Comparative analysis of carbon dioxide emission in West Bengal and India

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Abstract: - During the last few years we, the human being is feeling the effects of extreme heat due to global warming caused mainly for the reckless carbon dioxide emission of various sector such as industry, agriculture etc. The average temperature of Earth is rising up in such a way that the friends to the environment are seriously worried about our existence. The situation has reached such a alarming stage that all the countries around the world find it difficult to retain the sustainability of natural resources for the next generation. In the Paris convention, the policy of 'zero emission' is adopted specially for the developed and developing countries. In this paper we have tried to develop a mathematical model to find the tendency carbon dioxide emission in West Bengal and India. For this purpose, we have considered the data set about 21 years of the gas emission and tried to fit a third-degree algebraic polynomial curve by the non-linear regression method. From our proposed model one can predict the long term or short-term evolution trend of the said gas emission in India and the state of West Bengal.

Keywords ---Global Warming; Green House Gas; Least square method; Residual analysis; R square.

I. INTRODUCTION

We are surrounded by air but unfortunately the airs from which we breathe become highly polluted. The average temperature of the Earth has been increased by 2°C during the last two decades. Scientists are very much anxious to overcome the problem. Several conferences from Rio-Je-Zane to Paris has been organised but there is no sign in mitigating the problem. Various environmental problems induced by global warming has become a global issue throughout the universe. According to the Intergovernmental Panel on Climate Change (IPCC), emission of carbon dioxide (CO_2) gases is mainly responsible for the extreme heat of the Earth [9]. It has serious evil effect on human health [2]. For example, the name of Erythromelalgia can be taken [1]. According to World Health Organization (WHO), the impact of extreme heat on human health causes various ailments such as cardiovascular disease, disease, asthma etc. Not only the physical health impacts of climate change are well known but the impact on mental health has been identified in the last decade [10].

The nature of global rainfall, stream flow, evaporation, snow etc. is changing as the weather and climate warms up. India is an agriculture-based country and a significant amount of greenhouse gases (GHG) emitted during agricultural food production system [4]. As the report of IPCC, the emission rises up 10-20% even it become 17% during the changes of land due to agriculture. Extreme heat is directly related to some water-based disaster like flood, tsunami etc that destroy homes and habitats and peoples are bound to take shelter elsewhere [3].

The motivation of the paper is understanding the CO_2 in India as a whole and one of the agricultural states as a contributory part. The work of Basak and Nandi, 2014[6] and Tokos and Xu, 2009 [5] is followed where authors suggested a third-degree polynomial model to explain the emission pattern of the gas. Third degree polynomial is taken using the data set of about 21 years (1980-2000) following the non-linear least square method. Instantaneous rate of change (IROC) is calculated for future prediction of the emission of CO_2.

II. MODEL AND DATA

A] Data source

Carbon dioxide emission data is exported from the paper of Ghoshal and Bhattacharyya, 2008[8].

B] Model formulation

The data of CO_2 emission for the 21 years (1980-2000) is utilized for the purpose of modelling. We formulated a third-degree polynomial model for the analysis of CO_2 emission of the state of West Bengal and India. For generating the model of CO_2 emission, we followed the work of Jin *et al.*, 2010 [7], Tokos and Xu (2009) [5] and Basak and Nandi (2014) [6]. Authors suggested a third-degree polynomial model for emission of CO_2 such as

$$Y = a + bx + cx^2 + dx^3 \quad ....(1)$$

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where Y is the emission of carbon dioxide in metric ton and x is represents time in years.

With the help of the given data$\{(x_1,y_1),(x_2,y_2),\dots\dots.(x_n,y_n)\}$, we may define the error associated by

$$F(a,b,c,d) = \sum_{i=1}^{n}(y_i - a - bx_i - cx_i^2 - dx_i^3)^2) \qquad \text{............(2}$$

is a function of four variables a, b, c and d.

For minimization of error and to estimate corresponding a, b, c and d, we use multivariate calculus to have,

$$\frac{\partial F}{\partial a} = \frac{\partial F}{\partial b} = \frac{\partial F}{\partial c} = \frac{\partial F}{\partial d} = 0.$$

Differentiating (2) partially and equating to zero, the result is

$$-2\sum(y_i - a - bx_i - cx_i^2 - dx_i^3) = 0$$

$$-2\sum x_i(y_i - a - bx_i - cx_i^2 - dx_i^3) = 0$$

$$-2\sum x_i^2(y_i - a - bx_i - cx_i^2 - dx_i^3) = 0$$

$$-2\sum x_i^3(y_i - a - bx_i - cx_i^2 - dx_i^3) = 0$$

Corresponding normal equations are,

$$\sum y_i = na + b\sum x_i + c\sum x_i^2 + d\sum x_i^3$$

$$\sum y_i x_i = a\sum x_i + b\sum x_i^2 + c\sum x_i^3 + d\sum x_i^4$$

$$\sum x_i^2 y_i = a\sum x_i^2 + b\sum x_i^3 + c\sum x_i^4 + d\sum x_i^5$$

$$\sum x_i^3 y_i = a\sum x_i^3 + b\sum x_i^4 + c\sum x_i^5 + d\sum x_i^6 \qquad \text{...........(3)}$$

For given set of points (x_i, y_i); (i=1, 2,..., n), the equations (3) are solved for a, b, c, d to evaluate estimated $a^*, b^*, c^* and d^*$. It has been found that in all the cases, the value of the 2nd order derivatives evolve to be positive at the points a, b, c, d and assigns the minimization of F.

Estimated third degree fitted polynomial of CO_2 emission may be represented as

$$Y(x) = a^* + b^*x + c^*x^2 + d^*x^3 \qquad \text{........... (4)}$$

III. INSTANTANEOUS RATE OF CHANGE (IROC) OF EMISSION

For computing the rate of change of the gas, the derivative of equation (4) is given by

$$\frac{dY}{dx} = b^* + c^*x + d^*x^2 \qquad \text{............. (5)}$$

The equation (5) may be used to predict the emission of CO_2 at any instance.

IV. QUALITY OF PROPOSED MODEL AND PREDICTION

Equation (4) may be utilised for estimating emission of CO_2 for medium or short terms of time. The goodness of fit is tested by using various statistical tools like R^2, R^2 (adjusted) and residual analysis.

A] Coefficient of Determination (R^2)

The coefficient of determination R^2 provides an overall measure of how well the model fits. The general definition of the coefficient of determination is

$$R^2 = 1 - \frac{SS_{err}}{SS_{tot}}$$

Where $SS_{tot} = \sum_i(y_i - \bar{y})^2$, $SS_{reg} = \sum_i(f_i - \bar{y})^2$, $SS_{reg} = \sum_i(y_i - f_i)^2$

Here, SS_{tot} = Total sum of square (proportional to the sample variance),

SS_{reg} = the regression sum of squares or the explained sum of square and SS_{err} = the sum of squares of residuals, also called the residual sum of square. y_i and f_i are observed and estimated values of CO_2 emission.

B] Adjusted Coefficient of Determination

The adjusted R^2 is defined as:

$$\bar{R}^2 = 1 - (1 - R^2)\frac{n-1}{n-p-1} = R^2 - (1 - R^2)\frac{p}{n-p-1}$$

where p is the total number of regressors in the model excluding the constant term and n is the sample size. It is however another advanced measure how well the model fits with the observed data.

V. RESULT AND OBSERVATION

To characterize the emission pattern of CO_2 in West Bengal and India a comparative study diagram is added in Fig. (1). From the diagram it could be observed that the increasing emission trend is observed for the states of West Bengal and the same trend is followed by India form the beginning up to 1997. The emission of CO_2in West Bengal contributes about 20% of total CO_2 emission in India, although the area of West Bengal is about 2.7% of all India area. In the considered time span (1980-2000) the CO_2 emission rate is high both in India and in West Bengal. But after the year of 1997 as observed from the graph, the emission of CO_2 visualizes a decreasing tendency for the both, India and West Bengal.

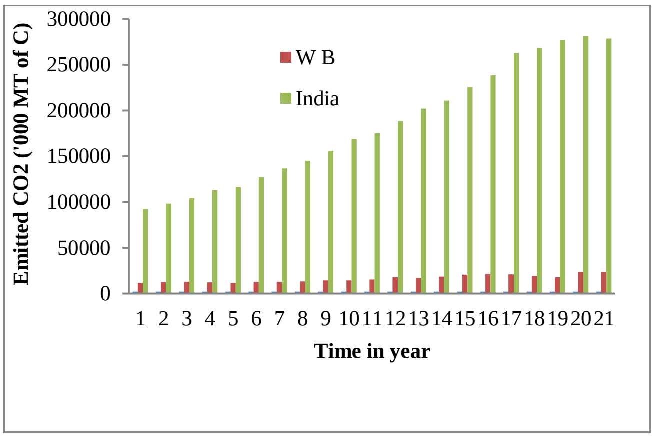

Fig.1 Comparative bar diagram of CO2 emission in West Bengal and India.

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A] Third degree polynomial model

The proposed polynomial model for the emission of CO_2 using the dataset of 21 years from 1980 to 2000, for the states of West Bengal and India is represented as follows.

$$Y(WestBengal) = 2.23109 \times 10^{10} - 3.36086 \times 10^{7}x + 16875.3x^2 - 2.82437x^3 \qquad ....(6)$$

$$Y(India) = 2.13547 \times 10^{11} - 3.21716 \times 10^{8}x + 161552x^2 - 27.0405x^3 \qquad ....(7)$$

where x represents time in year.

The graphical visualization of the real data and solution of the models for emission of CO_2 by least square method are displayed in Fig. 2(a-b). In both the cases increasing tendency of emission of CO_2 is observed here.

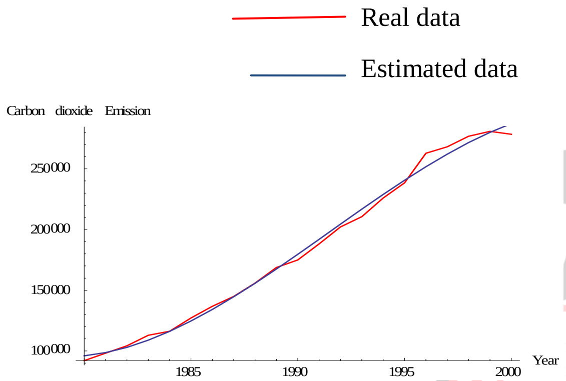

Fig. 2 (a): CO_2 emission in India.

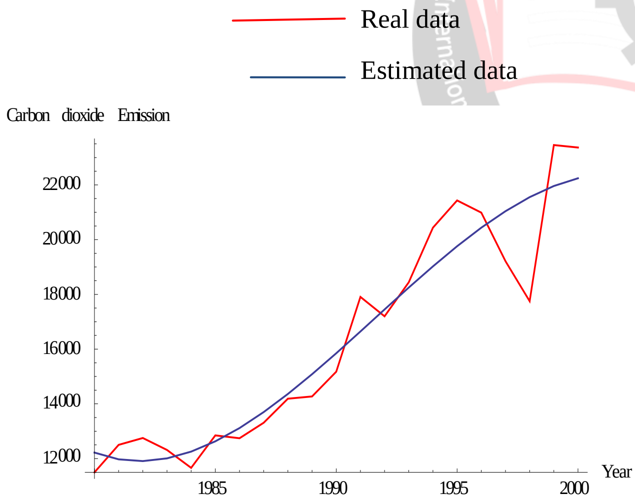

Fig. 2 (b): CO_2 emission in West Bengal.

B] Instantaneous rate of change (IROC)

IROC is that particular tool using which one can evaluate the future emission of CO_2 at any instance. IROC of the gas for India and West Bengal is formulated analytically as

$$\frac{dY(India)}{dx} = -3.21716 \times 10^{8} + 323104x - 81.1215x^2 \qquad ....(8)$$

$$\frac{dY(WestBengal)}{dx} = -3.36086 \times 10^{7} + 33750.6x - 8.47312x^2 \qquad ....(9)$$

Equations (8) and (9) present the IROC of emission equation of CO_2 for the state of West Bengal and India respectively. These equations are function of time and which can be presented graphically in Fig. 2(a-b). The figures may be utilized for the estimation of emission in future for short or medium term of time. In the diagram the vertical lines showing completion of 21 years of estimated IROC values for the gas. Beyond the vertical line future IROC value is easily predictable and from here future emission can be obtained for short or medium terms of time.

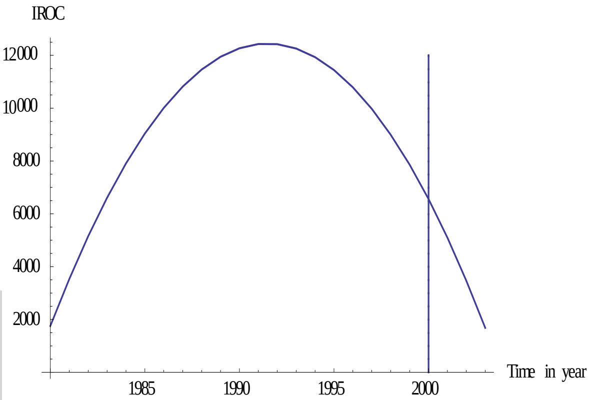

Fig. 3(a): IROC of India.

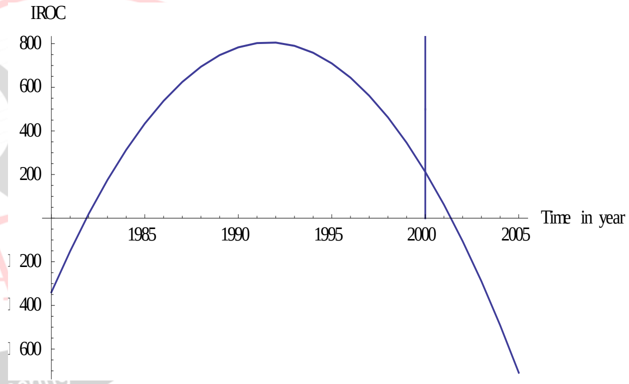

Fig. 3(b): IROC of West Bengal.

From Fig. 2 (a-b), we get total CO_2 emission in West Bengal in 2004, 2008 and 2012 are 21773, 17952 and 9693 ('000 MT of carbon) respectively and the same for India are 300709, 281657 and 219723 ('000 MT of carbon) respectively.

C] Residual Analysis

Residual analysis is calculated on our proposed polynomial model for the emission of CO_2 in West Bengal and India and is presented in the Table (1-2).

Table 1: Residual analysis for CO_2 in West Bengal.

Year	Observed data('000 MT of Carbon)	Estimated data('000 MT of Carbon)	Residuals
1980	11499.3	12218.1	-718.793
1981	12501.5	11974.	527.514

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1982	12753.5	11910	843.548
1983	12313.3	12009.1	304.226
1984	11663.2	12254.5	-591.257
1985	12848.3	12629.2	219.165
1986	12742.4	13116.2	-373.74
1987	13308.	13698.6	-390.588
1988	14190.2	14359.4	-169.21
1989	14268.3	15081.7	-813.473
1990	15175.4	15848.6	-673.228
1991	17909.2	16643.1	1266.01
1992	17197.9	17448.3	-250.373
1993	18439.5	18247.2	192.359
1994	20435.9	19022.8	1413.07
1995	21432.4	19758.3	1674.13
1996	20984.9	20436.6	548.283
1997	19212.7	21040.9	-1828.18
1998	17753.2	21554.2	-3800.93
1999	23457.1	21959.5	1497.59
2000	23363.7	22239.8	1123.87
Standard Deviation of residual			1255.59
Mean of residual			0
Standard Error of residual			273.99

Table 2: Residual analysis for CO_2 in India.

Year	Observed data('000 MT of Carbon)	Estimated data('000 MT of Carbon)	Residuals
1980	92060	95978.4	-3918.39
1981	98167	98636.2	-469.221
1982	104246	102994	1251.5
1983	112913	108891	4022.02
1984	116208	116163	44.5865
1985	127151	124650	2501.43
1986	136776	134187	2588.81
1987	144873	144614	258.956
1988	155917	155768	149.116
1989	168741	167486	1254.53
1990	174918	179608	-4689.55
1991	188203	191969	-3765.88
1992	202114	204408	-2294.23
1993	210579	216763	-6184.35
1994	225921	228872	-2951.
1995	238450	240572	-2121.92
1996	262786	251701	11085.1
1997	268128	262097	6031.34
1998	276821	271597	5224.03
1999	280853	280040	813.398
2000	278432	287262	-8830.3
Standard Deviation of residual			4505.65
Mean of residual			0
Standard Error of residual			983.21

From Table 1 and Table 2 it is found that the residuals and standard error are small comparatively than data. This reflects the fact that we have identified a good mathematical model both for the states of West Bengal and India for the emission of CO_2.

D] Calculation R^2 and R^2 (Adjusted)

Table 3: Statistical evaluation criteria.

	West Bengal	India
R^2	0.9001	0.9952
R^2 (Adjusted)	0.8825	0.9943

The values of coefficient of determination R^2 and R^2 (adjusted) is evaluated and presented in the Table 3 given below. The analytical expressions for emission have been tested with the statistical procedures R^2 and R^2 adjusted to identify the efficacy of our mathematical expression and each of them attest the good quality of the proposed systems (cubic polynomial model).

VI. FINDINGS

This paper will help to predict the tendency of CO_2 emission in India and the State of West Bengal. A comparative study is provided of the dimension the pollution of the State of west Bengal in respect to our country. It is seen that the trend of emission of carbon - dioxide gas is increasing for both in the states of West Bengal and India. So, it is an important study at the present situation as the whole world is seriously worried about the global warming and emission of CO_2 is the main reason behind it. India is a developing country, so contribution of India towards emission of carbon-dioxide is vital in extent of global of emission. Under the circumstances, it will be easier to adopt right policy to combat the measure of CO_2 emission.

VII. CONCLUSION

Mathematical models using non-linear least square method have been developed for the characterization of the behavioural pattern of CO_2 emission for India and West Bengal. The pattern of growth is not uniform; it is mainly area and time dependent. The proposed model is found to be in well agreement with the CO_2 emission data in the considered time span. In each case the proposed model is tested with various statistical tools like R^2 and R^2 adjusted and residual analysis. The numeric value of R^2 and R^2 adjusted for the state of West Bengal are 0.9001 and 0.8825 indicating that a good model is identified. For India the numeric value of R^2 and R^2 adjusted are 0.9952 and 0.9943 which reflect that proposed model is fitted very well with

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observed data of emission that indicates that the model fits slightly better in India compared to the state West Bengal. A theoretical basis for the future researches regarding CO_2 emission in different regions in India can be obtained from this study and the model may be used for working planning and strategic assignment to reduce terrifying global warming in near future. Also, the model may be used for characterizing the emission pattern of other GHG's throughout the country. Finally, it comes to the solution that the model of India is slightly more effective than the state of West Bengal and CO_2emission of West Bengal state is 20% of India's emission.

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