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AIR POLLUTION ESTIMATION IN ERBIL CITY CENTER USING BOX MATHEMATICAL MODEL

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ABSTRACT

Erbil city center, topographically, is a low basin surrounded by highlands from all sides and is characterized as relatively humid weather during the autumn, winter and spring days. These factors with the increasing number of cars in the street, added to the vast number of private electric generators using poor quality of fuels caused the high level of air pollution in the basin and black clouds over the city. In this paper, the concentration of accumulated pollutants was estimated at different points by using a known mathematical model called "Fixed Box Model". This mathematical model was developed and processed, by researchers, using computer mat lab to calculate the concentrations of pollutants in Erbil's city center at any time of the day in different levels. The collected data of the contributing cars, trucks and electric generators were processed by the developed model and shows that the accumulated pollutants, on the breathing level 4 hours after the morning rash time, were as follows: NOx= 300 μg/m^3, HC= 54 μg/m3, CO= 350 μg/m^3, PM2.5= 9 μg/m^3, PM Brake= 0.15 μg/m^3 and CO_2= 2.04*104 μg/m^3 which may often be the reason for the black cloud appearing over Erbil's city center.

KEY WORDS: Air Pollution, Erbil City, Pollution dispersion, Fixed Box Model.

1. INTRODUCTION

Greenpeace, as an international nongovernmental organization (INGO), and according to the results of an unprecedented analysis of recent satellite data between June 1 and August 31 of 2018, has revealed a list of 50 cities as hot spots of the most polluted sites around the globe in terms of contaminated gas nitrogen dioxide in the air. The mentioned list included hot spots of eight Middle Eastern cities among which, were Baghdad and Erbil cities in Iraq, Dubai in the United Arab Emirates, Riyadh in Saudi Arabia, Ahmadi in Kuwait, Jounieh in Lebanon, Cairo in Egypt and Doha in Qatar (Greenpeace, the environmental organization, 8/1/2019).

Nitrogen dioxide, Hydro-Carbon and Particulate Matter are the most dangerous pollutant, emitted into the air when burning fossil fuels such as oil, petrol and diesel. In Erbil city the transport sector, electricity production plants and industry are the main source of those pollutants.

Air pollution disperses from its source to the atmosphere and its dispersal in the air is affected by many factors, including wind direction and wind speed, type of topography and heating effects. For better and easer estimation of the ground level concentration (GLC) of pollutants, the atmospheric conditions can be described simply as either stable or unstable, where the stability is determined by wind (which stirs the air) and heating effects (which cause convection currents). Atmospheric stability affects pollution released from ground level and elevated contributors. Ground level source pollutants are readily dispersed and reduced in the unstable conditions due to the dilution and mixing. Elevated sources, such as those released from a chimney, are returned more readily to ground level, leading to higher ground level concentrations. Stable conditions mean less atmospheric mixing and therefore higher concentrations around ground level sources, but for elevated plumes, better dispersion rates occurs, which leads to lower ground level concentrations (Yannawar Vyankatesh, May 2014).

Air pollution source is another significant factor affecting the pollution dispersion estimation. The types of air pollutant sources are commonly characterized as point, line, area or volume sources. Sources may be classified as either stationary or mobile. Flue gas stacks are examples of stationary sources and automobiles are examples of mobile sources. Sources, may also, be characterized by their elevation relative

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to the ground, so it is called ground level concentration when it is near to the surface. The period of exposure time is another characteristic of sources, i. e. continuous puff sources or intermittent emission sources, short term or long term sources (for example, accidental emission releases puffs for short term).

2. METHODOLOGY

The most commonly used models for pollutants estimation which, known as the air pollution dispersion models are: ***Box Model, Gaussian Model, Lagrangian Model, Eulerian Model and Dense Gas Model.*** Box model usually used for the line, area and volume sources of pollution while other models used to estimate the dispersion of point source (Kulshresth Singh, 2018).

Box model is the simplest model type. It assumes the air shed in a geographical region is in the shape of a box. The other effective assumption of this model is that the air pollutants inside the box are homogeneously distributed and the estimation of the average pollutant concentrations anywhere within the air shed depends on this theoretical assumption. In spite of its simplicity and usefulness, this model is very limited in its ability to accurately predict the dispersion of air pollutants over the specified geographical region as the assumption of homogeneous pollutant distribution is not realistic.

2.1. **Theory of Box Model**

As shown in figure 1, the schematic diagram of box representing a simple urban air quality including source emissions, adjective inflow and outflow to and from the sides, vertical height (Z), chemical transformations and wind direction. The length, breadth and height of the box model may represent expected wind dimension. Since uniform mixing is assumed to occur within the box whose horizontal boundaries close the urban area of interest, the model can predict only the volume-averaged concentration as a function of time. In box model, instead of the individual source of emission, we considered all sources in estimating source emissions within the box. For the simplest box model without chemical transformations, one can derive a simple differential equation for the average concentration C within the box from the consideration of mass conservation within the box. The rate of change of mass within the box must be equal to the sum of the rates at which the pollutant mass is added by all the emission sources in the box, the change due to horizontal advection and the change due to entrainment from the top resulting from the growth in mixed height (Kulshresth Singh, 2018 and Yannawar Vyankatesh, May 2014).

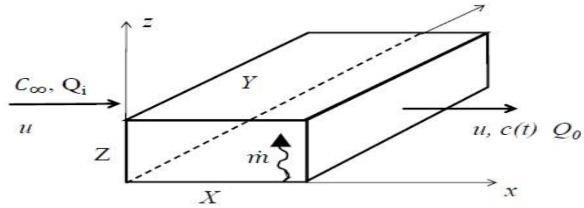

Fig. (1): Schematic diagram of the Box Model

Box model further assumptions are:

- Perfect mixing within the box should be assumed (through the calculation domain).
- Air velocity is constant and perpendicular to the inlet surface.
- The model can be applied for one pollutant only, which means that the program must be repeated for each pollutant separately.

C_a = Concentration of the pollutant in the ambient (mg/L)
u = Velocity of air (with pollutant) (m/s)
C = Concentration of the pollutant within the box and the exit (mg/L)
ṁ = Pollutant source term (g/s)
X, Y and Z are the Box 3 dimensions

Conservation of mass of the air can be presented by: $Q_i = Q_o = Q = u\,Z\,Y$ (1)

Conservation of mass of pollutant can express by the following differential equation:

$$\frac{dC}{dt}\,(ZYX) = (\dot{m} + u\,ZY\,C_i) - u\,Z\,Y\,C \qquad (2)$$

When U, ṁ, C_a = constants, Model Solution can be expressed by the following equation:

$$\int_{c\infty}^{c} \frac{dC}{(\dot{m}+uZ_x\,YC_i)-uhwC} = \frac{1}{Z_xYX}t \qquad (3)$$

When u, ṁ and C_i are constants, the steady-state concentration C_{ss} in the box is:

$$C_{ss} = C_i + \frac{\dot{m}}{uZY} \qquad (4)$$

Integration of eq. (3) leads to the following equation:

$$\frac{C(t)-C_i}{C_{SS}-C_i} = 1 - exp(-\frac{ut}{X}) \qquad (5)$$

Where X. is the length of the box in the direction of the airflow (km)

For the simplicity of pollutants estimation, C_i assumed to be zero, which means that no concentration of pollutants before contribution. Then the above equation will become:

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At any time $C_{(t)} = C_{SS}[1 - exp\left(-\frac{ut}{x}\right)]$ (6)

A plot of Concentration VS time can show the accumulated pollutants at any time (t).

2.2. Study Area and Data Collection

The selected study area in Erbil City was the area confined by the ring road 120 meters, which is expected to be responsible for the formation of a black cloud over the city of Erbil, generated by pollutants, resulting from the huge number of cars and on-site fixed electricity generators. The average number of moving cars and fixed electricity generators were approximately counted by the researchers in certain days, as shown in Table.1. Emissions factors caused by contributors are shown in Table.2 (Carbon Dioxide emissions in the United Kingdom (UK) from 2000 to 2018), which shows the expected pollutants factors emitted by cars, trucks and electricity generators using the standard fuels (petrol and diesel). From Table.1 and Table.2, the rates of emitted pollutants $\dot{m}$ were calculated in gram/second as shown in Table. 3.

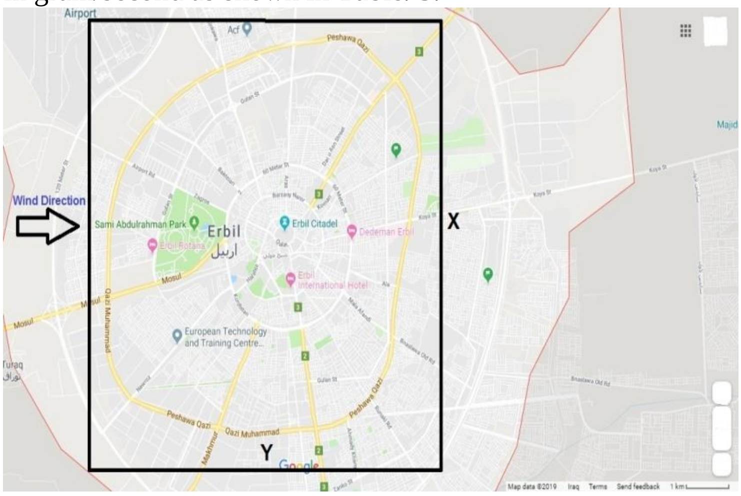

Fig. (2): Case study area of Box Model Pollution Estimation (Virtual map)

Table (1): Estimated Average Number of Moving Vehicles and Fixed Generators of Study Area.

Item	Name of Street or Avenue	Estimated Area (m^2)	Petrol Passenger Vehicles (No.)	Diesel Light Duty Vehicles (No.)	Diesel Heavy Duty Trucks (No.)	Diesel Generators ≤ 200KW (No.)	Diesel Generators ≤ 500KW (No.)	Diesel Generators ≤ 1000KW (No.)
1	100m St. Ring Road	3,455,750	31112	2600	864	--	--	--
2	40m St Ring Road	1,080,700	19453	1621	540	--	--	--
3	60m St Ring Road	753,980	13500	1125	375	--	--	--
4	30m St Ring Road	188,490	4524	377	126	--	--	---
5	City Center	3,411,000	36000	~500	~300	612	209	10
6	Area between 100 and 40m St.	36,945,000	43900	~800	~300	3455	1151	6
7	Area between* 40-60m St.	45,520,000	48800	~1100	~100	2700	900	12
8	Area between 60-30m St.	12,566,600	12400	~1500	~100	1242	418	20
9	Total	103,921,520	209689	9623	3005	8009	2678	48

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Table (2): Emission Factors of the Vehicles and Generators (London Air Quality Data, Jan, 2012 and others)

Item	Gas Emission Type*	Petrol Passenger Cars (g/km)	Diesel Light Duty Vehicles (g/km)	Diesel Heavy Duty Trucks (g/km)	Diesel Generators ≤ 200KVA (g/sec)	Diesel Generators ≤ 500KVA (g/sec)	Diesel Generators ≤ 1000KVA (g/sec)
1	Exhaust NO_X	0.5381	0.4036	0.6252	0.8110	2.025	4.055
2	Exhaust CO	5.1633	3.8354	2.3179	0.1860	0.464	2.320
3	Exhaust CO_2	180.000	200.000	210.000	39.200	97.920	196.000
4	Total HC	0.5758	3.8354	8.6023	0.0236	0.0589	ulpher0.130
5	Exhaust $PM_{2.5}$	0.0120	0.0910	0.3798	0.0238	0.060	0.119
6	Barack & Tire wear $PM_{2.5}$	0.00245	0.0028	0.0107	-----	------	----

***Sulfur oxides SOx were not included because no data available about the sulfur content in the used fuels.

2.3 Calculations

Calculations, through this research work, were conducted by researchers either using governmental data or by direct counting to construct the basic data for Box model processing according to the equations 1-6. All counting and related calculations were undergoing the following assumptions and conditions:

1- The virtual box dimensions and areas were calculated by using Google maps, withdrawn from websites.

2- All Vehicles were assumed to move, inside the city center, with an average speed of 40 km/hr. then from Tables 1 &Table 2, and by using the following equation, which used to recalculate ($\dot{m}_1$ g/km) for all pollutants to be converted to ($\dot{m}$) in g/sec as follows:

($\dot{m}$) = [($\dot{m}_1$ g/km) × (40 km/hr.)]/3600 s/hr = 0.0111× $\dot{m}_1$(g/sec). Results are shown in Table 3.

3- Citadel zone and the zones between ring roads are areas containing, a roughly estimated number of, private generators of capacity range between 100 – 1100 KW. The number of generators was calculated as an average depending on the available governmental data and the equivalence of energy demand for those regions, which have no available data.

4- The numbers of vehicles were counted at different times during peak hours and then averaged.

5- Pollutants were assumed to be distributed in the whole virtual Box in the same concentration (homogeneous).

6- Wind speed and direction were assumed to be constant through the day and whole study area.

7- Emission factors, (Table 2.) were constructed using different sources such as London Air Quality Data, Jan, 2012, Worldwide Emission Standards, May 2019 and others. Measurements were approximated without taking in account the different ambient temperature, machine design, fuel type, moving speed and effects of decay, due to working hour, on calculated emission. The worst conditions were considered.

8- Simple calculations were conducted using Table 1 and Table 2 to construct Table 3, which is used as the basic data to be processed by Box mathematical model to calculate the pollutants concentrations as a function of time (through 7 days a week between 6 am to 6 pm), for different heights as shown Figure, 3-A to 3-E.

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Table (3): Total Calculated Emission Rates (ṁ) of the study area

Item	Type of Contributor	Exhaust NO_X g/km	Exhaust CO g/km	Exhaust CO_2 g/km	Total HC g/km	Exhaust $PM_{2.5}$ g/km	Brake & Tire wear PM g/km
	Vehicles and Trucks						
1	Petrol Passenger Cars (g/km)	112833.65	1082687.2	37744020.0	120738.9	2516.3	513.7
2	Diesel Light Duty Vehicles (g/km)	3883.84	36908.1	1924600.0	36908.1	875.7	27.0
3	Diesel Heavy Duty Trucks	1878.73	6965.3	631050.0	25849.9	1141.3	32.1
4	Total Vehicle Emission $\dot{m}_1$ (g/km)	118596.22	1126560.6	40299670.0	183496.9	4533.3	572.8
5	Total Vehicle Emission ṁ (g/sec)#	1304.55	12392.2	443296.37	2018.5	50.0	6.3
	Local Stationary Generators						
6	Diesel Generators ≤ 200KW Emission (g/sec)	6495.3	1489.7	313952.8	189.0	190.6	---
7	Diesel Generators ≤ 500KW Emission (g/sec)	5423.0	1242.6	262229.8	157.8	160.7	---
8	Diesel Generators ≤ 1000KVA Emission (g/sec)	194.7	111.4	9408.0	6.3	5.7	---
9	Total Generator Emission ṁ (g/sec)	12113.0	2843.7	585590.6	353.1	357.0	---
10	Erbil Total Emission (ṁ) (g/sec)	13417.55	15235.9	$1.03*10^6$	2371.6	407.0	6.3

2.4 Data Processing

The data from Table 1, Table 2, and Table 3 were processed using the Mat lab language programs which, been developed by the researchers. All conditions of the box model and all equations (eq. No.1 to eq. No.6) were considered. Figures (3-A, 3-B, 3-C, 3-D, 3-E, 3-F) shows the results obtained which indicates the pollutants concentrations as a function of time during the day from 6 am to 6 pm and at different levels in the space of Erbil city center. From these curves, we can estimate the accumulated pollutants at any time during the working day and at different heights of buildings in the study area.

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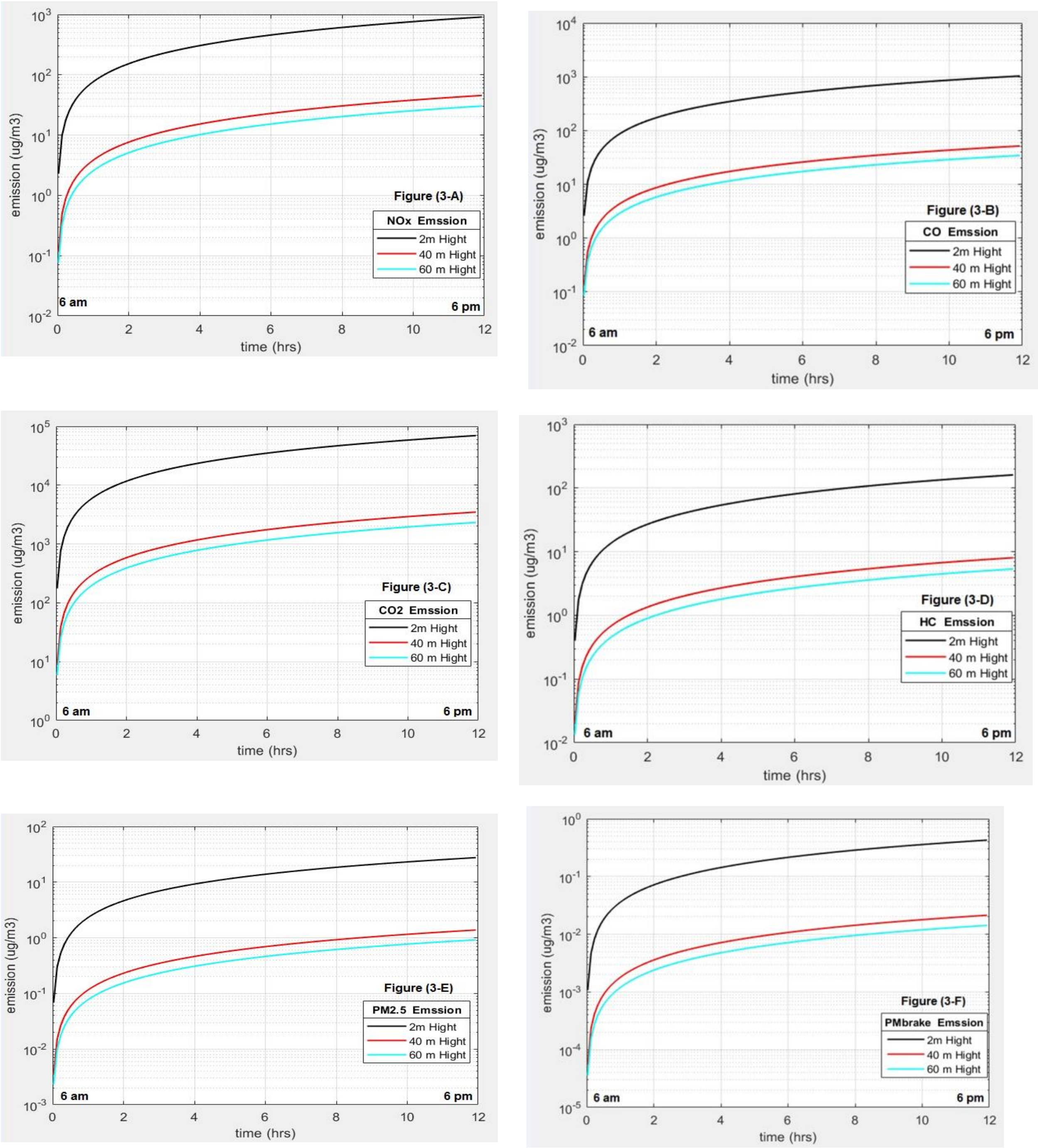

Fig. (3): Pollutants Concentrations as a Function of Time (through 7 days a week between 6 am to 6 pm), for different Heights

3. RESULTS AND DISCUSSION

The curves with black color indicate the average breathing level concentrations reviles that after 4 hours, the accumulated NOx concentration is 300 µg/m^3 and after 8 hours (2 pm) becomes 520 µg/m3 which exceeds the accepted levels of WHO (WHO Air quality guidelines, Global update 2005). The total emitted NOx of 211568 tons/year found been mainly produced by the fixed diesel generators, the majority of CO and HC was emitted by vehicles at rates of 81% and 85% respectively, while, the fixed generators found been responsible for $PM_{2.5}$ emissions at rate of 88% as all. Both CO and HC accumulated

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concentrations are obviously above the accepted International limits.

Figure (3-E) shows that after 8 hours the accumulated $PM_{2.5}$ goes beyond 10 μg/m^3 exceeding the accepted limit set by WHO.

Table (4): Total Yearly Emitted Pollutant in Erbil City*

Pollutants	Vehicles (Tons/Year)	Generators (Tons/Year)	Total Emission (Tons/Year)	Vehicles %	Generator %
Exhaust NO_X	20570	190998	211568	10	90
Exhaust CO	195400	44839	240239	81	19
Exhaust CO_2	6989897	9233593	16223490	43	57
Total HC	31828	5567.7	37395.7	85	15
Exhaust $PM_{2.5}$	788.4	5629.2	6417.6	12	88
Barack & Tire wear $PM_{2.5}$	993.4	-------	993.4	100	0

*It is assumed that 12 hours/day of full load of pollutants contributed by vehicles and fixed generators.

Figure (3) curves show that air pollutants decreases in the higher levels, which could be explained by the dispersion and dilution occurring for pollutants as we go higher. The increased rate of carbon dioxide may be attributed to the huge number of fixed generators used due to the lack of supplied central electricity.

For comparison, (Greater London Authority) shows that the air pollutants measured in London City Center-UK which shows that the high band readings of NO_2 and $PM_{2.5}$ are more than the accumulated 6 hours readings of this study (Figure 1&5). Particulate matter caused by tires and brake mechanisms wear in all types of vehicles are considered very mild compared with diesel generators exhaust PM.

The WHO accepted limits of fine particulate matter ($PM_{2.5}$) is 10 μg/m^3 annual mean and 25 μg/m^3 24-hour mean. While the NO_2 limits is 40 μg/m3 annual mean, and 200 μg/m^3 1-hour mean (WHO, Ambient, outdoor air pollution).

4. CONCLUSION

From research results analysis, following may be concluded:

1. Although it is not possible to obtain very accurate readings using Box Model to calculate accumulated pollutant concentrations, it has been used because of the lack of modern devices and technologies to estimate pollutant concentrations in the near term. The reduced accuracy of using this mathematical model is due to unrealistic assumptions such as homogeneity, constant wind speed and direction within the specified default box, but it can be used as an indication of the serious problem of air pollutants while there are no other tools used in the monitoring at the present time.
2. The results of all accumulated pollutants concentrations studied in this research showed exceeding the acceptable level except for PM and only for the first 4 hours of rash time. Thereafter 8 hours of rash time, all studied pollutants including PM become much higher than the acceptable limits.
3. The increasing accumulated concentration of CO and CO_2 gases may be attributed to the spread of high number of fixed diesel generators in commercial areas and accommodation towns as well as to the huge number of moving vehicles in Erbil city center. It can also be concluded that the emission of nitrogen oxides, particular matter and carbon dioxide causes black clouds that frequently appears in Erbil city, particularly with increased relative humidity.
4. Figures (3-A to 3-F) shows that the high points above the breathing level have lower pollutants concentrations, which mean that pollutants are exposed to dispersion and dilution whenever they rise to the upper layers.
5. Non-availability of sufficient data led the researchers to precede statistical models for better estimation. Hence, the average number of moving vehicles and fixed generators were roughly estimated with ∓3-5% accuracy to be within the acceptable level of difference which, believed acceptable and has not affected the obtained results.

5. RECOMMENDATIONS

Further research works and serious measures are recommended in order to minimize the

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impacts of air pollution levels in Erbil city as follows:

1. Further adequate and continuous investigations of air pollution (with sophisticated devices and equipment) are needed by relevant local authorities.
2. Further researches in the field of air pollution are recommended to use this mathematical model to be implemented in assessing the air pollution country wide of Iraq.
3. Governmental authorities are invited to implement a long-term plan with respect to constructing lines of public transport including domestic trains, trams and busses networks in order to eliminate the huge number individual vehicles. It also recommends to abandon (or limit) the use of fixed electrical generators by increasing the capacity of central generation.
4. Local authorities are invited to issue an environmental code of ethics which, helps in reducing the risks of air pollution and establishing precaution strategies in term of protecting the public health.

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