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Assessing and Modelling of Some Air Emissions Produced from MOPCO Fertilizers, Damietta, Egypt

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ABSTRACT

This study assesses the environmental aspects and air quality in chemical fertilizer industry. Misr Fertilizers Company (MOPCO) at Damietta, Egypt was used as a case study to monitor indoor and outdoor air emissions to find out the main source of air pollution and evaluate the air quality in the facility. MOPCO is located within the general free zone of Damietta Port and covers an area of 400,000 m^2 including three factories, three ammonia plants, and three urea production plants and a service area. Monitoring of carbon monoxide (CO), nitrogen dioxide (NO_2), ammonia (NH_3) and sulfur dioxide (SO_2) in addition to particulate matter (PM_{10}), noise and heat stress was carried out in the production units in MOPCO (e.g., filling area, ammonia pumping area, and boiler area (BFW) from January 2018 to July 2019. Outdoor air emissions were measured from the outlet stacks of granulation, reformer and the boiler at MOPCO. The obtained results from the three sites were less than the maximum permissible limits for CO (25 ppm), SO_2 (2 ppm), NO_2 (3 ppm), and NH_3 (25 ppm) according to Egyptian Environment Protection Low No. 4/1994 and its amendments (No. 9/2009). Detailed air dispersion modeling (AERMOD) was applied to determine the likelihood ground level concentrations resulting from the outdoor air emissions of NO_2, NH_3, CO and PM_{10} from the stacks in MOPCO. The individual risk exposures from MOPCO have been evaluated and found to be below the maximum tolerable risk levels allowed by the Egyptian Environment Protection Low No. 4/1994.

Keywords

Risk Assessment, Air quality, AERMOD, Fertilizers, MOPCO, Damietta

1. INTRODUCTION

The industrial activities have doubled levels of reactive nitrogen in circulation, largely come from fertilizer plants and fossil fuel burning. Interactions between nitrogen and climate need to be better assessed, taking also into account the other effects of nitrogen on human health and the environment [1]. This study investigates the environmental risk assessment of the chemical fertilizer industry, and MISR Fertilizers Production Co. (MOPCO) in Damietta, north Egypt as case study for nitrogen fertilizers (Fig. 1). We have applied a quantitative risk assessment method to map cumulative risk levels arising from a few risks located in MOPCO, a densely populated area where several industrial plants storing and processing dangerous substances are located [2]. Environmental risk assessment is an important step in the safety analysis of process systems in MOPCO. Therefore, this tendency urges the need for developing new criteria for environmental risk assessment [3]. Risk assessment (RA) has demonstrated its capabilities as a scientific method to analyse and prevent any process-equipment failure in MOPCO. Plant operations such as start-up performed repeatedly on the life cycle of a plant. Hence, the risk reduction measures for the environmental risk assessment of manufacture process which based on statistical analysis [4, 5]. Risk Communication (RC) is important to the chemical industries in case of major incidents that have a frequency less than many other chemical industries. RC provides benefits to society that largely save more lives [6]. The probability of the corresponding emergency response action in the proposed method is estimated through the accident probability analysis and its certain response actions [7, 8]. This estimation of the environmental consequence is applied on MOPCO plant based on a test of air exchange rate.

Air quality can be reduced by indoor and outdoor (from stacks) gas emissions from operation of the MOPCO plant such as SO_2, NO_2, CO and NH_3 [9]. Health impacts from occupational heat stress have significant impact in MOPCO, therefore heat stress was measured in the production units. The Wet Bulb Globe Temperatures (WBGT) was used to quantify the risk of heat stress, according to international workplace guidelines [10]. A noise notation can be used to indicate an increased risk of hearing loss after exposure to chemicals at a level close to the occupational exposure limit (OEL) with concurrent noise exposure [11].

Mitigation measures of particulate matter (in terms of PM_{10}) are carried out in MOPCO and will be adopted during the progress of the preconstruction and site preparation phase to reduce air pollution and to maintain the baseline air quality within the acceptable limits set by the Egyptian Environmental Affairs Agency (EEAA) [9].

This paper investigates the risk estimation and prediction of process hazards and air emissions within MOCPO, Egypt. Indoor and outdoor air emissions, heat stress, particulate matter and noise were measured at MOPCO according to the Egyptian Environmental Law guidelines [12]. In addition, a quantitative hazard model is applied on the measured data of MOPCO [13]. In this study, detailed air dispersion modelling (AERMOD) was applied to determine the likelihood ground level concentrations resulting from the outdoor air emissions of NO_2, NH_3, CO and PM_{10} from the stacks in MOPCO. In addition to provide a graphical and mathematical representation for risk modelling and reasoning [14], applied to the complexity of equipment in MOPCO. This study highlights the severity of the risk posed by the chemical fertilizer industry and thus generate safety consciousness among plant managers, also it assists in developing plans for accident prevention and environmental protection [15, 16].

2. MATERIALS AND METHODS

In this study, the criteria used in estimating the environmental risk of MOPCO Plant, Damietta, Egypt (Fig. 1) is utilized by measuring the following parameters; a) indoor emissions of hazardous gases (e.g., CO, NH_3, NO_2 and SO_2) in the production units in MOPCO (near Boiler Feed Water (BFW), Ammonia Bumps and Bagging site) using portable device IBRID MX6, USA; b) noise in the production units (at Main Boiler, BFW, Ammonia Bumps, Primary Reformer, Urea Bagging and Storage Sites, Ammonia Cooling Tower, Nitrogen Production Unit, Compressor Site, Ammonia Loading Unit, inside Zero Liquid Discharge (ZLD) unit, in and outside Main Control Room using CENTER 390 Digital Sound Level Meter USA; c) PM_{10} in the production units (e.g., Urea Bagging and Storage sites) using EVM-3 Portable Dust Indicator USA; d) heat stress in the production units (previously mentioned) using Kestral Heat Stress meter, USA; e) outdoor emissions of CO, NH_3, NO_2 and SO_2 from equipment's stacks in MOPCO (e.g. Boiler, Primary Reformer, Outlet vent stack of Granulation Plant) using Universal Stack sampler, Apex instrument and Flue gas analyzer, Lancom, USA.

Figure (1): Location map showing the measured sites at MOPCO, Damietta, north Egypt; 1) Ammonia Loading; 2) Compressor; 3) Boiler; 4) Boiler Feed Water (BFW); 5) Urea Bagging Site; 6) Urea Bagging Cars; 7) Urea Storage Site.

The AMS/EPA Regulatory Model (AERMOD) is a comprehensive multi-level air dispersion modelling system, was published in September 2004 with the US EPA document number EPA-454/R-03-004, which simulates essential atmospheric physical processes and provides refined concentration estimates over a wide range of meteorological conditions and modelling scenarios [9]. Dispersion Model (version 04300) is used in this study to evaluate the spatial distribution of outdoor air emissions in MOPCO site. AERMET pre-processor combines meteorological observations (e.g., wind speed, wind direction, temperature and cloud cover) with surface characteristics in the form of albedo, surface roughness and Bowen ratio. AERMET was used to calculate friction velocity, Monin-Obukhov length, convective velocity scale, temperature scale, mixing height and surface heat flux [9] which is needed by AERMOD. This data, whether measured off-site or on-site, must be representative of the meteorology in the modelling domain. The study area was assumed to be flat, which most closely approximates the actual topography, and no variations in receptor elevations were considered [9]. AERMAP uses gridded terrain data for the modelling area to calculate a representative terrain-influence height associated with each receptor location. The gridded data is supplied to AERMAP in the format of the Digital Elevation Model (DEM) data. The terrain pre-processor can also be used to compute elevations for both discrete receptors and receptor grids. Plume volume molar ration method (PVMRM) is introduced in AERMOD for modelling the conversion of NO_x to

NO_2 [17]. f) Preliminary quantitative risk assessment of MOPCO site is utilized using HAZARD calculator software (downloaded from the website: www.zedsoftwarwe.com.au), which calculates risk levels identified in safety, environmental or other hazards.

The statistical analysis of data was carried out using Excel 2016 according to [18].

3. RESULTS AND DISCUSSION

3.1 Indoor Gas Emissions in MOPCO

Monitoring was carried out in the production units (e.g. BFW, Ammonia pump and Bagging unit) at MOPCO plant and involved the measurement of carbon monoxide (CO), nitrogen dioxide (NO_2), ammonia (NH3) and sulfur dioxide (SO_2) from January 2018 to July 2019 (Table 1). Results showed that the mean concentrations of NO_2 and NH_3 were 0.2 and 1 ppm in the Boiler area. In ammonia pumping area, the mean concentrations of NO_2 and NH_3 were 0.16 and 1.2 ppm, respectively. The highest value of CO (1 ppm) was recorded in the Bagging unit. The highest value of SO_2 was recorded (0.2 ppm) in September near the BFW. In general, the highest measurements of air emissions were found in the Ammonia pumping area. The obtained results within the three sites were less than the maximum permissible limits of CO (25 ppm), SO_2 (2 ppm), NO_2 (3 ppm), and NH_3 (25 ppm) according to [12]. In comparison to indoor gas emissions measured in the Emethanex Methanol Plant in Damietta, within 5 km distance from MOCPO, SO2 =0.006 ppm; NO2 = 0.008 ppm and CO=0.4 ppm [19]. It seems that the indoor gas emissions in MOPCO are higher than those of Emethanex Methanol Plant.

Table (1): Mean monthly measurements of indoor air emissions at MOPCO in comparison to national and international limits (US EPA and WHO), ND (not detected).

MOPCO Units	CO (ppm)	SO_2 (ppm)	NO_2 (ppm)	NH_3 (ppm)
Near BFW	ND	0.2	0.2	1
Near Ammonia pumps	ND	ND	0.16	1.2
Inside Bagging unit	1	ND	ND	ND
US EPA limit	9 ppm/8h	75 ppb/1h	100 ppb/1h	
WHO limit	10 mg/m^3/8h	0.4 ppm/8h	40 µg/m^3/8h	
Egyptian Env., Law 4/94	25 ppm/8h	2 ppm/8h	3 ppm/8h	25 ppm/8h

3.2 Noise

Noise monitoring was carried out in the production units (e.g. near Boiler, BFW Bump, CO_2 Removal & Primary Reformer, Urea Bagging Cars & Urea Storage, Ammonia Cooling Tower, Nitrogen Production Unit, Compressor site, ZLD unit and inside and outside Main control room) at MOPCO from January 2018 to July 2019 (Fig. 2). MOPCO takes protection precautions such as employee wear suitable air muff or air plug. Noise decreases in other production units such as Boiler, BFW pump, primary reformer,

Ammonia and urea cooling tower and Nitrogen production unit. Results showed that the mean measurement of noise was 85 dB in the Boiler area, 80 dB in Ammonia Loading Unit, 79 dB in the Bagging unit, and 82.5 dB near the BFW. The highest value of noise in MOPCO was recorded in the Compressor site (96 dB). The obtained results of noise within the production units are less than the maximum permissible limit (90 dB per 8 Hours) according to [12]. In comparison to noise levels in MOPCO, the noise level measured in the K.S. Aluminum Industries Ltd. (KSAIL) was 97 dB, while in the Delli Aluminium Factories Ltd. (DAFL) was 91dB [20].

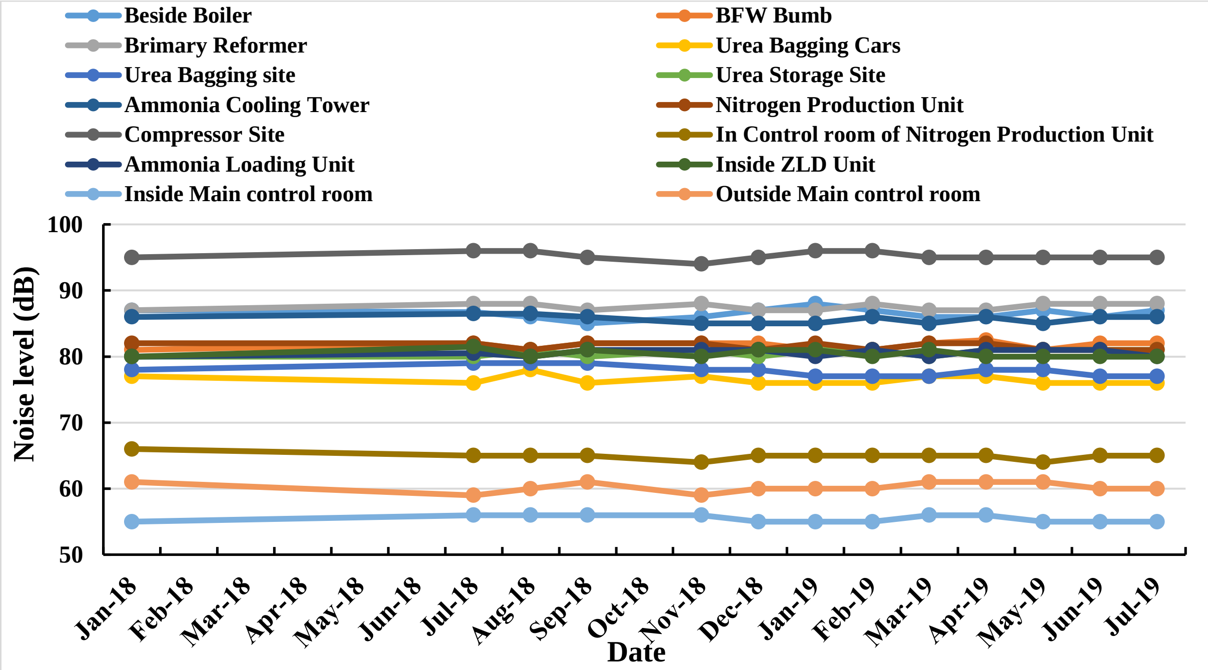

Figure (2): Mean monthly measurements of Noise in the production units at MOPCO from January 2018 to July 2019.

3.3 Particulate Matter (PM_{10})

PM_{10} values increase in the Urea Storage unit as a result of increasing the production especially in October and November, while it decreases in the Urea Bagging Cars because it is an open unit (Fig. 3). Results of PM_{10} in MOPCO are within the safe limit (3 mg/m^3/8 hours) according to [12]. In comparison to similar measurements from the Emethanex site which has PM_{10} in arrange of 32 - 44 µg/m^3 [15].

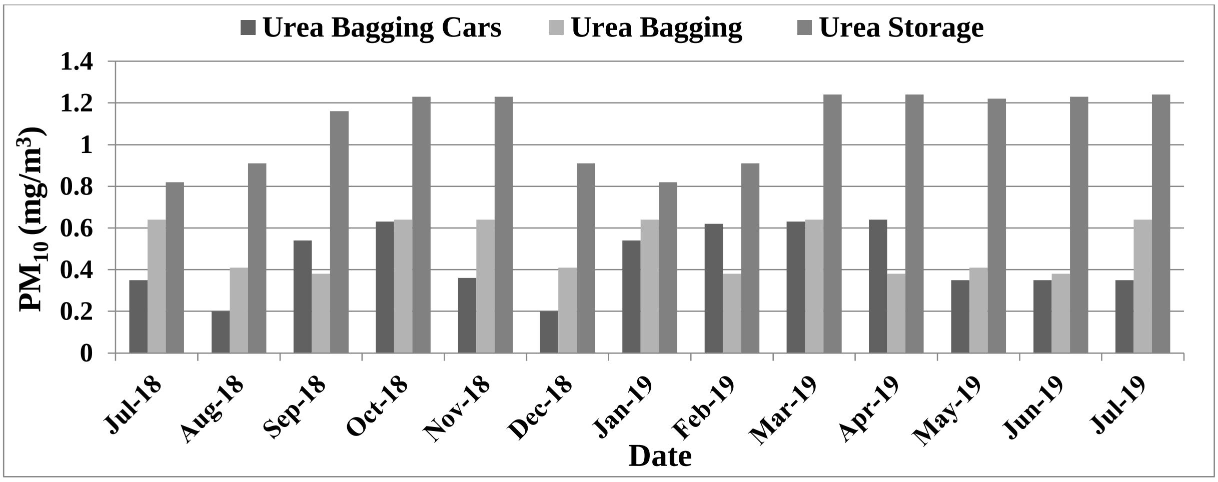

Figure (3): Mean monthly measurements of PM_{10} at MOPCO from July 2018 to July 2019.

3.4 Heat Stress

Heat stress increases in the Urea Storage and beside the Boiler in summer and decreases in all office units and in the Urea Bagging unit because it is an open area (Fig. 4). About 90% of heat stress measurements were higher than recommended limit values (e.g., 27.2-41.7C) for heavy and moderate workloads and radiation heat from processes [21].

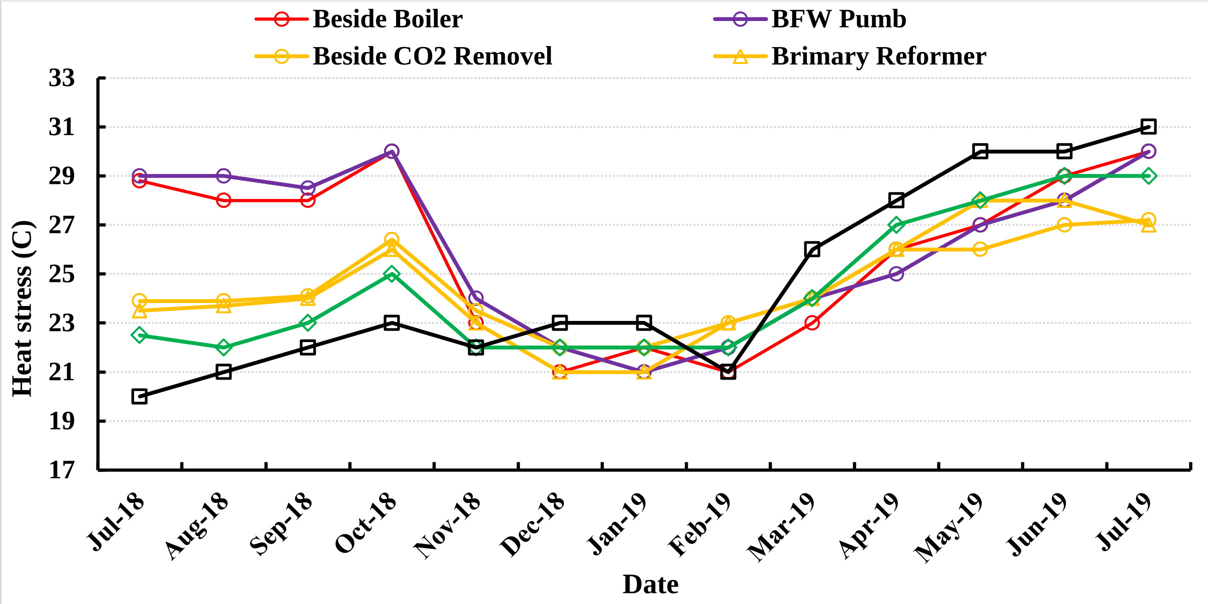

Figure (4): Mean monthly measurements of Heat stress in the production units at MOPCO from July 2018 to July 2019.

3.5 Hazard Calculator

The hazard modelling for indoor air emissions in the production units at MOPCO was calculated using HAZARD software. Results show that MOPCO has low values of PM_{10}, heat stress and noise and low emissions of CO, NH_3 and SO_2 in workplace. Therefore, all measured sites have low risk factor (Table 2).

Table (2): Hazard model calculations for indoor air emissions in MOPCO.

Parameters measured in production units at MOPCO	Minimum	Maximum	Risk Factor	Comments
CO	0 ppm	1 ppm	Low	Manage by routine procedures. A work instruction should be developed for this task.
NH_3	0 ppm	1.2 ppm	Low	
SO_2	0 ppm	0.2 ppm	Low	
NO_2	0 ppm	0.2 ppm	Low	
PM_{10}	0.21 mg/m^3	1.23 mg/m^3	Low	
Heat Stress	21 degree	30 degree	Low	
Noise	83 db	98 db	Low	Manage by routine procedures. A work instruction should be developed for this task & management responsibility must be specialized. Nominate a responsible person to follow up in short term.

3.6 Outdoor air emissions from stacks (Granulation & Primary reformer and Boiler) at MOPCO

Results of outdoor emissions from the stacks, from July 2018 to June 2019, show that NH_3 has a mean of 70.4 mg/m^3 in the granulation plant while it is absent in the boiler and reformer (Fig. 5). Whereas NO_x has a mean of 190.8 mg/m^3 in the boiler, 64.4 mg/m^3 in the reformer and 56.8 mg/m^3 in the granulation plant (Fig. 6). Co emissions have a mean of 67.4 mg/m^3 in the boiler decreased to 26.8 mg/m^3 in the reformer and is absent in the granulation plant (Fig. 7). SO_2 was absent in all the three sites from July 2018 to June 2019.

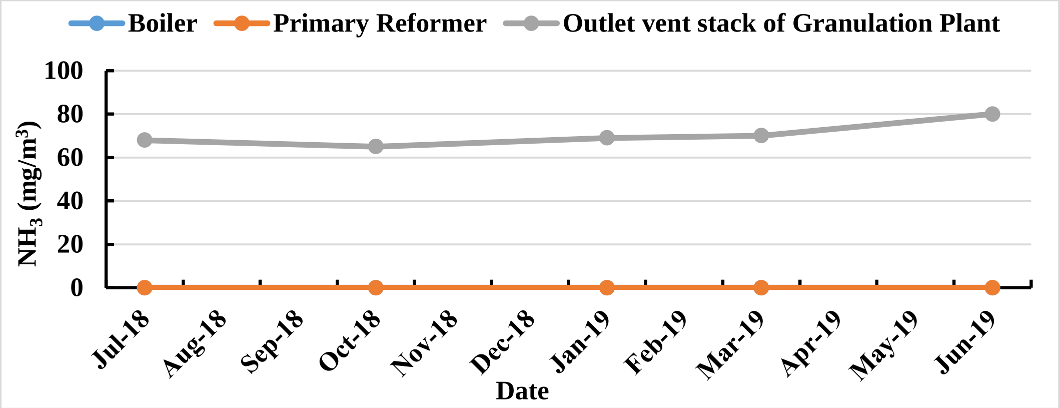

Figure (5): Outdoor air emissions of NH_3 from the stacks at MOPCO from July 2018 to June 2019.

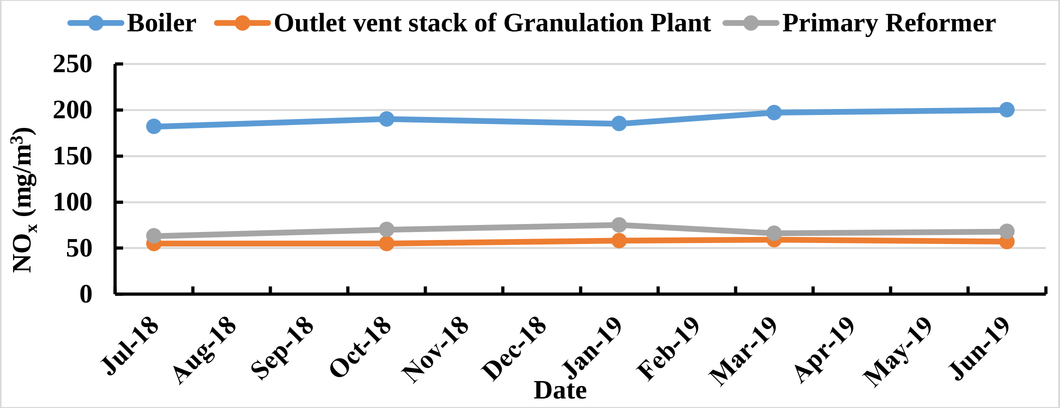

Figure (6): Outdoor air emissions of NO_x from the stacks at MOPCO from July 2018 to June 2019.

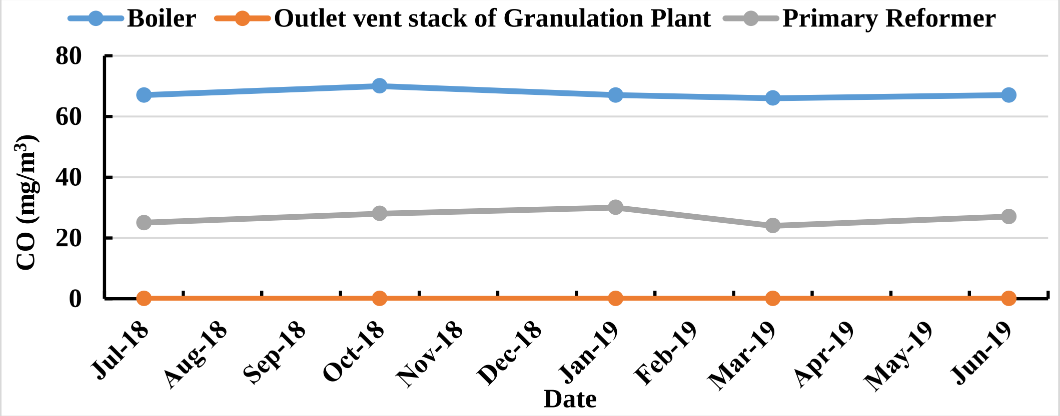

Figure (7): Outdoor air emissions of CO from the stacks at MOPCO from July 2018 to June 2019.

3.7 Application of AERMOD model

AERMOD was applied on the MOPCO air emissions data e.g. CO, NO_x, SO_2, PM_{10}, NO_x, SO_2 and NH3. These emissions would be toxic if released into the atmosphere in heavy quantities. For example, minimal NH_3 concentrations should be emitted during normal facility operation (Table 3) and it is of concern only under an emergency release situation [9].

Table (3): Emission inventory data within normal operation.

Pollutant (μg/m³)	Reformer	Boiler
NO_x	14	5.3
CO	2	0.5
PM_{10}	5.9	1.9

The input (source) data for AERMOD model including the following: source UTM coordinates; flow rate (g/s) calculated with the flow gas and pollutant concentrations; speed (m/s); inside stack diameter (m); total height (m) of the stack; and temperature (K) (Table 4).

Table (4): Emission characteristics for stacks of granulation, reformer and boiler that utilized as input data for the model.

		Unit	Granulation	Reformer	Boiler
Stack parameters	**Temp.**	°K	313	393	449
	Diameter	m	3.05	3	2
	Velocity	m/sec	19.43	1.84	3.3
	Stack Height	m	55	40	35
Pollutant Emission Rate	**PM_{10}**	g/s	2.27	0.47	0.59
	NH_3	g/s	9.65	0	0
	NO_2	g/s	7.8	3.3	7.6
	CO	g/s	0	1.2	2.8

Wind rose for the study area in 2018 which used in the model indicates the domination of North West and West wind directions during all 2018 (Fig. 8). While North and North East wind directions were dominated during spring. West and South West wind were remarkable during winter.

3.7.1 Maximum 1-hour mean concentrations of NO_2

NO_2 1-hour mean concentration is 192.76 μg/m³ in a distance 212 m from the stack of MOPCO, which is lower than the safe limit of NO_2 in urban and industrial areas (300 μg/m³) (Table 5, Fig. 9a).

Table 5. maximum 1-hour mean concentrations of NO_2 extracted from the model.

	NO_2	Distance	Long.	Lat.	X	Y
Units	μg/m3	m	Deg	Deg	m	m
1-hour mean	192.76	212	31.7775	31.4684	150	150
Urban	300	EEPL Maximum Limits of Outdoors Air Concentrations (μg/m³)				
Industrial	300					

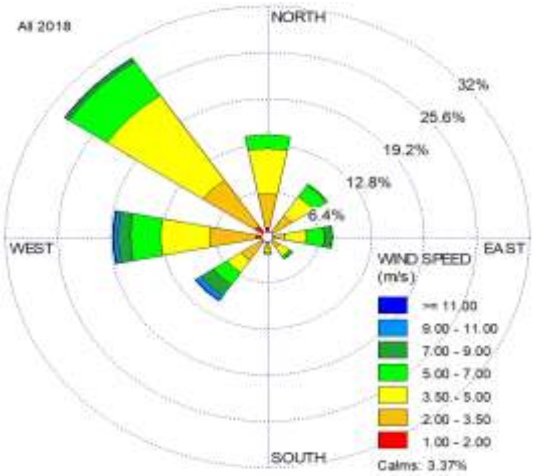

Figure (8): Wind rose for the study area used in the model for 2018.

3.7.2 Maximum 1-day mean concentrations of NO_2

NO_2 1-day mean concentration is 87.89 µg/m^3 in a distance 269 m from the stack of MOPCO, which is lower than the safe limit of NO_2 in urban and industrial areas (150 µg/m^3) (Table 6, Fig. 9b).

Table (6): Maximum 1-day mean concentrations of NO_2 extracted from the model.

	NO_2	Distance	Long.	Lat.	X	Y
Units	µg/m3	m	Deg	Deg	m	m
1-day mean	87.89	269	31.7785	31.468	250	100
Urban	150	EEPL Maximum Limits of Outdoors Air Concentrations (µg/m^3)				
Industrial	150					

3.7.3 Maximum annual mean concentrations of NO_2

NO_2 maximum annual mean concentration is 8.58 µg/m^3 in a distance 292 m from the stack of MOPCO, which is lower than the safe limit of NO_2 in urban (60 µg/m^3) and industrial areas (80 µg/m^3) (Table 7, Fig. 9c). Moreover, all NO_2 concentrations in MOPCO complies with the Egyptian Environment Protection Law guidelines [12].

Table (7): Maximum annual mean concentrations of NO_2 extracted from the model.

	NO_2	Distance	Long.	Lat.	X	Y
Units	µg/m3	m	Deg	Deg	m	m
1-year mean	8.58	292	31.7785	31.4657	250	-150
Urban	60	EEPL Maximum Limits of Outdoors Air Concentrations (µg/m3)				
Industrial	80					

3.7.4 Maximum 1-day mean concentrations of NH_3

NH_3 maximum 1-day mean concentration is 20.22 µg/m^3 in a distance 364 m from the stack of MOPCO, which is lower than the safe limit of NH_3 in urban and industrial areas (120 µg/m^3) (Table 8, Fig. 9d). Moreover, all NH_3 emissions in MOPCO complies with the Egyptian Environment Protection Law guidelines [12].

Table (8): Maximum 1-day mean concentrations of NH_3 extracted from the model.

	NH_3	Distance	Long.	Lat.	X	Y
Units	µg/m3	m	Deg	Deg	m	m
1-day mean	20.22	364	31.7796	31.468	350	100
Urban	120	EEPL Maximum Limits of Outdoors Air Concentrations (µg/m3)				
Industrial	120					

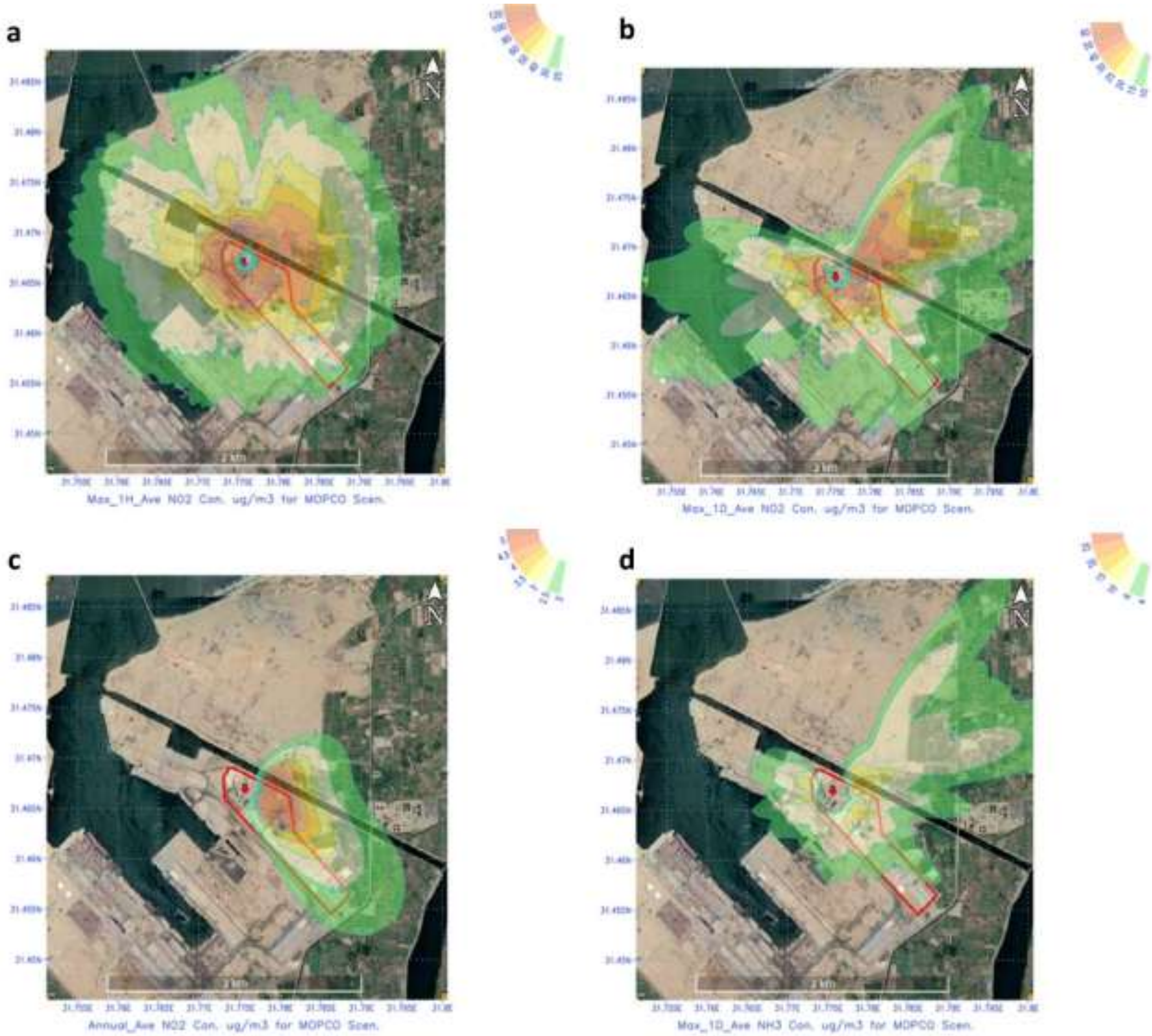

Figure (9): Mean concentrations of maximum 1-hour of NO_2 (a), 1-day of NO_2 (b), annual mean of NO_2 and 1-day of NH_3 (d) at MOPCO which extracted from AERMOD model.

3.7.5 Maximum 1-hour mean concentrations of CO

CO maximum 1-hour mean concentration is 13.44 µg/m^3 in a distance 180 m from the stack of MOPCO, which is lower than the safe limit of CO in urban and industrial areas (30,000 µg/m^3) (Table 9, Fig. 10a).

3.7.6 Maximum 8-hour mean concentrations of CO

CO maximum 8-hour mean concentration is 12.16 μg/m^3 in a distance 180 m from the stack of MOPCO, which is lower than the safe limit of CO in urban and industrial areas (10,000 μg/m^3) (Table 10, Fig. 10b). Moreover, all CO emissions in MOPCO complies with the Egyptian Environment Protection Law guidelines [12].

Table (9): Maximum 1-hour mean concentrations of CO extracted from the model.

	CO	Distance	Long.	Lat.	X	Y
Units	μg/m3	m	Deg	Deg	m	m
1-hour mean	13.44	180	32.0863	31.3517	150	100
Urban	30,000	EEPL Maximum Limits of Outdoors				
Industrial	30,000	Air Concentrations (μg/m3)				

Table 10. Maximum 8-hour mean concentrations of CO extracted from the model.

	CO	Distance	Long.	Lat.	X	Y
Units	μg/m3	m	Deg	Deg	m	m
8-hour mean	12.16	180	32.0863	31.3517	150	100
Urban	10,000	EEPL Maximum Limits of Outdoors				
Industrial	10,000	Air Concentrations (μg/m3)				

3.7.7 Maximum 1-day mean concentrations of PM_{10}

PM_{10} maximum 1-day mean concentration is 10.97 μg/m^3 in a distance 316 m from the stack of MOPCO, which is lower than the safe limit of PM_{10} in urban and industrial areas (150 μg/m^3) (Table 11, Fig. 10c).

Table (11): Maximum 1-day mean concentrations of PM_{10} extracted from the model.

	PM_{10}	Distance	Long.	Lat.	X	Y
Units	μg/m3	m	Deg	Deg	m	m
1-day mean	10.97	316	31.7791	31.468	300	100
Urban	150	EEPL Maximum Limits of Outdoors				
Industrial	150	Air Concentrations (μg/m3)				

3.7.8 Maximum annual mean concentrations of PM_{10}

PM_{10} maximum annual mean concentration is 1.07 μg/m^3 in a distance 292 m from the stack of MOPCO, which is lower than the safe limit of PM_{10} in urban and industrial areas (70 μg/m^3) (Table 12, Fig. 10d). Moreover, all PM_{10} emissions in MOPCO complies with the Egyptian Environment Protection Law guidelines [12].

Table 12. Maximum annual mean concentrations of PM_{10} extracted from the model.

	PM_{10}	Distance	Long.	Lat.	X	Y
Units	µg/m3	m	Deg	Deg	m	m
1-year mean	1.07	292	31.7785	31.4657	250	-150
Urban	70	EEPL Maximum Limits of Outdoors Air Concentrations (µg/m3)				
Industrial	70					

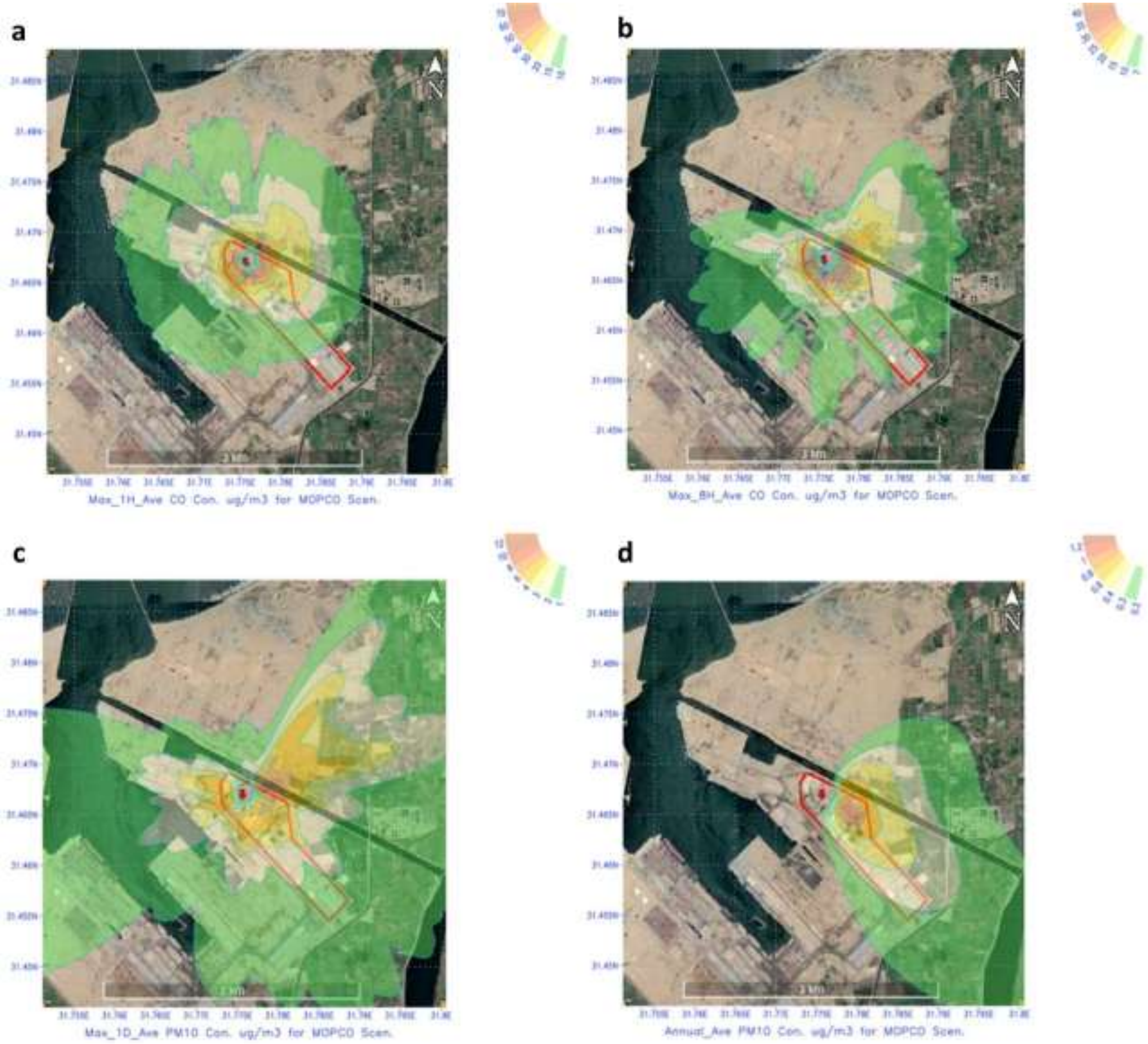

Figure (10): Mean concentrations of maximum 1-hour of CO (a), 8-hour of CO (b), 1-day of PM_{10} and annual mean of PM_{10} (d) at MOPCO which extracted from AERMOD model.

4. CONCLUSION

In this study, we assessed the indoor air emissions such as CO, NO_2, NH_3, SO_2 in addition to PM_{10}, heat stress and noise in MOPCO from January 2018 to July 2019. Detailed air dispersion modelling

(AERMOD) has done to determine the likelihood ground level concentrations resulting from the outdoor air emissions of NO_2, NH_3, CO and PM_{10} from the stacks in MOPCO. The individual risk exposures from MOPCO have been evaluated and found to be below the maximum tolerable risk levels allowed by the UK HSE criteria when all individuals are assumed to be present 100 % of time. This risk assessment considered only MOPCO plant without any adjacent industries. The overall individual risk may increase slightly if other industries were considered, however, if one assumes that the other facilities apply a similar risk acceptance regime as in MOPCO, this incremental risk should represent a close to negligible contribution to the overall risk. Furthermore, when one assumes a more realistic estimate of the amount of time that individuals are in the area, the individual risk exposure falls far below the maximum tolerable risk levels allowed by the UK HSE criteria and Egyptian Environment Protection Low [12] and its amendments (No. 9/2009).

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