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Spatiotemporal Monitoring of CO_2 and CH_4 over Pakistan Using Atmospheric Infrared Sounder (AIRS)

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Abstract. Carbon dioxide (CO_2), Methane (CH_4) are two most potent greenhouse gases and are major source of climate change. Human activities particularly fossil fuels burning have caused considerable increase in atmospheric concentrations of greenhouse gases. CO_2 contributes 60% of anthropogenic greenhouse effect whereas CH_4 contributes 15%. Ice core records also show that the concentrations of Carbon dioxide and methane have increased substantially. The emission of these gases alters the Earth's energy budget and are drivers of climate change. In the present study, atmospheric concentration of CO_2 and CH_4 over Pakistan is measured using Atmospheric Infrared Sounder (AIRS). Time series and time averaged maps are prepared to measure the concentrations of CO_2 and CH_4. The results show considerable increase in concentration of Carbon dioxide and methane. The substantial increase in these concentrations can affect human health, earth radiative balance and can damage crops.

1. Introduction

The major source of changing climate is anthropogenic emission of greenhouse gases such as Carbon dioxide (CO_2), Methane (CH_4) and Nox (N_XO), where, CO_2 and CH_4 are most potent greenhouse gases [1]. Since 1750, anthropogenic emissions of these greenhouse gases have increased considerably due to human activities [2]. These gasses are affecting the earth's energy balance leading to changes in climate. Primarily, anthropogenic greenhouse effect is contributed by CO_2 with 60% and CH_4 with 15 to 25% [1, 3]. By the year 2065, CO_2 levels in atmosphere will reach the double of pre-industrial levels [4]. Fossil fuel emissions followed by land use changes such as logging and deforestation have been reported as major source of CO_2 with an increase of 29% (8.7 + 0.5 Pg C/yr) from year 2000 to 2008 [5]. Similarly, 60% of CH_4 emissions are from human activities due to fossil fuels, rice paddies, landfill wastes and livestock with an average lifetime of 12 years. Although, concentration of CH_4 in atmosphere is lower than CO_2 but absorbs infrared (IR) radiation much more strongly making it 3.7 times more potent than CO_2 for global warming [6]. CH_4 is produced naturally by thermal, pyrogenic and microbial processes due to dilapidation of organic material under the earth's crust, biomass burning and metabolism of methanothropic bacteria respectively [7, 8, 9]. Therefore, CH_4 can be released in to atmosphere from deep earth, above surface and from lakes etc. This makes mining of fossil fuel, forest fires, landfills, fields of grass, rice and peat as major natural sources. Anthropogenic activities in major cities, in addition to preceding sources, play an important role in spatiotemporal variations in concentration of CO_2 and CH_4.

Increasing concentration of CO_2 and CH_4 is much more challenging for developing countries especially in Asia which is indirectly affecting the developed world. Developing countries in Asia have less emission controls that dump significant amount of CO_2 and CH_4 in atmosphere which is already very warmer than global mean [10]. In addition, anthropogenic emissions, emissions from enteric fermentation and livestock has placed Pakistan in upper five countries of CH_4 emission [11, 12]. This might be the reason that Pakistan is placed among top ten countries that are highly vulnerable to clime change [13]. According to Environmental Protection Agency (EPA) report (http://www.epa.gov/methane/sources.html), Pakistan was ranked on 13th position in 2005 for anthropogenic Methane emissions. Regional emissions also bring challenges at global scales as monsoon meteorology of this region shifts the concentration of these gases to high altitudes [14], whereas, tropical easterly jet transport some of its concentration to Middle east, Africa and Europe as well [15, 16].

Developing countries like Pakistan have inadequate mechanism to even monitor such emissions due to involvement of high cost in deploying ground based monitoring networks. However, with latest developments in the field of atmospheric Remote Sensing (RS), reliable sensors such as Atmospheric Infrared Sounder (AIRS) have made monitoring of CO_2 and CH_4 have become feasible [17, 18]. Closure studies involving RS and in-situ data been very useful for identifying the sources and sinks at regional and global level [19]. Along with loading of CO_2 and CH_4 satellites can provide the additional information of particle size and vertical profile [20]. Xiong et al., (2010) [21] reported maximum error of 1.5 % in retrieval of CH_4 using AIRS. AIRS has been reported more accurate for retrieving CH_4 over tropics and mid latitudes [21, 22]. Although, spatiotemporal resolution hinders the performance of some sensors like Greenhouse Gases Observing Satellite (GOSAT), even then Kort et al., (2012) [23] mapped and quantified the anthropogenic emissions with significant accuracy. Similarly, Rakitin et al., (2015) [24] reported accuracy of AIRS for CH_4 retrieval with strong coefficient of determination (R^2 = 0.96) over Russia. A satellite based sensor with reasonable accuracy as discussed earlier can characterize the emission sources for a given region. Sharma et al., (2010) [25] has identified crop residual burning as major source of air pollution in India. Unfortunately, effective use of satellite RS in monitoring of CO_2 and CH_4 for Pakistan is still very rarely reported. Therefore, this study is designed to map the spatiotemporal distribution of CO_2 and CH_4 over Pakistan. Results of this study help in identifying the hotspots for regional CO_2 and CH_4 emissions leading to suggestions for developing low-carbon scenario of Pakistan.

2. Data and Methodology

Carbon dioxide and Methane Total Column data is obtained from AIRS NASA Giovanni online data system for the study area of Pakistan [26]. The CO_2 monthly gridded data is obtained on spatial resolution of 2.5^o x 2.5^o, whereas, the CH_4 data is obtained on spatial resolution of 1^o x 1^o. The Total Column Methane is the atmospheric density of Methane (CH_4) in a vertical column of air. The Carbon dioxide parameter is the CO_2 mole fraction. This is a total tropospheric column property, and is in mole fraction units (data x 10^6 = ppm by volume) [26]. AIRS on board NASA's Aqua satellite is launched in May 2002 and used for earth's weather and climate related research. The primary purpose of this satellite is to measure the trace greenhouse gases such as ozone, carbon monoxide, carbon dioxide, and methane. Due to its cutting edge IR technology, it develops 3D maps of water vapor, cloud properties, air and surface temperature. The AIRS instrument provides spectral coverage in the range of 3.74 – 4.61 µm, 6.20 – 8.22 µm and 8.8 – 15.4 µm IR wave bands. The concentration of CO_2 is measured in parts per million by volume (ppmv) with peak sensitivity at 400 hPa pressure level. The nadir resolution is 90 km x 90 km. AIRS map global distribution of CO_2 every day due to its broad swath [27]. The concentration of CH_4 is measured in parts per billion by volume (ppbv) with peak sensitivity at 400 hPa. Its algorithm is based on optimal estimation and retrieval is performed for 10 layers. It utilizes an eigenvector regression algorithm for efficient retrieval of atmospheric temperature, moisture and ozone [28]. The 2D raster data of CO_2 and CH_4 were converted into point vector format and IDW (Inverse Distance Weighted) algorithm was applied to interpolate the concentration for assessing the spatial extents. The CO_2 and CH_4 concentration were determined using area-average over entire study for graphical analysis.

3. Results and Discussion

Time series and time-averaged maps are analyzed to observe the spatiotemporal changes in concentrations of CO_2 and CH_4. The observed changes can be attributed to anthropogenic activities mainly based on the spatial extent of each gas. A significant increase in CO_2 concentration is noted from January 2010 to December 2015, where, CO_2 average concentration was 390 ppm in 2010 that increased up to 400 ppm in 2015 leading to an increase of 1.75 ppm/year (Figure 1). This indicates an average CO_2 value of 395.33 ± 3.77 (ppm average ±standard deviation) for the whole study period with a significant increase of 3.22%. It is alarming to note that observed increase in the concentration of CO_2 during the study period is equaling to 5.37% per decade which is significantly higher than reported for Pakistan [29]. The CO_2 concentration can be a by-product during combustion of low grade fuel and improper combustion system which can be found in open market due to lack of quality control by the competent authorities. Traffic congestion, road conditions, and industrial exhaust are the major causes of CO_2 concentration and similar results were perceived with Haq et al. (2015) [29] over Pakistan.

Spatial distribution of CO_2 during the study period is found correlated with the locale of anthropogenic emission sources of CO_2 in Pakistan. Major cities of Pakistan except in southern part have high concentration of CO_2. Although Karachi in Sindh is the biggest city of Pakistan located in southern part but still low to moderate loading of CO_2 is observed similar to coastal line of Sindh and Balochistan. This can be attributed to natural cycle of land and sea breeze in this area that keep on sweeping the portion air pollutants all around the year. Similarly, there is less concentration of CO_2 in extreme north of Pakistan firstly due to no anthropogenic activity and secondly, these areas are located 5000m above sea level and meteorology at these heights cap the pollutants at lower heights. Similarly, time-averaged map of CO_2 shows a large concentration in northern and central Pakistan, especially in industrial and densely populated regions (Figure 2).

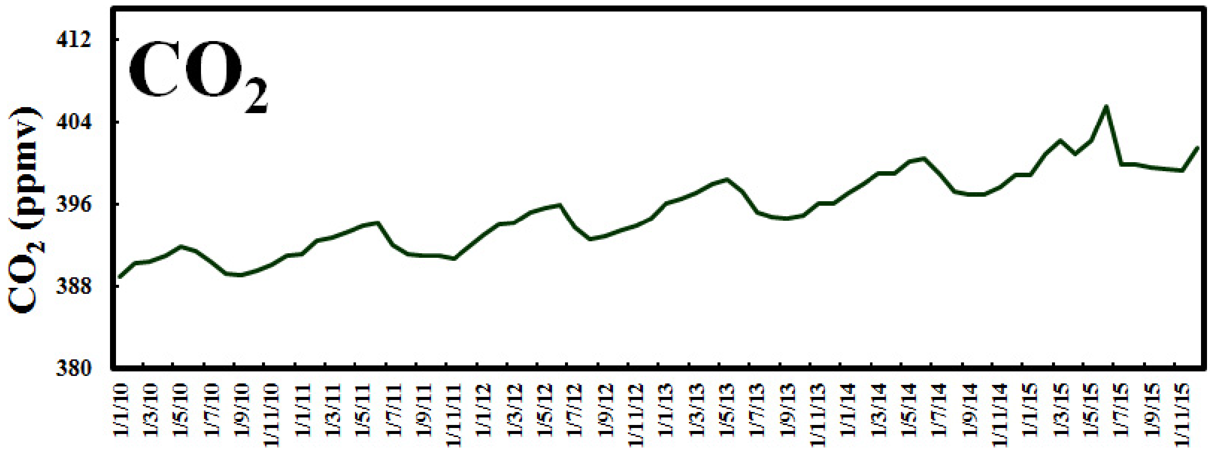

Fig. 1: Time Series Analysis map of CO_2 concentration over Pakistan (2010-2015)

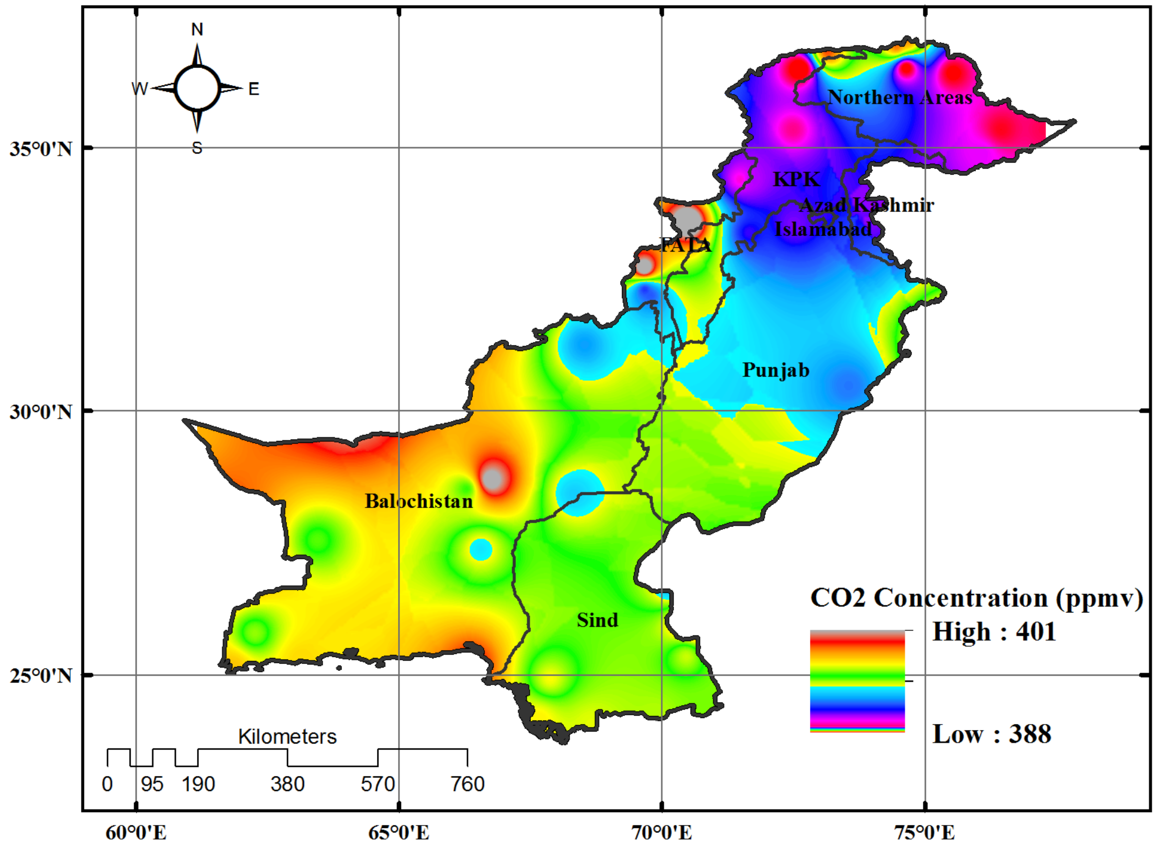

Fig. 2: Time Averaged Map of CO_2 concentration over Pakistan (2010-2015)

Methane total column data was utilized from 1st January 2003 to 31st December 2015 for Pakistan. A significant increase in CH_4 concentration is noted from 2003 to 2015, where, CH_4 average concentration was 1791.09 ppb in 2003 that increased up to 1856.39 ppb in 2015 leading to an increase of 5.02 ppb/year (Figure 1). This indicates an average CH_4 value of 1823.83 ± 30.01 (ppb average ± standard deviation) for the whole study period with a significant increase of 3.65%. It is alarming to note that observed increase in the concentration of CH_4 during the study period is equaling to 2.80% per decade. Similar concerns have been reported in the only study available for whole Indo-Gangetic region, Afghanistan and parts of Russia from 1990-2008 using another satellite called Scanning Imaging Absorption SpectroMeter for Atmospheric Chartography (SCIAMACHY) [30]. The comparative analysis between CO_2 and CH_4 were also performed. Figure 5 shows increasing concentration of both the gases approximately with same magnitude.

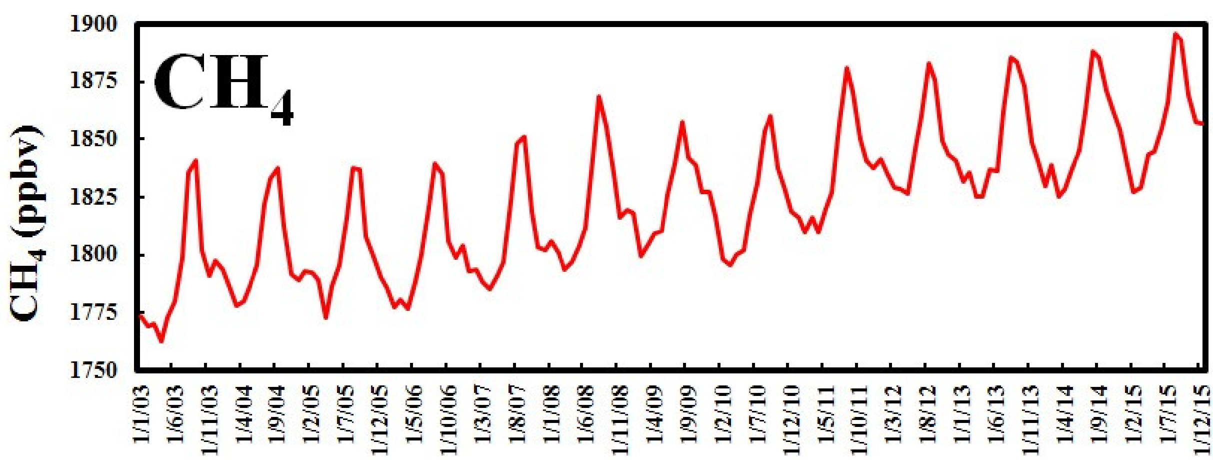

Fig. 3: Time Series Analysis map of CH_4 concentration over Pakistan (2003-2015)

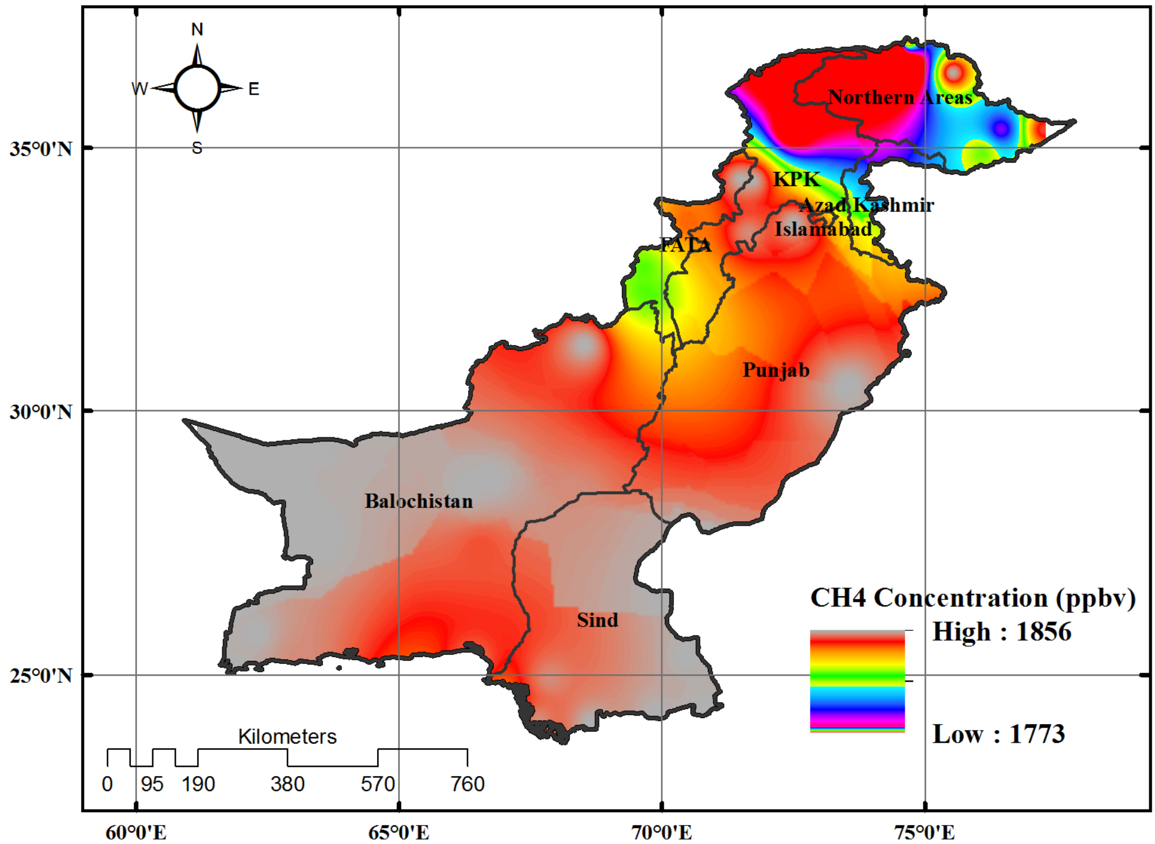

Fig. 4: Time Averaged Map of CH_4 concentration over Pakistan (2003-2015)

Major emission sources of CH_4 are observed from time-averaged map of Methane Total Column (MTC) showing a large concentration of Methane in most parts of Pakistan (Figure 4). However, CH_4 concentration is in acceptable range in Northeastern Pakistan which can be due to same meteorological conditions that inhibit the concentration of CO_2 in this part of Pakistan as described previously. However, the high concentration of CH_4 in some parts of southern Pakistan is in contrast to CO_2 concentration in the same area. This might be due to wet lands in Indus Delta Region along the coastal belt of Pakistan. Areas with high concentration of CH_4 include major cities and industrial locations in Pakistan which are associated with lots of transportation. During past couple of decades, a major portion of the transport, power and industrial sector has shifted on Compressed Natural Gas (CNG i.e. CH_4) as major fuel. This has triggered increase in extraction from ground and expansion in distribution network of CH_4. It is still challenging for the authorities to control the quality of distribution network during this rapid increase in demand and supply of CH_4. This is the reason that leakage during filling of CNG can be attributed as major emission source of CH_4 in different cities. Moreover, the spatial distribution of CH_4 perceived in this study encompasses almost all areas that can be source of CH_4 due to activities such as (1) Thermogenic - largest CH_4 reserves at Sui in Baluchistan, (2) Pyrogenic - industries in Lahore in Punjab, Karachi in Sind, Biomass burning in Punjab and lastly (3) Microbial - landfills of the major cities that are mostly located in Punjab, Sindh and Khyber Pakhtunkhwa. Westeren part of Pakistan observe relatively less CH_4 loading may be as most of this region is of barren mountains that can act as sink for CH_4 due to dry soil oxidation [28]. Overall, significant increasing concentration of CH_4 and CO_2 can be observed over Northern Pakistan that can be attributed to the rapid melting of glaciers due to warming of climate possibly liberating a large amount of Methane hydrates and CO_2 stored in permafrost.

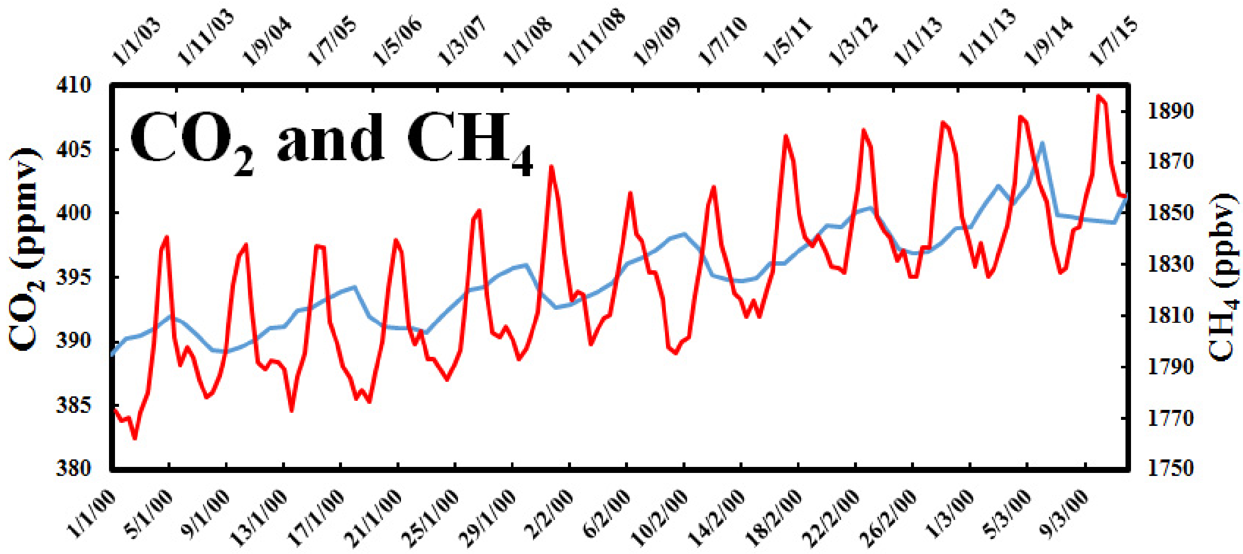

Fig. 5: Comparative analysis of CO_2 and CH_4 for assessing the magnitude of concentration

4. Conclusions

Anthropogenic emission of greenhouse gases builds up in the atmosphere leading up to climate warming. CO_2 and CH_4 data from AIRS shows an increase in concentration of both the gases over Pakistan. Fossil energy consumption is the major cause of increase in CO_2 and CH_4 emissions and is driven mainly by emerging economies. Due to warming of climate, large amount of Methane hydrates and CO_2, which is stored in permafrost in Northern Pakistan, can be released. Both agricultural production and food quality will be affected by rising levels of CO_2. Stabilization in concentrations of atmospheric CO_2 and CH_4 is required to control climate change. Agriculture, coalmines, municipal solid waste, natural gas and oil are major contributors of Methane emissions from Pakistan. Results of this study also point toward the opportunities to understand the dynamics for carbon emission in Pakistan in future researches.

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