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Methane and Other Hydrocarbon Gas Emissions Resulting from Flaring in Kuwait Oilfields

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1. Introduction

KUWAIT is shaped roughly like a triangle, surrounded by land on its northern, western and southern sides and sea on its eastern side, with 195 kilometers of coastlines, has an area of about $1.8x10^4$ square kilometers and its most distant points, are about 200 kilometers north to south and 170 kilometers east to west. The bulk of the Kuwaiti populations live in the coastal area of Kuwait. Smaller populations inhabit the nearby city of Al-Jahrah. Kuwait's land is mostly flat and arid with little or no ground water.

Crude oil is the only energy viable source and the major generating commodity in Kuwait. Kuwait Oil Company (KOC) is a state owned subsidiary of Kuwait Petroleum Corporation (KPC) that explores, produces and exports crude oil from the State of Kuwait. With a production of over two million barrels of oil a day it is one of the largest oil producing companies in the world. KOC is organized into four main producing areas: North Kuwait (NK), West Kuwait (WK) and South and East Kuwait (SEK). The second largest oil field in the world is Burgan Field which is managed and operated since 1938. Kuwait Oil Company manages the production and export of oil and gas with the associated facilities from more than twelve developed oil fields in the state of Kuwait. Crude is processed through a network of 21 gathering centres, where gas and water are separated. The processed oil is exported or refined at Kuwait’s large refining Industries. Separated gas that cannot be utilized economically is flared. This flaring produces a number of undesirable atmospheric emissions, including CO, CO_2, SO_2, H_2S, NOx and particulates ($PM_{2.5}$ and PM_{10}). These pollutants are also released from other activities associated with the production of crude oil, such as local power generation (Gas Turbines, Diesel Turbines, Gas Engines, Gas/Diesel Engines,), and heating operation (Gas Boilers, Gas Heater Furnaces). Ambient air in Kuwait has the highest hydrocarbon concentrations by comparison to any developed country. The oilfields spread over the State and split off into four main parts of North Field, West Field, South and East Field that are locally administered at the site headquarters. Approximate distance from Ahmadi city: North Field is 70 miles (112 Km), West Field is 38 miles (60 Km) and South East Field is 12 miles (20 Km) (See Figure 1).

A comprehensive emission inventory from Kuwait Oilfields has been published[1] which provides an overall accurate account of all emissions of primary pollutants associated from flaring activities in the Kuwait Oilfields. This inventory records the annual emissions of air pollutants: NO_X, SO_2, CO, CO_2, methane and non-methane hydrocarbons. The emissions are generated from various fixed point sources and mobile sources aggregated to obtain total pollutants load of ambient air. The emissions of pollutants from the flaring associated with all types of operations in the oilfields, gathering centers (GC), booster stations (BS), tank areas and other oil production related activities is the largest among other sources. The calculated emissions inventories data used in this works are the compulsory input for the ISCST3 model.

The ground level concentrations of two selected primary pollutants (i.e. methane and non-methane hydrocarbons) emitted from flaring activities at oil production facilities at North Kuwait have been discussed elsewhere[2]. Obviously methane and non-methane hydrocarbons are not the only pollutants gasses which result from flaring activities, but their high concentrations in ambient air is a matter of grave concern to select the right methodology for the calculation of ground level concentrations.

2. Mathematical Model

Industrial Source Complex (ISCST3) dispersion model modified by the US EPA[3] [4] in 1999 is used in the present study. The ISCST3 algorithm is based on a Gaussian plume dispersion model (i.e. it solves the steady-state Gaussian plume equation) and calculates short-term pollutant concentrations from multiple point sources at a specified receptor grid on a level or gently sloping terrain.

A. The Main Inputs Data Requires in the ISCST3 Model

The ISCST3 model implementation requires three main inputs data as follows;

***Source Information*:** The source parameters required for the ISCST3 numerical model are pollutant emission rate (g/s), location coordinates (UTM), source height (m), exit inner diameter (m), exit gas speed (m/s), and exit gas temperature (°C). The required information on all the location coordinates, the respective emission rates and stacks characteristic (height, diameters), flue gas velocity and temperature at the discharge have been obtain from all flaring activities from all Kuwait oilfield [1]. A total of 18 stacks approximated with total emission rate of methane and non-methane hydrocarbons equal to 1084 g/s and 16884 g/s contributed by WK Oilfields respectively a total of 28 stacks were used with total emission rate for methane non-methane hydrocarbons equal to 85.11 g/s and 847 g/s contributed by SEK Oilfields were used as input sources in the model.

Receptor Information: The ISCST3 model has considerable flexibility in the specification of receptor locations, has the capability of specifying multiple receptor networks in a single run, and can also mixes Cartesian grid receptor networks and polar grid receptor networks in the same run.

Two different kinds of Cartesian coordinate receptors were used as an input to the ISCST3 model, these are;

I. The course mesh for WK Oilfields covers approximately 40 km by 40 km with 441 receptors superimposed with two finer meshes of 25km by 26km and 10km by 10km and SEK Oilfields covers approximately 40 km by 40 km with 441 receptors superimposed with two finer meshes of 17km by 38km and 5km by 5km. The three meshes are implemented to facilitate `accurate evaluation of ground level concentration using refined interpolation for computed results. The grid base elements are a square with side length of around 1 kmx1km.

II. Discrete Receptors points corresponding to the location of the major population centers and the existing monitoring stations in the State of Kuwait. The matrix of concentrations is plotted as a contour map for the selected meteorological data file. These receptors are selected based on actual sites in UTM location coordinate of Kuwait map.

Meteorological Information: The meteorological data required are anemometer height (m) wind speed (m/s), wind direction (degree) clockwise from the north, air temperature, total and opaque cloud cover (%), stability class at the hour of measurement (dimensionless) and mixing height (m). The anemometer height about 10 m, wind speed, wind direction, air temperature and cloud cover have been obtained from direct measurements from Kuwait International Airport (KIA). One year hourly record of the surface and upper air meteorological data for year 2006 obtained from KIA weather Station[2] and is used in the present study for simulation of the dispersion of methane and non-methane hydrocarbons emitted from flaring in all Kuwait Oilfields areas (NK, SEK, WK) during the oil production. The hourly stability class mixing height is estimated using PCRAMMET[5] that is a meteorological pre-processor for preparing National Weather Service (NWS) data for use in the ISCST3 US-EPA. The routine measurements of the surface and upper air meteorological data obtained from KIA for the year 2006 is used to run the PCRAMMET to generate an hourly ASCII input meteorological file containing the meteorological information parameters needed for the executed of the ISCST3 model.

The stability class was defined on the basis of Pasquill categories, which are mainly a function of the hour of measurement, wind speed and sky cover (i.e., the amount of clouds). Based on temperature profile measurements, the mixing height was estimated by the model.

3. Study Area

The study area covers all of the Kuwait's oil producing zones which are located in three selections in the state of Kuwait. Figure 1 shows the Kuwait map with the location of the three oil producing areas (SEK, WK and NK). The total area of Kuwait around $1.8x10^4$ km^2 is divided into three independent sectors to calculate the ground level concentrations of methane and non-methane hydrocarbons. The modeling exercises are:

1. South East Kuwait (SEK) Area : Consisting of Greater Burgan area having 14 gathering centers.
2. West Kuwait (WK) Area: Consisting of Minagish and Umm Gudair fields having 4 GCs and two BS's.
3. North Kuwait (NK) Area: Consisting of Ratqa, Raudatin and Sabiriyah having 3 GCs and one BS.

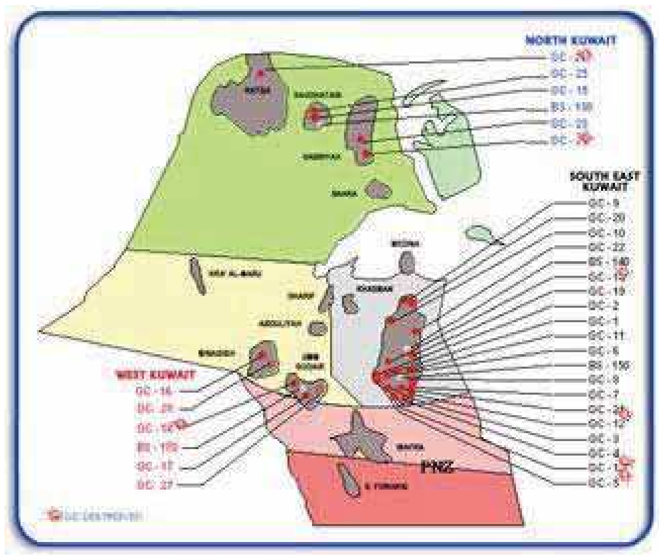

Fig. 1. Major Oilfields and Gathering Center (GC) in the State of Kuwait

4. Results And Discussions

ISCST3 model was used to simulate the ground level concentrations of methane and non-methane hydrocarbons emitted from flaring activities in KOC at all points covered by the receptors information. ISCST3 model was then executed by summing the steady state concentration contributions from each source at each receptor point in the study area. The calculations were completed based on the model input parameters as described in the previous sections. The simulated results of the emission scenarios using the ISCST3 are on an hourly mean predicted ground level concentrations of methane and non-methane hydrocarbons.

The hourly, daily and annual average maximum ground level concentrations of methane and non-methane hydrocarbons were evaluated and output results were compared with Kuwait Ambient Air Quality Standards (KAAQS) at all of the grid point receptors under the study area (443 receptors). Allowable levels of pollutants specified by KAAQS are shown in Table I.

KUWAIT EPA STANDARDS FOR AMBIENT AIR

Pollutants	Units	Standards			
		Annual	24 hours	8 hours	Hourly
NO_2	ppb	30(67μgm^{-3})	50(112μgm^{-3})		100(2253(μgm^{-3})
SO_2	ppb	30(80μgm^{-3})…	60(157μgm^{-3})		170(444μgm^{-3})
H_2S	ppb	6(8μgm^{-3})	30(40μgm^{-3})		140(200μgm^{-3})
CO	ppm		8(9μgm^{-3})	10(115)	30(34μgm^{-3})
O_3	Ppb			60(120)	80(157μgm^{-3})
Non-methane Hydrocarbons	ppm				0.24(3hrs mean) 6:00-9:00 a.m.
PM_{10}	μgm^{-3}	90	350		

Table 1.

The background concentration of each pollutant, methane and non-methane hydrocarbons in the ambient air prior to computation input data were considered almost negligible (Zero).

A. Effect of Meteorological Conditions

In general, clear sky, high temperature and airborne dust is the feature of the summer season whereas mid to relatively cold with light rain is feature of the winter season in Kuwait. These two contrasting weather conditions would have opposite effects on the dispersion of the pollutants and the concentrations levels through the processes of transport and reaction in the atmosphere. In winter season, the present of the cloud cover results in the reduction of the solar energy, ambient temperature and wind speed. These conditions decrease the photochemical reactions for the formation of ozone and increase the incidence of the surface based inversion that results in lower mixing height. Thus, these meteorological conditions during winter season would tend to increase the concentrations of the primary pollutants.

B. North Kuwait Oilfield Area Results

The predicted ground level concentrations of methane and non-methane hydrocarbons emitted from flaring activities at oil production facilities at North Kuwait have been discussed in detailed elsewhere[2]. The modeling results are presented as the 50 highest hourly, 50 highest daily and the 10 highest annual maximum ground level concentrations of methane and non-methane hydrocarbons resulting from 12 stacks with total emission rate equal to 218.3 g/s and 2909.1 g/s. The calculated values at the uniform grid receptors considering GC-15 (Source coordinate of X= 7.6×10^5, Y= 3.3×10^6) is considered as a reference point to interpret the location of not spots.

The results reflect the increase in flaring in January 2006, due to regular shut down of Condensate Recovery Unit (CRU's) in NK Oilfields and the strong influence of NW prevailing wind direction in Northern field Kuwait. It is concluded that the weather pattern in Kuwait in January 2006, especially the mean prevailing wind direction, significantly contributed to high concentrations of methane and non- methane hydrocarbons at ground level in residential areas located nearly 11 km bearing 104° N from the reference location.

C. South and East Kuwait Oilfield Area Results

5. Non-methane hydrocarbons Concentrations

Figures 2a-2c show the modeling results as the 50 highest hourly, 50 highest daily and the 10 highest annual maximum ground level concentrations of non-methane hydrocarbons. The calculated values from the uniform grid receptors are discussed in the proceeding section and GC-2 (Source coordinate of X= 7.8×10^5, Y= 3.2×10^6) is considered as a reference point to interpret all the location of high concentration. Isopleths plots (contours) were generated, as shown in Figures 3a-3c. The predicted values are in terms of $\mu g/m^3$ and converted to ppm and ppb by using an average Molecular weight (46.9 g/gmole) for non-methane hydrocarbons.

Fig. 2a ISCST3 output data modeling results for the Maximum predicted hourly average concentrations of non-methane hydrocarbons with respect to GC-2 Source

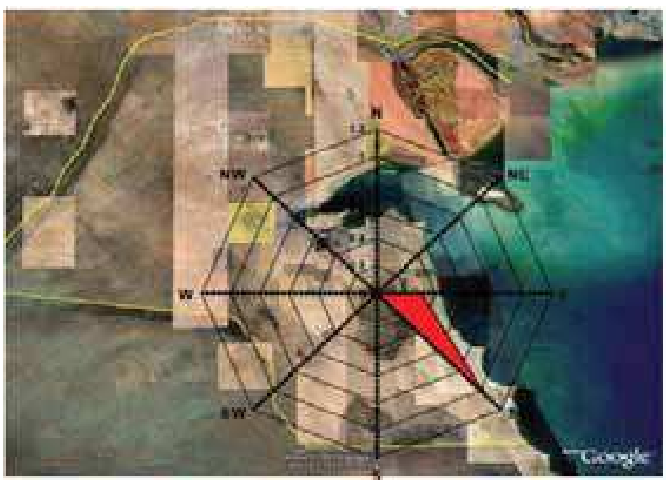

Fig. 2b ISCST3 output data modeling results for the maximum predicted daily average concentrations of non-methane hydrocarbons with respect to GC-2 Source

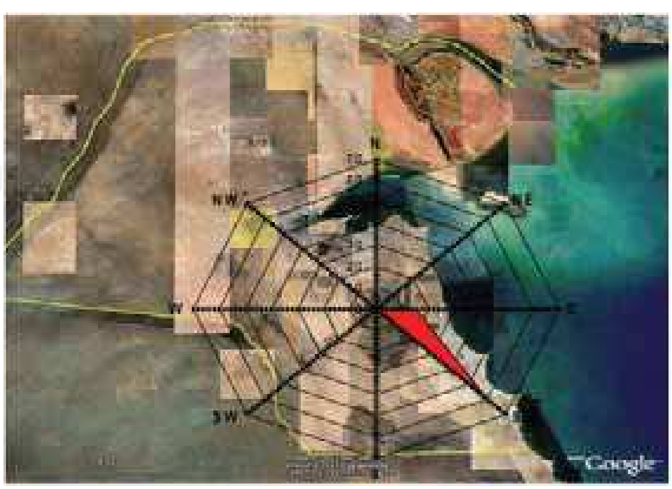

Fig. 2c ISCST3 output data modeling results for the maximum predicted annual average concentrations of non-methane hydrocarbons with respect to GC-2 Source

Fig. 3a Isopleths plot for the maximum hourly average ground level concentrations of non-methane hydrocarbons in μg/m^3

Fig. 3b Isopleths plot for the maximum daily average ground level concentrations of non-methane hydrocarbons in μg/m^3

Fig. 3c Isopleths plot for the maximum annual average ground level concentrations of non-methane hydrocarbons in μg/m^3

The predicted maximum hourly average ground level concentration of non-methane hydrocarbons in the study area is 11.5 ppm on 14th May 2006 at 04:00 Hr at the receptor located nearly 8.3 km bearing 114 °SE as shown in Figure 2a and Figure 3a.
The predicted maximum daily average ground level concentration of non-methane hydrocarbons in the study area are shown in Figure 2b and Figure 3b is 1.06 ppm on 27th May 2006 at the receptor located nearly 8.1 km bearing 116 °SE. This value is 11 times less than the maximum hourly average ground level concentration value. For the same location, Figure 2c and Figure 3c show that the highest annual maximum concentration of non-methane hydrocarbons is equal to 60.4 ppb, which is 17 times less than the maximum daily average ground level concentration value.
Kuwait-EPA has specified the concentration of non- methane hydrocarbons for early morning 3 Hours 6:00 -9:00 AM not exceeding 0.24 ppm. The computed 3 hours average data reveal that the predicted ground level concentration of non-methane hydrocarbons for the specified time 6:00 -9:00 AM has exceeded 120 times almost 48% of the total study period of the KAAQS ambient air quality standard.

6. Methane Concentrations

Figs. 4a-4c show the modeling results for the 50 highest daily and the 10 highest annual maximum ground level concentrations of methane resulting from 12 stacks with total emission rate equal to 218.32 g/s. The calculated values from the uniform grid receptors are discussed in the proceeding section and GC-2 (Source coordinate of X= 7.8x10^5, Y= 3.2x10^6) is considered as a reference point to interpret the location of high concentration. Figures 5a-5c depicts the concentration variations in different zones. These present the maximum hourly, daily and annual ground level concentration of methane in ppm and ppb calculated at the specified uniform grid receptors are tabulated.
The results presented in Figures 4a-4c and 5a-5c reveals predicted ground level concentrations of methane. The predicted maximum hourly average ground level concentration of methane in the study areas is 2.53 ppm on 14th May 2006 at 04:00 Hr at the receptor located nearly 8.3 km bearing 114° SE.
The predicted maximum daily average ground level concentration of methane in the study areas (Figure 4b) is 0.233 ppm on 27th May 2006. This value is 11 times less than the maximum hourly average ground level concentration value at location nearly 8.1 km bearing 116°SE. It is not surprising that the highest annual maximum concentration of methane also at the same spot as the maximum hourly and daily. The highest annual maximum concentration of methane is 17.8 ppb which is 13 times less than the maximum daily average ground level concentration value.
The above results reflect the increase in flaring in May 2006, due to regular shut down of Condensate Recovery Unit (CRU's) in SEK Oilfields integrated with wind direction in Kuwait. Considering Figures 2a-2c, 3a-3c, 4a-4c and 5a-5c together, it can be concluded the weather pattern in Kuwait in May 2006, especially the mean prevailing wind, significantly contributed to high concentrations of methane and nonmethane hydrocarbons at ground level in residential areas located nearly 8.3 km bearing 114°SE.

Fig. 4a ISCST3 output data modeling results for the Maximum predicted hourly average concentrations of methane with respect to GC-2 Source

Fig. 4b ISCST3 output data modeling results for the maximum predicted daily average concentrations of methane with respect to GC-2 Source

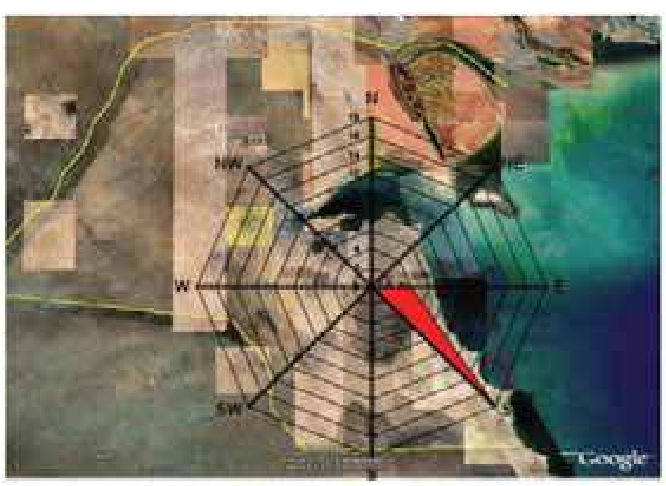

Fig. 4c ISCST3 output data modeling results for the maximum predicted annual average concentrations of methane with respect to GC-2 Source

Fig. 5a Isopleths plot for the maximum hourly average ground level concentrations of methane in μg/m^3

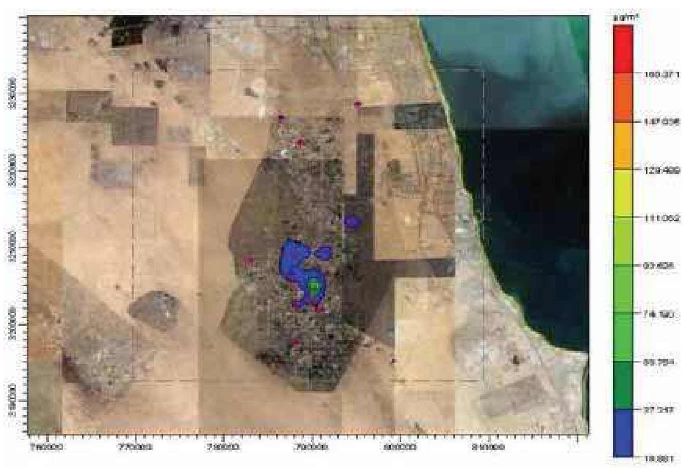

Fig. 5b Isopleths plot for the maximum daily average ground level concentrations of methane in μg/m^3

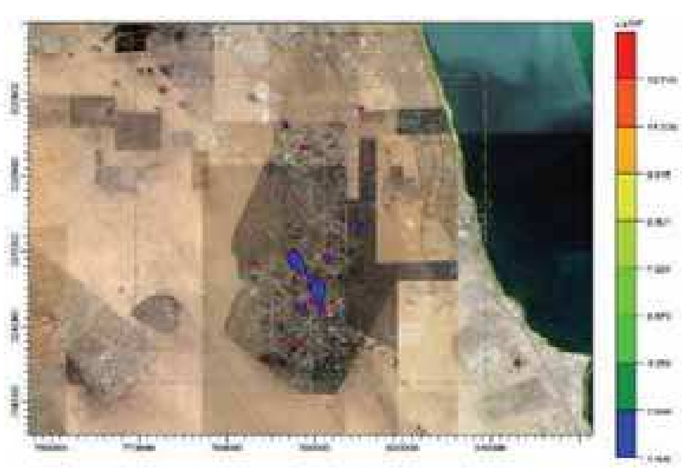

Fig. 5c Isopleths plot for the maximum annual average ground level concentrations of methane in μg/m^3

D. West Kuwait Oilfield Area Results

1. Non-methane hydrocarbons Concentrations Figures 6a-6c show the modeling results as the 50 highest hourly, 50 highest daily and the 10 highest annual maximum ground level concentrations of non-methane hydrocarbons. The calculated values from the uniform grid receptors are discussed in the proceeding section and GC-28 (Source coordinate of $X=7.5x10^5$, $Y=3.2x10^6$) is considered as a reference point to interpret the location of high concentration. Isopleths plots (contours) were generated, as shown in Figures 7a-7c. The predicted values are in terms of $\mu g/m^3$ and converted to ppm and ppb by using an average Molecular weight (46.9 g/gmole) for non-methane hydrocarbons.

The predicted maximum hourly average ground level concentration of non-methane hydrocarbons in the study area is 2.53 ppm on 28th August 2006 at 09:00 Hr at the receptor located nearly 23.8 km bearing 139° SE, confirming source strength with Poe valued meteorological conditions. (Figure 6a and Figure 7a). The predicted maximum daily average ground level concentration of non-methane hydrocarbons in the study area given in Figure 6b is 0.275 ppm on 25th August 2006 at the receptor located nearly 22.7 km bearing 140° SE. This value is 10 times less than the maximum hourly average ground level concentration value. Figures 6c and 7c show that the highest annual maximum concentration of non-methane hydrocarbons is equal to 39.5 ppb, which is 7 times less than the maximum daily average ground level concentration value. 2. Methane Concentrations Figure 8a-8c show the modeling results for the 50 highest hourly, 50 highest daily and the 10 highest annual maximum ground level concentrations of methane. The calculated values from the uniform grid receptors are discussed in the proceed section and GC-28 (Source coordinate of $X= 7.5x10^5$, $Y= 3.2x10^6$) is considered as a reference point to interpret the location of high concentration. Figures 9a-9c depicts the concentration variations in different zones that present the maximum hourly, daily and annual ground level concentration of methane in ppm and ppb are calculated at the specified uniform grid receptors and are tabulated.

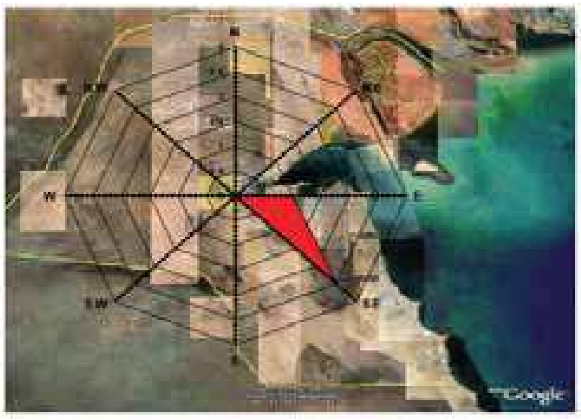

Fig. 6a ISCST3 output data modeling results for the Maximum predicted hourly average concentrations of methane with respect to GC-28 Source

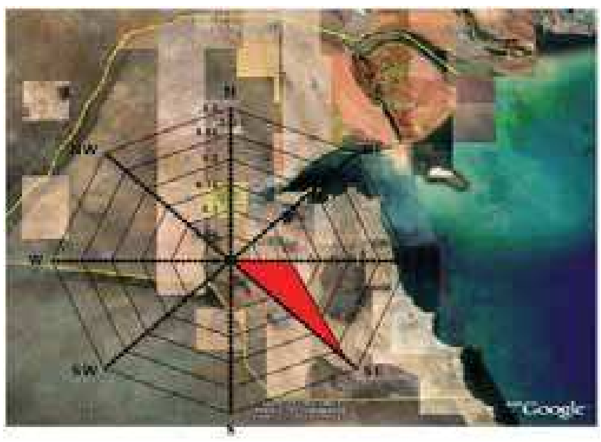

Fig. 6b ISCST3 output data modeling results for the maximum predicted daily average concentrations of methane with respect to GC-28 Source

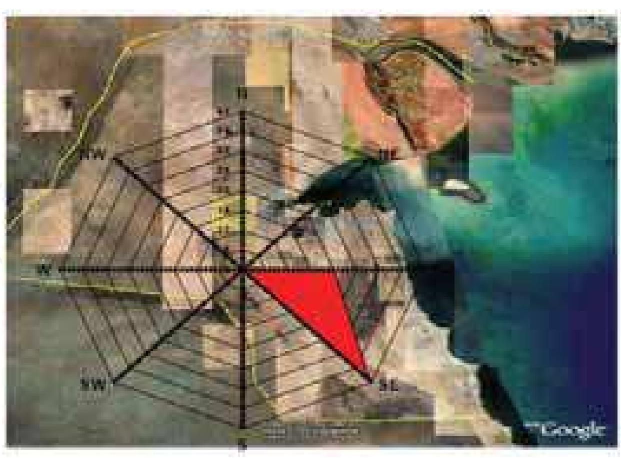

Fig. 6c ISCST3 output data modeling results for the maximum predicted annual average concentrations of methane with respect to GC-28 Source

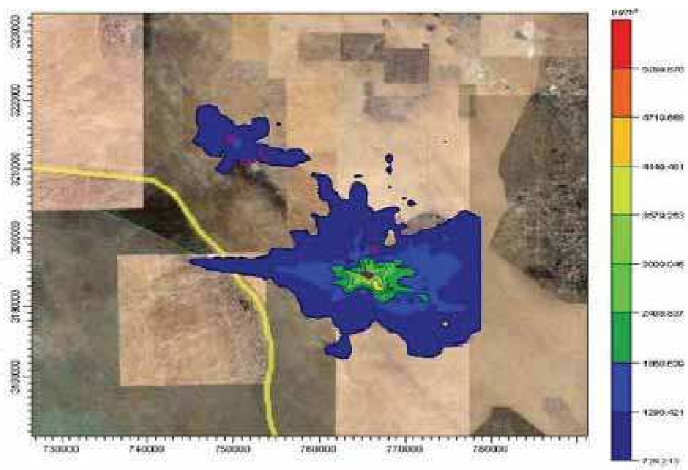

Fig. 7a Isopleths plot for the maximum hourly average ground level concentrations of non-methane hydrocarbons in μg/m^3

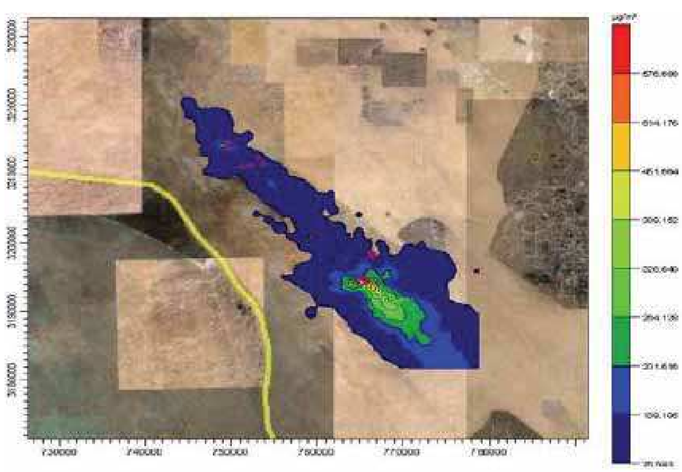

Fig. 7b Isopleths plot for the maximum daily average ground level concentrations of non-methane hydrocarbons in μg/m^3

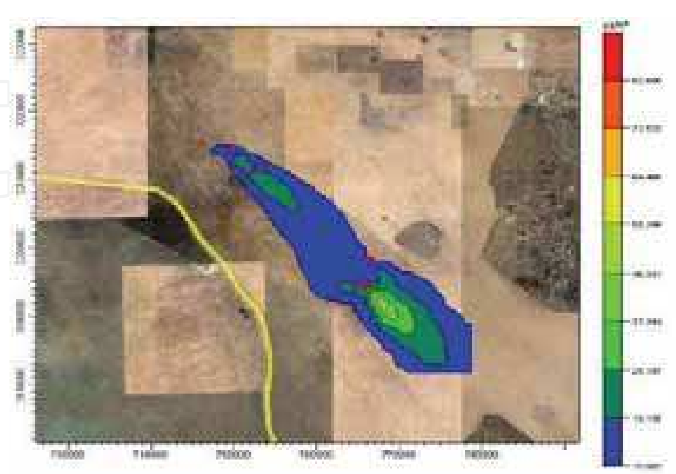

Fig. 7c Isopleths plot for the maximum annual average ground level concentrations of non-methane hydrocarbons in μg/m^3

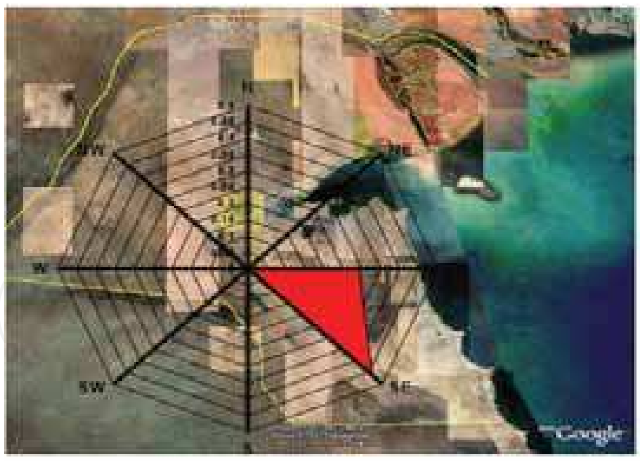

Fig. 8a ISCST3 output data modeling results for the Maximum predicted hourly average concentrations of methane with respect to GC-28 Source

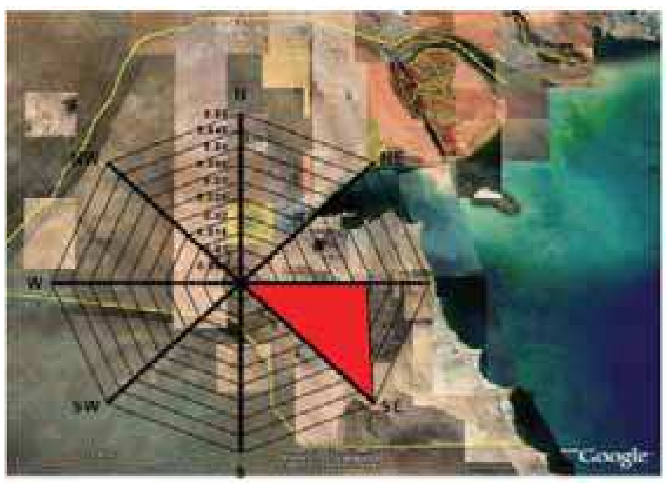

Fig. 8b ISCST3 output data modeling results for the maximum predicted daily average concentrations of methane with respect to GC-2 Source

Fig. 8c ISCST3 output data modeling results for the maximum predicted annual average concentrations of methane with respect to GC-28 Source

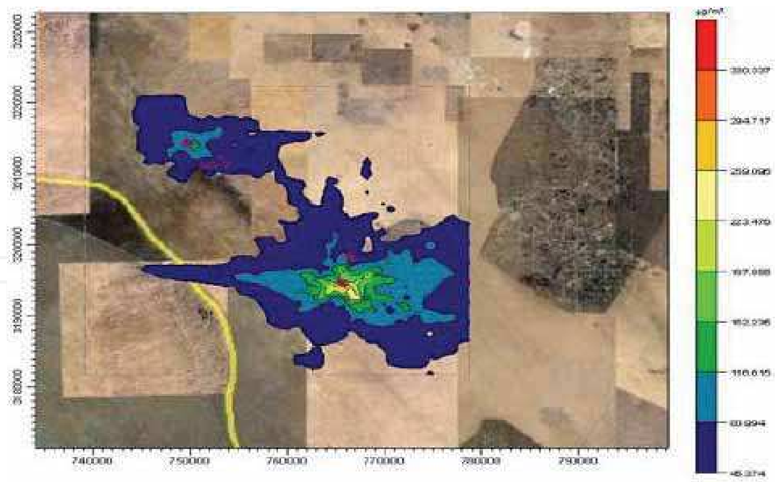

Fig. 9a Isopleths plot for the maximum hourly average ground level concentrations of methane in μg/m^3

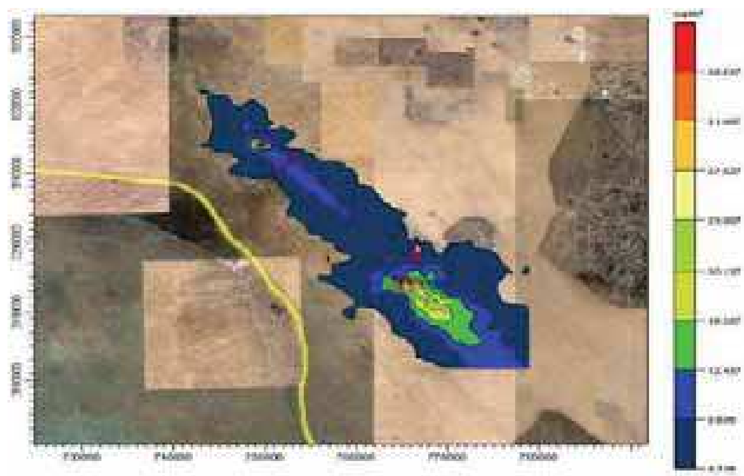

Fig. 9b Isopleths plot for the maximum daily average ground level concentrations of methane in μg/m^3

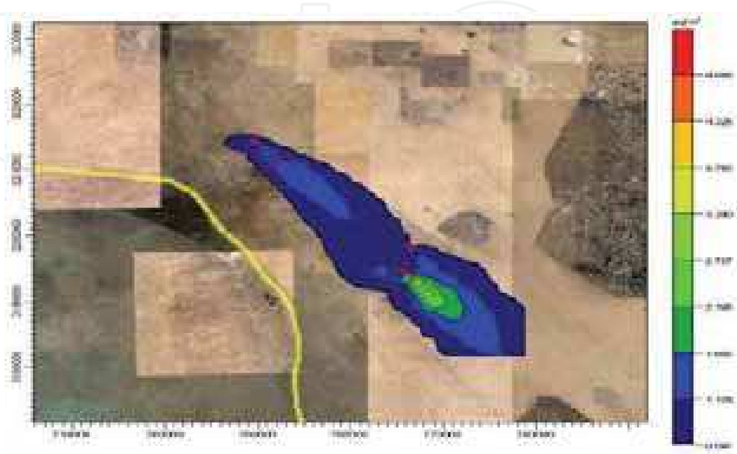

Fig. 9c Isopleths plot for the maximum annual average ground level concentrations of methane in μg/m^3

The results presented in Figures 8a-8c and 9a-9c revealed that predicted ground level concentrations of methane. The predicted maximum hourly average ground level concentration of methane in the study areas is 0.462 ppm on 28th August 2006 at 09:00 Hr at the receptor located nearly 23.8 km bearing 141 ° SE. The predicted maximum daily average ground level concentration of methane in the WK Oilfields is 50 ppb on 25th August 2006 given in Table VB. This value is 9 times less than the maximum hourly average ground level concentration value. This receptor is located nearly 22.7 km bearing 140° SE. It is not surprising that the highest annual maximum concentration of methane also at the same spot as the maximum hourly and daily. The highest annual maximum concentration of methane is 6.8 ppb which is 7 times less than the maximum daily average ground level concentration value. Due to Shutdown in KNPC (Acid Gas Removal Plant, AGRP), the percentage of flaring on WK Oilfields was high for months July and August (87% and 95%). There is strong influence of prevailing north west wind in Summer, August hours morning. Most of the highest values predicted were in summer and early morning hours due to low temperature and low in version layer. The total gas production is from mainly three major oilfields and associated gas are 55%,12%,33% from SEK, WK, NK respectively. The flaring due to complication in gas handling facilities are 3.8 %, 66.8% and 29.4% from SEK, WK, NK respectively.

7. Conclusion

From the comparison between the simulated results for emission scenarios in the North, Southeast and West Kuwait Oilfields it can be concluded the following;

- Methane and non-methane hydrocarbons are not the only green house gasses which result from flaring activities. The flaring of excess gas is the largest single source of atmospheric emissions arising from KOC operations. However, flaring produces carbon dioxide, oxides of sulphur and nitrogen (NOx) and other chemical species that are results of incomplete combustion, such as carbon monoxide, aldehydes, ketones and other organic compounds known as VOCs (Volatile Organic Compounds). However the methane and non-methane hydrocarbons gases provide typical samples which are focus of this research. The emissions from flaring activities in different oilfields are used as an input for the ISCST3 model to investigate the impact on the air quality and methane and non-methane hydrocarbons levels. The statistical comparison between the 50 highest daily measured and predicted concentrations emissions at SEK, WK and NK existing air quality monitoring site showed a good agreement validating the model results.
- SEK, WK, NK represented 22.1%, 4.9% and 73%from total emissions respectively. The highest predicted concentration of methane and non-methane in NK Oilfields occurred from the centre of GC-15 near Um Al-Aish monitoring station and not far from the residential areas.
- NK Oilfields have generated a high ground level concentration of methane and non-methane hydrocarbons than SEK and WK Oilfields. This is because of the unexpected problems in NK Oilfields. The highest average ground level concentration of methane and nonmethane hydrocarbons, hourly, daily and annually were in the months of January and September due to high emission rates resulted due to malfunctioning of condensate recovery unit. The prevailing meteorological conditions in the month of

January have resulted into the top highest ground concentrations due to low temperatures and low inversion layer and calm wind conditions.

- There is a need for correct and adequate emission inventory for all oil production facilities to minimize the impact of pollutants released from flaring activities.

In future this work can be extended to include other pollutants such as NO_X, SO_2, CO, CO_2 and the organic components. Therefore, there is a need for a proper emission inventory strategy for KOC to minimize the impact of NO_X, SO_2, CO, CO_2, methane and non-methane hydrocarbons released from flaring activities.

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9. References

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The techniques of computer modelling and simulation are increasingly important in many fields of science since they allow quantitative examination and evaluation of the most complex hypothesis. Furthermore, by taking advantage of the enormous amount of computational resources available on modern computers scientists are able to suggest scenarios and results that are more significant than ever. This book brings together recent work describing novel and advanced modelling and analysis techniques applied to many different research areas.

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