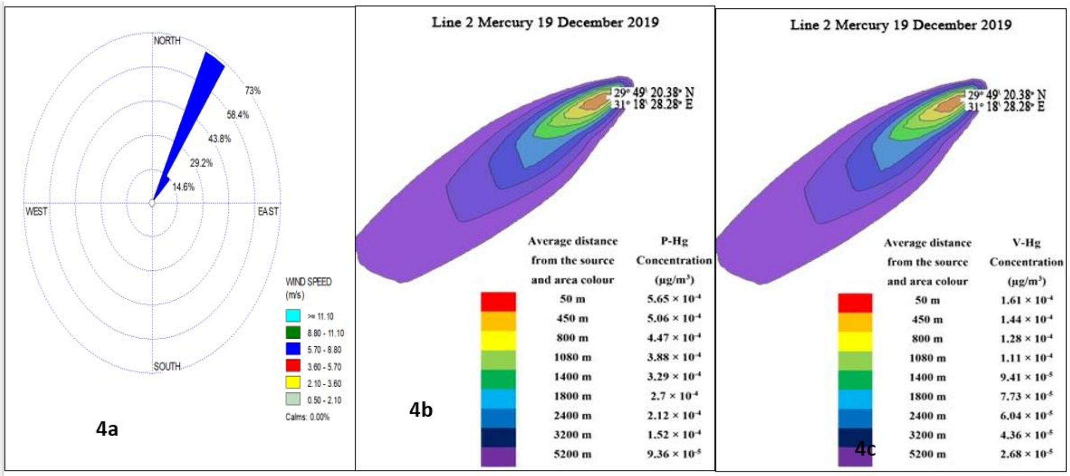

Figure (4): Output of the AERMOD model of line 2 in Helwan area during the day of sampling (December 19th, 2019) 4a (Wind speed (m/sec) and direction), 4b (Dispersion model of Particulate Mercury emission load in line 2), and 4c (Dispersion model of Vapour Mercury emission load)

Table (5): Non-Carcinogenic Inhalation Hazard Quotient and inhalation Health Index of the predicted ambient mercury around line 2 stack – December 2019 (Winter)

Mercury HQ	50 m	450 m	800 m	1050 m	1400 m	1800 m	2400 m	3200 m	5200 m
Mercury Vapour - Adults	7.96E-7	7.13E-7	6.30E-7	5.47E-7	4.64E-7	3.81E-7	2.98E-7	2.15E-7	1.32E-7
Mercury Particulate - Adults	2.79E-6	2.50E-6	2.21E-6	1.91E-6	1.62E-6	1.33E-6	1.04E-6	7.52E-7	4.62E-7
HI of adults	3.59E-06	3.21E-06	2.84E-06	2.46E-06	2.08E-06	1.71E-06	1.34E-06	9.67E-07	5.94E-07
Mercury Vapour - Children	5.31E-8	4.75E-8	4.20E-8	3.65E-8	3.09E-8	2.54E-8	1.99E-8	1.43E-8	8.80E-9
Mercury Particulate - Children	1.86E-7	1.66E-7	1.47E-7	1.28E-7	1.08E-7	8.89E-8	6.95E-8	5.02E-8	3.08E-8
HI of children	2.39E-07	2.14E-07	1.89E-07	1.65E-07	1.39E-07	1.14E-07	8.94E-08	6.45E-08	3.96E-08

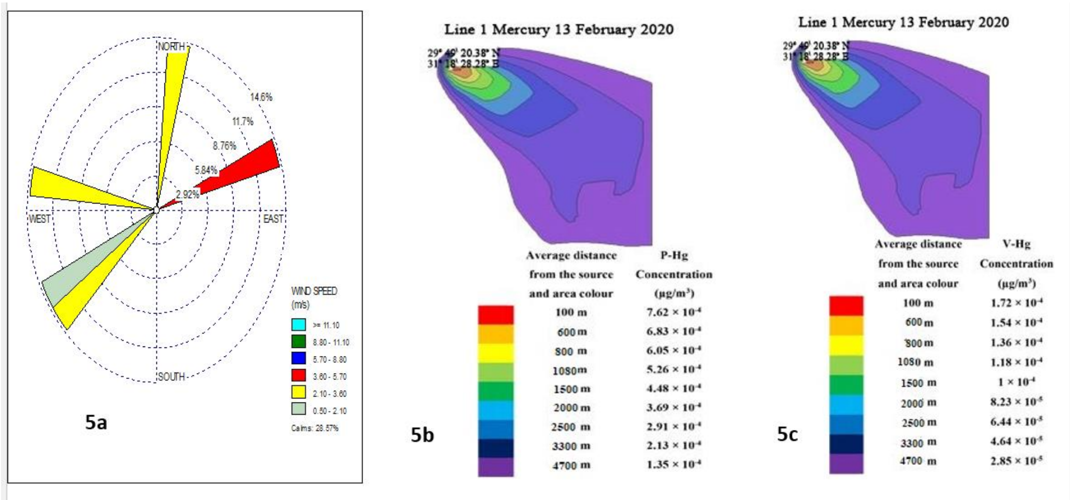

Figure (5): Output of the AERMOD model of line 1 in Helwan area during the day of sampling (February 13th, 2020)5a (Wind speed (m/sec) and direction), 5b (Dispersion model of Particulate Mercury emission load in line 1), and 5c (Dispersion model of Vapour Mercury emission load)

Table (6): Non-Carcinogenic Inhalation Hazard Quotient and inhalation Health Index of the predicted ambient mercury around line 1 stack – February 2020 (Winter)

Mercury HQ	100 m	600 m	800 m	1080 m	1500 m	2000 m	2500 m	3300 m	4700 m
Mercury Vapour - Adults	8.48E-7	7.60E-7	6.71E-7	5.83E-7	4.94E-7	4.06E-7	3.17E-7	2.29E-7	1.41E-7
Mercury Particulate - Adults	3.76E-6	3.37E-6	2.98E-6	2.60E-6	2.21E-6	1.82E-6	1.44E-6	1.05E-6	6.63E-7
HI of adults	4.61E-06	4.13E-06	3.65E-06	3.18E-06	2.70E-06	2.23E-06	1.76E-06	1.28E-06	8.04E-07
Mercury Vapour - Children	5.66E-8	5.07E-8	4.48E-8	3.89E-8	3.30E-8	2.71E-8	2.12E-8	1.53E-8	9.37E-9
Mercury Particulate - Children	2.50E-7	2.25E-7	1.99E-7	1.73E-7	1.47E-7	1.22E-7	9.57E-8	7.00E-8	4.42E-8
HI of children	3.07E-07	2.76E-07	2.44E-07	2.12E-07	1.80E-07	1.49E-07	1.17E-07	8.53E-08	5.36E-08

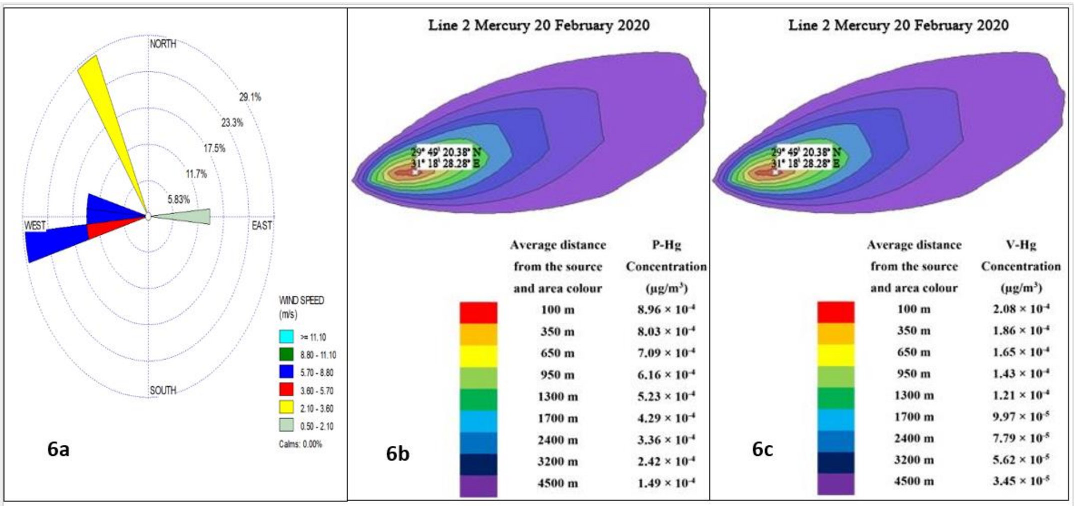

Figure (6): Output of the AERMOD model of line 2 in Helwan area during the day of sampling (February 20th, 2020) 6a (Wind speed (m/sec) and direction), 6b (Dispersion model of Particulate Mercury emission load in line 2), and 6c (Dispersion model of Vapour Mercury emission load)

Table (7): Non-Carcinogenic Inhalation Hazard Quotient and inhalation Health Index of the predicted ambient mercury around line 2 stack – February 2020 (Winter)

Mercury HQ	100 m	350 m	650 m	950 m	1300 m	1700 m	2400 m	3200 m	4500 m
Mercury Vapour - Adults	1.03E -6	9.20E-7	8.13E-7	7.06E-7	5.99E-7	4.91E-7	3.84E-7	2.77E-7	1.70E-19
Mercury Particulate - Adults	4.42E -6	3.96E-6	3.50E-6	3.04E-6	2.58E-6	2.12E-6	1.65E-6	1.19E-6	7.32E-7
HI of adults	5.45E -06	4.88E-06	4.31E-06	3.75E-06	3.18E-06	2.61E-06	2.03E-06	1.47E-06	7.32E-07
Mercury Vapour - Children	6.85E -8	6.13E-8	5.42E-8	4.70E-8	3.99E-8	3.28E-8	2.56E-8	1.85E-8	1.13E-8
Mercury Particulate - Children	2.95E -7	2.64E-7	2.33E-7	2.02E-7	1.72E-7	1.41E-7	1.10E-7	7.95E-8	4.88E-8
HI of children	3.64E -07	3.25E-07	2.87E-07	2.49E-07	2.12E-07	1.74E-07	1.36E-07	9.80E-08	6.01E-08

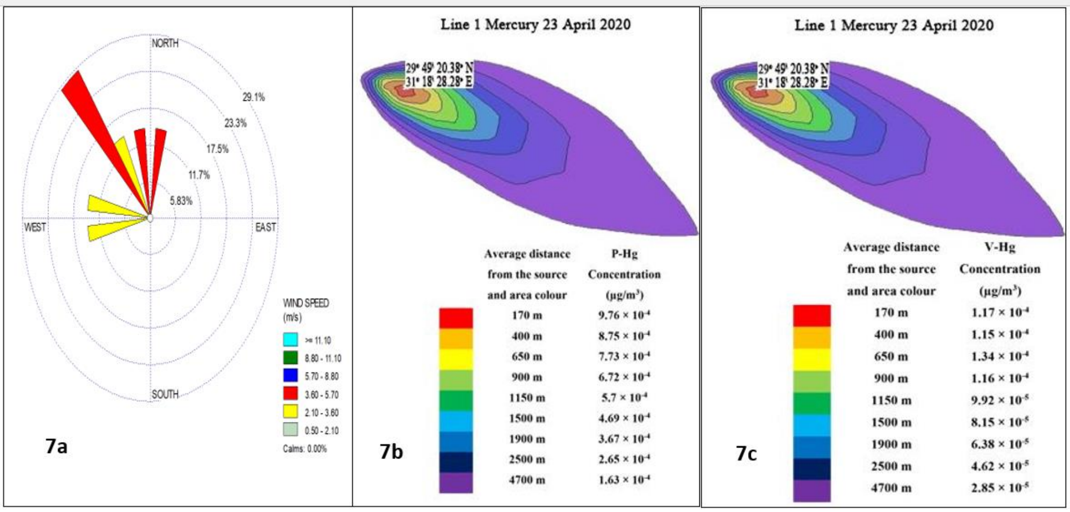

Figure (7): Output of the AERMOD model of line 1 in Helwan area during the day of sampling (April 23rd, 2020) 7a (Wind speed (m/sec) and direction), 7b (Dispersion model of Particulate Mercury emission load in line 1), and 7c (Dispersion model of Vapour Mercury emission load)

Table (8): Non-Carcinogenic Inhalation Hazard Quotient and inhalation Health Index of the predicted ambient mercury around line 1 stack – April 2020 (Spring)

Mercury HQ	170 m	400 m	650 m	900 m	1150 m	1500 m	1900 m	2500 m	4700 m
Mercury Vapour - Adults	8.38E -7	7.51E-7	6.63E-7	5.76E-7	4.89E-7	4.02E-7	3.15E-7	2.28E-7	1.41E-7
Mercury Particulate - Adults	4.82E -6	4.32E-6	3.81E-6	3.31E-6	2.81E-6	2.31E-6	1.81E-6	1.31E-6	8.08E-7
HI of adults	5.66E -06	5.07E-06	4.47E-06	3.89E-06	3.30E-06	2.71E-06	2.13E-06	1.54E-06	9.49E-07
Mercury Vapour - Children	5.58E -8	5.00E-8	4.42E-8	3.84E-8	3.26E-8	2.68E-8	2.10E-8	1.52E-8	9.37E-9
Mercury Particulate - Children	3.21E -7	2.88E-7	2.54E-7	2.21E-7	1.88E-7	1.54E-7	1.21E-7	8.73E-8	5.39E-8
HI of children	3.77E -07	3.38E-07	2.98E-07	2.59E-07	2.21E-07	1.81E-07	1.42E-07	1.03E-07	6.33E-08

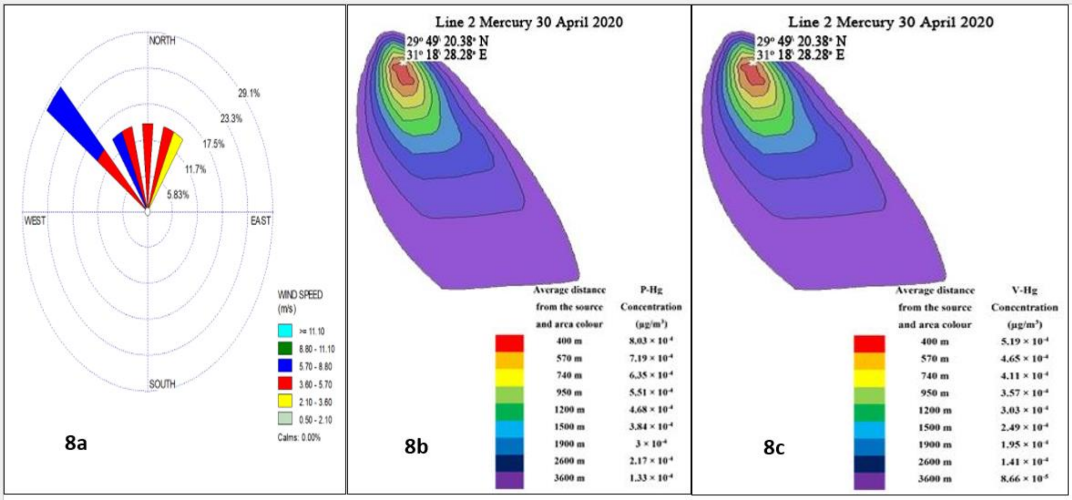

Figure (8): Output of the AERMOD model of line 2 in Helwan area during the day of sampling (April 30th, 2020) 8a (Wind speed (m/sec) and direction), 8b (Dispersion model of Particulate Mercury emission load in line 2), and 8c (Dispersion model of Vapour Mercury emission load)

Table (9): Non-Carcinogenic Inhalation Hazard Quotient and inhalation Health Index of the predicted ambient mercury around line 2 stack – April 2020 (Spring)

Mercury HQ	400 m	570 m	740 m	950 m	1200 m	1500 m	1900 m	2600 m	3600 m
Mercury Vapour - Adults	9.84E -7	8.81E-7	7.79E-7	6.77E-7	5.74E-7	4.72E-7	3.69E-7	2.67E-7	1.64E-7
Mercury Particulate - Adults	2.56E -6	2.29E-6	2.03E-6	1.76E-6	1.49E-6	1.23E-6	9.60E-7	6.93E-7	4.27E-7
HI of adults	3.54E -06	3.17E-06	2.81E-06	2.44E-06	2.06E-06	1.70E-06	1.33E-06	9.60E-07	5.91E-07
Mercury Vapour - Children	6.56E -8	5.88E-8	5.19E-8	4.51E-8	3.83E-8	3.14E-8	2.46E-8	1.78E-8	1.09E-8
Mercury Particulate - Children	1.71E -7	1.53E-7	1.35E-7	1.17E-7	9.95E-8	8.17E-8	6.40E-8	4.62E-8	2.85E-8
HI of children	2.37E -07	2.12E-07	1.87E-07	1.62E-07	1.38E-07	1.13E-07	8.86E-08	6.40E-08	3.94E-08

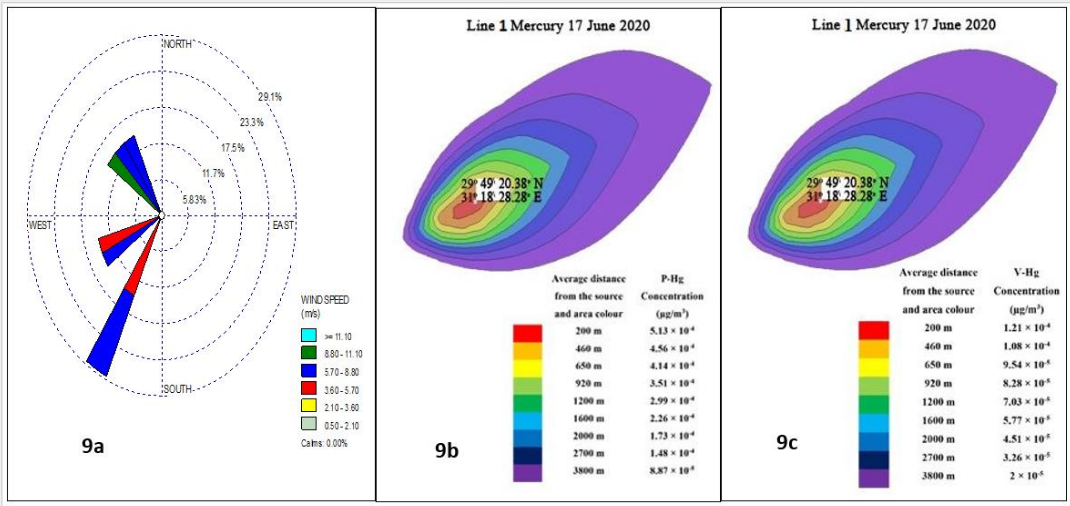

Figure (9): Output of the AERMOD model of line 1 in Helwan area during the day of sampling (June 17th, 2020) 9a (Wind speed (m/sec) and direction), 9b (Dispersion model of Particulate Mercury emission load in line 1), and 9c (Dispersion model of Vapour Mercury emission load)

Table (10): Non-Carcinogenic Inhalation Hazard Quotient and inhalation Health Index of the predicted ambient mercury around line 1 stack – June 2020 (Summer)

Mercury HQ	200 m	460 m	650 m	920 m	1200 m	1600 m	2000 m	2700 m	3800 m
Mercury Vapour - Adults	7.00E-7	6.27E-7	5.54E-7	4.81E-7	4.08E-7	3.35E-7	2.62E-7	1.89E-7	1.16E-7
Mercury Particulate - Adults	2.52E-6	2.26E-6	1.99E-6	1.73E-6	1.47E-6	1.21E-6	9.43E-7	6.80E-7	4.18E-7
HI-adult	3.22E-06	2.89E-06	2.54E-06	2.21E-06	1.88E-06	1.55E-06	1.21E-06	8.69E-07	5.34E-07
Mercury Vapour - Children	4.67E-8	4.18E-8	3.69E-8	3.21E-8	2.72E-8	2.23E-8	1.75E-8	1.26E-8	7.73E-9
Mercury Particulate - Children	1.68E-7	1.51E-7	1.33E-7	1.15E-7	9.79E-8	8.04E-8	6.29E-8	4.54E-8	2.78E-8
HI-children	2.15E-07	1.93E-07	1.70E-07	1.47E-07	1.25E-07	1.03E-07	8.04E-08	5.80E-08	3.55E-08

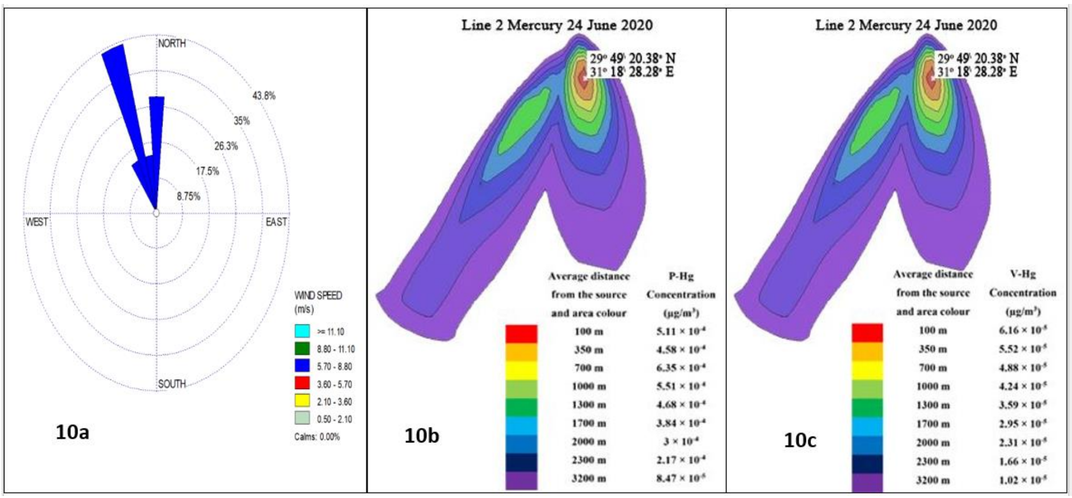

Figure (10): Output of the AERMOD model of line 2 in Helwan area during the day of sampling (June 24th, 2020) 10a (Wind speed (m/sec) and direction), 10b (Dispersion model of Particulate Mercury emission load in line 2), and 10c (Dispersion model of Vapour Mercury emission load)

Table (11): Non-Carcinogenic Inhalation Hazard Quotient and inhalation Health Index of the predicted ambient mercury around line 2 stack – June 2020 (Summer)

Mercury HQ	200 m	460 m	650 m	920 m	1200 m	1600 m	2000 m	2700 m	3800 m
Mercury Vapour - Adults	5.94E-7	5.32E-7	4.70E-7	4.08E-7	3.46E-7	2.84E-7	2.23E-7	1.61E-7	9.87E-8
Mercury Particulate - Adults	2.52E-6	2.26E-6	1.99E-6	1.73E-6	1.47E-6	1.21E-6	9.43E-7	6.80E-7	4.18E-7
HI of adults	3.11E-06	2.79E-06	2.46E-06	2.14E-06	1.82E-06	1.49E-06	1.17E-06	8.41E-07	5.17E-07
Mercury Vapour - Children	3.96E-8	3.55E-8	3.14E-8	2.72E-8	2.31E-8	1.90E-8	1.48E-8	1.07E-8	6.58E-9
Mercury Particulate - Children	1.68E-7	1.51E-7	1.33E-7	1.15E-7	9.79E-8	8.04E-8	6.29E-8	4.54E-8	2.78E-8
HI of children	2.08E-07	1.87E-07	1.64E-07	1.42E-07	1.21E-07	9.94E-08	7.77E-08	5.61E-08	3.44E-08

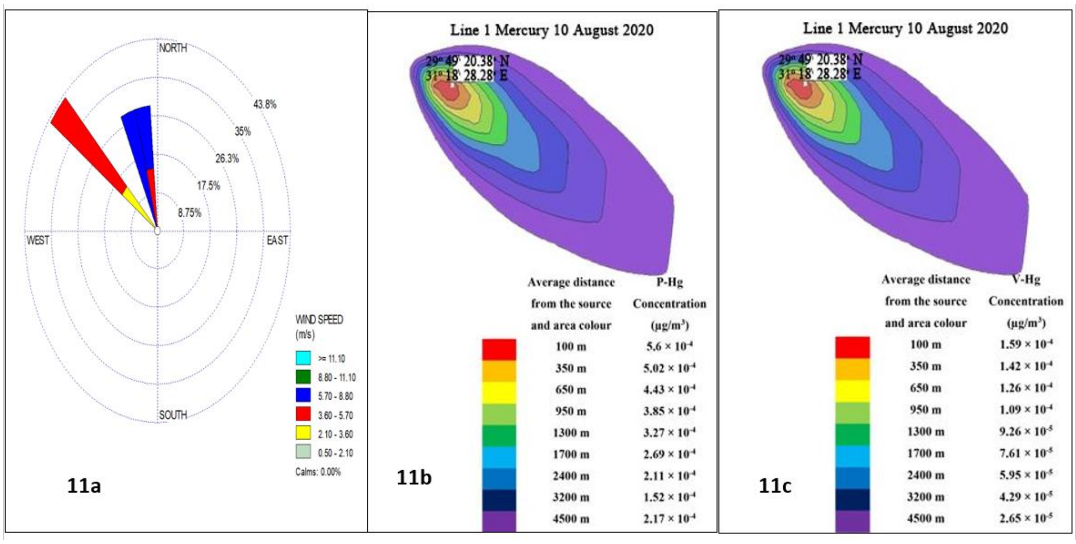

Figure (11): Output of the AERMOD model of line 1 in Helwan area during the day of sampling (August 10th, 2020) 11a (Wind speed (m/sec) and direction), 11b (Dispersion model of Particulate Mercury emission load in line 1), and 11c (Dispersion model of Vapour Mercury emission load)

Table (12): Non-Carcinogenic Inhalation Hazard Quotient and inhalation Health Index of the predicted ambient mercury around line 1 stack – August 2020 (Summer)

Mercury HQ	100 m	350 m	650 m	950 m	1300 m	1700 m	2400 m	3200 m	4500 m
Mercury Vapour - Adults	7.83E-7	7.01E-7	6.20E-7	5.38E-7	4.57E-7	3.75E-7	2.94E-7	2.12E-7	1.30E-7
Mercury Particulate - Adults	2.76E-6	2.47E-6	2.19E-6	1.90E-6	1.61E-6	1.33E-6	1.04E-6	7.51E-7	4.64E-7
HI of adults	3.54E-06	3.17E-06	2.81E-06	2.44E-06	2.07E-06	1.71E-06	1.33E-06	9.63E-07	5.94E-07
Mercury Vapour - Children	5.22E-8	4.68E-8	4.13E-8	3.59E-8	3.04E-8	2.50E-8	1.96E-8	1.41E-8	8.70E-9
Mercury Particulate - Children	1.84E-7	1.65E-7	1.46E-7	1.27E-7	1.08E-7	8.84E-8	6.92E-8	5.01E-8	3.09E-8
HI of children	2.36E-07	2.12E-07	1.87E-07	1.63E-07	1.38E-07	1.13E-07	8.88E-08	6.42E-08	3.96E-08

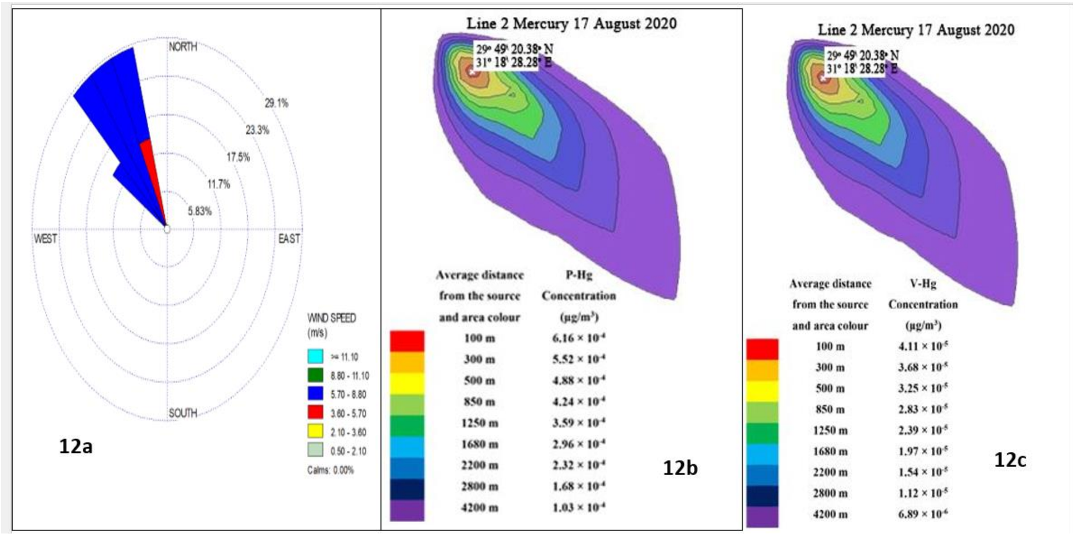

Figure (12): Output of the AERMOD model of line 2 in Helwan area during the day of sampling (August 17th, 2020) 12a (Wind speed (m/sec) and direction), 12b (Dispersion model of Particulate Mercury emission load in line 2), and 12c (Dispersion model of Vapour Mercury emission load)

Table (13): Non-Carcinogenic Inhalation Hazard Quotient and inhalation Health Index of the predicted ambient mercury around line 2 stack – August 2020 (Summer)

Mercury HQ	100 m	300 m	500 m	850 m	1250 m	1680 m	2200 m	2800 m	4200 m
Mercury Vapour - Adults	2.03E-7	1.82E-7	1.60E-7	1.39E-7	1.18E-7	9.72E-8	7.62E-8	5.51E-8	3.40E-8
Mercury Particulate - Adults	3.04E-6	2.72E-6	2.41E-6	2.09E-6	1.77E-6	1.46E-6	1.14E-6	8.26E-7	5.10E-7
HI of adults	3.24E-06	2.90E-06	2.57E-06	2.23E-06	1.89E-06	1.56E-06	1.22E-06	8.81E-07	5.44E-07
Mercury Vapour - Children	1.35E-8	1.21E-8	1.07E-8	9.29E-9	7.89E-9	6.48E-9	5.08E-9	3.67E-9	2.27E-9
Mercury Particulate - Children	2.03E-7	1.82E-7	1.60E-7	1.39E-7	1.18E-7	9.72E-8	7.62E-8	5.51E-8	3.40E-8
HI of children	2.17E-07	1.94E-07	1.71E-07	1.48E-07	1.26E-07	1.04E-07	8.13E-08	5.88E-08	3.63E-08

Discussion

Mercury in the air has both deleterious health and environmental effects. (Rice et al., 2014) This study was based on the collection of twelve stack samples of air emitted from a cement plant using anthracene coal as an alternative fuel in the Helwan area. The sampling was conducted on the two production lines of the plant. The AERMOD model was used to predict the resultant ambient concentrations of P-Hg and V-Hg at different distances from the cement plant. Accordingly, the human health risks of the predicted ambient concentrations of Hg were estimated, and the safe distances free of ambient Hg were identified (Hereher, 2018).

Although more than 83% of the source V-Hg samples and 100% of the source P-Hg samples exceeded the emission limits stated in Table 6, Annex 6 of the Egyptian Prime Minister's Decree No 1963 for 2017 (P.E.Minister, 2017), all predicted ambient HQs and hazard indices HIs constitute low risks. In Poland, study of total gaseous mercury (TGM) and particulate mercury (PM2.5 bounded mercury - PBM) was measured at the urban background station in Zabrze in winter and summer season 2014–2015 (median 2.31 ng.m^{-3}). Selected results of TGM and PBM measurements in European locations and for comparison, in some urban sites of North America and Asia, are summarized in Table 3. The mean of TGM concentrations in Zabrze was lower than for Chinese cities, like those found in Seoul (South Korea), 2012–2013, and higher than reported by Mao and co-authors for urban sites in Europe, North America, and Asia (median 2.1 ng.m^{-3}). (Pyta, 2020)

The median and mean of hazard quotients (HQ) and hazard indices (HI) for TGM (total gaseous mercury) and PBM (particulate bounded mercury) concentrations was as follow:

- Zabrze location: HQ for TGM = 0.04010, while it was 0.00100 for PBM. HI in this location was 0.04109.
- Złoty Potok location: HQ for TGM = 0.02488, while it was 0.00055 for PBM. HI in this location was 0.02543. (Pyta, 2020)

This all considered with and the proposal of revised EPA's reference concentration (RfCR) = 0.07μg/m^3.

In the present study, the values of the ambient HI-Hg were greatly lower than one for both adults and children at all distances from the stacks of the two production lines. This indicates the very low inhalation health risk of the ambient Hg from the anthracene coal stacks of the cement plant. The HQs of adults were about 15 times higher than those of the children. This may be attributed to the higher inhalation rate (2.7 times), exposure duration (5.0 times), and body weight (11.7 times).

Conclusion

Living, working, or even studying in a place around a mercury releasing source must be controlled. In this study we found some concentration of mercury which may directly affect adults and children living beside the mercury source (plant stacks). Continuous monitoring of mercury in the atmosphere must consider in the environmental studies, research, and governmental control. It is very important to control the amount of mercury which can be releasing from different type of industrial plants and to obey the Minamata convention.(Kessler, 2013)

Using of coal in any type of it as a source of energy is produce an amount of mercury in air as an air pollutant. Also, we conclude that that movement of mercury particles with air is not make it go so far, as the wind speed in different sampling days was from calm or gentle breeze type (Guo & Technology, 2019), so the high concentration of mercury particles in all samples dispersion model was not exceeding the 4000 meters (4 kilometres) in all samples. That mean the main danger of mercury particles will directly affect the labours which work in the production lines directly, while the people outside the cement production plant with area more than 4000 meters from the point source will exposes to very low concentration of mercury or without any exposure, according to static phase of mercury in air which shown by the AERMAP diagram.

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