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SPATIOTEMPORAL MONITORING OF METHANE OVER IRAQ DURING 2003-2015: RETRIEVED FROM ATMOSPHERIC INFRARED SOUNDER (AIRS)

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ABSTRACT

Observations of methane (CH_4) retrieved from Atmospheric Infrared Sounder (AIRS) on the EOS/Aqua platform from 2003-2015 show a strong, plume-like enhancement of CH_4 over central and southern-east parts of Iraq during August - September, with the maximum occurring in early September and minimum in March - May over western, southwest, and north-east regions. The percentage change differences results shows the highest differences occurred over the central and southern regions and the smallest differences occurred over the western and southwest regions. To better validate the retrieved data from AIRS three stations at different locations were chosen for trend analysis. The mean and standard deviation in Mosul, Baghdad and Basrah was (3.610 ± 0.042, 3.818 ± 0.048, 3.824 ± 0.055) $x10^{19}$ $Mole.Cm^{-2}$ respectively for monthly long term trend analysis. Annual trend analysis shows positive trends, and ranged between (0.0083 and 0.0097) $Mole.Cm^{-2}.y^{-1}$ for Mosul and Basrah, respectively. Monthly trend analysis have positive trends (0.0092) $Mole.Cm^{-2}.y^{-1}$ for Mosul and (0.0107) $Mole.Cm^{-2}.y^{-1}$ for Baghdad and Basrah. The annual linear growth rate were (2%) for Mosul, and (3%) for Baghdad and Basrah, and monthly linear growth rates were (5%) for Mosul and Baghdad, and (6%) for Basrah. Further daily long term trend shows significant linear increase of (3.7 %) caused a trend of (0.0107×10^{19}) $Mole.Cm^{-2}.y^{-1}$ in Baghdad. The standard deviation of variation in daily average CH4 as a percentage deviation from the mean for the departure from the mean was (1.62%), (0.06×10^{19} $Mole.Cm^{-2}$). And the day to day variation with a clear seasonal change shows standard deviation of enter sequential changes was (0.053×10^{19}) $Mole.Cm^{-2}$. These results indicate that Satellite observations efficiently show the temporal variations of the CH_4 values over different regions.

Keywords: methane, AIRS, remote sensing.

INTRODUCTION

The Atmospheric methane (CH_4) is a second most potent anthropogenic greenhouse gas (GHGs) only to CO_2, and plays an important role in atmospheric chemistry. Since 1750, the major source of changing climate and earth's energy balance is increased the anthropogenic emission of GHGs considerably due to human activities. The CO_2 contributed by 60% and CH_4 with 15 to 25% (Lagzi *et al.*, 2014, Bartlett and Harriss, 1993). The fossil fuels, rice paddies, landfill wastes and livestock have been reported as 60% of CH_4 sources with an average lifetime of 12 years (Rajab *et al.*, 2012). In absorbing long- wave radiation, the CH_4 25 times more effective on per unite mass basis than CO2, and worm's planet 86 times as much as CO_2(Bernstein *et al.*, 2008, Pachauri *et al.*, 2014). Its concentrations increased more than doubled since preindustrial revolution with a current globally – averaged mixing ratio of 1.750 ppbv, and began to ascend again in 2007 after a decade of near-zero growth (Wuebbles and Hayhoe, 2002, Wang *et al.*, 2016) .

It might be the stability of CH_4 measurements during 1999-2006 include: an decrease in wetland emissions and coincident increase in anthropogenic emissions (Bousquet *et al.*, 2006); a combination of stable-to-increasing microbial emissions and decreasing-to stable fossil fuel emissions (Kirschke *et al.*, 2013); and decreased northern hemisphere microbial sources (Kai *et al.*, 2011). Might be few reasons for the renewed increase of CH_4 concentrations after 2006 been suggested such as; the increase of anthropogenic contribution in the northern hemisphere at tropics and mid-latitudes during the period 2007-2010 (Bergamaschi *et al.*, 2013), from agriculture (Schaefer *et al.*, 2016), the growth emissions from oil- and gas use and production during 2007-2014 (Hausmann *et al.*, 2016), and the expansion of wetland emissions during 2007 and 2008 in either the tropics, due to greater than average precipitation, and/or in the Arctic, because of high temperatures (Dlugokencky *et al.*, 2009).

The CH_4 formed and emitted to the atmosphere by biological processes occurring in anaerobic environments. Many sources released CH_4 into the atmosphere; biogenic (natural and anthropogenic) and non-biogenic (geological).the natural sources include wetlands, termites, livestock, ocean, hydrates, wild animals and wild fires, but the anthropogenic sources are rice agriculture, landfills, biomass burning, energy and industry like fossil fuel (Wuebbles and Hayhoe, 2002) .The single largest sources of CH4 into the atmosphere is wetlands due to their saturated soils, which account about 20-40% of the global CH4 sources (Rajab *et al.*, 2012). The growth rates of atmospheric CH_4 is determine by the balance between surface emissions and chemical distraction by hydroxyl radicals, the most atmospheric oxidant (Bousquet *et al.*, 2006).

Prediction of CH_4 evolution in the atmosphere needs knowledge for the sinks and sources. In the earth's atmosphere, the CH4 absorbs and emits infrared and causes 4-9% of the greenhouse effect (Blais and Lorrain, 2005). The tropical wetlands dominated by marshes and swamps emit large amount of CH_4 into the atmosphere compare to the northern peat lands. In addition, the CH_4 emissions are higher in open peat lands than the forested peat lands, this related to the increase in water table depth and temperature (Melling *et al.*, 2005) . The exchange of CH_4 between atmosphere and the ecosystems depends on the climate by influencing CH_4 production, oxidation and transport in soil (Spahni *et al*., 2011).

Tropospheric hydroxyl radicals (OH) are the major sink for methane besides two other minor sinks which are dry soil oxidation and transport to the stratosphere, hydroxyl radicals (OH) take place in the troposphere, the lowermost part of atmosphere , ranged between (7-16) Km, which is depending on the latitude and season , and containing 80% of the atmosphere mass (Lagzi *et al*., 2014). Always people have contended with excessive heat, dust storms, shortage of rainfall and harsh geography across the Middle East area. During last century industrial development, climate change, political upheaval and war had left a legacy of environmental influences and health problems (Jasim *et al*., 2010).

The elevation of CH_4 concentration is more challenging for Asia developing countries and indirectly affecting the developed world, which have less emission controls and throw significant amount of CH_4 to atmosphere (Atique *et al.*, 2014). In addition, the percentage Change in CH_4 Emissions Between 1990 and 2020 at Middle East was 179% *(Kreft et al.*, 2015). Iraq is one of the middle east country, rapid traffic growths, urbanization and industrialization have contributed significantly to economic growth, the heavy pollution emissions created from manufacturing facilities, major industrial zones, a dramatic increase in the number of residences , office buildings, and increase in the number of motor vehicles (Cohen, 2006).

It is important to record and observe the changes of gases to understand and evaluate their impact on climate change and to obtain more reliable and longer range projections. The abundances of the atmosphere gases, last few decades, were obtained from different sources by sparsely distributed measurements sites, Balloons and airplanes. These observations are more sensitive to sources and mostly limited to the surface. And major shortfall is not able to have continuously daily global variations evolutions (Rajab *et al*., 2009). The IRAQ as developing countries, have inadequate mechanism to monitor such emissions due to involvement of high cost in spread out the ground monitoring networks.

Only observations from the space by satellite remote sensing allows for such measurements, which has good global coverage increase our ability to access the impact of human activities on the climate change and GHG's. The in-situ measurements have poor spatial coverage compared to satellite measurements surface, but are more precise and less subject to biases (Wang *et al.*, 2016).

The CH_4 spatiotemporal distributions and variations from satellite measurements used in several studies for different regions, which provide some information and evidence for its sources and traces in the atmosphere (Mahmood *et al.*, 2016, Rajab *et al.,* 2012, Zhang *et al.*, 2011). Xiong *et al* (Xiong *et al.*, 2013) selected the strong AIRS CH_4 channels near 1306 $Cm^{-1}$to detect methane depletion associated with the stratosphere intrusion , they suggested that AIRS and /or other thermal sounders can provide an observations of CH_4 variation associated with stratosphere intrusion. Xiong *et al* (Xiong *et al.*, 2009) studied methane plume over south Asia during monsoon season using AIRS data the period from 2003-2007, results shows a strong plume-like enhancement of CH_4 in the middle to upper troposphere over Asia.

This study is designed to map the spatiotemporal distribution patterns and trend of tropospheric CH_4 for the period 2003-2015 over IRAQ using the retrieved AIRS level 3 monthly products (AIRX3STM) and daily product (AIRX3STD) version 6 data. The results help in identify and analysis the hotspots for regional CH_4 emissions over study area. The CH_4 satellite data were evaluated over three stations; Mosul, Baghdad and Basrah respectively, the monthly mean CH_4 were generated using Kriging interpolation technique to analyze its distribution for the study area.

STUDY AREA

Iraq is one of the southern west Asia countries. Lies between (39^o- 49^o E) longitudes and (29^o-38^o N) latitude, comprises of 437,376 square kilometers and it is the 58th - largest country in the world (Figure-1). It is bordered by Turkey to the north, Iran to the east, Saudi Arabia and Kuwait to the south, and Jordan and Syria to the west. Topographically, Iraq is formed as a basin and divided into four major regions: alluvial plain in central and southeast sections; highlands in north and northeast; rolling upland between upper Tigris and Euphrates rivers; and desert in west and southwest. These two major rivers run through the centre of Iraq, flowing from northwest to southeast are fertile alluvial plains, which covers 19,425 square kilometers of marshland at south-eastern of Iraq. The Desert regions at south and west constitute half of Iraq. Mountains form most northern parts, the highest point being at 3,611 m (11,847 ft). Iraq has a narrow section of coastline measuring 58 km (36 mi) on the northern Arab Gulf (Activity, 1998).

The Iraq climate is continental, subtropical and semi-arid, and most parts have a hot arid climate with subtropical influence. Mountain region, the north and northeastern parts, are having a Mediterranean climate. The precipitation is low, the maximum rainfall happen during winter, and it's extremely rare during the summer.

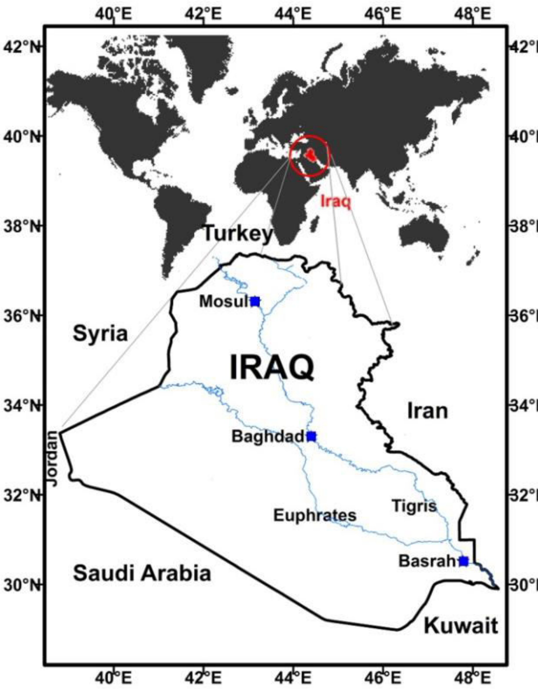

Figure-1. Study area Iraq and the main stations.

The mean annual rainfall about 216 mm and most places receive less than 250 mm. The winter is cool season and its temperatures infrequently exceed 21 °C and night-time lows 2 °C. Temperatures are colder at northern regions and have occasional heavy snows, sometimes causing extensive flooding. The summer is dry and hot season, and the shade temperature average above 40 °C daytimes for most of the country, frequently exceed 48 °C, and drops to 26 °C at nights. Summer months are prevailing by shamal winds; it is steady wind and blows from north and northeast (Frenken, 2009, Metz, 1990).

DATA ACQUISITION AND METHODOLOGY

Recently, the space-borne remote sensing has employed to measure CH_4 with the large spatial and temporal coverage, which can effectively compensate the lack of surface observations measurements. The AIRS, thermal infrared sounders, is one of several instruments was launched aboard NASA's EOS Aqua platform at a 705 Km -altitude, polar orbit, on 4 May 2002. Its Equator crossing time is 01:30/13:30, with global coverage due to a 1650 km cross track scanning swath, and spatial resolution field-of-view (FOV) is 13.5 km at nadir. In a 24-h period AIRS nominally observes the complete globe twice per day (Xiong *et al.*, 2008). With 2378 channels at high spectral resolution ($\lambda/ \Delta\lambda$ =1200) and low noise, the AIRS covering from 649–1136, 1217–1613 and 2169-2674 Cm^{-1}(Aumann *et al.,* 2003).

AIRS Version 6- L3 is providing three products: daily, 8-day and monthly (total column) each product provides separate ascending (daytime) and descending (nighttime) besides 24 Standard Pressure Levels for volume mixing ratio (VMR). Level 3 files contain geophysical parameters that have been averaged and binned into 1°x1° grid cells. Grid maps coordinates range from -180.0° to +180.0° in longitude and from -90.0° to +90.0° in latitude (Olsen *et al.*, 2007). There are about 200 AIRS channels spanning the 7.66μm CH4 absorption bands, about 70 AIRS channels used for the CH_4 retrieval, and the surface temperature, atmospheric temperature profile, water profile and surface emissivity demanded as inputs are derived from other AIRS channels (Xiong *et al.*, 2008).

AIRS standard CH_4 products are derived from the IR stage of the combined IR/MW retrieval. This study was used effective CH4 total column (CH_4) (Mole.Cm^{-2}). Generally, 156 monthly L3 ascending granules were downloaded to obtain the desired output. Extract the AIRX3STM version 6 (V6) product's files from the AIRS website, and saves in HDF-EOS4 files, which is a convenient file extension can be easily take out data from it and arrange in table using MS Excel. The monthly data basis including the corresponding time and location along the satellite track were in a Hierarchical Data Format (HDF) format.

Map of the study area was conducted by using geographic information system (GIS) software to analyze the CH_4 data distribution along the study period. The CH_4 data were obtained from 1° × 1° (latitude × longitude) spatial resolution ascending orbits. The percentage change also used, which is a method gives a more precise description as how the data has changed over a period of time; it is describe the change as a percentage of previous value. This method was applied between two years 2003 and 2015 for monthly CH_4 values- total column (Bennett *et al*., 2008).

The Regression analysis is a technique to study the connection (relationship) between a dependent variable and one or several independent variables (Angelbratt *et al*., 2011). In this paper we studied the relationship between the independent variable (time) and the dependent variable (CH_4, annually and monthly) over three considered stations Mosul, Baghdad and Basrah. Also, the daily long-term CH_4 over Baghdad used to study and estimate the daily time series of CH_4 from 1 January 2003 till 31 December 2015. Furthermore, the moving average and day to day variation method were applied for daily CH_4 data to get better overall idea of trend because of these methods are useful for forecasting long term-trends.

RESULT AND DISCUSSIONS

Monthly analysis long- term CH4 data over Iraq

Figure-2 (a, b) illustrated the monthly mean CH_4 total column over the study area from January 2003 to December 2015. From CH_4 values observed the spatial variation over most parts of Iraq, minor differences in spatial patterns for each season, and various seasonal fluctuations depended on weather conditions and topography. The lowest values were at pristine desert environment in western and southwest regions, and over mountainous areas at the north-east regions. The highest values were at the central and southern-east parts of Iraq, especially over Baghdad and Basrah during the study

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period. This is due to the many natural sources such as; alluvial plain, agriculture, wetlands, salt marshes, anthropogenic activities, and industrial emissions.

Figure-2 (a) shows that the lowest value ($3.083x10^{19}$) $Mole.Cm^{-2}$ of CH_4 throughout the year over the study area occurred during the spring season (March - May) at the pristine desert environment in western and southwest regions. Also decrease over mountainous areas at the north-east regions. Elevation in CH_4 values ($3.858 x10^{19}$) $Mole.Cm^{-2}$ on March appeared from western north of Baghdad to south east area till the Iraqi - Iran border, by unit area, which is mostly connected to the increase in temperature and the presence of water swamps. The mean and slandered deviation of CH_4 for spring was ($3.483 \pm 0.002\ x10^{19}$) $Mole.Cm^{-2}$ and the mean CH_4 values in Mosul, Baghdad and Basrah on April were (3.651, 3.800 and 3.837×10^{19}) $Mole.Cm^{-2}$ respectively.

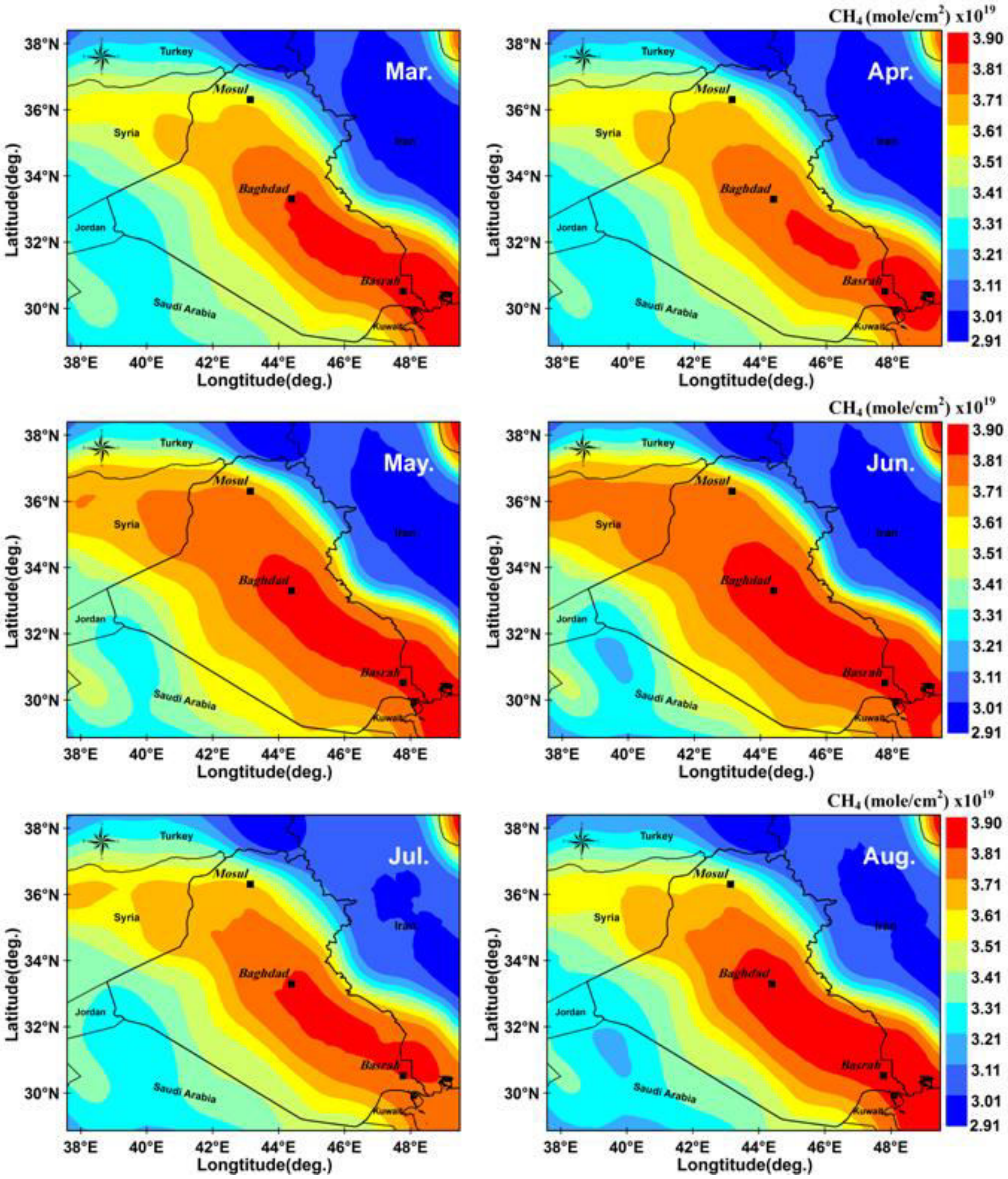

Figure-2a. Spring and summer mean monthly CH_4 Spatial and temporal variation over Iraq (March - August) 2003 - 2015.

The temperature is the dominant factor in acceleration the CH_4 concentration. The reduction of CH_4 values during the year cycle due to the low air temperature. In addition, during spring and summer seasons in Iraq the most predominant prevailing is strong northwesterly winds known as "shamal winds", which is steady and blows from the north and northeast (low air temperature). The winter Shamal events occur as frequently as two to three times per month between December and early March (Abdi Vishkaee *et al.*, 2012). Also, the prevalent sources of CH_4 represented by wetlands rather than the anthropogenic sources are mainly

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affected by temperature, which is comparatively mild in Iraq during spring beside precipitation. The CH_4 emissions are decreases with decreases temperature (Nisbet *et al.*, 2016, Li *et al.*, 2015).

A plainly evident and gradual increase in CH_4 values during the summer season (June - August) especially at the center and southeast areas along the Tigris and Euphrates basin. And drop over desert and mountainous areas. The highest values were (3.873×10^{19}) Mole.Cm^{-2} on June, and the lowest were (3.144×10^{19}) Mole.Cm^{-2} on August at late summer. In July CH_4 for Mosul, Baghdad and Basrah were (3.678, 3.814, and 3.808) $\times 10^{19}$ Mole.Cm^{-2}, respectively. The gradually increases of CH_4 emissions during summer compare to its values in spring are due to increasing sunny hours leads to increasing temperature, and Higher temperatures alone would increase methane production in saturated areas (*Akumu et al.*, 2010).

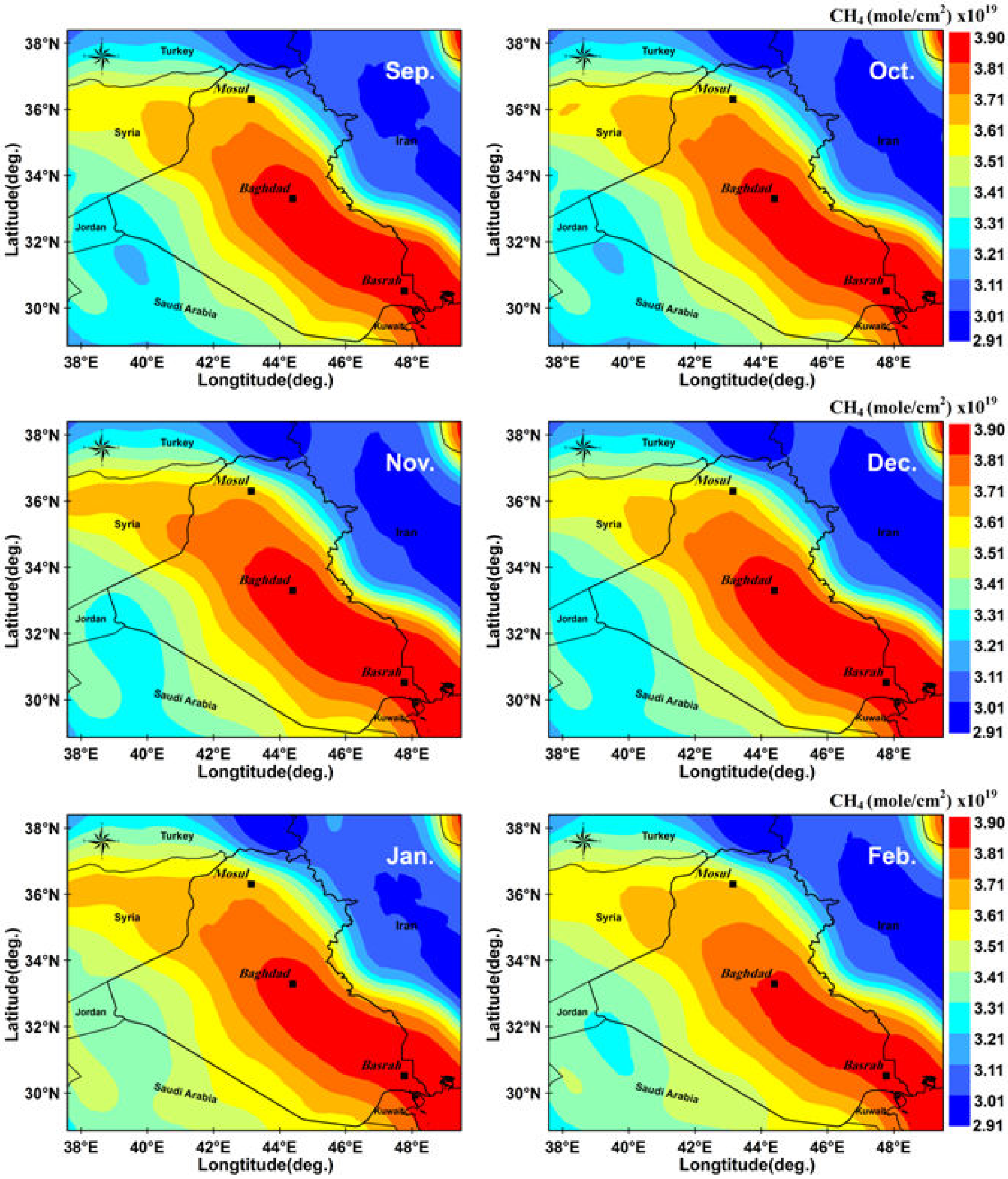

Figure-2b. Autumn and winter mean monthly CH_4 spatial and temporal variation over Iraq (September - February) 2003 - 2015.

Figure-2 (b) illustrated the CH_4 distributions during autumn and winter seasons (September - February). At autumn (September - November) the highest CH_4 value was (3.894×10^{19}) Mole.Cm^{-2} particularly on September. The lowest CH_4 value through this entire period was (3.161 x 1019) Mole.Cm-2. The mean CH_4 values in Mosul, Baghdad and Basrah on October were (3.695, 3.843 and 3.884) $\times 10^{19}$ Mole.Cm^{-2}, respectively. Normally the late autumn concurs with minimum OH levels. In additions, the CH_4 emissions in different regions of Iraq affects by the instability of the climatic conditions with subtropical anticyclones importantly. Therefore, CH_4 fluxes have significant enhancement in the late autumn and early winter seasons due to reductions in OH, which formed from water vapor collapse by O_2 atoms that come from the cleaving of O_3 by UV radiations (Rajab *et al.*, 2012, Langenfelds *et al.*, 2002).

During winter, the minimum CH_4 values were at western, southwest and north-east regions, and the maximum values were at the central and southern-east regions. The highest CH_4 value in December was ($3.909x10^{19}$) Mole.Cm^{-2}, and the lowest was in February ($3.143x10^{19}$) Mole.Cm^{-2}. The mean and slandered deviation CH4 values throughout the winter was (3.512 ± 0.041x1019) Mole.Cm-2, and its values for Mosul, Baghdad and Basrah in January were (3.669, 3.842 and 3.860) $x10^{19}$ Mole.Cm^{-2} respectively. Observed lowest values of CH_4 in the northern region than southern at winter season due to the shorter days, few sunny hours, and low temperatures during the winter. Furthermore, because of the maximum precipitation occurred, rain is a great cleanser of gases from the atmosphere because of their solubility (Hoskins, 2001), and the lack of rice cultivation during the winter season also contributes to reduction in CH_4 emissions.

Percentage change analysis long- term CH_4 data

The CH_4 total column measurements from AIRS for two months (January and October) were selected to investigate the percentage change method. Also, a direct comparison of the CH_4 is straightforward with the use of mapping. Figure 3 illustrate the maps of Iraq for the CH_4in January and October during 2015 (top), 2003 (middle), and the percentage change between the two measurements (2015 - 2003, bottom). The spatial distribution patterns of CH_4 maps for percentage change method (Figure-3 bottom) shows high variation and significant differences.

In January, the difference for CH_4 values between 2015 and 2003 ranges from 0.023 to 0.0395 in most areas, in the north less than the south and in the west less than the east. The greatest differences were in the south regions (0.036 - 0.0395) over Basrah. And the west and north regions had a less difference (0.023 - 0.027) than the rest of the areas. The highest differences were at southern area 0.0395, whereas the lowest in the northern area 0.023 and at Mosul, Baghdad and Basrah were 0.0253, 0.0335 and 0.0394, respectively.

For October, the differences ranged from 0.018 to 0.034, and the west regions still had the smallest difference, while the greatest difference was on the south due to the expansion and proliferation of rice farms and increased production of oil fields. The maximum difference was (0.034) whereas the minimum was (0.018) and at Mosul, Baghdad and Basrah were 0.0262, 0.0259 and 0.0277, respectively.

We can deduce from the percentage change differences (Figure-3 bottom) that the highest differences occurred over agriculture, wetlands, salt marshes, industrial and congested urban zones, usually in the central and southern regions when CH_4 values were high. The smallest differences CH_4 values, between 2015 and 2003, occurred in the pristine desert environment in western and southwest regions.

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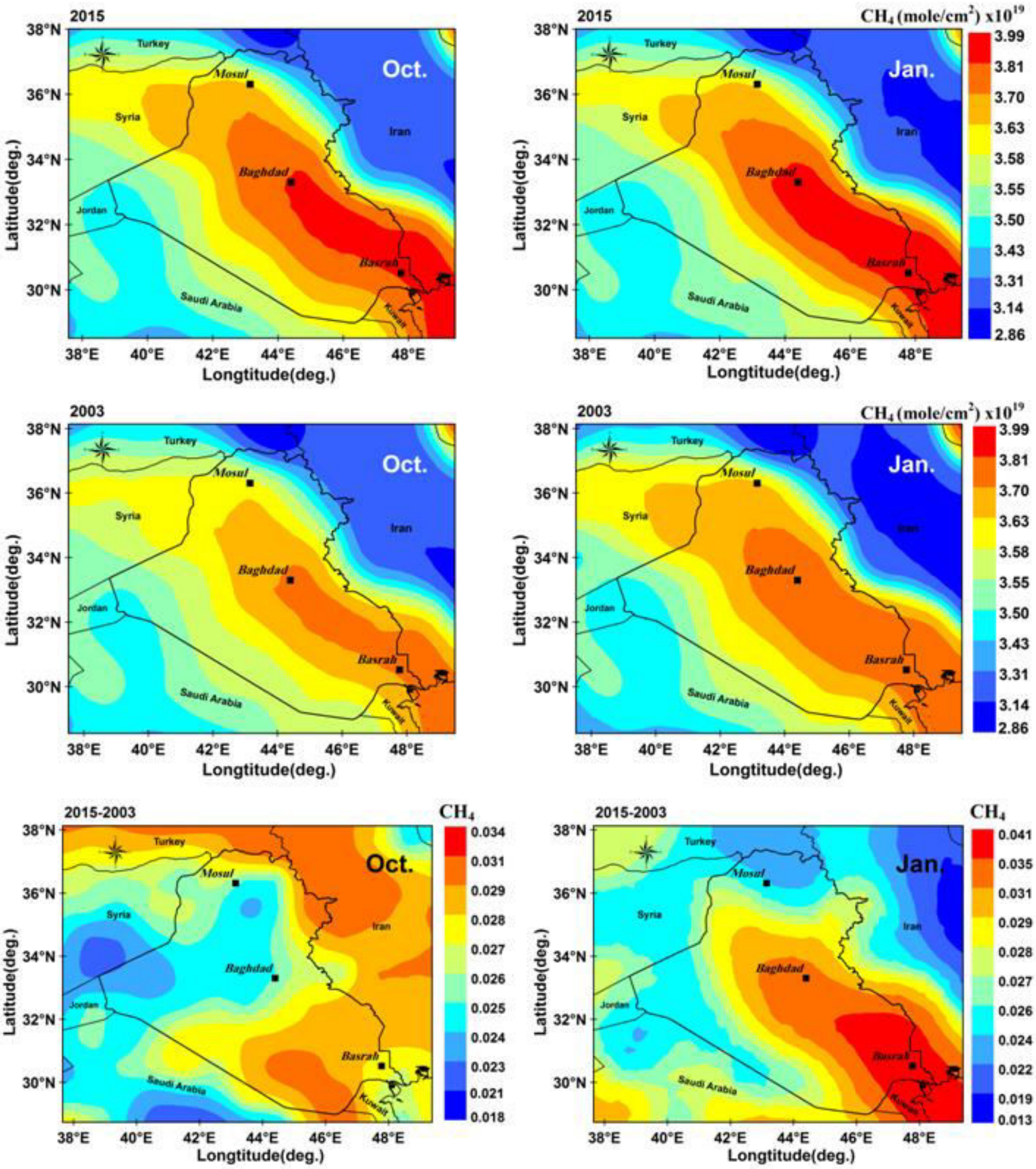

Figure-3. The percentage change of CH_4 values between October and January 2003 and 2015.

Trend analysis

Annually long - term CH_4 data trend

To evaluate the annual mean CH_4 total column over the study area, we selected three sites across Iraq: Mosul, Baghdad and Basrah. Figure-4, show the annually CH_4 from 2003 to 2015 for these three cities. The mean and standard deviation was $(3.751\pm\ 0.108)\ x\ 10^{19}$ Mole.Cm^{-2} for an entire period shows CH_4 experience various seasonal fluctuations depending on weather conditions and topography. There is a progressive increase in the CH_4 values with prominent growth rate variations observed during the 2003-2015 period. An increasing, long-term trend in CH_4 can be attributed to the increase of human activities and anthropogenic emissions.

In addition, the observed atmospheric increase of CH_4 due to the combination of decreasing sinks and increasing sources. If OH radicals are depleted in the troposphere, the Atmospheric CH_4 may increase. Such depletion could occur from the growing industrial activities of carbon monoxide (CO) levels. The change of OH,CO, and CH_4 are coupled together at the long term, thus possible slow decrease of OH levels may add to the rate of rise CH_4(Khalil and Rasmussen, 1983).

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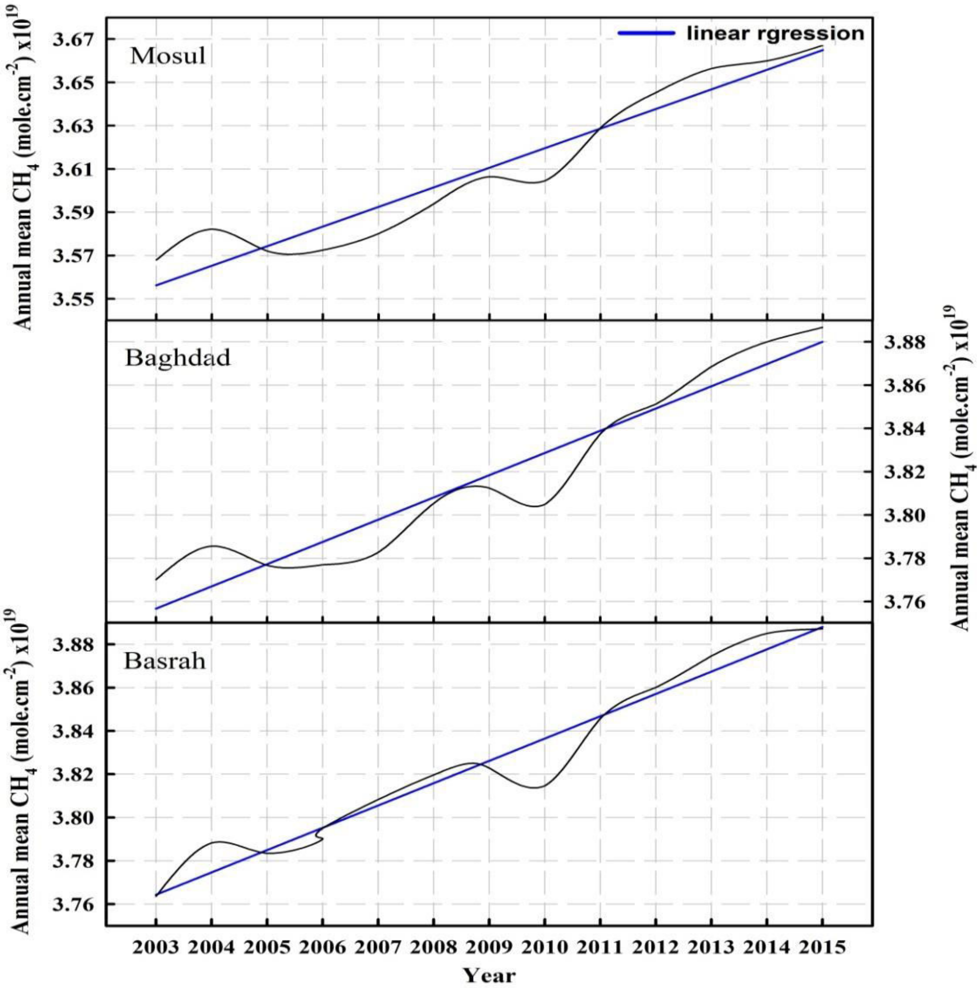

Figure-4. Annually CH_4 values (2003-2015) over Mosul, Baghdad and Basrah.

The maximum annual CH_4 was $3.887x10^{19}$ $Mole.Cm^{-2}$ over Basrah in 2015, and the minimum was 3.568 $x10^{19}$ $Mole.Cm^{-2}$ over Mosul in 2003. The linear growth rate for each station was (2%) for Mosul, and (3%) for Baghdad and Basrah, (this percentage value is with respect to the mean Value). The annual trend analysis shows positive trends (i.e. increasing CH_4 concentration is associated with increasing years). This results shown in Table-1, and ranged between (0.0083 and 0.0097) $Mole.Cm^{-2}.y^{-1}$ for Mosul and Basrah, respectively.

Table-1. The locations, Annual mean CH_4, Maximum, Minimum, and Trend of CH_4 for the period (2003-2015).

Station	**Latitude** (Nº)	**Longitude** (Eº)	**Mean of Annual CH_4 x10^{19}** (Mole/Cm^2)	**Maximum CH_4 x10^{19}** (Mole/Cm^2)	**Minimum CH_4 x10^{19}** (Mole/Cm^2)	**Standard deviation CH_4 x10^{19}** (Mole/Cm^2)	**Trend CH_4 x10^{19} Mole/Cm^2.year^{-1}**
Mosul	36.31	43.15	3.6106	3.6671	3.5680	0.0366	0.0083
Baghdad	33.3	44.40	3.8184	3.8866	3.7702	0.0417	0.0094
Basrah	30.52	47.78	3.8240	3.8872	3.7636	0.0428	0.0097

Monthly long-term CH_4 data trend

The mean monthly CH4 are presented in Figure-5, which shows a graph of a monthly long series for mean CH_4 over Mosul, Baghdad and Basrah from January 2003 to December 2015. The CH_4 experience various seasonal fluctuations depending on weather condition and topography, with minimum in March - May and maximum at September. Observed a stagnation and stability feature as obvious during 2003 until 2008, and began to ascend again in 2009 after five years of near-zero growth. It might be the stability of CH_4 measurements during 2003-2008 include: a decrease in anthropogenic emissions, decreasing-to stable fossil fuel emissions and coincident with USA occupation of Iraq, which caused to stop all industrial activities.

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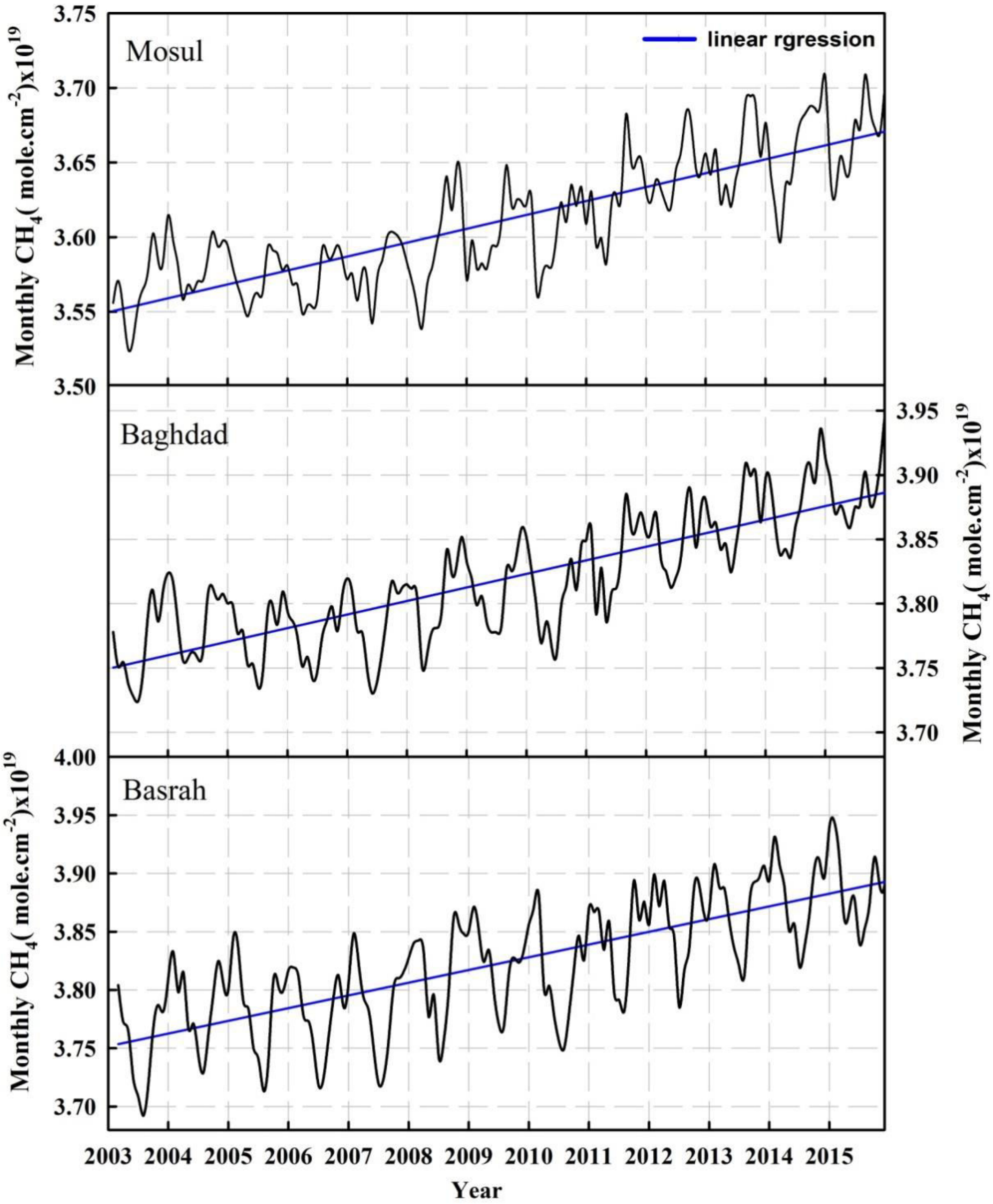

Figure-5. The monthly CH_4 value (2003-2015) over Mosul, Baghdad and Basrah.

The renewed increase of CH_4 concentrations after 2009 could be suggested by few reasons such as; increased renovation and reconstruction of war remnants, the number of vehicles has doubled, increase of oil extraction operations, and expansion of agricultural areas, especially the paddies. Furthermore, because of the reduction in (OH) radicals this is the main removal for many species, beside CH_4, such as CO, CO_2 and NO_2. These species are resulting from different sources such as the oxidation process of CH4 by OH radicals, which can be removed later by OH radicals from the atmosphere, and its reactions with OH are slowing down the CH_4 removal process, especially the reaction between CO and OH radicals. Also, the significant reduction of OH due to the increasing in anthropogenic emission of CO2 (from transport) coupled with CO from CH4 Oxidation, which led to slowdown in the rate of CH4 removal (Jardine *et al.,* 2004).

The trend analysis of CH_4 for these three cities were estimated and had a positive trends (0.0092) Mole.$Cm^{-2}.y^{-1}$ for Mosul and (0.0107) Mole. $Cm^{-2}.y^{-1}$ for Baghdad and Basrah, as summarized in table 2. The linear growth rates were (5%) for Mosul and Baghdad, and (6%) for Basrah (growth rate is the percentage calculated with respect to the mean). The mean and standard deviation for the entire period was (3.751±0.11) x10^{19} Mole .Cm^{-2}.

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Table-2. The locations, annual mean CH_4, maximum, minimum, and trend of CH_4 for the period (2003-2015).

Station	Latitude (N°)	Longitude (E°)	Annual Mean CH_4 x10^{19} (Mole/Cm^2)	Maximum CH_4 x10^{19} (Mole/Cm^2)	Minimum CH_4 x10^{19} (Mole/Cm^2)	Standard deviation CH_4 x10^{19} (Mole/Cm^2)	Trend CH_4 x10^{19} Mole/Cm^2.y^{-1}
Mosul	36.31	43.15	3.6106	3.7087	3.5250	0.0425	0.0092
Baghdad	33.3	44.40	3.8184	3.9483	3.7240	0.0489	0.0107
Basrah	30.52	47.78	3.8240	3.9438	3.6921	0.0554	0.0107

Daily long - term data trend over Baghdad

Figure-6 (a-b), Show the daily CH_4values and 12 point binomial smoothing in applied to daily CH_4 values (to reduce the complexity of variation) over Baghdad from 1 January 2003 to 31 December 2015. In spite of important short term variation during study period, there is exists a seasonal change with mean, maximum and minimum of CH4 values [(3.81 ± 0.62), 4.06 and 3.54] × 10^{19} Mole.Cm^{-2}, respectively. The linear regression analysis for daily measurements shows significant enhancement about 0.139 × 10^{19} Mole.Cm^{-2} which represents (3.7 % of the mean value) during the entire period produced a positive trend (0.0107 × 1019) Mole. Cm^{-2}.y^{-1}.

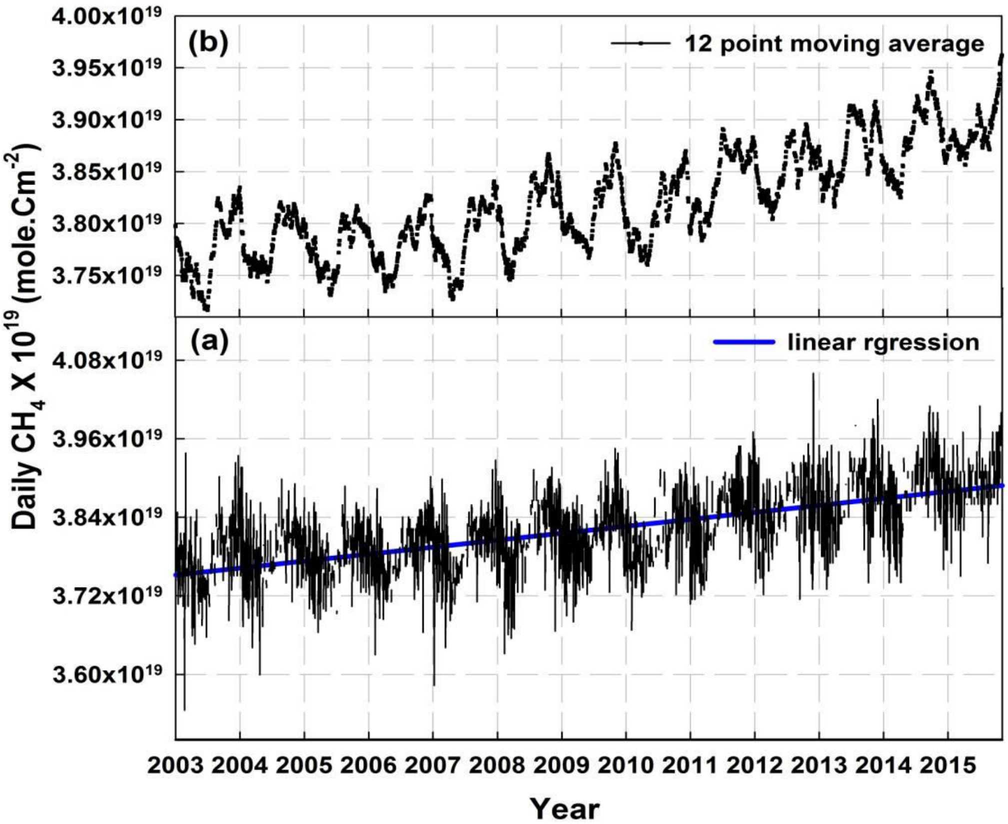

Figure-6 (a). Daily CH_4 over Baghdad from 1 January 2003 to 31 December 2015; and (b) 12 point smoothing in applied to daily CH_4values.

The variation in daily average CH_4 as a percentage deviation from the mean (for 13 year daily data) is shown in Figure-7. The maximum increase and decrease daily variation in Baghdad were (6.2 %) (0.236 × 10^{19} Mole. Cm^{-2}) and (- 7.2%) (- 0.274 × 10^{19}) Mole.Cm^{-2}, and the standard deviation for the departure from the mean was (1.62%), (0.06×10^{19} Mole.Cm^{-2}). Figure-8 presents the day to day variation with a clear seasonal change, which shows enter sequential change of time series in Figure-6. The maximum increase in the day to day CH_4 variation was (0.18 × 10^{19}) Mole. Cm^{-2} and minimum increase was (- 0.17 × 10^{19}) Mole.Cm^{-2}. The standard deviation of enter sequential changes was (0.053 × 10^{19}) Mole.Cm^{-2}. (Ogunjobi, 2007).

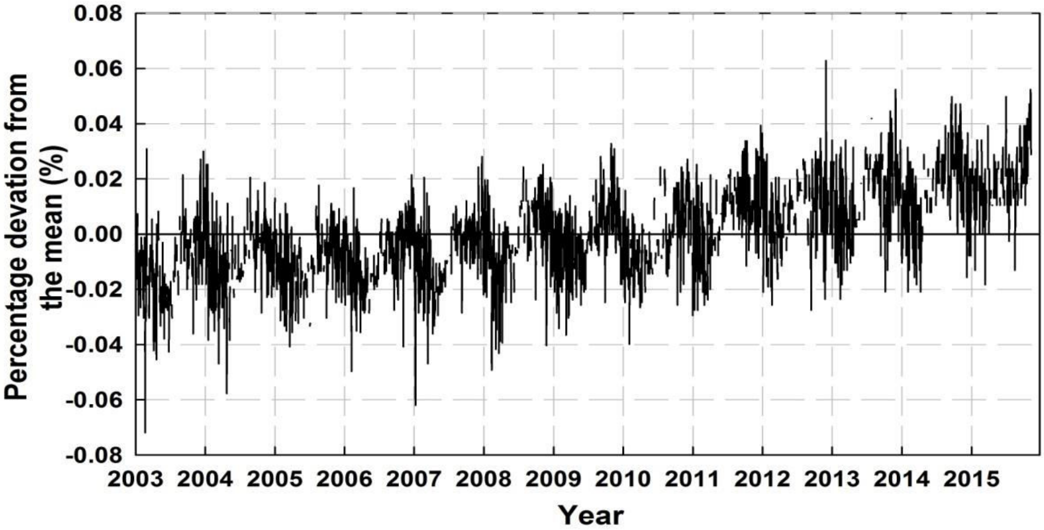

Figure-7. Variation of average CH_4 expressed as percentage deviation from the meanover Baghdad from 1 January 2003 to 31 December 2015.

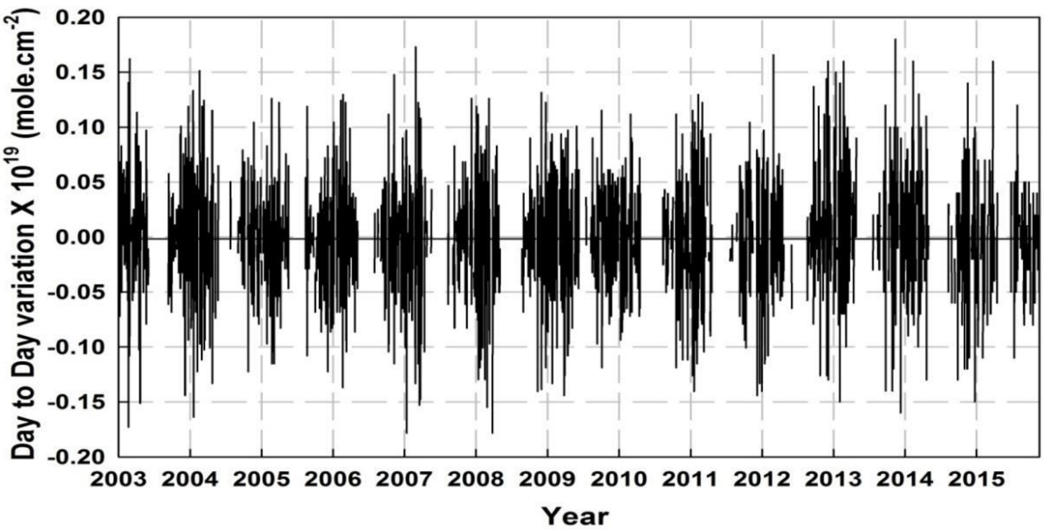

Figure-8. Day to day CH_4 variations at Baghdad city.

From the Figures 6 (a-b), 7 and 8, there is a quasi-biennial variation in CH_4 over Baghdad in September is evident in the daily values with various seasonal fluctuations. The significant increasing trend a results of varying influences which include vertical mixing, large scale dynamics and redistribution through convection, advection of pollution with CH_4 precursors, the increase of anthropogenic emissions and human and agricultural activities, especially the paddies.

CONCLUSIONS

The GHGs concentration in the atmospheric has increased due to continuous increases in anthropogenic emissions resulting from increased industrialization, deforestation, and human activity. In this article, an analysis was undertaken of CH_4 total column retrieved from satellite data over Iraq using AIRS on EOS/Aqua from January 2003 to December 2015. The high concentrations of averaged CH_4 column over Iraq are mainly located in the regions of central and southern-east parts. The significantly low concentrations are mainly located in the pristine desert environment in western and southwest regions, and over mountainous areas at the north-east regions. There is a strong association between CH_4 concentration and human activity, but CH_4 concentrations in the southern regions of Iraq not only are affected by human activity but are clearly also caused by agriculture, municipal solid waste, and natural gas and oil extractions.

The transport effect is the reason that CH_4 concentration is higher in the crowded cities, especially over Baghdad and Basrah. The seasonal fluctuations of the CH_4 plume are observed by AIRS with maximum in September and minimum in March - May. These results indicate that AIRS observations contain significant information about the CH_4 distributions over different regions. Therefore, AIRS CH_4 product may be valuable for studying at variance weather conditions and topography.

From percentage change differences results between 2015 and 2003, its values in January (0.023 - 0.0395) more than in October (0.018 - 0.034), and the highest differences occurred over the central and southern regions when CH_4 values were high. The smallest differences CH_4 values occurred in the pristine desert environment in western and southwest regions. To better validate the retrieved CH_4 data from AIRS, three surface stations at different locations and with various elevations were chosen; Baghdad, Mosul and Basrah. The mean and standard deviation was 3.751± 0.108) x10^{19} Mole.Cm^{-2} for annual long term trend analysis. The linear growth rate for each station was (2%) for Mosul, and (3%) for Baghdad and Basrah. The annual trend analysis shows positive trends, and ranged between (0.0083 and 0.0097) Mole. $Cm^{-2}.y^{-1}$ for Mosul and Basrah, respectively.

The study further estimated a monthly trend analysis with positive trends (0.0092) Mole. $Cm^{-2}.y^{-1}$ for Mosul and (0.0107) Mole. $Cm^{-2}.y^{-1}$ for Baghdad and Basrah. The mean standard deviation for the entire period was (3.751±0.11) x10^{19} Mole.Cm^{-2}. The linear growth rates were (5%) for Mosul and Baghdad, and (6%) for Basrah. The daily long term trend shows significant linear increase of (3.7 %) caused a trend of (0.0107 × 10^{19}) Mole. $Cm^{-2}.y^{-1}$ in Baghdad. There is exists a seasonal change for CH_4 values and 12 point binomial. The variation in daily average CH_4 as a percentage deviation from the mean shows standard deviation for the departure from the mean was (1.62%), (0.06×10^{19} Mole.Cm^{-2}). And the day to day variation with a clear seasonal change shows standard deviation of enter sequential changes was (0.053 × 10^{19}) Mole.Cm^{-2}.

The trends are assumed to be due to the reduction in (OH) radicals this is the main removal for many species, beside CH_4, such as CO, CO_2 and NO_2. In addition, increased the human activities and oil extraction operations, the number of vehicles has doubled, and expansion of agricultural areas, especially the paddies. The Satellite results efficiently show the temporal variations of the CH_4 values. The observations retrieved from AIRS show a good consistency for the contrasted seasonal analysis results. The AIRS data and satellite measurements can be used to measure the increases of the atmosphere CH_4 values over different area.

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