International Research Journal of Environment Sciences ISSN 2319–1414
Vol. **6(2),** 55-58, February **(2017)** *Int. Res. J. Environment Sci.*

A comparative mathematical analysis of methane emission in India and USA

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Available online at: www.isca.in, www.isca.me
Received 4th January 2017, revised 12th February 2017, accepted 18th February 2017

Abstract

Global anthropogenic methane mission causes an alarming environmental situation for the last few decades. Methane is one of the important green gases which is reported its stronger global warming potential than carbon dioxide. Among the greenhouse gases, methane is supposed to be the second most damaging greenhouse gas after carbon dioxide produced mainly by anthropogenic activities. The main sources of methane emission include mainly industry, agriculture and waste product. The paper makes an attempt for a comparative analysis of methane emission in two countries such as India and United States of America (USA) using historical data of about 100 years by non-linear least square regression analysis method. The validation of emission mode of methane is incorporated upon examination of Coefficient of determination and residual analysis. The paper also utilizes the instantaneous rate of change (IROC) of the gas emission trend of the model for long term prediction of the two countries.

Keywords: Global warming, Regression analysis, Instantaneous rate of change, Least square method, Residual analysis.

Introduction

Human activities are contributing a large amount of green house gases (GHGs) to the atmosphere for the last few decades which severely changes global climate and behavioural pattern of weather. Different GHGs like carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), ozone (O_3) etc. are responsible for this unwanted situation. Though CO_2 is the most contributing in this regard but methane is the second most damaging greenhouse gas produced primarily through human activities which is now a concern to the scientists, researchers and environmentalists. In trapping radiation, methane is more efficient than carbon dioxide and reasonably high warming potential (28-36 unit). It has been reported that methane has 25 times the global warming potential of carbon dioxide over a 100-year time frame[1]. It has also been claimed that methane is an important greenhouse gas, with a 100-year global warming potential 28 times stronger than that of carbon dioxide[2]. The single largest source of atmospheric methane is from unwanted formation of wetlands though estimated emissions vary from 80 to 260 Tg annually[3,4]. Process of agriculture, coal mining, landfills, enteric fermentation, natural gas and petroleum are also the sources of emission of methane[5,6]. A view of pattern of methane emission in the subjected countries such as sectoral view, effect on livestock, economy and paddy are available in few literatures[7,8].

Green house gas emission through mathematical modeling have been analysed by several researchers[9-11]. But comparative gas emission modeling along with its future prediction is little studied for the emission of methane for India and USA. Zhu et al. studied methane emission modeling based on TRIPLEX-GHG model[12]. DNDC (De Nitrification and De Composition) model was studied by Jagadeesh Babu et al. and it was tested against experimental data on methane emission from rice fields[13]. Sensitivity of wetland methane emissions model was discussed by Meng et al. considering average global wetland emission and rice paddy emission of methane[14]. Modeling methane emission from arctic lakes was also developed by Tan et al.[15]. Present authors also analysed methane emission through mathematical understanding for some Asian countries like India, China, Japan and South East Asian countries[16]. In the present research investigation, a comparative emission of methane for two parts of the globe e.g. India and USA has been studied based on non linear least square regression analysis method along with its future prediction.

Methodology

Mathematical model for the methane gas emission has been extracted from the works of Tokos and Xu[9], Jin et al.[10] and our previous research work[17]. With these understanding, the third degree polynomial model for the gas emission in the present study has been identified as,

$$Y = A + B.x + C.x^2 + D.x^3 \quad (1)$$

Where: Y is the emission of methane gas in Terragram (Tg), x represents time in years and A, B, C and D are parameters.

By the application of least square methodology, given data (x_1,y_1), (x_2,y_2),…,(x_n,y_n), an error associated for estimation may be formulated as

$$E(A,B,C,D) = \sum_{i=1}^{n}(y_i - A - Bx_i - Cx_i^2 - Dx_i^3)^2 \quad (2)$$

The equation (2) represents the variance of the data set of errors $\{y_1 - (A + Bx_1 + Cx_1^2 + Dx_1^3), \ldots, y_n - (A + Bx_n + Cx_n^2 + Dx_n^3)\}$. Equating to zero, the normal equations based on the partial derivatives of equation (2) are

$$\sum y_i = nA + B\Sigma x_i + C\Sigma x_i^2 + D\Sigma x_i^3$$

$$\sum x_i y_i = A\Sigma x_i + B\Sigma x_i^2 + C\Sigma x_i^3 + D\Sigma x_i^4$$

$$\sum x_i^2 y_i = A\Sigma x_i^2 + B\Sigma x_i^3 + C\Sigma x_i^4 + D\Sigma x_i^5$$

$$\sum x_i^3 y_i = A\Sigma x_i^3 + B\Sigma x_i^4 + C\Sigma x_i^5 + D\Sigma x_i^6 \quad (3)$$

The equations (3) are solved for A, B, C and D for the given n data sets to yield best fitted third degree polynomial. Also, we can say that the values of the second order partial derivatives viz. $\frac{\partial^2 E}{\partial A^2}, \frac{\partial^2 E}{\partial B^2}$, …………etc. are positive in all cases confirming minimization of E. So the equation becomes

$$Y = \hat{A} + \hat{B}.x + \hat{C}.x^2 + \hat{D}.x^3 \quad (4)$$

For the computation of rate of change of gas emission and to identify IROC, the derivative of equation (4) is presented as

$$dY/dx = \hat{B} + \hat{C}.x + \hat{D}.x^2 \quad (5)$$

The equation (5) has been utilized for prediction of the methane emission for a particular year. Quality of the proposed model is estimated from diagnostic tools such as coefficients of determination (R^2)[18] and residual analysis.

Results and discussion

A comparative methane emission during hundred years for India and USA has been shown in Figure-1. It is observed from the figure that the methane emission rate is quite high in USA for the last hundred years whereas in India, the emission trend is nominal and not remarkable. The growth emission in USA is rapid, almost in an exponential pace after 1930.

In order to have a comprehensive analysis of emission of methane in India and USA, the model equations utilizing the corresponding data sets are extracted as

$$Y_{IND} = 431.853302 + 0.0532173999.x - 0.000408524502.x^2 + 1.38360321E\text{-}007.x^3 \quad (6a)$$

$$Y_{USA} = 4027.70068 + 0.432645977.x - 0.00377246621.x^2 + 1.28068302E\text{-}006.x^3 \quad (6b)$$

For India and USA, a comparative graphical representation regarding the observed and estimated results for the emission of methane is presented in Figure-2a and 2b respectively. A power series growing trend of emission of methane is observed for the two counties though USA emits methane in much higher amount than India.

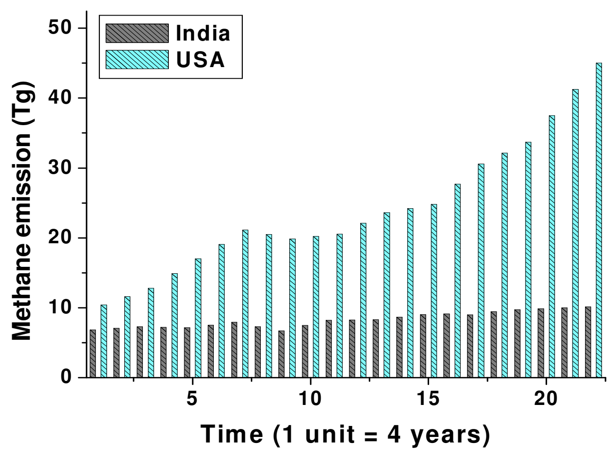

Figure-1: Comparative methane emission.

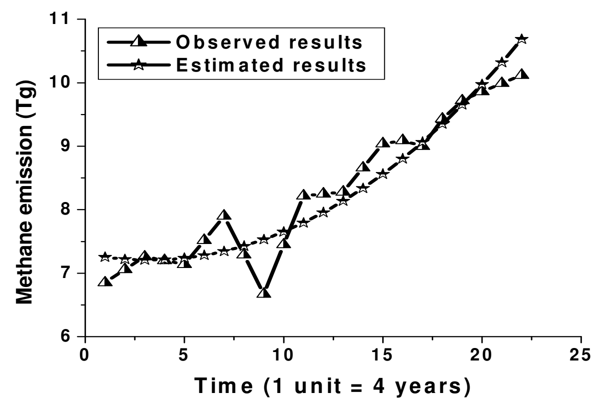

Figure-2(a): Methane Emission in India.

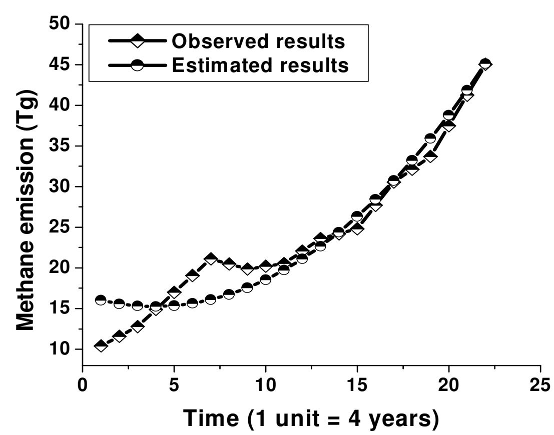

Figure-2(b): Methane Emission in USA.

The model efficacy are estimated by utilizing the statistical criteria, namely coefficient of determination R^2 (R^2 adjusted) and residual analysis. The calculated values of R^2 (R^2 adjusted) for India and USA are presented in Table-1.

Table-1: Methane Emission: Statistical Criteria.

Country	R^2	R^2 adjusted
India	0.9033	0.8872
USA	0.9291	0.9173

The value of R^2 (R^2 adjusted) supports the efficiency of the identified model for methane emission in India and USA.

The determination of IROC: IROC for India and USA can be expressed by the following differential equations as it is utilized as a significant tool for the future gas emission

$$dY/dx\ (\text{India}) = 0.0532173999 - 0.00408524502.x + 1.38360321E\text{-}007.x^2 \quad (7a)$$

$$dY/dx(\text{USA}) = 0.43264577 - 0.00377246621.x - 1.28068304E\text{-}006.x^2 \quad (7b)$$

Below Figures-(3(a) and 3(b)) elaborate the graphical representations of equations 7a and 7b respectively for India and USA.

From the below analysis based on IROC, prediction of emission can be made for both the countries. It can be said that before the year 1900, decreasing emission trend is observed for India while for USA trend is enormously increasing form the beginning. This indicates unrestrained emission of methane from different sources which ultimately stands a dreadful situation for the last few decades.

While vertical lines (Figure-3a and 3b) mark one hundred year completion of IROC values (estimated) for the emitted methane gas, one can easily predict the IROC of future methane emission for long and short period of time. A control measure should be taken for the benefit of mankind based on increasing trend of IROC which implies uninhibited emission of methane from different sources.

With such predicted IROC values, future emission of methane is worked out and is presented in Table-2. From Table, we observe the higher amount of methane emission in future if proper care is not taken appropriately.

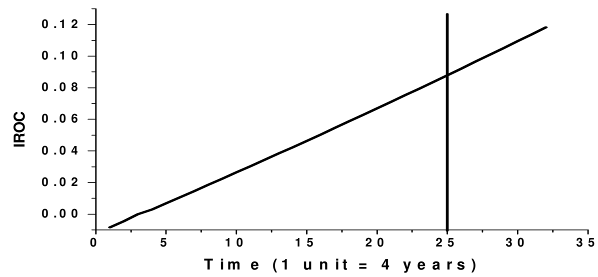

Figure-3(a): IROC of India.

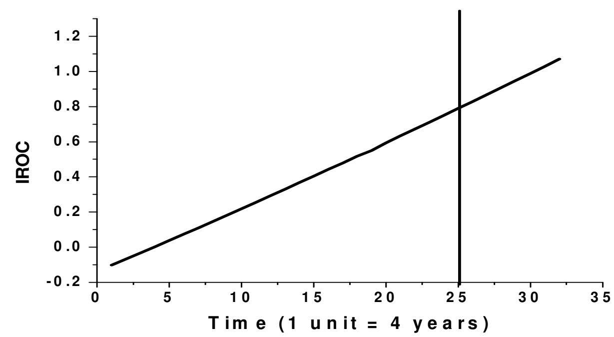

Figure-3(c): IROC of USA.

Conclusion

Mathematical models using non linear least square method have been developed for the characterization of the behavioural pattern of methane emission for two major and opposite parts of the globe namely India and USA. 100 years (1890 to 1995) data set has been utilized for this purpose considering natural and anthropogenic emission of methane. The analytical expressions for emission have been tested with three different statistical procedures, namely R^2, R^2 adjusted along with residual analysis to identify the efficacy of our mathematical expression. Finally, models have been applied for the prediction of emission of methane in future using IROC. Our models may be helpful for the future researchers for functional planning and strategic applications to curb green house gas emission for pollution free planet.

Table-2: Methane emission prediction.

Year		2020	2025	2030	2035	2040
IROC	India	0.0965	0.1008	0.1051	0.1095	0.1138
	USA	0.8689	0.9089	0.9491	0.9894	1.0300
Emission Prediction (Tg)	India	12.8312	13.3244	13.8392	14.3756	14.9339
	USA	64.3863	68.8310	73.4766	78.3280	83.3766

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