# A Statistical Evolutionary Analysis and Prediction of Carbon-dioxide Emission in Gujarat, Maharashtra and Madhya Pradesh of India

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**Abstract**

**Purpose of the study:** The change of climate due to global warming has become a burning problem throughout the world. India is a country where global warming causes a concern to the scientists. Unrestricted emission of different green house gases mainly carbon dioxide is responsible for this alarming situation. This paper develops a state-wise nonlinear emission model of carbon dioxide, an important green house gas.

**Methodology:** Non linear least-square and regression analysis method used to explain the emission of the gas.

**Main Findings:** The short term and long-term forecast of carbon dioxide emission trend in the states are presented.

**Applications of this study:** Model is used in the states of Gujarat, Maharashtra and Madhya Pradesh of India.

**Novelty/Originality of this study:** Future prediction of emission of $CO_2$ may be evaluated from our proposed model. This paper may be helpful for the future researchers for finding emission of $CO_2$ and other GHGs for the remaining states in India.

## INTRODUCTION

Global warming has reached at an alarming stage throughout the world. As a result we see the abrupt change of climate and weather. It is not a local issue now, it is a global phenomenon and the scientists along with the environmentalists are seriously worried about the evil effects of the unnatural change of weather. Polar ice sheets and glaciers are melting very fast resulting the rise of sea level (Khan, Z. A. (2017)). All on a sudden we often observe very extra weather events like tsunami, typhoons, droughts, heat wave etc. (Khan, A. A. (2018)).

This unnatural and unpredictable diversity of weather are caused due to indiscriminate human activities. Uncontrolled use of pesticides in agricultural field, unplanned set up of industry, indiscriminate deforestation, abuses of natural resources generates huge amount of Green House Gases (GHG) which gives result the high rise of temperature of the Earth known as Global Warming (Basak, P. and Nandi, S. (2015)). Among the GHG, carbon dioxide ($CO_2$) is mainly responsible for the high rise of temperature of the Earth (Battle, M., et al. (2010), Ghoshal, T. and Bhattacharyya, R. (2008)). In augmentation of $CO_2$ concentration in atmosphere, India is one of the leading countries in the world. Since India is a developing country, so there occur industrials set up in a rapid and unplanned way. Moreover, there are vast agricultural lands in India and as a result emissions of GHGs are occurring for burning of fossil fuels and land use changes and other industrial processes (Murthy, N. S., Panda, M. and Parikh, J. (1997a), Murthy, N. S., Panda, M. and Parikh, J. (1997b)). Due to degradation of $O_3$ layer, the heat wave radiates back down to the Earth which gives rise of temperature (Dewitte, S. and Clerbaux, N. (2018)). Moreover, burning of fossil fuels and emission from transport vehicles along with the rapid industrialization releases $CO_2$ and other GHGs that increases the temperature of atmosphere and it is being able to absorb more radiation and would warm up rapidly (Khansis, A. A. and Nettleman, M. D. (2005), Rufael, Y. W. (2010)). The main harmful gas which is responsible for global warming is $CO_2$ and that is why emission of $CO_2$ is the burning problem throughout the country. Few states of India are badly affected mainly for agricultural, industrial and population growth and increase emission of transportation. While some states are comparatively less emitter and less affected. Hence, it is important to study about the nature of emission of $CO_2$ in different states in India (Kram, T., et al.(2000)). Several research works has done about $CO_2$ emission (Basak, P. and Nandi, S. (2014), Ghoshal, T. and Bhattacharyya, R. (2008), Mondal, K., Basak, P. and Sinha, S. (2019a). in India. Also the emission is studied for different states of India (Mondal, K., Basak, P. and Sinha, S. (2019b)). In this article, the pattern of emission in the states of Gujarat, Maharashtra and Madhya Pradesh are studied and we would like develop a mathematical model to find the trend of $CO_2$ emission.

## METHODOLOGY

### Method of Least Square

The data of $CO_2$ emission for the 21 years (1980-2000) is utilized for the purpose of modeling. We formulated a third degree polynomial model for the analysis of $CO_2$ emission in the states of Gujarat, Maharashtra and Madhya Pradesh (Jin, R., et al.(2010)). For generating the model of $CO_2$ emission, we followed the works of (Basak, P. and Nandi, S. (2014), Tokos, C. P. and Xu, Y. (2009). Authors suggested a third degree polynomial model for emission of $CO_2$. For example:

$$Y = \alpha + \beta x + \gamma x^2 + \delta x^3 \quad \ldots\ldots (1)$$

Where Y is emission of carbon dioxide in '000 Metric ton of carbon and x represents time in years.

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

$$v(\alpha, \beta, \gamma, \delta, \mu) = \sum_{i=1}^{n} (y_i - \alpha - \beta x_i - \gamma x_i^2 - \delta x_i^3)^2 \quad \ldots\ldots (2)$$

is a function of five variables $\alpha$, $\beta$, $\gamma$ and $\delta$ For minimizing the error and to estimate corresponding $\alpha, \beta$, $\gamma$ and $\delta$ multivariate calculus is used to have,

$$\frac{\partial v}{\partial \alpha} = 0, \ \frac{\partial v}{\partial \beta} = 0, \ \frac{\partial v}{\partial \gamma} = 0, \ \frac{\partial v}{\partial \delta} = 0,$$

Now corresponding normal equations are:

$$\sum y_i = n\alpha + \beta \sum x_i + \gamma \sum x_i^2 + \delta \sum x_i^3$$

$$\sum y_i x_i = \alpha \sum x_i + \beta \sum x_i^2 + \gamma \sum x_i^3 + \delta \sum x_i^4$$

$$\sum x_i^2 y_i = \alpha \sum x_i^2 + \beta \sum x_i^3 + \gamma \sum x_i^4 + \delta \sum x_i^5$$

$$\sum x_i^3 y_i = \alpha \sum x_i^3 + \beta \sum x_i^4 + \gamma \sum x_i^5 + \delta \sum x_i^6 \quad \ldots\ldots\ldots (3)$$

For given set of points ($x_i$, $y_i$); (i=1, 2,…,n), the equations can be solved for $\alpha$, $\beta$, $\gamma$ and $\delta$ to find estimated $\alpha^\#, \beta^\#, \gamma^\# and\ \delta^\#$ It has been found that in all the cases, the value of the 2nd order derivatives evolves to be positive at the points $\alpha$, $\beta$, $\gamma$ and $\delta$. These satisfy the minimization criteria of $v$.

The third degree fitted polynomial of $CO_2$ emission is now estimated as,

$$Y = \alpha^\# + \beta^\# x + \gamma^\# x^2 + \delta^\# x^3 \quad \ldots\ldots\ldots (4)$$

### Instantaneous Rate of Change of emission

Instantaneous Rate of Change (IROC) is a useful parameter that may be utilized to predict future emission of gas. For the computation of rate of change of the gas, the derivative of equation (4) is presented as,

$$\frac{dY}{dx} = \beta^\# + \gamma^\# x + \delta^\# x^2 \quad \ldots\ldots\ldots (5)$$

The equation (5) at a particular time is utilized for prediction of $CO_2$.

### Quality of estimates

Equation (4) may be used for obtaining the estimation of the $CO_2$ emission for short and medium terms of time in a state. It remains to examine the goodness of fit for this estimation. The matter depends on the quality of the developed analytical models using the raw data. The quality of the proposed analytical models is verified with the statistical criteria, namely the coefficient of determination, adjusted coefficient of determination and residual analysis.

### Coefficient of determination

The coefficient of determination ($R^2$) is defined as the proportion of the total response variation that is explained by the model. It provides an overall measure of how well the model fits. The general definition of $R^2$ is defined as,

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

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

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.

### Adjusted Coefficient of Determination

The Adjusted Coefficient of Determination (Adj $R^2$) is defined as,

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

Where, p is the total number of regressors in the model (not counting the constant term) and n is the sample size. It is, however, another advanced measure how good the model fit the actual data.

**RESULTS / FINDINGS**

**Gujarat**

Using least square method, the $CO_2$ emission model for the state of Gujarat can be represent as,

$$Y(x) = -2.40393 \times 10^9 + 3.5957 \times 10^6 x - 1792.92x^2 + 0.298029x^3$$

Where, x represents time in year.

A graphical display of the observed data and estimated data for Gujarat is given in the Figure 1**.**

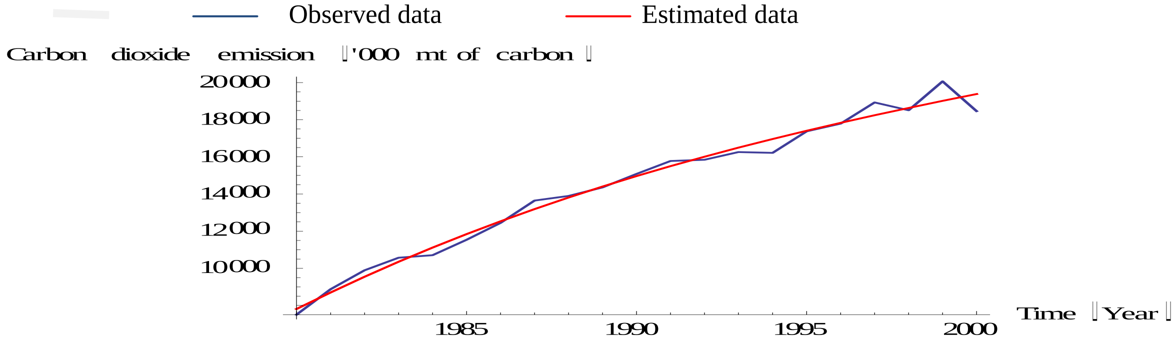


**Figure 1:** Emission of $CO_2$ in Gujarat.

From Figure 1, we can find out that $CO_2$ emission model for the state of Gujarat matches well with the actual status of $CO_2$ emission excepting a few years in the last lap. The model equation may be considered for obtaining the emission of $CO_2$ in Gujarat for short or medium term of time. It is necessary to measure the goodness of fit of the proposed model which can be obtained through the following analysis (Nandi, S. and Basak, P. (2014), Gokran, S. and Parikh, J. (1993)).

The values of $R^2$ (Adj $R^2$) are obtained and presented as:

**Table 1:** Statistical evaluation criteria for Gujarat

| R square | Adjusted R square | FVU (Frac. Var. Unexplained) |
|---|---|---|
| 0.9845 | 0.9818 | 0.0154 |
| $SS_{tot}$ | $SS_{reg}$ | $SS_{err}$ |
| 257047595 | 253072270 | 3975324 |

A residual analysis is calculated of the proposed model of emission of $CO_2$ for the state of Gujarat is given as:

**Table 2:** Residual Analysis of $CO_2$ of Gujarat state

| Year | Observed data ('000 MT of Carbon) | Estimated data ('000 MT of Carbon) | Residual | Standard Deviation of residual | Mean of residual | Standard Error of residual |
|---|---|---|---|---|---|---|
| 1980 | 7501.63 | 7809.68 | -308.054 | 445.832 | 0.0000055 | 97.2885 |
| 1981 | 8875.51 | 8699.37 | 176.136 | | | |
| 1982 | 9894.43 | 9545.59 | 348.836 | | | |
| 1983 | 10570.49 | 10350.1 | 220.36 | | | |
| 1984 | 10705.5 | 11114.8 | -409.272 | | | |
| 1985 | 11536.44 | 11841.3 | -304.868 | | | |
| 1986 | 12442.96 | 12531.5 | -88.5646 | | | |
| 1987 | 13644.8 | 13187.2 | 457.588 | | | |
| 1988 | 13893.88 | 13810.2 | 83.7234 | | | |
| 1989 | 14355.4 | 14402.1 | -46.7477 | | | |
| 1990 | 15081.9 | 14965 | 116.927 | | | |
| 1991 | 15776.39 | 15500.4 | 275.969 | | | |
| 1992 | 15840.44 | 16010.3 | -169.84 | | | |
| 1993 | 16255.28 | 16496.3 | -241.058 | | | |
| 1994 | 16214.27 | 16960.4 | -746.113 | | | |
| 1995 | 17375.52 | 17404.2 | -28.6828 | | | |
| 1996 | 17786.82 | 17829.6 | -42.7662 | | | |
| 1997 | 18932.99 | 18238.3 | 694.669 | | | |
| 1998 | 18511.16 | 18632.2 | -121.036 | | | |

| | | | |
|---|---|---|---|
| 1999 | 20066.85 | 19013 | 1053.85 |
| 2000 | 18461.46 | 19382.5 | -921.058 |

According to the Table 2, the residuals are very small compared to data and the so is standard error. The results of Table 2 suggest a good quality of model in Gujarat.

**Prediction of emission in Gujarat State**

IROC of $CO_2$ emission for the state of Gujarat can be represent by the differential equation

$$\frac{dY}{dx}(Gujarat) = 3.5957 \times 10^6 - 3585.84x + 0.894087x^2 \qquad ................ (6)$$

The graphical visualization of the IROC is presented in Figure 2.

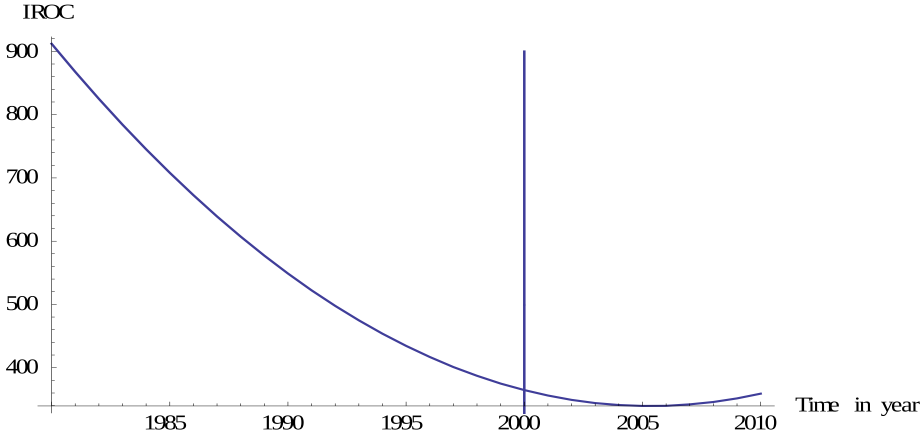


**Figure 2:** IROC of Gujarat

Equation (6) or the graph may be utilized to estimate the rate of change of $CO_2$ emission in Gujarat, for short or long term of time We get total $CO_2$ emission in Gujarat in 2005, 2009 and 2012 are 21123.4, 22495.5 and 23587.5 ('000 Mt of carbon) respectively.

**Maharashtra**

The $CO_2$ emission model for the state of Maharashtra can be represented as,

$$Y(x) = 3.59853 \times 10^{10} - 5.42562 \times 10^7 x + 27267.2x^2 - 4.56767x^3$$

The observed data and model data can be represented graphically as below,

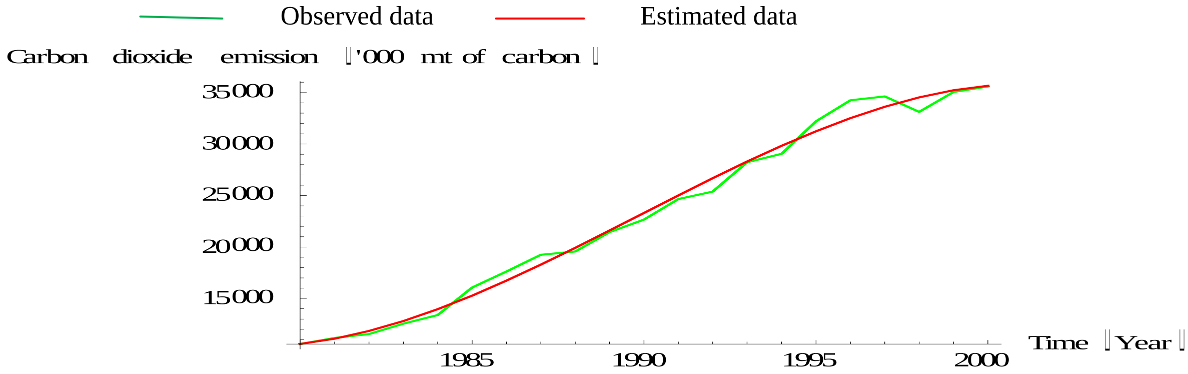


**Figure 3:** Emission of $CO_2$ in Maharashtra

According to the Figure 3, observed status of $CO_2$ emission and the data evaluated by the model matches almost perfectly. The statistical evaluation is given below in Table 3. For verifying the goodness of fit of the model $SS_{tot}$, $SS_{reg}$, $SS_{err}$ and $R^2$ (Adj $R^2$) calculated. The value of R square is 0.99178 which is quite satisfactory and ensures that 99% of the total variation is extracted by the model.

**Table 3:** Statistical evaluation criteria for Maharashtra

| R square | R square adjusted | FVU (Frac.Var. Unexplaned) |
|---|---|---|
| 0.9917 | 0.9903 | 0.0082 |
| $SS_{tot}$ | $SS_{reg}$ | $SS_{err}$ |
| 1557968449 | 1545161988 | 12806459 |

Residual analysis is computed and the result is presented in the following Table 4. It is observed that residuals and standard errors of the residuals are considerably small compared to observed emission.

**Table 4:** Residual Analysis of $CO_2$ emission in Maharashtra

| Year | Observed data ('000 MT of carbon) | Estimated data ('000 MT of Carbon) | Residual | Standard Deviation of residual | Mean of residual | Standard Error of residual |
|---|---|---|---|---|---|---|
| 1980 | 10564.23 | 10575.7 | -11.441 | | | |
| 1981 | 11166.82 | 11084.2 | 82.5841 | | | |
| 1982 | 11534.16 | 11835.7 | -301.582 | | | |
| 1983 | 12544.69 | 12802.8 | -258.093 | | | |
| 1984 | 13382.98 | 13958 | -574.973 | | | |
| 1985 | 16059.59 | 15273.8 | 785.744 | | | |
| 1986 | 17613.07 | 16723.1 | 890.014 | | | |
| 1987 | 19243.15 | 18278.2 | 964.973 | | | |
| 1988 | 19564.25 | 19911.8 | -347.553 | | | |
| 1989 | 21449.69 | 21596.5 | -146.837 | | | |
| 1990 | 22660.12 | 23304.9 | -644.825 | 800.202 | 0.00 | 174.618 |
| 1991 | 24651.46 | 25009.6 | -358.189 | | | |
| 1992 | 25387.39 | 26683.2 | -1295.84 | | | |
| 1993 | 28229.36 | 28298.3 | -68.9329 | | | |
| 1994 | 29056.75 | 29827.4 | -770.671 | | | |
| 1995 | 32216.88 | 31243.2 | 973.668 | | | |
| 1996 | 34255.33 | 32518.3 | 1737.07 | | | |
| 1997 | 34626.23 | 33625.2 | 1001.07 | | | |
| 1998 | 33120.79 | 34536.5 | -1415.71 | | | |
| 1999 | 35051.86 | 35224.9 | -173.019 | | | |
| 2000 | 35595.43 | 35662.9 | -67.4623 | | | |

The result of statistical criteria and Residual analysis suggest that proposed model may be used as future prediction of emissions of $CO_2$ for the state of Maharashtra.

**Prediction of emission in Maharashtra State**

The IROC of $CO_2$ emission for the states of Maharashtra can be represent by the differential equation,

$$\frac{dY}{dx}(Maharashtra) = -5.42562 \times 10^7 + 54534.3x - 13.703x^2 \quad \text{.................. (7)}$$

The graphical display of expression (7) is given by,

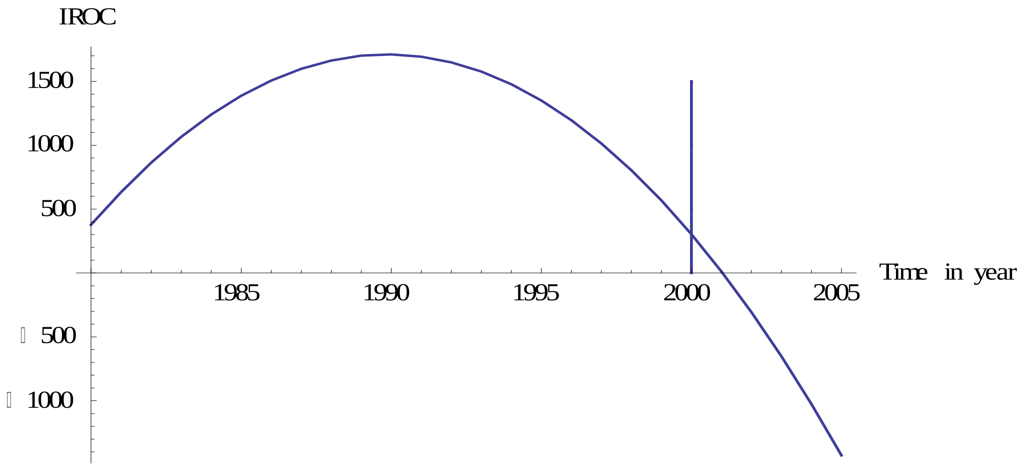


**Figure 4:** IROC of Maharashtra

Equation (7) or Fig. 4 may be utilized to estimate the rate of change of $CO_2$ emission in Maharashtra for short or long term of time. Total $CO_2$ emission in the state in 2005, 2009 and 2012 are 33138.2, 23816.5 and 11414.6 ('000 Mt of carbon) respectively. IROC shows rapid rate of decrease towards the end of the data.

**Madhya Pradesh**

The model for the $CO_2$ emission of Madhya Pradesh can be represent as,

$$Y(x) = 3.91803 \times 10^{11} - 5.91014 \times 10^{7}x + 29716.2x^{2} - 4.98026x^{3}$$

A graphical display of the actual data and model data for Madhya Pradesh is given by Figure 5.

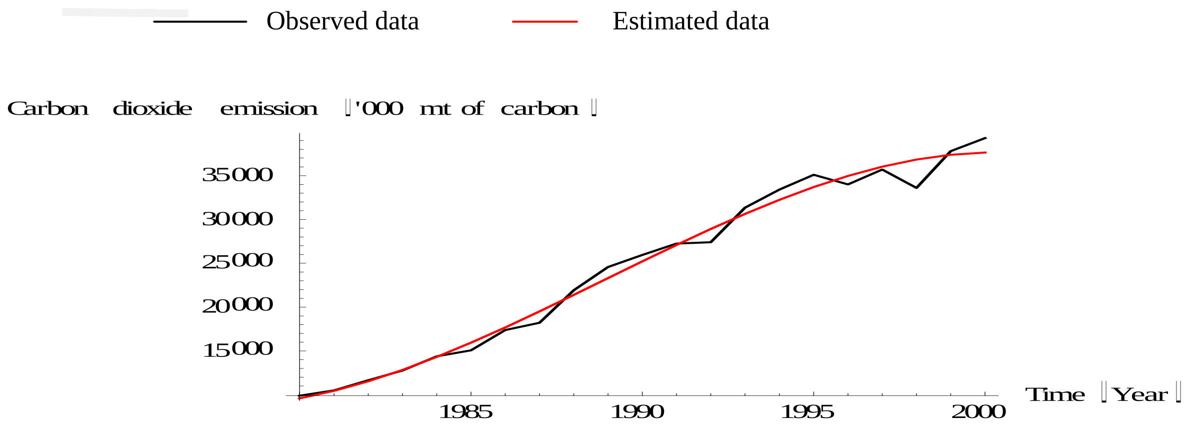


**Figure 5:** Emission of $CO_2$ in Madhya Pradesh

Above model may be used to get estimation of $CO_2$ emission for the state of Madhya Pradesh for short or medium terms of time. The R square and R square (adjusted) are also computed and the result indicates that a good model have been identified. The statistical criteria are displaced in Table 5.

**Table 5:** Statistical evaluation criteria of Madhya Pradesh

| **R Square** | **R square adjusted** | **FVU (Frac. Var. Unexplained)** |
|---|---|---|
| 0.9868 | 0.9845 | 0.0131 |
| $SS_{tot}$ | $SS_{reg}$ | $SS_{err}$ |
| 1949980722 | 1924359560 | 25621161 |

Finally, the residual analysis is computed on the proposed model of $CO_2$ emission for the state of Madhya Pradesh. From the Table 6 it is clear that the residuals and standard error of residuals are too small compared to the data. It endorses that a good model is identified.

**Table 6:** Residual Analysis of $CO_2$ emission in Madhya Pradesh

| **Year** | **Observed data ('000 MT of Carbon)** | **Empirical data ('000 MT of carbon)** | **Residual** | **Standard Deviation of residual** | **Mean of Residual** | **Standard Error of residual** |
|---|---|---|---|---|---|---|
| 1980 | 9890.58 | 9593.81 | 296.77 | 1131.84 | 0.00476 | 246.988 |
| 1981 | 10501.97 | 10448.2 | 53.77 | | | |
| 1982 | 11656.09 | 11539.5 | 116.59 | | | |
| 1983 | 12753.7 | 12837.8 | -84.10 | | | |
| 1984 | 14390.89 | 14313.3 | 77.59 | | | |
| 1985 | 15065.49 | 15936.1 | -870.61 | | | |
| 1986 | 17388.37 | 17676.2 | -287.83 | | | |
| 1987 | 18206.35 | 19503.9 | -1297.55 | | | |
| 1988 | 21916.93 | 21389.2 | 527.73 | | | |
| 1989 | 24574.08 | 23302.2 | 1271.88 | | | |
| 1990 | 25945.04 | 25213 | 732.04 | | | |
| 1991 | 27238.76 | 27091.9 | 146.86 | | | |
| 1992 | 27406.21 | 28908.8 | -1502.59 | | | |
| 1993 | 31345.35 | 30634 | 711.35 | | | |
| 1994 | 33412.05 | 32237.5 | 1174.55 | | | |
| 1995 | 35096.14 | 33689.5 | 1406.64 | | | |
| 1996 | 33988.91 | 34960 | -971.09 | | | |
| 1997 | 35698.32 | 36019.2 | -320.88 | | | |
| 1998 | 33601.08 | 36837.2 | -3236.12 | | | |
| 1999 | 37790.15 | 37384.2 | 405.95 | | | |
| 2000 | 39279.35 | 37630.2 | 1649.15 | | | |

**Prediction of emission in Madhya Pradesh State**

The IROC of $CO_2$ emission for the state of Madhya Pradesh can be represent by the differential equation,

$$\frac{dY}{dx}(Madhya\ Pradesh) = -5.91014 \times 10^7 + 59432.3x - 14.9408x^2 \quad \text{.............. (8)}$$

The expression (8) can expressed visually as ,

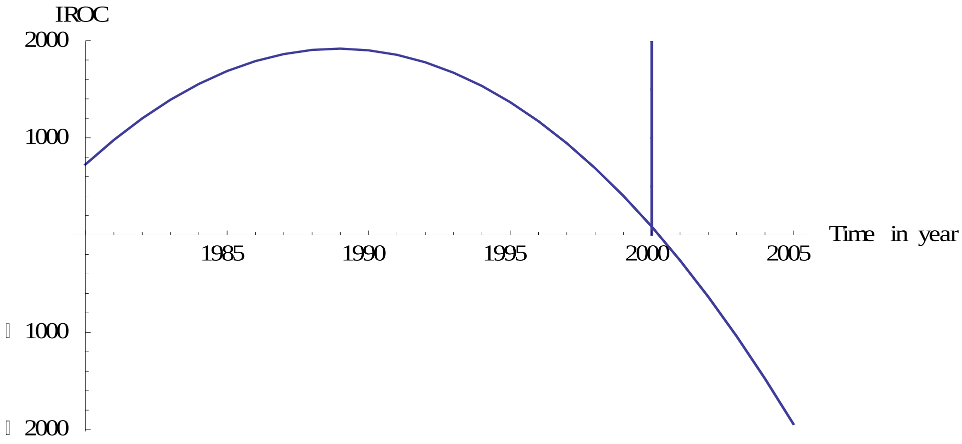


**Figure 6:** IROC of Madhya Pradesh

## ANALYSIS

Considering the proposed model, the future emission of $CO_2$ is evaluated and shows a rapid decreasing rate of change at the end of the curve and total $CO_2$ estimated emission in Madhya Pradesh in 2005, 2009 and 2012 are 33299.9, 21370.6 and 6230.66 ('000 Mt of carbon) respectively.

## CONCLUSION

Regarding the prediction, for Gujarat state IROC graph is strictly decreasing, whereas for the states of Maharashtra and Madhya Pradesh it is increasing up to the year of 1990 and then it gradually decreases. Increasing trend of IROC indicates that uncontrolled emission of $CO_2$ from different sources. Certainly, it indicates that in Gujarat, the uncontrolled emission still persists and is somewhat controlled as a whole in the states of Madhya Pradesh and Maharashtra. In this article, a third degree polynomial has been developed as a $CO_2$ emission model utilizing the observed data of the emission of $CO_2$ of about 21 years and using the method of least square that characterize well the emission pattern for the states of Gujarat, Maharashtra and Madhya Pradesh. Besides, computing total emission of the gas for the subjected states, some statistical procedure applied to clarify the goodness of fit of the proposed model namely, coefficient of determination $R^2$, $R^2$ (Adjusted) and residual analysis. The numerical value of the statistical procedure reflects the fact that we have chosen a good model. The value of $R^2$ for the states Gujarat and Madhya Pradesh is 0.9845 and 0.9868 respectively where that is for Maharashtra is 0.9903. These numerical values indicate that proposed model is fitted fairly well. Future prediction of emission of $CO_2$ may be evaluated from our proposed model. This paper may be helpful for the future researchers for finding emission of $CO_2$ and other GHGs for the remaining states in India.

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## AUTHORS CONTRIBUTION

The authors confirm contribution to the manuscript as follows: study conception and design: Kartick Mondal, data analysis: Umashankar Singh; analysis and interpretation of results: Om Prakash Dubey and Anmol Kumar Lal, draft manuscript preparation: Om Prakash Dubey.

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