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**Research Article – Remote Sensing- Atmospheric Science**

# Space-borne observation of methane from atmospheric infrared sounder: data analysis and distribution over Iraq

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## Abstract

Methane ($CH_4$) Volume Mixing Ratio (VMR) at pressure level 925hPa data extracted from Atmospheric Infrared Sounder (AIRS) with spatial resolution of 1°× 1° covering whole of Iraq and surrounding regions (28.5°–38.5°N, 37.5°–49.5°E) have been examined for the period from January 2003 to December 2013. The results show a considerable increasing of $CH_4$ with maximum values at north and north eastern regions during autumn and the early winter, whereas the minimum values appeared at the pristine desert environment at the west and the south-west region during spring months. For more accuracy validation the trend analysis was applied on the retrieved AIRS data at three different stations are Mosul, Baghdad and Basrah. The mean and standard deviation in Mosul, Baghdad and Basrah was (1.8657 ± 0.0198, 1.8536 ± 0.0196, 1.8448 ± 0.0212) ppmv respectively for monthly long term trend analysis. Monthly trend analyses have positive trends (0.0040, 0.0039 and 0.0042) ppmv.$y^{-1}$ for Mosul, Baghdad and Basrah Consecutively. These results indicate that Satellite observations efficiently present the temporal and spatial variations of the $CH_4$ for the considered study Area.

*Key words:* Methane, AIRS, remote sensing, Baghdad, Iraq.

## Introduction

The ($CH_4$) is an important greenhouse gas (GHG) and has a warming effect 25 times per molecule larger than that of carbon dioxide ($CO_2$) [1]. Its increased more than doubled since preindustrial revolution with a current globally – averaged mixing ratio of 1.750 ppbv. 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, And the anthropogenic sources are rice agriculture, landfills ,biomass burning, energy and industry [2]. The fossil fuels, rice paddies, landfill wastes and livestock have been contributed in 60% of $CH_4$ sources which has an average lifetime of about 12 years [3]. The rice paddies in the tropics are a major seasonally varying $CH_4$ emission source. Although a lot of field observations of $CH_4$ emission from rice paddies have been prepared under a variety of soils, agricultural practices and climates in Asia, precise estimates of $CH_4$ from global or regional rice paddies via-scaling have been difficult due to the large differences temporal and spatial due the variability in soils, agricultural practices and climate [4].

The 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

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containing 80% of the atmosphere mass [5]. Over the past three decades, the abundances of the atmosphere gases were obtained from a lot of sources such as Balloons, airplane and sparsely distributed measurement sites. The observations were mostly limited to the surface and more sensitive to sources and sinks with best accuracy from ground and aircraft, but the major shortfall is not being able to make daily global variations evaluation [6].

The remote sensing techniques (satellite measurements) were employed to study the spatiotemporal distributions and variations of $CH_4$ in various researches for different regions in the world, which provide some information and evidence of $CH_4$ sources and traces in the atmosphere [6-8]. Xiong *et al.* [9] studied methane plume during monsoon season using AIRS measurements entire the period from 2003-2007 over south Asia, results shows a strong plume-like enhancement of $CH_4$ in the middle to upper troposphere over Asia. Ricaud *et al.*[10] analyze the variability of $CH_4$ mixing ratio spatiotemporal domain over the Mediterranean Basin (MB) using space-born measurements from AIRS for the study period from 2008 to 2011 and from 2001 to 2010, the results shows that $CH_4$ in Mid to upper troposphere over the study area is mainly affected by long-term range transport. Especially in summer from Asia in low to Mid troposphere.

This work is prepared in order to studying the spatiotemporal distribution patterns and trend of $CH_4$ (VMR) for the period 2003-2015 over Iraq using the retrieved AIRS level 3 monthly products (AIRX3STM) 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 estimated over three stations; Mosul, Baghdad and Basrah respectively.

*Study Area*

Iraq is one of the southern west Asia countries. It extends between (38º 45`E and 48º 45` E) longitude and between (29º 05` N and 37º 22`N) latitude. It bordered by turkey to the north ,Iran to the east , Kuwait and Arab gulf to the south ,Saudi Arabia, Jordan and Syria to the west [11]. Figure (1) shows Iraq geographic location and its borders with surrounding countries.

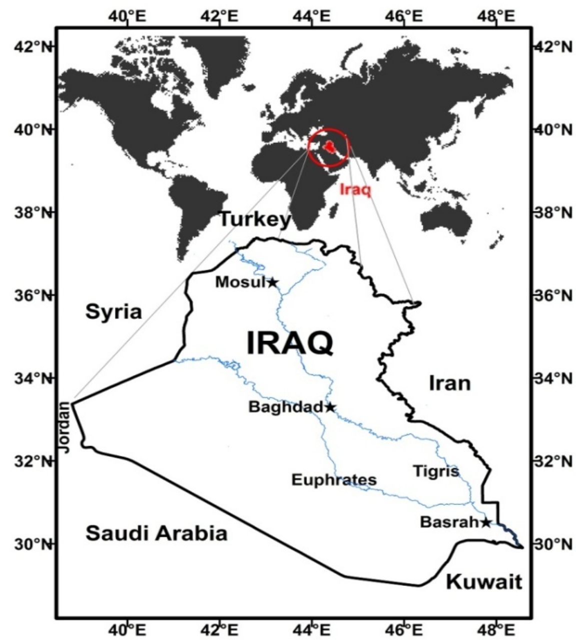


**Figure 1.** Iraq geographic location and its borders with surrounding countries

The total area of Iraq is (438320) Km$^2$ [12]. And its topography can be divided into four parts: Mesopotamian plain (Mesopotamian means the land between two rivers the Tigris and the Euphrates): alluvial plain is occupies a quarter of the total area of Iraq. It extends southeasterly from north of Baghdad across Al Basrah to the Arabian Gulf. This area is flat and encompasses (19425) Km$^2$ of marshlands, the lakes are present also in the southeastern of Iraq. The second part of Iraq includes the desert plateau: which is located to the west and south west of the alluvial plain it comprises less than half of Iraq's total area. It is an extension of the Arabian Peninsula .This arid steppe area continuous into Syria, Jordan and Saudi Arabia and consists of a wide and stony plain interspersed with a few sand stretches. The mountainous region: located to the north and northeast of Iraq and can reach altitude of (3550) meter above the sea level. The last part of Iraq comprise undulating region: or the rolling upland between the Tigris and the Euphrates rivers. It is a transition zone between the alluvial plain in the south and the high mountains in the far north and northeast [11, 13].

Due to its location between 29º and 37º N latitude, Iraq is strongly affected in summer by the subtropical high pressure systems which influence desert regions across North Africa and the Arabian Peninsula; by contrast, in winter the subtropical high pressure is replaced by periodic low pressure travels from the west to east across Iraq bringing winter rains and snow in north of Iraq. Therefore the annual migration of the subtropical high pressure and the mid-latitude low pressure is reflected on Iraq's climate and result in three distinct climate regions: The southern half of Iraq from the coastal areas near Basrah, Iraq has a narrow section of coastline measuring 58 Km on the northern Arabian Gulf [14], to the Syrian Desert is nearest to the subtropical high pressure zone and classified as a subtropical desert. The upland region north of Baghdad is considerably wetter, especially in winter and can be classified as a subtropical steppe. Lastly, the northern mountains region where the conditions are much cooler with more rainfall abundant, the climate is Mediterranean or dry summer subtropical [15] as shown in Figure 2.


**Figure 2.** The climate map of the three regions (source: base map after Thomson, 2002; Climate Data From Air Force Combat Climatology Center 2001 [16]

Wherefore, Iraq climate is classified as a continental, subtropical, and semi-arid and the mountains region in the north and northeastern having a Mediterranean climate or dry summer subtropical.

Winters in Iraq are cold with average daily temperature reach (16ºC) dropping at night to reach (2ºC), While summers are dry and hot to extremely hot, the shade temperature over (43ºC) during July and August, and dropping at night to (26ºC). Most of the rain falls during winter, spring and Autumn and it is non-existence in summer, the average annual rainfall is (154 mm) and it ranges from less than (100 mm) over 60% of the country in the south up to (1200 mm) in the northeast, The rainy season is limited to between October to April most of that falls between December and March [17].

The dominant wind type for most of Iraq is the "Shamal" throughout the year, winds from the north and northwest brings a very dry and hot air across Iraq preventing clouds development and thus precipitation. During summer months, the average daily wind speed are excess of 10 knots causing repeated dust and sand storms, whilst in winter conditions often generate faster winds with less frequent. There is a different type of wind blows over Iraq in early summer and early winter is the "Sharki" which blows from the south and southeast [15] .The Sharki is a dry, dusty wind with incidental gusts of 80 kilometers per hour that occurs from April to early June and again from late September through November [12]. June is the worst month for this type of activity due to the combined frequency of the Shamal and the Sharki in central of Iraq [15].

*Data Acquisition and Methodology*

In recent years, the space-borne remote sensing 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 [18]. 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 $cm^{-1}$ [19] .

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 [20]. Fifty to sixty bands of $CH_4$ absorption near (7.66 μm = 1306 $cm^{-1}$) were selected for the $CH_4$ retrieval, and the atmospheric temperature profiles, water vapor profile, surface temperatures and surface emissivity are required as inputs to compute are derived from other AIRS channels [21].

AIRS standard $CH_4$ products are derived from the IR stage of the combined IR/MW retrieval. This study was used effective $CH_4$ volume mixing ratio-VMR- for 925hPa ($CH_4$) (ppmv). Generally, 156 monthly L3 ascending granules were down loaded to obtain the desired output. Extract the AIRX3STM-VMR 925hPa version 6 (V6) product's files from the AIRS website, and saves in HDF-EOS 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-kriging interpolation technique 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 Regression analysis is a technique to study the connection (relationship) between a dependent variable and one or several independent variables [22]. In this paper we studied the relationship between the independent variable (time) and the dependent variable ($CH_4$, monthly) over three considered stations Mosul, Baghdad and Basrah.

## Results and Discussion

### *Monthly analysis long –term $CH_4$ over Iraq*

Figure 3a,b shows the monthly mean $CH_4$ (VMR) at 800 meters above the earth surface over the study area from January 2003 to December 2015. The $CH_4$ values observed over most parts of Iraq illustrated spatial variations and tested various seasonal fluctuations considerably among four seasons which depends on weather conditions and topography.

The lowest values were at the pristine desert environment in western and south- west regions of Iraq during the year cycle due to it is a desert area and receives less than (200 mm) of rainfall annually besides it is sparsely populated and cultivated with a just few crops in some irrigation spots which means lack of methane sources. While the highest values were at the north and the north- east parts of Iraq, this is because of many reasons include; the northern area has a nine month of growth season in a year, an average annual rainfall over (400-1000 mm), natural sources of $CH_4$ represented by the cultivated areas by rain fed crop field of grain (wheat, barley and rice), as well as the vegetation cover of pasture land in a good conditions with dominant forest of Oak and Pine trees which covers 70% whereas grass and shrubs covers 30% of the northern area, livestock population besides anthropogenic activities and industrial emissions[12,15,23].

Figure 3a shows the $CH_4$ values in spring and summer seasons (March –July). The lowest value of $CH_4$ (1.759 ppmv) during the spring season (March-May) was appeared at the pristine desert environment at the west and the south-west region While the highest value (1.880 ppmv) appeared on May at the north and north east regions of Iraq. The mean and standard deviation of $CH_4$ for spring season was (1.834±0.0028 ppmv) which is the lowest during the entire period for the study area and the mean $CH_4$ values for Mosul, Baghdad and Basrah on April (mid spring) were 1.759, 1.874 and 1.836 ppmv, respectively.

A gradually increase in $CH_4$ values was observed during summer season (June-August) especially at the north and northern-east parts toward Baghdad, while $CH_4$ values dropped over desert and the south- western parts to reach (1.759 ppmv). The highest value was (1.879 ppmv) on June appeared at the north and the north-east regions. And the mean and standard deviation of $CH_4$ for summer season was (1.839±0.0059 ppmv), the mean $CH_4$ values at Mosul, Baghdad and Basrah on July (midsummer) were 1.871, 1.860 and 1.845 ppmv, respectively. The gradually increase of $CH_4$ emission in summer season is related to temperature because there is much more emissions when temperature is about 35°C from the rice paddies, lakes and rivers [8].

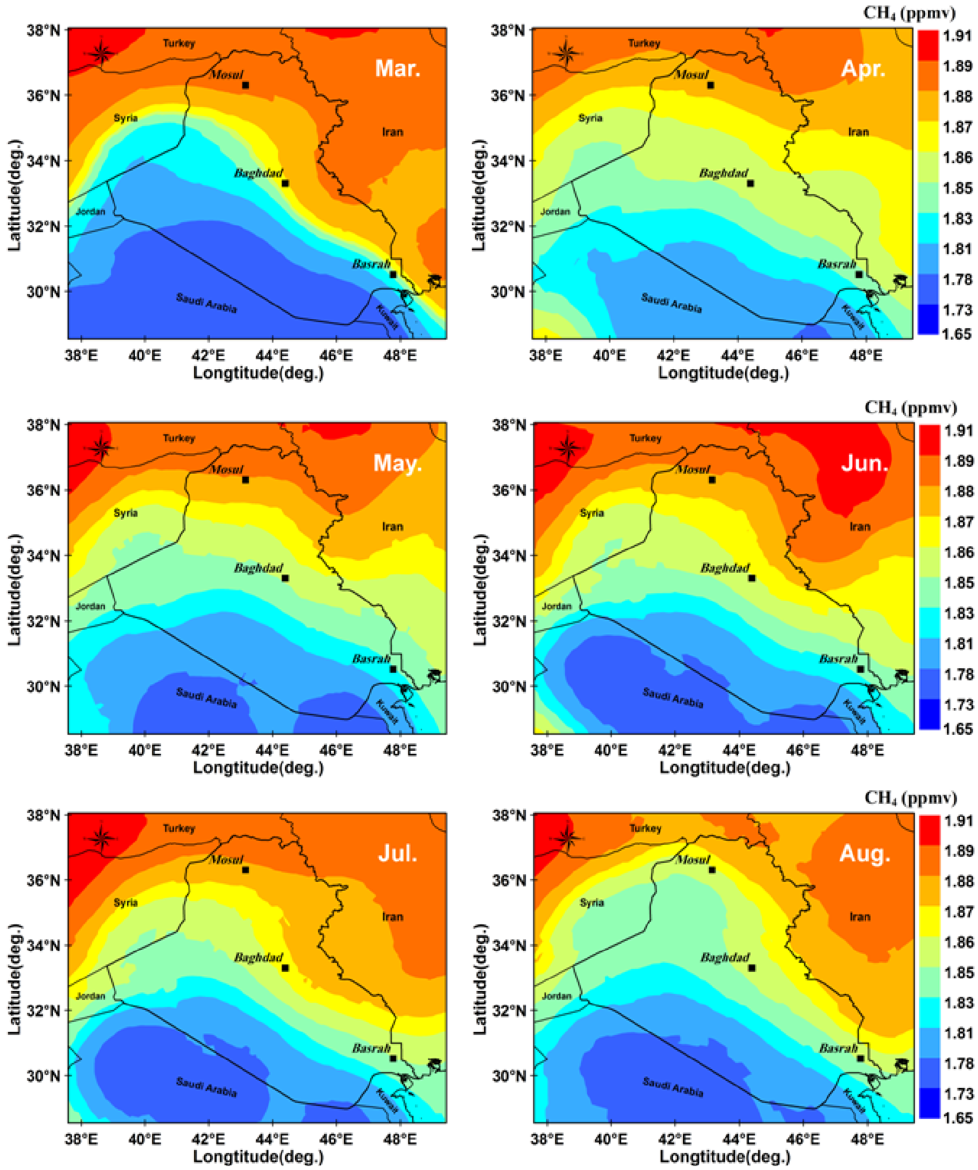


**Figure 3a.** Spring and summer mean monthly $CH_4$ (VMR-925hPa) spatial and temporal variation over Iraq (March-August) 2003-2015

Figure 3b shows the $CH_4$ distribution during autumn and winter seasons (September- February), at autumn the highest $CH_4$ value was (1.880 ppmv) on September appeared at the far north-east part of Iraq, and the lowest value was (1.781 ppmv) at the south east part of Iraq .The mean values of $CH_4$ at Mosul, Baghdad and Basrah on October (mid autumn) were 1.871, 1.845 and 1.849 ppmv, respectively. The mean and standard deviation of $CH_4$ values was (1.846 ± 0.0034 ppmv) which is the highest throughout the year cycle due to autumn season coincides with the minimum levels of OH radicals (the main sink of $CH_4$) which formed from the collapse of water vapor by $O_2$ atoms resulting from O3 dissociation by UV radiation [6].

During winter, the minimum values of $CH_4$ appeared at the south-west region of Iraq and have widened to cover large parts of Iraq including Baghdad and Basrah, particularly on February. The lowest value was (1.784 ppmv) on February, while the highest value was (1.891 ppmv) on December at north-eastern region. The mean value and standard deviation of $CH_4$ for winter was (1.836±0.0068 ppmv).

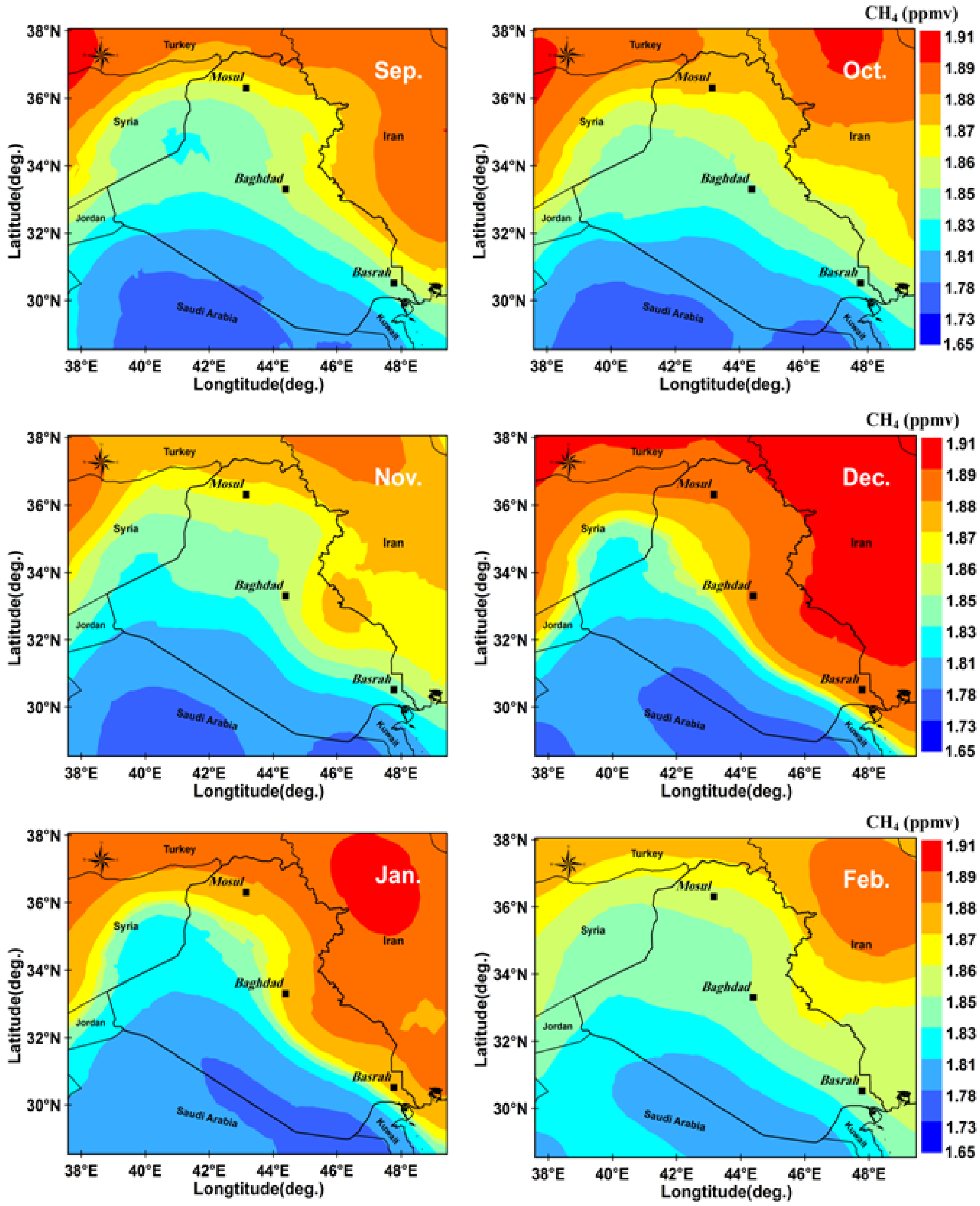


**Figure 3b.** Autumn and winter mean monthly $CH_4$ (VMR-925hPa) spatial and temporal variation over Iraq (September- February) 2003-2015

And the mean $CH_4$ values at Mosul, Baghdad and Basrah on January (mid winter) were 1.870, 1.874 and 1.875 ppmv, respectively. The lowest values of $CH_4$ occurred due to decreases temperatures and $CH_4$ emissions are decreases with decreases temperatures particularly from wetlands and saturated area like the area of rice field under cultivation [24].

In addition to weather conditions, the topography of Iraq is the main factor that affects the $CH_4$ distribution. Where the highest values appeared at the mountainous areas because the $CH_4$ sources (natural and anthropogenic) are located close to the height of the (VMR-925 hPa) pressure level due to mountains elevation , and because of $CH_4$ concentrations are always high near its sources, and decreases when increase the distance or height from these sources [8], while the lowest values of $CH_4$ appeared at the pristine desert environment due to the winds which plays an important role in mixing gases and result into mitigate the concentration of $CH_4$ on height 800 meters at the rest parts of Iraq. In Iraq "Shamal winds" is the most predominant prevailing strong northwesterly wind; it is steady and blows from the north and northwest. The winter Shamal events occur as frequently as two to three times per month between December and early March [25].

*Monthly long-term $CH_4$ trend analysis*

The monthly mean $CH_4$ volume mixing ratio (VMR) are presented in figure 4, shows a graph of 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 conditions and topography. The minimum values were on January, March and June and the maximum were on March, October and November for Mosul, Baghdad and Basrah, respectively. During 2003 until 2008, a stagnant and stability feature was observed obviously and began to ascend again in 2009 after five years of near-zero growth, particularly in Mosul and Baghdad. The stability of $CH_4$ measurements during 2003-2008, might be due the decreasing in the anthropogenic emissions.

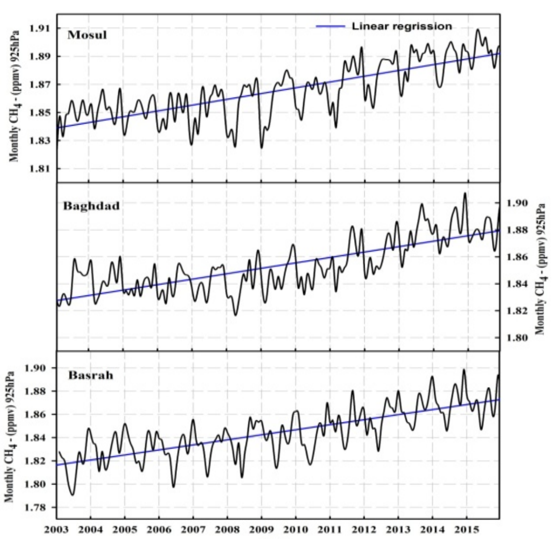


**Figure 4.** The monthly $CH_4$ –volume mixing ratio (925 hPa) (2003-2015) over Mosul, Baghdad and Basrah

After 2009, the renewed increase of $CH_4$ concentration could be related to the magnitude of $CH_4$ sources in large cities which affected by many factors such as; human activities and population, energy demands and agriculture practices (expansion of rice field), land use and land cover, temperature, precipitation [26]. As well as, 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 $CH_4$ 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 $CO_2$ (from transport) coupled with (CO) from $CH_4$ Oxidation, which led to slowdown in the rate of $CH_4$ removal [27].

The maximum $CH_4$ was (1.908 ppmv), over Mosul in 2015, and the minimum was (1.791 ppmv), over Basrah in 2003. The mean and standard deviation was (1.854±0.01 ppmv) for entire period and the linear growth rate for each station was (4%) for Mosul and Baghdad and (5%) for Basrah, (this percentage value is with respect to the mean value). The trend analysis of $CH_4$ for three cities was estimated and had a positive trends (i.e. increasing $CH_4$ concentrations is associated with increasing years) which ranged between (0.0039 to 0.0042 ppmv. $y^{-1}$) for Baghdad and Basrah, respectively. As tabulated in table (1).

We can deduce from the data tabulated in table 1 and figure 4, Mosul had maximum values of $CH_4$, whereas Basrah had the minimum values of $CH_4$. This could be related to the topography. $CH_4$ emissions in the northern area may affected by the presence of mountains which have elevation reach the altitude of the pressure level of 925 hPa-800 meters above earth's surface and exceed it to (3,611 meters). Besides the enhancement of natural sources of methane represented by the cultivated areas of rain fed field crops and the vegetation cover at mountains, but the growth rate for Basrah was more than Mosul and Baghdad that's due to increasing operations of oil extraction.

**Table 1.** The locations, Annual mean, Maximum, Minimum, and Trend of $CH_4$-VMR (925hPa) for the period (2003-2015)

| Station | Latitude (N°) | Longitude (E°) | Annual Mean (ppmv) | Maximum (ppmv) | Minimum (ppmv) | Standard deviation (ppmv) | Trend [28] ppmv.y$^{-1}$ |
|---|---|---|---|---|---|---|---|
| Mosul | 36.31 | 43.15 | 1.8657 | 1.9080 | 1.8241 | 0.0198 | 0.0040 |
| Baghdad | 33.3 | 44.40 | 1.8536 | 1.9073 | 1.8167 | 0.0196 | 0.0039 |
| Basrah | 30.52 | 47.78 | 1.8448 | 1.8987 | 1.7919 | 0.0212 | 0.0042 |

## Conclusion

The GHGs values in earth's atmosphere has an obvious enhancement resulted by a continuous increases in anthropogenic emissions and human activity. In present paper, an analysis was undertaken of $CH_4$ (VMR) retrieved from satellite data over Iraq using AIRS on EOS/Aqua from January 2003 to December 2015. The high levels of averaged $CH_4$ (VMR) over Iraq are mainly located in the mountainous regions at the north and northern-east parts. The significantly low concentrations are mainly located at the pristine desert environment in western and southwest regions. There is a strong association between $CH_4$ (VMR) concentration and human activity.

The human activities and population, energy demands and agriculture practices (expansion of rice field), land use and land cover, temperature and precipitation are the reasons that $CH_4$ (VMR) values have a maximum values in the crowded cities, especially over Mosul and Baghdad. The seasonal fluctuations of the $CH_4$ (VMR) are measured by AIRS with maximum on September and minimum on March - May. These results indicate that AIRS measurements include significant information about the $CH_4$ (VMR) distributions over various locations. Therefore, AIRS $CH_4$ (VMR) product may be important for analyzing associated with variance atmospheric conditions and topography.

In order to more accurate validation of the retrieved $CH_4$ (VMR) data from AIRS, three selected stations at different locations and with various elevations were chosen; Mosul, Baghdad and Basrah. The monthly trend analysis estimated with positive trends 0.0040, 0.0039 and 0.0042 ppmv.y$^{-1}$ for Mosul, Baghdad and Basrah respectively. Finally the Satellite results efficiently present spatiotemporal variations of the $CH_4$ (VMR) concentrations. The AIRS data and satellite measurements can be used to measure the increases of the atmosphere $CH_4$ (VMR) over different regions.

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