



Spatial Analysis of the CO Emission from Nineveh Governorate Using Remote Sensing Techniques and GIS

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Abstract

Carbon Monoxide (CO) has a significant indirect effect on greenhouse gasses due to its ozone and carbon dioxide precursor, and its mechanism of degradation involving the hydroxyl radical (OH) which control the oxidizing ability of the tropospheric. To understand the effect of human activities on atmospheric composition, accurate estimates of the sources of atmospheric carbon monoxide (CO) are necessary. MOPITT (Measurements of Pollution in the Troposphere) is a NASA Terra satellite instrument designed to allow both Thermal-Infra-Red (TIR) and Near-Infra-Red (NIR) observations to be used to collect vertical CO profiles in the Troposphere via the concept of correlation spectroscopy. The objective of the current study is to analyze and map the monthly, seasonal and annual trend of CO concentration for year 2016 in Nineveh governorate using the retrieved CO Surface Mixing Ratio Day mode of level 3, version 7 dataset. The dataset was downloaded from the National Aeronautics and Space Administration (NASA) operated GIOVANNI portal. The results of dataset analysis in GIS software showed many sources of carbon monoxide in Nineveh Governorate, which change with months and seasons of the year. Generally, the observed CO concentration levels in the southern and western of the governorate were more than in the northern and eastern parts. The annually average CO ranges from (115.374 ppbv) to (132.452 ppbv). Also, CO emissions and concentrations were higher in winter (128.638-157.567 ppbv) than summer season (97.144-106.515 ppbv).

Keyword: MOPITT, GIS, CO, Nineveh, Terra

التحليل المكاني لأنبعاثات اول اوكسيد الكربون من محافظة نينوى باستعمال تقانات التحسس النائي ونظم المعلومات الجغرافية

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الخلاصة

يلعب غاز اول اوكسيد الكربون (CO) دورا مهما وغير مباشر في الغازات الدفيئة بسبب تأثيره على توازن الهيدروكسيل راديكال (OH) والاوزون (O₃) والعمليات الكيميائية في الغلاف الجوي السفلي. ويتطلب دراسة تأثير الانشطة البشرية على نسبة غاز اول اوكسيد الكربون في الغلاف الجوي ، تحديد المصادر الرئيسية

لهذا الغاز. يعتبر متحسس قياسات التلوث في التروبوسفير (MOPITT) أحد منظومات الاستشعار عن بعد المحمولة على القمر الاصطناعي تيرا (TERRA) التابع للإدارة الوطنية للملاحة الجوية والفضاء (NASA)، صمم هذا المتحسس لرصد وتسجيل تراكيز غاز أول أكسيد الكربون في طبقة التروبوسفير من خلال حزمة الأشعة تحت الحمراء الحرارية (TIR) والأشعة تحت الحمراء القريبة (NIR) من خلال مفهوم التحليل الطيفي. الهدف من الدراسة الحالية هو تمثيل وتحليل خرائط الاتجاه الشهري والموسمي والسنوي لتركيز ثاني أكسيد الكربون في طبقة التروبوسفير لعام (2016) في محافظة نينوى باستعمال نماذج الملفات المسترجعة للغاز ضمن الوضع النهاري في المستوى (3) والإصدار (7). تم تحميل البيانات من بوابة (GIOVANNI) التي تديرها (NASA). أظهرت نتائج تحليل البيانات في برمجيات نظم المعلومات الجغرافية العديد من مصادر أول أكسيد الكربون في محافظة نينوى والتي تتغير مع شهور وفصول السنة. كانت مستويات تركيز ثاني أكسيد الكربون الملحوظة في جنوب وغرب المحافظة أعلى منها في الأجزاء الشمالية والشرقية. تراوح المتوسط السنوي لتركيز أول أكسيد الكربون من (115.374 ppbv) إلى (132.452 ppbv). أيضًا، كانت انبعاثات وتركيزات ثاني أكسيد الكربون أعلى في الشتاء (128.638–157.567 ppbv) مقارنة بموسم الصيف (97.144–106.515 ppbv).

1. Introduction

Climate change is a direct result of human activities that release large amounts of greenhouse gasses (water vapor, carbon dioxide, methane, and nitrous oxide, Ozone and CFC) into the Earth's atmosphere as a result of the industrial revolution and high growth rates in many developed and developing countries due to many uses that are harmful to the environment. Global warming results from increased release of these greenhouse gases into the atmosphere. This increment absorbs the infrared radiation emitted from the earth's surface by these gases and hold it in the Earth's atmosphere led to occurrence of climatic change phenomenon [1]. Carbon monoxide (CO) has a major indirect impact on greenhouse gasses because of its ozone and carbon dioxide precursor, and its degradation process involving the hydroxyl radical (OH) which regulates the oxidizing capability of the troposphere [2]. CO is unique in the lower atmosphere where pollutants last for about a month, long enough to move it over long distances, but not so long that it is distributed almost uniformly [3]. Most (CO) emissions come from anthropogenic activities while the remainder comes from burning and oxidation of biomass. In IRAQ, open dumping fires, terrorist attack on oil pipes and burning of associated petroleum gases in oil field productions represent a real challenge to control CO emissions as open dump firing happens every day in most parts of the country while attacks on oil pipe line happens on routinely bases [4]. Another source of CO emission in Iraq, is hospitals' incinerations which used in Iraq to deal with healthcare medical waste, especially most these incinerators are in very bad technical conditions without active burning systems [5]. However, accurate estimates of sources of atmospheric carbon monoxide (CO) are important for understanding the effects of human activities on the composition of the atmosphere. The growing number of Earth observation satellite systems, together with advances in GIS processing and analysis techniques, provide a new mechanism for monitoring the concentration of CO in the troposphere in a city or on a regional scale [3]. MOPITT is a NASA Terra satellite instrument designed to allow collection of vertical CO profiles in the atmosphere using both thermal-infrared (TIR) and Near-infrared (NIR) observations [6, 7]. The objective of the current study is to analyze and map the monthly, seasonal and annual trend of CO concentration for the year 2016 (i.e. during the period of time that the governorate was under the occupation of Islamic State of Iraq and Syria (ISIS) terrorist organization which lasts from 10-June-2014 to 10-July-2017) in Nineveh governorate using the retrieved CO Surface Mixing Ratio Day mode of the level 3 version 7 dataset. The dataset was downloaded from the (NASA) operated GIOVANNI portal [8]. The study is mainly dealing with the CO MOPITT datasets of the study area by using the Geographical

Information System (GIS) software for the cartographic representation of the output results. While some researches relied mainly on analyzing CO distribution maps that can be accessed and activated directly from CO MOPITT data sites [9, 10].

2. Region of Interest

Nineveh governorate is located in northwestern Iraq between the latitudes (34 °: 56' and 37 °: 03') north and longitudes (41 °: 25' and 44 °: 25') east as shown in Figure 1. Its estimated total land area is 37,323 km². The surface of the Nineveh Governorate is described by its varying topographical characteristics from one region to another, its surrounding hills and high mountain chains affect wind direction, lowlands and paths [11]. The climate of studied region is classified as semi-arid, subtropical, Mediterranean climate, with a hot, dry summer and cold winter climate. In winter and spring, most rain occurs (October to May). No rainfall during summer (June-September period) [12].

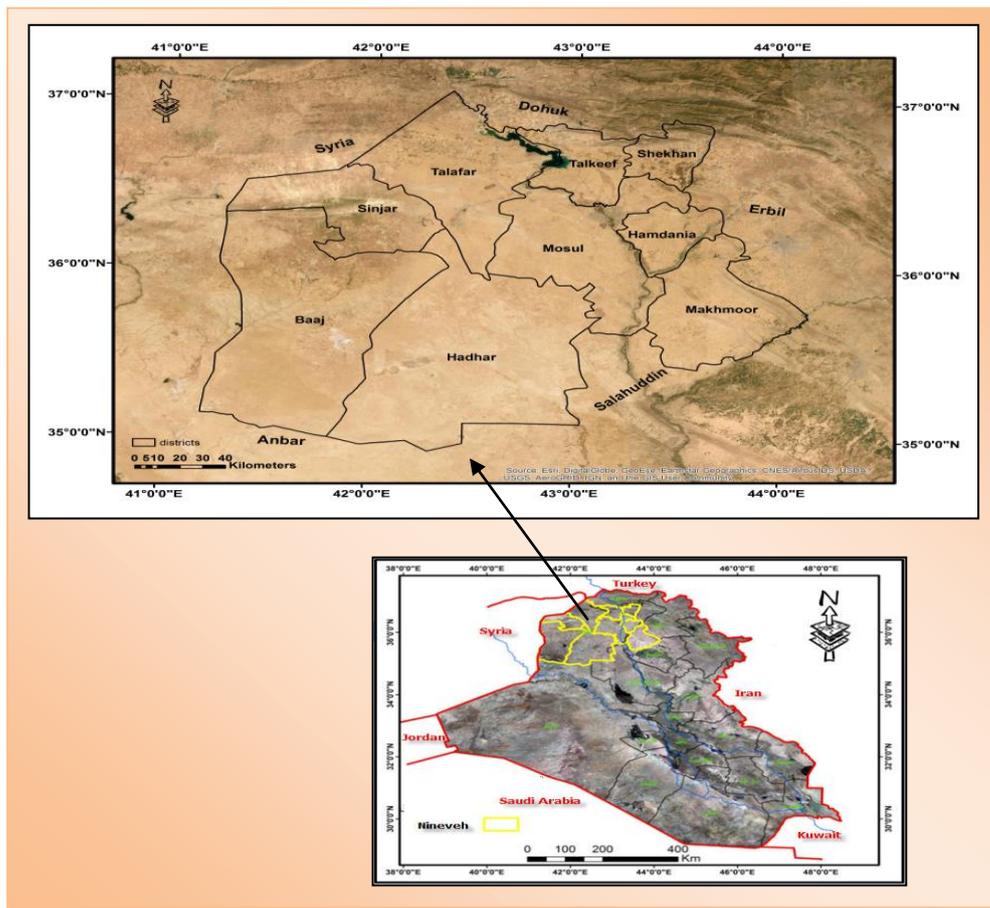


Figure 1-Site of the studied area

3. MOPITT Background

Since 1999, the Canadian MOPITT instrument has continuously scanned the Earth's atmosphere for long-term measurements of CO concentration level. It was one of five instruments launched on 18-December-1999 on the Terra satellite, by the (NASA) [13]. The MOPITT instrument used correlation spectroscopy concept to measure the concentrations of carbon monoxide (CO) at three troposphere levels using thermal radiation at 4.7 μm, total column level of CO, and methane CH₄ by reflected sunlight at around 2.3 μm. Correlation spectroscopy uses a gas-containing sample cell to be measured in a simple radiometer path and modulates the amount of gas in the cell. The resulting signal can be analyzed to visualize enhanced radiance sensitivity at optical frequencies near the target gas spectral lines. To reach

its goals, the MOPITT system uses two gas modulation cells: Pressure Modulation Cell (PMC) and Length Modulation Cell (LMC) as shown in Figure 2. Here, the signal passes through a cell that contains the target gas (CH₄ or CO) varying according to cell pressure or length, that results a variation of cell opacity along the target gas lines, while the cell opacity stays constant at other frequencies [14].

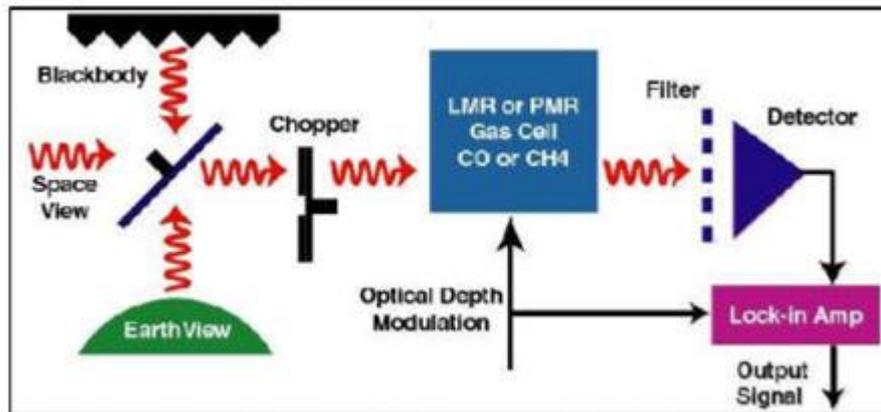


Figure 2- Correlation spectroscopy mechanism in the MOPITT

The Terra and MOPITT specifications are listed in the table 1. [15, 16, and 17]

Table 1- Terra / MOPITT specifications

Item	Detail
Responsible Center	University of Toronto
Agency Responsible	The Canadian Space Agency
MOPITT Launch	18 December 1999, and in March 2000, nominal scientific measurements began.
Spectral Bands	1- 4.7 μm channels with high absorption properties of CO and referred as CO thermal channels. 2- 2.3 μm channels that have poor absorption of CO and referred as CO solar channels. 3- 2.2 μm channels that have poor methane CH ₄ absorption for the band where reflected sunlight is the main signal source and referred as methane solar channels.
CO Retrieval Grid Pressure	10 levels (100, 200, 300,900 hPa) at surface
Spatial Resolution	(22 X 22) km horizontally and (3 X 3) km vertically with an accuracy of 10 percent
Orbital Type	Sun-synchronous low-earth polar orbit
Swath	640 km
Altitude	705 km
Inclination Angle	98.4 ⁰ , resulting in a nadir coverage from 82 S to 82 N.
Duration of Earth's Satellite Orbits	approximately 98 min with an exact 16 day repeat period
Nominal Equator Crossing Time	10:30 am local time in descending node
Instrument IFOV	22 km across track, 88 km along track
Channels	Eight- channels radiometer

4. MOPITT CO Data

MOPITT is a vertically down-point mode and nadir sounding instrument measuring upwelling infrared radiation at 4.7 μm and 2.2-2.4 μm. Correlation spectroscopy is used to calculate total column observations, CO, and CH₄ concentrations below a vertical column of

the atmosphere. It was designed to provide an increasing experience in the tropospheric chemistry and to observe how it interacts with the biosphere of land and oceans.

The current data versions of MOPITT CO retrievals (products of Level 2 and Level 3) are: TIR: thermal infrared-only (wavelength of 4.7 μm), NIR: near infrared-only (wavelength of 2.3 μm) and multispectral bands of TIR and NIR product. Table 2 lists the summary of old and new MOPITT data version products [18].

Table 2- Summary of the MOPITT data products

Version Products	Spectral Band (μm)	Operational Period	Meteorological Model
V3*	TIR	2002-2009	NCEP GDAS Global Data Assimilation System
V4*	TIR	2009-2012	
V5*	TIR, NIR, TIR&NIR	2011-2016	
V6	TIR, NIR, TIR&NIR	2013-present	MERRA Modern-Era Retrospective Analysis for Research and Applications
V7	TIR, NIR, TIR&NIR	2016-present	MERRA2 Modern-Era Retrospective Analysis for Research and Applications-2
V8	TIR, NIR, TIR&NIR	2018-present	

* no longer available

For each CO retrieval process, the MOPITT retrieval algorithm needs a dataset of temperature, water vapor profiles, and a priori surface temperature values which are derived from meteorological stations [8].

5. Data Access and Processing

Retrieved CO Surface Mixing Ratio Day mode of level 3 version 7 dataset, was taken from NASA- operated GIOVANNI portal [19]. The dataset was express in unit of Part Per Billion Volume (ppbv) and covered all Nineveh governorate area as a grid of 12-points with a uniform grid interval of 1-degree latitudes-longitudes as shown in Figure 3 below.

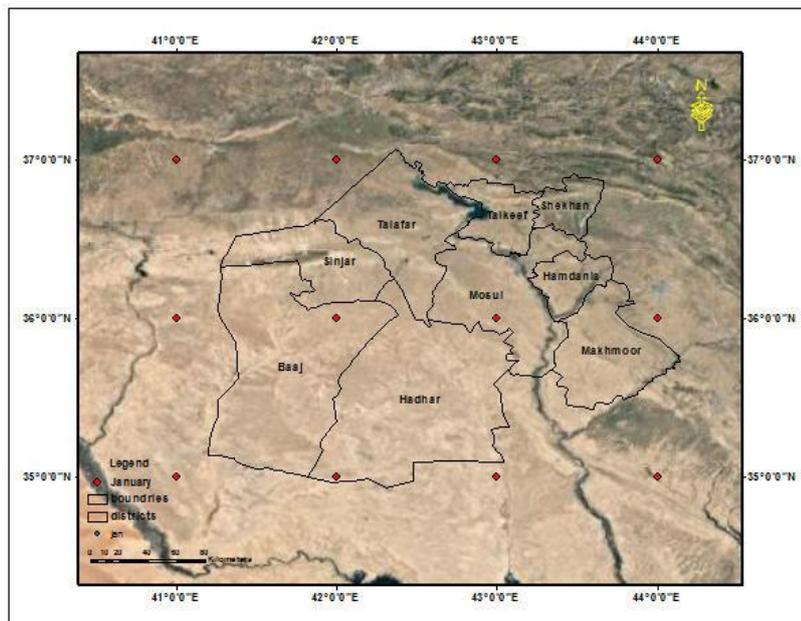


Figure 3- CO grid distribution with interval of 1 degree

The retrieved CO was downloaded for period from 1st-January to 31st-December 2016. Generally, the MOPITT data were archived and delivered using Hierarchical Data Format

(HDF) which is the common data format for all NASA Earth Observing System (EOS) datasets. The HDF-EOS extension is a swath structure defined along with the Application Program Interfaces (APIs). The API offers functionality for creating, accessing and manipulating grid, point and swath configurations [20]. The HDF-EOS products can be processed, analyzed and visualized into Panoply software [21]. Panoply is an advanced and complex Java application designed to enable users to easily plot raster images of geo-gridded datasets of HDF-EOS extension. In order to reach the stage of mapping the average distribution of carbon monoxide concentrations, the following steps were followed in the study:

1- CO MOPITT datasets of the study area were accessed and downloaded from the Giovanni website for the 12 months of year 2016.

2- The CO downloaded datasets were opened using Panoply visualization software (version 4.10.3). Grids/MOPITT files for each month was selected. The variable's full name of the files is:

HDFEOS/GRIDS/MOP03/Data_Fields/RetrievedCOSurfaceMixingRatioDay

3- From the Panoply windows, selecting a month variable enables the plotting function in the data browser, then plot window will display a map. The data array used to create the map is tucked away behind the map tab in the plot window. The values for individual grid cells for the displayed map will be listed by latitude/longitude in separate column. The grid cells values of the study area for each month will be selected according to the geographical coordinates and copied to be pasted in Excel files.

4- Finally, the Excel files for the 12 months will be add to ArcGIS10.6, converted to shapefiles and Spatial Analyst/ Inverse Distance Weight (IDW) interpolation function will be done to creates the CO spatial concentration mapping over the Nineveh governorate. The IDW gave best representation for the MOPITT CO dataset adopted in the present study. IDW interpolation is good when the points in a region are distributed evenly and systematically [22].

6. Results and Discussion

This study aims to evaluate the trend of CO concentration over Nineveh governorate using MOPITT dataset of the year 2016 (1st January - 31st December). Figure 4 and Figure 5 shows the monthly average of the CO concentration at the surface level. The CO concentration values show spatial variation according to months on most parts of the study area, especially in the western, southern parts and the center of the governorate (Singar, Baaj, Hadher, Talafar, and Mosul). It shows maximum levels in January (167 ppbv), December (160.869 ppbv), April (147.211 ppbv), February (145.563 ppbv) and November (142.5 ppbv). Figure 4 and Figure 5 also indicates that the northern and eastern parts (Shekhan, Makhmoor, Talkeef, and Hamdania) are generally characterized by low levels of CO concentration in most months of 2016, in April (127.06 ppbv), December (125.77 ppbv), January (113.037 ppbv), May (107.225 ppbv), September (97.67 ppbv), and October (97.24 ppbv). The red spots appeared in some months are founds in cloud-free regions where there is a large thermal contrast between the earth surface and the troposphere (daytime, overland and areas not surrounded by vegetation) [9].

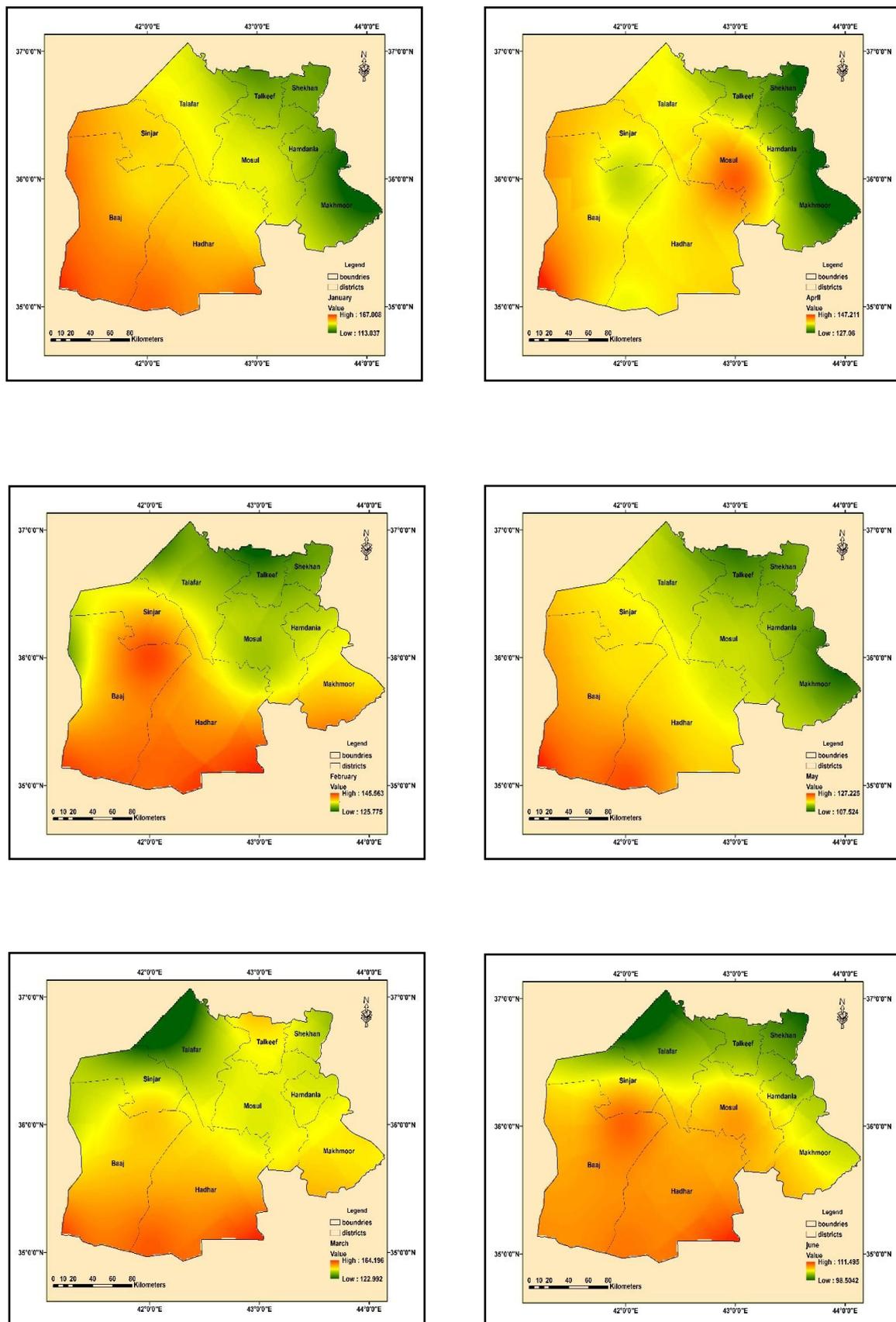


Figure 4-The spatial variations of the monthly average of the CO concentration in the study area (January- June)

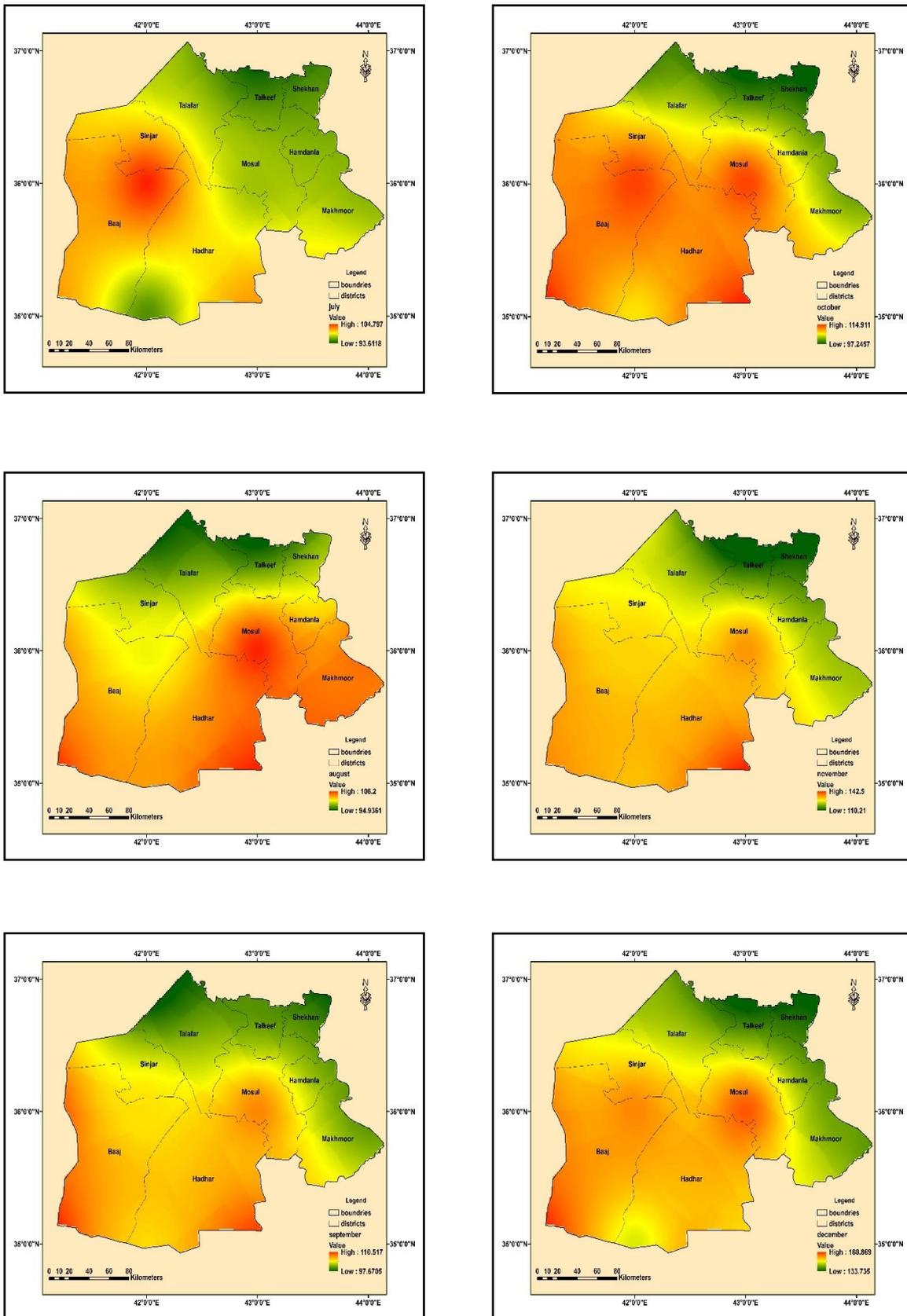


Figure 5- The spatial variations of the monthly average of the CO concentration in the study area (July- December)

Figure 6-illustrates the maximum and minimum CO concentration values between January and December 2016. The figure shows a high level of CO concentrations, whether in the maximum or minimum values in the cold months (November-May) and a low level in the remaining months, especially in the summer months (June, July and August). There are several reasons for this spatial variation of CO concentrations, and they will be clarified through the seasonal and annual maps that show the values of the gas concentrations over the study area.

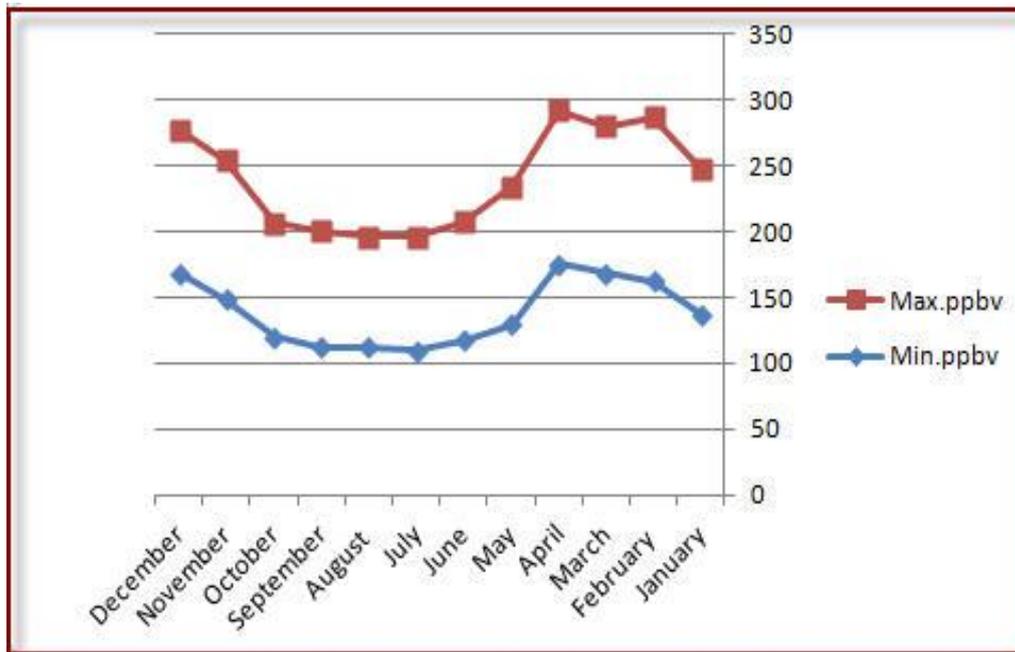


Figure 6- Monthly average variations in CO concentration at the study region

Figure 7, shows the spatial variation of the seasonal CO concentration in the study area. From Figure 7, it can also be observed that the level of CO emission concentrations in the southern and western districts of the governorate (Ba'aj, Hadhar, Sinjar) and Mosul is much higher than the northern and eastern districts (Talkeef, Shekhan, Makhmoor, Hamdania, and Talafar), especially in winter (128.638-157.567 ppbv), followed by spring (125.541-145.814 ppbv), followed by autumn (103.174-122.406 ppbv), then summer (97.144-106.515 ppbv). Again, it can be noted that the results indicate that CO emissions and concentrations are higher in (winter, spring and autumn) seasons than in summer season. In fact, the difference between seasons with high values in winter and low values in summer is the result of the seasonal photochemical cycle of OH, which is mainly CO oxidizer, winter and early spring, coincide with the minimum concentration of OH and hence the maximum concentration of CO [23]. Increasing CO concentration in winter may also be correlated with fuel consumption as a source of heating in homes during cold weather.

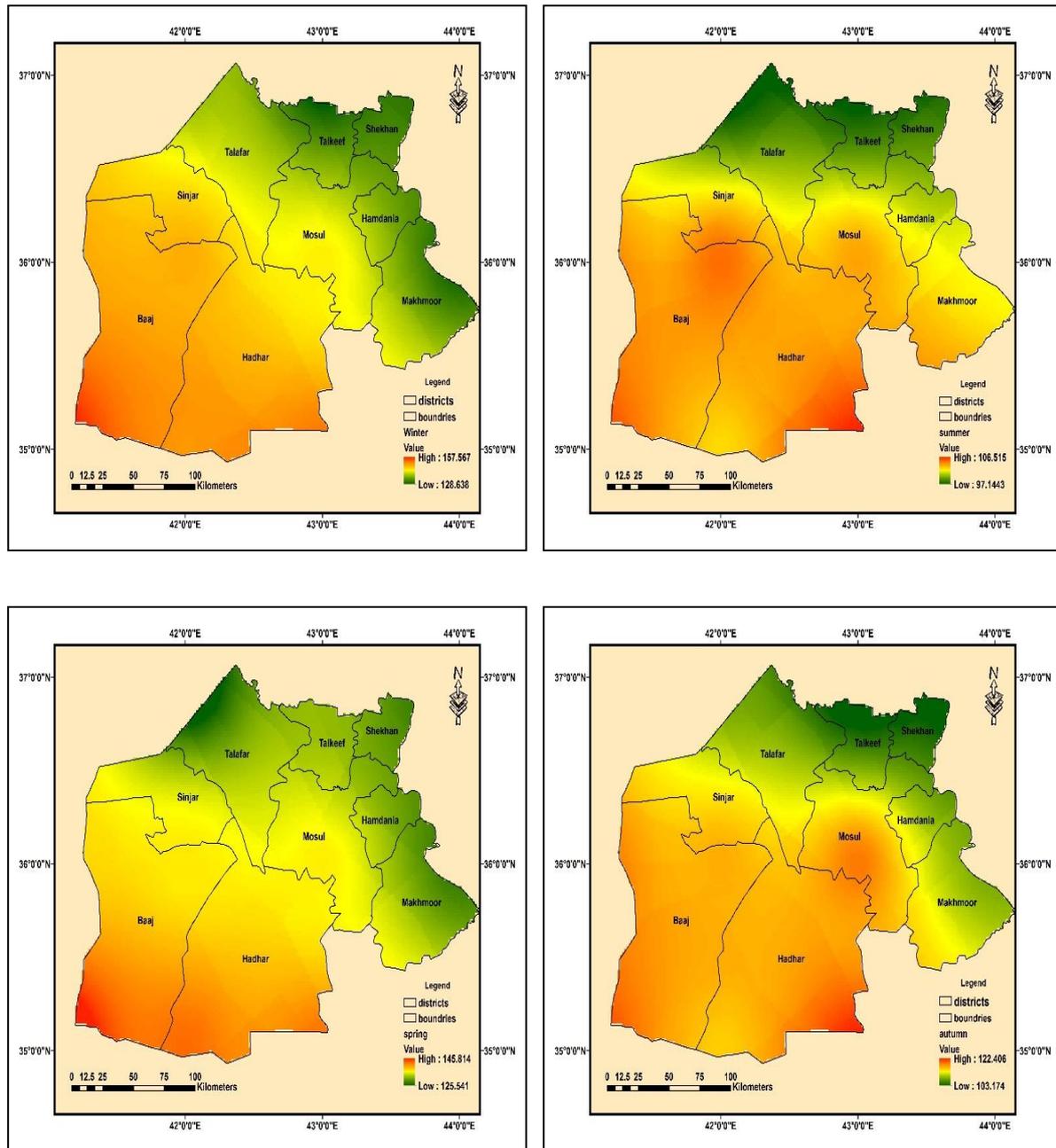


Figure 7- The spatial distribution of the seasonal CO concentration in the study area

Finally, Figure 8 shows the annually average of the spatial variation of the of CO surface concentration for 2016. The figure indicates that the CO emission was highly concentrated over the west and south regions of Nineveh governorate and relatively in the south of Mosul district, the CO concentration ranges from (115.374 ppbv) in the north and east of the governorate to (132.452 ppbv) in the south and west.

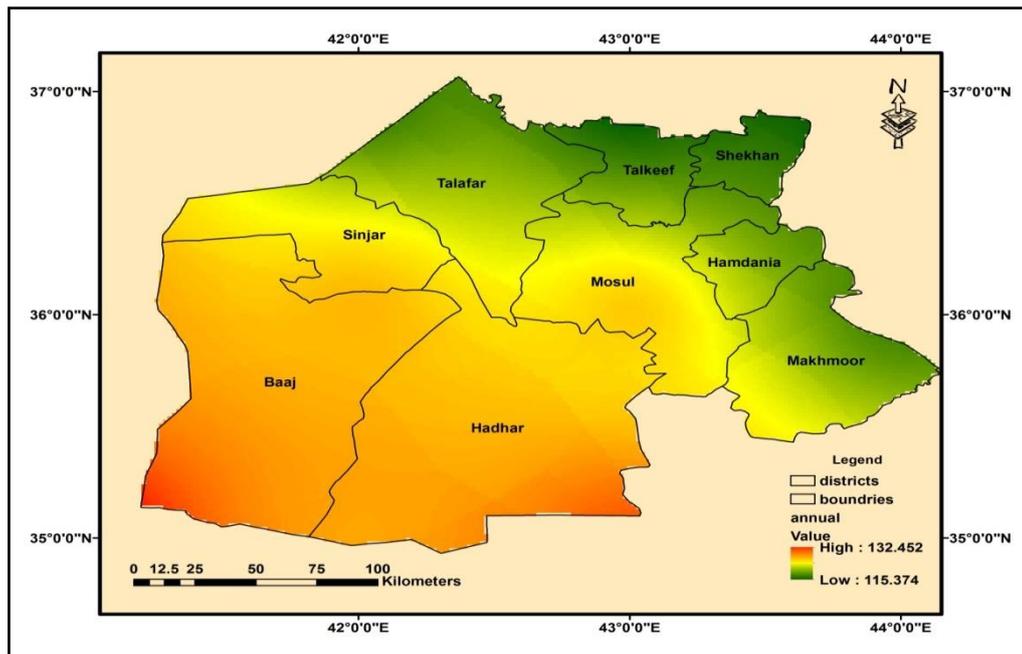


Figure 8- The spatial distribution of the annual average of the CO concentration in the study area

There are several reasons for monthly, seasonal, or annual spatial changes in CO concentrations over Nineveh governorate. In Mosul city, it is resulted from the large number of human population (estimated 1,588,427 in 2011), many human activities, large number of cars as well as large number of diesel generators that are used to generate electricity for homes [24]. In the south of Mosul, specifically the Qayyarah region, which is characterized by the presence of many oil fields, the terrorist organization ISIS burned many of these oil fields, that led to emission of large quantities of pollutants plume to reach the atmosphere including CO. This pollutants plume was extended to the neighboring districts. The fires in the oil fields continued from mid-June 2016 to the last of March 2017 [25]. Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA Terra satellite recorded daily fire detection data of these fires for (1-May-2016 to 28-October-2016), Figure 9.

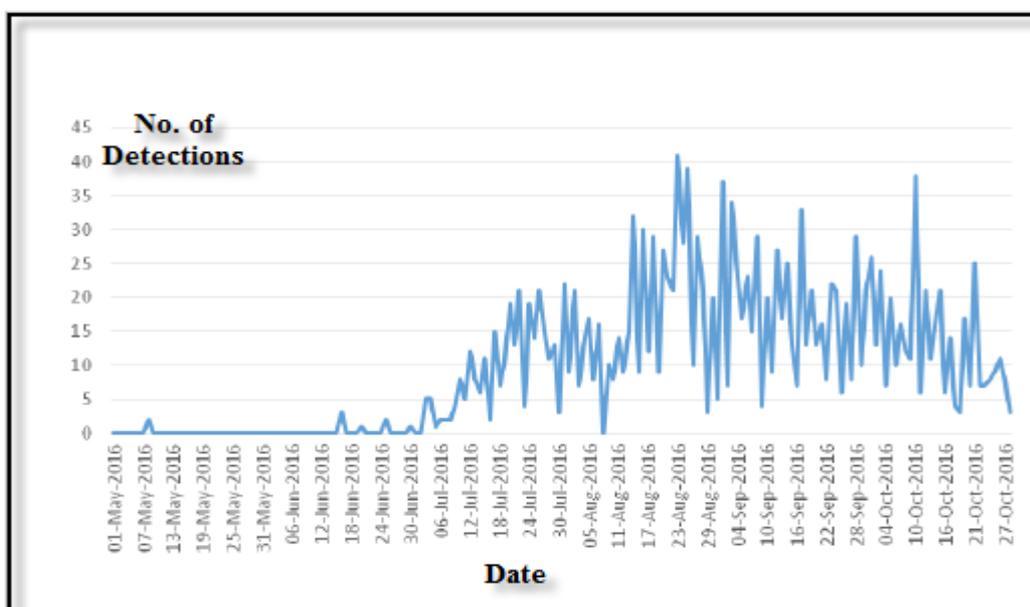


Figure 9- Daily MODIS fire detections, 1 May - 28 October, 2016

During the period of the occupation of Nineveh governorate by the terrorist organization ISIS, many old technology of small refiners called (Harraqat) were installed to produce oil products (specially different types of car fuel), all these Harraqat work without any air pollution control measurements leading to discharge heavy pollutants including CO to atmosphere [26]. Most of these Harraqat were concentrated in the south and west of the governorate, Figure 10. The same technology was used along the Syrian – Iraqi borders, which also caused an increase in CO concentrations in west parts of the study area with very small contribution to CO concentrations to the central, north and east parts.



Figure 10- The old technology of harraqat

Another important reason of the large concentration of CO in the south of Mosul as indicated in Figure 5 above, is Mishraq Sulfur Factory fire, which continued from 21 -27 October, 2016. It also emitted a large quantity of SO₂ and other pollutants plume including CO gas [27]. Figure 11 shows a satellite image acquired by NASA's Aura and Soumi satellites carry the Ozone Monitoring Instrument (OMI) and Global Ozone Monitoring Experiment-2 (GOME-2) described the spreading of the pollutants plume from 22 to 27 October, 2016 [28].

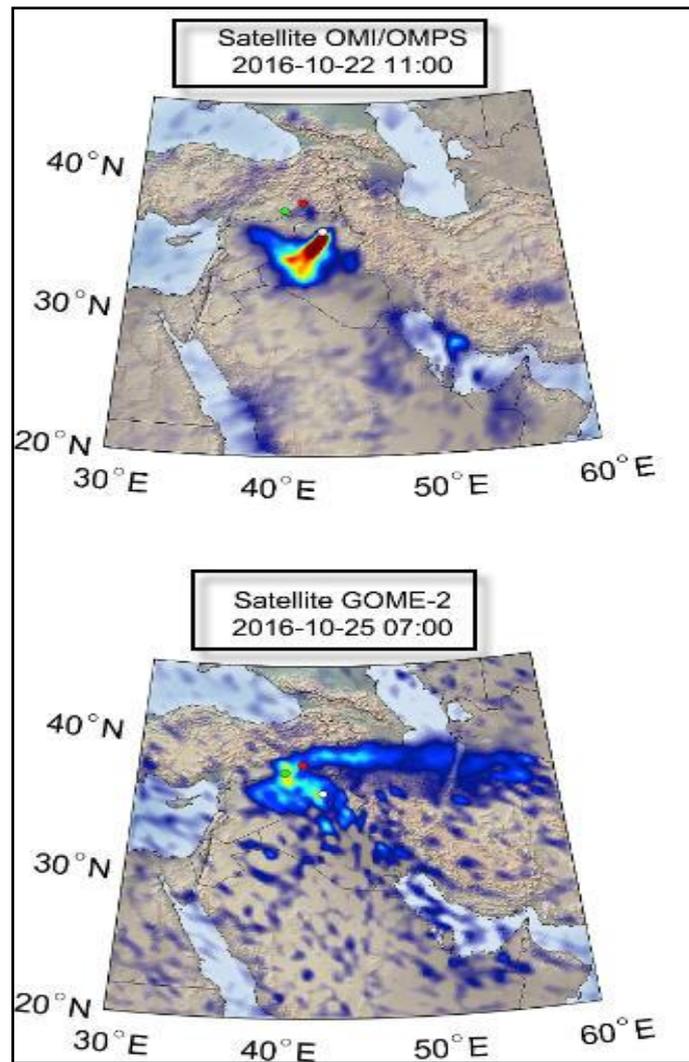


Figure 11-Satellite data for the spreading of pollutants plume from Mishraq Sulfur Fires

From the study results, it was noticed that the highest monthly average CO concentration level appeared in January (167.008 ppbv), while the highest level in the seasons appeared in winter (157.567 ppbv) and the highest annually level was (132.452 ppbv). By comparing these values with the Iraqi national ambient air standards and European air quality standards related to the air quality, including CO (9000 ppbv) measures over an eight hour period, it can be seen that the level of pollution with this gas in all districts of Nineveh governorate is very, very far from dangerous level [29, 30].

7. Conclusions

The study focused on a period during which the Nineveh governorate was under the control of the terrorist organization ISIS, 1st January - 31st December, 2016, when there were many variables that affected the levels of CO emission to the troposphere. From the results, it can conclude the following:

- 1- The retrieved MOPITT CO dataset detected by infrared thermal band at the lower troposphere are able to provide valuable information on CO surface emissions.
- 2- The observed seasonal and annually CO concentration levels in the southern and western districts of the governorate and south of Mosul is much higher than the northern and eastern districts, the annually average CO concentration ranges from (115.374 ppbv) in the north and east of the governorate, to (132.452 ppbv) in the south and west. Also, CO emissions and

concentrations were higher in winter (128.638-157.567 ppbv) than in summer season (97.144-106.515 ppbv).

3-. Qayyarah Oil field and Mishraq sulfur factory fires as well as the man-made of small refiners (Harraqat) increased significantly CO concentration levels in west, south and middle parts of the study area.

4- All CO concentration levels were within national standards limit of ambient air quality as well as European air quality standards.

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