Atmospheric CO_2 Observations at Madurai for the Period 2003-2016

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ABSTRACT

The estimate of ambient carbon dioxide (CO_2) concentration has been carried out in Madurai during 2003-2016 by using satellite retrieved dataset. Annual, seasonal and monthly variations of carbon dioxide are observed in this study. Annual averages of carbon dioxide vary from 375 to 403 ppm. Maximum carbon dioxide concentration is observed in summer and minimum during the winter. The strong correlation is observed with wind speed (0.65), planetary boundary layer height (0.51) and rainfall (-0.78). Multiple linear regression analysis results show that the temperature and wind speed are statistically significant. In addition, Mann Kendal trend analysis results clearly elucidate that there is a significantly increasing trend in CO_2 in this study area. The increase in carbon dioxide is mainly due to the increasing anthropogenic sources in and around the study area.

Keywords: *Greenhouse gas, Carbon dioxide variations, AIRS and Meteorological parameters.*

1. Introduction

Increasing greenhouse gases (GHGs) are one of the contributors to climate change. To avoid climate change by stabilizing the atmospheric greenhouse gas concentrations, implementation of some ethical and effective approaches is necessary (Dilmore and Zhang 2018). High population densities (urbanization) and industrialization are the main traders of fossil fuels and due to that large amount of greenhouse gases are emitted in the atmosphere. In urban regions, it is essential to know the variability of GHGs emission sources of natural as well as from anthropogenic activities. Globally, 70 % of anthropogenic carbon dioxide is emitted in urban areas (Fragkias et al. 2013). The major contributors to the increase of carbon dioxide concentrations in the urban areas are electric power sectors, cement production, steel production and transportation (Birat 2010; U.S. Environmental Protection Agency 2015). CO_2 is a strong absorber of longwave infrared radiation, which causes the mean surface temperature of the earth to be warmer than the radiative temperature. The measurement of atmospheric carbon dioxide is continuously monitored at Mauna Loa Observatory in Hawaii by Charles D. Keeling and his team members reported that the global mean carbon dioxide concentration reached about 409 ppm in April 2018 (NOAA 2017). Many scientists have monitored the carbon dioxide concentration in global and regional scale by using various instruments and satellite observations. George et al. 2007 monitored the carbon dioxide concentrations, air temperature and other environmental variables in an urban area which compares to suburban and rural sites for five years (2002-2006) in Baltimore. The study reports that CO_2 concentration and air temperature are high at the urban site compared to that of the suburban and rural sites. The continuous measurement of CO_2 concentration, air temperature, wind speed and direction, and relative humidity is observed in the upper Spanish plateau for the period 2004–2005. The study revealed that the photosynthetic activity in the annual cycle plays a vital role in the CO_2 variation and also the influence of wind direction which allows the emissions from the nearby cities in the study are reported by Garcia et al. 2012. Fang et al. 2016 reported that the measurement of carbon dioxide and carbon monoxide are done at the Shangri-La station, China (September 2010-2013). The concentration variation is due to the influence of the regional terrestrial ecosystem. Hassan A.G.A. 2015 studied the relationship between CO_2 and some meteorological parameters such as air temperature, relative humidity, and wind speed in Qena, Upper Egypt.

India is the second largest population and fastest growing country and in GHG emissions, it ranked in the third position by emitting fossil-fuel burning in the world. Though, there will be less atmospheric CO_2 concentration monitoring over India till date (Tiwari et al. 2011). By this goal, the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) in collaboration with the Physical Research Laboratory (PRL), Ahmedabad and National Institute of Oceanography (NIO), Goa, established an air-sampling station to monitor the carbon dioxide concentration and other trace-gas species at Cape Rama, India, in 1993. The station operated for 10 years (Francey et al. 2003). Tiwari et al. 2013 monitored the variability and growth rate of atmospheric CO_2 concentrations during the annual cycle (1993-2000) in Cape Rama, west coast of India. The relationship between CO_2, rainfall, and vegetation are observed. There is a simultaneous inverse relationship observed between CO_2 and rainfall, which increased vegetation for the sinks of CO_2. Monthly CO_2 concentration and summer monsoon (JJAS) precipitation are well correlated. A negative correlation is found between CO_2 concentration and vegetation. This study reported that the increasing trend of carbon dioxide and the decreasing trend of the vegetation level observed during the study region. The measurement of CO_2 concentration is carried out in Udaipur city (categorized as an industrial area, institutional area, high traffic area, and residential area). The study concluded that the industrial emissions and vehicular emissions are playing a major role by contributing the CO_2 concentration in the study region reported by Lohar (2016).

The level of CO_2 increasing decade by decade and researcher suggests that it is because of fossil fuels are burned at an enhanced rate and an increasing trend of carbon efficiency of economies (Canadell et al. 2007). The possibility of increasing temperature after 100 years will cause drastic changes in the ecosystem. If the current trend of warming continues due to a rise in the concentration of GHGs, melting of ice glaciers in polar regions and the rise of sea level will occur. In case, the higher temperatures can lead to the release of CO_2 from terrestrial ecosystems and to increase oceanic denitrification, stratification which results in nutrient inadequacy of algal growth reducing the CO_2 sink to the ocean. By this, an attempt is made to find out the CO_2 trend, the relationship between CO_2 and meteorological parameters by using satellite measurements on a regional scale during the period from 2003-2016.

2. Data and Method

Madurai is located at 9° 92' N and 78° 12' E with an area of 153 km^2. The elevation is about 101m above the mean sea level. As per 2011 census, the population in this city is about 10, 17,865. The maximum and minimum temperature is about 42°C and 19°C and from October to December, most rainfall events occur in this city. Satellites are provided global coverage data sets of the earth's surface which is impossible to be collected through ground-based measurement techniques (Hertzfeld et al. 2007). Many remote sensing satellites are launched, which differs by their operations, spatial and temporal resolutions. Chedin et al. 2003 have initially reported the global mid-tropospheric CO_2 concentration in the tropical region and the data is derived from TIROS Operational Vertical Sounder (TOVS). Presently, some of the satellites are used for the measurement of carbon dioxide (i.e.) Atmospheric Infrared Sounder (AIRS), Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY), Greenhouse Gases Observing Satellite (GOSAT), Orbiting Carbon Observatory (OCO) and CarbonSat. In this study, monthly carbon dioxide and temperature data are retrieved from AIRS platform at 2.5^o x 2^o and 1^o x 1^o spatial resolution. Atmospheric Infrared Sounder (AIRS) an instrument which is a sun-synchronous orbit mounted on earth observatory satellite launched on May 4, 2002. It constitutes an innovative atmospheric sounding group of visible, infrared and microwave sensor. As twice a day, it has continuously covered the globe at day and night with an altitude of 705 km. Rainfall data are obtained from Tropical Rainfall Measuring Mission (TRMM) launched in 1997 with the spatial resolution of 0.5° longitude and 0.5° latitude which are a Joint program conducted by US and Japan for measuring tropical and subtropical rainfall by using Precipitation Radar, TRMM Microwave

Table 1. Descriptive Statistics of CO_2 over Madurai

Year	Minimum (ppm)	Maximum (ppm)	Mean (ppm)	S.D	C.V
2003	373	376	375	1.0	0.26
2004	374	378	376	1.1	0.30
2005	376	380	378	1.3	0.35
2006	378	382	380	1.1	0.30
2007	380	385	382	1.3	0.35
2008	382	386	384	1.0	0.27
2009	383	390	387	1.7	0.44
2010	387	392	389	1.8	0.46
2011	389	393	391	1.2	0.30
2012	392	395	393	1.0	0.26
2013	392	399	395	1.8	0.46
2014	395	400	398	1.7	0.43
2015	391	403	399	3.2	0.80
2016	400	406	403	1.6	0.40

Imager and the Visible and Infrared Scanner (Kaufman et al. 2005). MERRA version 2 (Modern-Era Retrospective analysis for Research and Application) are used to collect the planetary boundary layer height data and wind speed data with the spatial resolution 0.5^o x 0.625^o. The mean values of data retrievals which fall within the grid cell over the month and the data have been averaged and binned into the specific grid cells of the study location. Pearson correlation and multiple linear regression analysis are carried out to find the relationship between CO_2 with meteorological parameters and Mann Kendal analysis is used to find the trend of CO_2 in the study area.

3. Results and discussion

Table 1 shows the descriptive statistics of ambient CO_2 from 2003 to 2016. The mean CO_2 ranged from 375 to 403 ppm and the maximum is observed in 2016 (406 ppm) and minimum is observed in 2003 (373 ppm). Growth of vehicle population, open burning of harvesting materials, domestic cooking by using woods, and more usage of fireworks using in the city are common throughout the year. The development of the city such as an extension of roads, the encroachment of buildings leads cutting of vegetation (deforestation) observed in this study area. Land clearance processes by burning and grazing by livestock, which is also the main reason for the carbon dioxide level rise in the atmosphere. Constricted and unplanned roads are the main reason for the increase in pollution in the city. The roads and streets are encroached by tall buildings and narrow roads with street canyon nature resulting in the accumulation of pollutants which surrounds the emissions in and around the city. However, the road quality has not improved with the development of infrastructure created in the city which is also a major reason for the pollutant level (Daniel and Kumar 2016). Numerous gases released from transport sector and industries emit large amounts of carbon molecules which react with atmospheric oxygen results in the formation of more amounts of carbon dioxide and carbon monoxide. Depending on the regional transport process and confined atmospheric circulation, the carbon dioxide concentrations are varied (Randel and Park 2006). The geographic location of the city may also one of the factors for increasing the level of carbon dioxide. For seasonal variation, the seasons are classified as winter (January, February – JF), summer (March, April, May – MAM), monsoon (June, July, August, September – JJAS) and post monsoon (October, November, December – OND). The overall average seasonal variation of CO_2 is high starting from summer (388.3 ppm) and gradually decreasing by monsoon (388.2 ppm), post monsoon (387.7 ppm) and finally a lower level is observed in winter season (386.2 ppm). During summer, the high temperature results by encouraging the chemical transformation rates and the efficiency of atmospheric chemical reactions lead in the conversion of CO to CO_2 (Daniel and Kumar 2016). Various festivals celebrated throughout the year, and the cultural events are attracted more tourist and local peoples to visit in and around the city in these seasons (Thangamani and Srividya 2017). During the winter season, the level of CO_2 is low because of the large intake of CO_2 during photosynthesis, convective mixing in minimal solar intensity and temperatures (Miyaoka et al. 2007). Monthly variations of CO_2 concentration and meteorological parameters are depicted in Figure 1 for Madurai city. The overall monthly CO_2 level starts increasing from January (385.73 ppm) and gradually increased and reaches its peak in the month of May (389.58 ppm) and slowly decreased in December. It can be seen that high concentrations are recorded mostly in the month of June in almost all study years. The highest average (406.3 ppm) is recorded in July 2016. The lowest concentrations are mostly recorded in the month of January for all years of the study period and the lowest average (373.4 ppm) is recorded in January 2003.

The CO_2 and ambient temperature plot clearly shows that the temperature is gradually increasing when the CO_2 concentration is increasing. The rise and fall of temperature is not only depend upon the CO_2 level but also the anthropogenic activities and local meteorological parameters. Naturally, temperature varies from decade to decade and even from century to century. Rise of temperature can exaggerate drought conditions and increase the possibility of fires. The

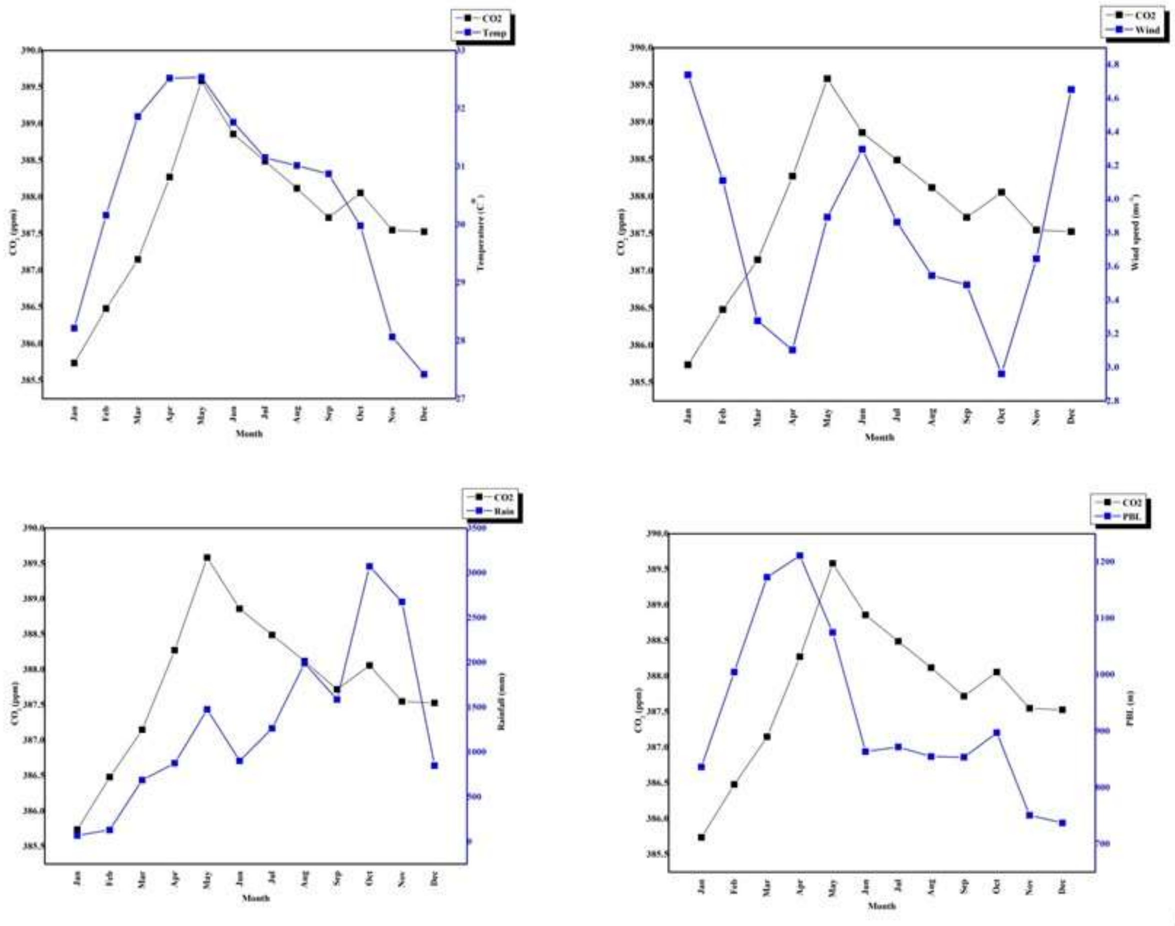

Figure 1: Average monthly variations of CO_2 concentration and meteorological parameters.

movement of atmospheric changes in this city is due to the extreme temperature and drought frequency. In this study, the level of CO_2 mainly depends on both regional transport processes and local atmospheric circulation (Randel and Park 2006), the temperature rise is also observed in April – July month. Mostly, the internal combustion engines in motor vehicles perform enhanced in cold temperature where the carbon monoxide emits fewer amounts in the atmosphere. But as the temperature increases, it reduces the engine efficiency by releasing more CO in the atmosphere (Wang 2010). During the combustion process, CO is co-emitted with CO_2, which results in a significant relationship between CO_2 and temperature (Ana 2015). The CO_2 and wind speed plot clearly shows that the high wind speed disperses CO_2 emissions. Wind speed is a predominant cause in the lowering of CO_2 concentration. Mostly the high and low concentrations are found to be related to low and high wind speeds. Generally, the transport sector is an important contributor to local emissions in the urban city and also there is no particular wind direction associated with the high levels found in the city (Chandra et al. 2016). The CO_2 and rainfall plot clearly shows that the level of CO_2 concentration is low when the rainfall is high. The amount of rainfall is higher, the growth response of plants also high which uptake the carbon dioxide by lowering their concentration. The heat trapping property in the middle of the atmosphere, CO_2 increases the precipitation rate. The warm air is higher in the atmosphere has a tendency to prevent the rising air motions that generate thunderstorms and rainfall. As a result, increasing CO_2 concentration suppresses the rainfall and decreasing carbon dioxide concentration tends to increase the rainfall. Scientists are reported that global warming cause previous dry areas to get drier and cause wet areas to get wetter (Cao et al. 2011). The CO_2 and planetary boundary layer (PBL) plot show when the PBL height is extended, the mixing ratio of emissions are high the CO_2 concentration is low and when it shrinks the mixing ratio is low and the concentration becomes high. CO_2 is primarily produced and consumed on the ground. The concentration at high altitudes is affected by the ground level variations ie., sources and sinks as well as by the atmospheric dispersion and transportation (Li et al. 2014). The surface exchange of CO_2 depends upon the boundary layer height. As this layer extends, the carbon uptake and release by plants through photosynthesis reduce the CO_2 concentration and also the concentration gets diluted (Denning et al. 1995; Gerbig et al. 2008). However, in lower altitude, the stable atmosphere weakens the vertical mixing ratio which causes accumulation of CO_2 and slows down the dispersion of CO_2. At higher altitude, the vertical mixing ratio and the atmospheric stability in the presence of wind flow diffused the CO_2 concentration (Li et al. 2014).

3.1. Statistical analysis

Figure 2 shows the correlation coefficients (r) between CO_2 with meteorological parameters. The result clearly shows that the variability of CO_2 associated with the meteorological parameters such as temperature (T), wind speed (WS), rainfall (R) and PBL height in the study area. There is a strong correlation between CO_2 with wind speed, rainfall and PBL height. Additionally, multiple linear regression analysis is also used to examine the influence of CO_2 with meteorological conditions analysis in Equation (1) (Benallal et al. 2017).

$$Y_{CO2} = a_0 + a_1 \text{ x } T + a_2 \text{ x } WS + a_3 \text{ x } R + a_4 \text{ x } PBL \qquad (1)$$

The p values of independent variables such as temperature (0.001), wind speed (0.008), rainfall (0.12) and PBL (0.14) are observed. The p values which less than 0.05 are accepted and p values which greater than 0.10 are rejected. In this test, temperature and wind speed which are statistically significant, whereas rainfall and PBL are rejected as the variables are statistically insignificant. The relationship between CO_2 variability with temperature and wind speed are

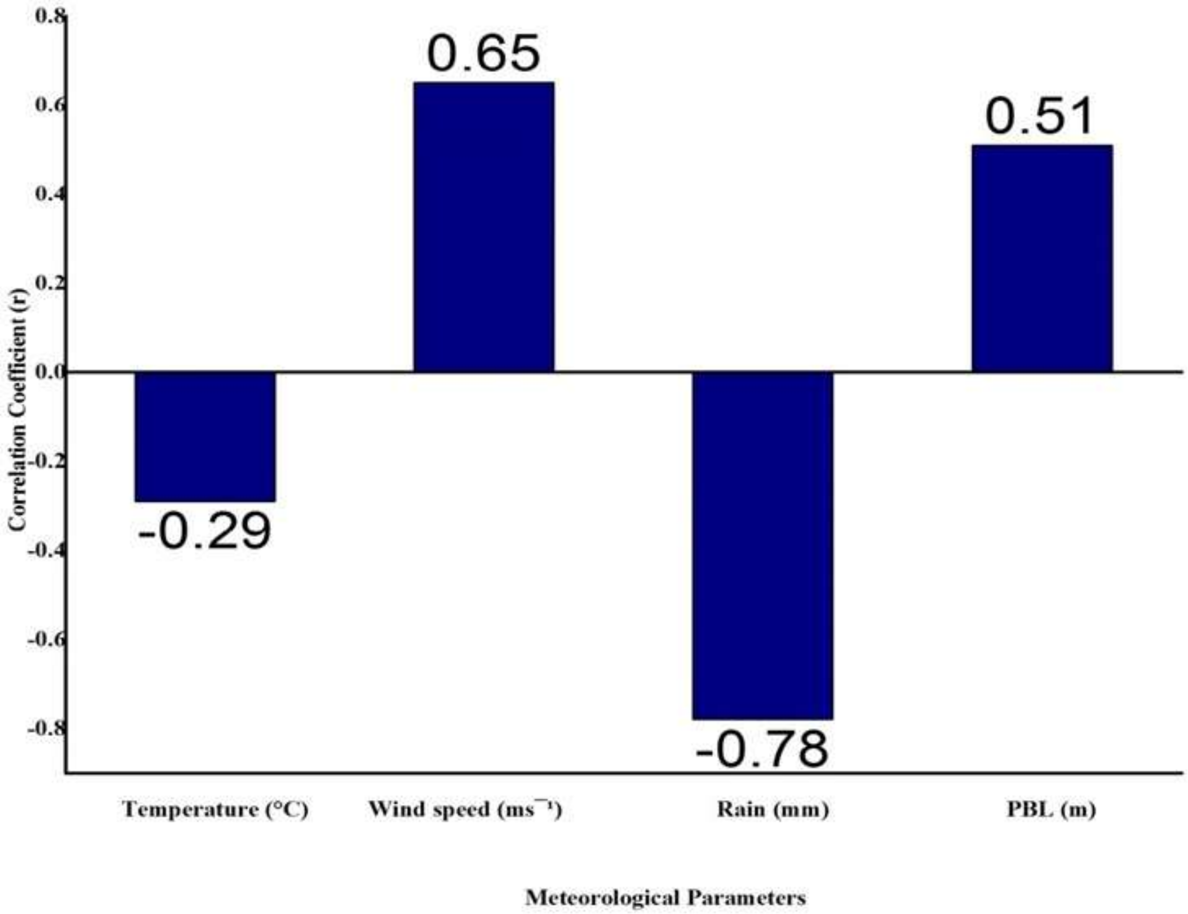

Figure 2: Correlation coefficients (r) between CO_2 with meteorological parameters.

established in the equation (2) and (3) for the study area.

$$Y_{CO2} = 792.52 - 15.08 \times T \quad (2)$$

Where $a_0 = 792.52$ and $a_1 = -15.08$.

$$Y_{CO2} = 792.52 + 5.7 \times WS \quad (3)$$

Where $a_0 = 792.52$ and $a_2 = 5.7$.

The Equation 2 & 3 clearly show that temperature and wind speed play a major role in the variation of CO_2 observed in the study area.

3.2. Trend analysis

Several advanced techniques are used for detecting the trend in the time series. It can be either parametric or non-parametric. Parametric methods assumed the data should normally distributed and free from outliers. On the other hand, non-parametric methods are free from such assumptions. The most popularly used non-parametric tests for detecting trends in the time series is the Mann-Kendall (MK) test. It is widely used for different climatic variables (Hirsch 1984). The Mann-Kendal (MK) test searches for a trend in a time series without specifying whether the trend is linear or nonlinear (Khaliq 2009). It is based on the test statistics S. The value of S' indicates the direction of the trend, the negative and positive value indicates declining and rising trend (Padma et al. 2013). In this study, the results of Mann-Kendall trend shows an increasing trend and here the null hypothesis about no trend is accepted due to the 'p' (1.0) value is greater than the significance level of alpha (0.05). This increase in trend is believed to be a result of increased anthropogenic emission in and around Madurai

4. Conclusions

In the present study, the assessment of annual, seasonal and monthly variations of CO_2 and their relationships with the meteorological parameters are analyzed by using satellite retrieved data during 2003-2016 in Madurai. Monthly variation of CO_2 reached its peak in the month of May (389.58 ppm) and minimum during the month of January (385.73 ppm). In the seasonal variation, the level of CO_2 reached high in summer and low in the winter season. From 2003-2016, the annual level of CO_2 gradual increase takes place in the study period and the maximum level is found in 2016 (403 ppm) and minimum level in 2003 (373 ppm). Multiple linear regression analysis is carried out for understanding the relationship of CO_2 with the meteorological parameters. The Mann Kendal trend analysis also carried out and the result show an increasing trend during the study period in Madurai. This study clearly revealed that CO_2 shows an increase in a very small domain and this may be due to the increase in transportation and some anthropogenic sources in and around the study area. Since the lifetime of CO_2 in the atmosphere is long and the impacts high, more studies are needed to understand its temporal and spatial variations with a view to control the anthropogenic sources.

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