

Long Term Carbon Dioxide (CO₂) Emissions over India

Dharmendra Singh¹, Md. Abdul Kader² and Jogobandhu Some²

¹ Department of Science and Technology, Haryana Space Applications Centre, CCS HAU Campus, Hisar, Haryana, India

² Bangladesh Space Research and Remote Sensing Organization (SPARRSO), Agargaon, Dhaka, Bangladesh

Abstract

Carbon Dioxide (CO₂) emission is a key issue for climate change mitigation for whole world and an up-to-date statistics regarding this is required for making effective policies. Current study is a step towards this requirement. Gridded data from EDGAR with spatial resolution of 0.1X0.1 degree spanning from 1970 to 2012 have been used for the assessment of CO₂ scenario over India and contribution of individual administrative units of India in CO₂ emissions. Satellite based data from MODIS are used to see the pattern of biomass burning hotspot and emission amplitude. Total emission during this time period has been found 31521576579 t with minimum 1.91 and maximum 8434972.26 t/yr/grid cell. Average composite of CO₂ emission showed the value ranging from 1.91 to 203774.4 t/yr with high emission in the Gangetic plain, Brahmaputra plain and eastern cost of India. Similar observations have been observed for minimum and maximum composite. Most of the part of India have showed minimum emissions values ranging from 1.91 to 73267.2 (t/yr) and maximum emission values ranging from 43502.4 to 203774.4 (t/yr). However, most of the values of Standard Deviation (SD) are ranging from 1.91 to 16714.08 (t/yr) with maximum SD in the Punjab, Haryana and West Bengal region. The states falling in the Ganges, Satluj and Brahmaputra rivers (Punjab, Haryana, Uttar Pradesh, Bihar, West Bengal and Assam) basin have showed maximum contribution in CO₂ emission. Interestingly the coastal states like Pondicherry and Goa have showed very high contribution in emissions despite the less coverage of total geographical area. The trends of emission indicate maximum rate of increase on decadal scale in the state of Himachal Pradesh, Madhya Pradesh, Nagaland, Rajasthan and Sikkim with more than 20%. The rate of increase in CO₂ emission is found high during 1980-1990 to 1990-2000 for all the states except for Karnataka and Maharashtra. In recent decade the rates of emission have decreased significantly for all the states except for Nagaland and Sikkim which shows the urgent need of implementing required practices of CO₂ emission reduction in these two states. Recent reduction in the rates of CO₂ emission may be due to the efforts of Indian Government for implementing afforestation and emission less energy Policies in India.

Key words: CO₂, Biofuels emission, India, Emission rates, Decadal Emission

1. Introduction

- CO₂ is a major greenhouse gas essentially required for life existence on earth [1]. It maintains the earth environment warm which makes the earth as a suitable habitat for all the living organisms. However, after industrialization in response to the demand of rapidly growing population, the atmospheric CO₂ concentration has increased drastically which creates excessive heat in the atmosphere and results into climate change vulnerability, extreme hot summers, glaciers melting, biodiversity loss, wildfires, species shifting, invasions, changes in streamflow and crop productivity, changes in earths energy budget, and sea-level rise, along with other associated risks [1-7]. The chances of these risks are high for the case of countries like India, Nepal, Sri Lanka etc. as it is reported that most of the CO₂ emissions will be generated by developing countries in near future despite the current major contribution of developed countries [3,8].
- CO₂ emission has increased by 35% with reference to its concentration of pre-industrial time and projected to be increased in near future [1,2]. This is mainly increasing due to anthropogenic activities like enhanced power consumption, tread openness, rapid urbanization, biofuels and fossil burning, deforestation and land use changes [3,9]. As per the report of NRC (2011), 1000 gigatonnes (Gt) increase in carbon emissions from anthropogenic origin leads to an increase in global average temperature by 1.75°C. Till the year 2010, approximately 500 Gt carbon of anthropogenic origin have been estimated which have immense potential of global warming with increase in atmospheric temperature [10]. Further, 5-15% reduced crop yields, 200-400% increased burnt area due to wildfire, 5-10% less streamflow per degree of temperature change have been reported by [2]. CO₂ induced warming of approximately 1°F have potential to increase the heavy rain by 3.9% and light rain by 1% [11]. There are several other associated issues needs to be understood for better management of CO₂ emissions. Starting from causes of anthropogenic emissions like population density, rapid urbanization, industrialization, forest degradation and deforestation and biomass/biofuels burning, several researchers have reported various causes of CO₂ emissions and its interrelationship, the most savior cause, extent of emissions and its severity over different regions of the earth [9,12-18]. Trends

of CO₂ emissions have also been studied by various organizations and researchers individually at regional and global scale [19-21].

- India is facing serious issue of CO₂ emission as it is the third largest CO₂ emitter in the world with a total of 5.98% contribution in global CO₂ emission and second largest populated country of world, constituting 17.57% population till the year 2013 and projected to be at first place by the year 2024 (UNDP, 2013; 9; Nejat *et al.* 2015; 22,23). Thus studies related to trends on CO₂ emissions over India have been carried out time to time using data from different sources. Sarkar *et al.* estimated 2.81% increase in CO₂ emission during 1991 to 2014 [20]. Al-mulali and Che Sab studied the impact of energy consumption and CO₂ emission on gross development product (GDP) in the top 10 coal consumptive countries including India and found short-run positive bidirectional causal relationship between total energy consumption and CO₂ emission [21]. Garg *et al.* studied the CO₂ emission trends over India at sectoral and district level during 1990 to 2013 and identified hotspots of Carbon emissions in India [19]. They reported a total of 5% compound annual growth rate in CO₂ emission during this period. Nejat *et al.* (2015) reported reduction in CO₂ emissions over residential sector of top 10 major CO₂ emitting and developed countries (except US and Japan, which showed a 4% rise) however, 84% increase in the emission of India during the year 1990 to 2011 have been reported. Despite the measures of emission reduction like REDD, REDD+, Kyoto protocol (1997), the Paris Agreement (2015) among others the concentration of CO₂ is still increasing and needs to be assessed in respect to scenario, cause and remedies which will be beneficial for policy makers [9]. Contributions of individual units of administration in CO₂ emission needs to be known for the identification of hotspots, assessment of effectiveness of activities implemented for cutting the emissions and to make further policies and prioritization of units to be scrutinize more. The work done earlier by Garg *et al.* at district level have provided the trends of CO₂ emissions and its change during the year 1990 to 2011 which is only statistics of twenty years and have ample opportunity to be studies again with a long time data series for better statistics and country and state level [19]. Thus the current study have been done using grid based CO₂ emission data over India for (a) The assessment of basic statistics of CO₂ emissions over India using a 43 years of time series data, (b) Estimation of contributions of different states of India in total CO₂ emission and (c) decadal change in the rate of change of CO₂ emissions (d) comparison of emissions from satellite data.

2. Materials and Methodology

2.1 Study Area

India, known in the world for its enormous diversity of both biotic and abiotic-environment. It is the second-largest country in the world by population and seventh-largest country by area. With an area of 3.52 million ha. it is situated in the center of the South-Asia and surrounded by Sea/Ocean from three side: Bay of Bengal in the eastern side; Arabian Sea in the western side and Indus Ocean in the southern side. It is bounded between the latitude of 7.965°N to 35.494°N and longitude of 68.176°E to 97.402°E [25]. It has a long coastline (~7500 km) with two group of Island besides mainland viz. The Andaman and Nicobar group of Island in the Bay of Bengal and Lakshadweep in the Arabian Sea (Figure 1). It has varied topography and forest extensions, with high mountains of Himalaya, Aravalli and Western Ghats, extensive plateaus of Rewa and Panna, gigantic riverine plains of Ganges and Brahmaputra and gregarious patches of forests of central part, Western Ghats, north eastern states and hill of Himalayas. Rainfall varies between 0 to 2622 mm and temperature between -2.3°C to 50°C (IMD).

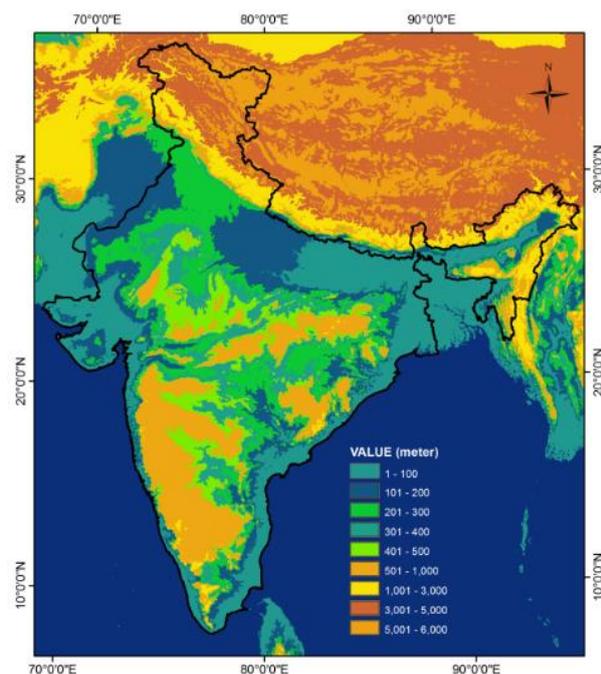


Figure 1: Study area bounded within black boundary showing elevation gradient

2.2 Data Used

Data related to CO₂ emissions were originally developed by European Commission, Joint Research Centre (EC-JRC) and Netherlands Environmental Assessment Agency (PBL). The data is provided in the form of Emissions Database for Global Atmospheric Research (EDGAR, v4.3.2) with both in .txt file and .nc file format and named as short cycle CO₂ emission (CO₂ emission from biomass/biofuels burning from here after). The data is having yearly temporal resolution with a spatial resolution of 0.1 × 0.1 degree where the CO₂ emission is filled in the unit “substance/m² /s” [26]. However for .txt format the unit is represented as “substance / 0.1degree x 0.1degree / year”.

2.3 Data processing

Year data on CO₂ emission were downloaded from <http://edgar.jrc.ec.europa.eu/overview.php?v=432> for 43 years i.e. from 1970 to 2012 in .nc file format for whole globe. Indian administrative region were then taken to analyze the statics of CO₂ emissions over India as a whole at the first stage and at state level in the second stage during the year 1970 to 2012. The extraction process was done in ENVI 4.4 software environment. Related parameters to open .nc file format in the software were taken from metadata provided in the readme file of downloaded emission data. Since the data was in hidden decimal form with total emission value of 1.00476e+012kg/year and original grid values was in the unit of kg/m²/s a factor of 2289600000000.00 was applied to convert all the individual grid cells substance values into the unit of t/yr/gridcell.

2.4 Statistical Analysis

Final statistics such a Average, Minimum (min), Maximum (max) and Standard Deviation (SD) for whole India was calculated by extracting individual statistics for each grid followed by kriging interpolation with a mask boundary of India. For state level statistics only average were calculated using grids of 0.1°×0.1° falling in each state. This was further allocated to individual states to make spatial map representing contribution of each state in CO₂ emissions. Fire hotspots from MODIS data (downloaded from <https://firms.modaps.eosdis.nasa.gov/map/#z:6;c:69.1,26.7;d:2019-12-15..2019-12-16> for the period of 2003 to 2018), generated in ArcGIS environment were compared at the last to validate the site specific emission amplitude and its relationship with biomass burning.

2.5 Decadal Change in the Rate of CO₂ Emissions

Ten years of average CO₂ emission i.e. from 1970 to 1980, 1980 to 1990, 1990 to 2000 and 2000 to 2010 was calculated for each state separately. After that the decadal changes of CO₂ emissions were estimated by subtracting average value of ending decade by the average value of initial decade. The changes obtained by subtracting the average value of CO₂ emission for the years between 1981 to 1990 and 1970 to 1980 is considered as changes of CO₂ emission for the first decade. Similarly, a difference for the CO₂ values between the years 2000 to 1990 and 1980 to 1990 is considered as the change in CO₂ emission for the second decade and difference of values between the years 2010 to 2000 and 1990 to 2000 is considered as change in the CO₂ emission for the third decade. The year 2011 and 2012 were left during the analysis of decadal emission changes. State-wise changes in the rate of CO₂ emission were than estimated using the formula:

$$\text{Rate of CO}_2 \text{ emission} = \frac{\text{CO}_2 \text{ emission for ending decade} - \text{CO}_2 \text{ emission for initial decade}}{\text{CO}_2 \text{ emission for initial decade}}$$

3. Results and Discussion

3.1 Total CO₂ Emission over India due to Biomass Burning

Analysis showed that the total CO₂ emission during last 43 years i.e. from 1970 to 2012 is ranging from 1.91 to 8471520 t/yr. The emissions were highest in the river plain areas of India (Figure 2). This may be due to intense agriculture produce and highest population density in these regions. In case of semi-arid regions of Punjab and Haryana the total CO₂ emission was higher for Punjab and ranging from 4350240 to 8471520 t/yr. Similar case has been observed for the coastal and southern part of West Bengal. It was also observed that the agriculture intense region with river delta and plain contributes highest in the CO₂ emission. This is obvious, because these parts are also having high population density due to availability of water and food. Northern, Western and North eastern part of India contributes less in CO₂ emission while Gangetic plain and eastern part of India contributes more.

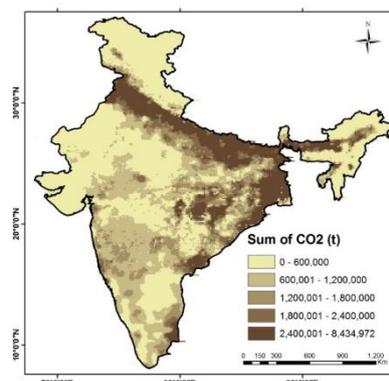


Figure 2: Total CO₂ Emission during 1970 to 2012 over India

It was also observed that the area with high vegetation cover contributes less in CO₂ emission. This is due to absorption of emitted CO₂ by the plants for the purpose of food and less population density in high elevation zones where most of the Indian forests resides. The findings are supporting earlier studies done to assess the impact of population density and urbanization on CO₂ emissions [3,9,27,28].

3.3 CO₂ Emission Statics over India

CO₂ emission over India was found to be varying from 0.00229 to 204058 t/yr. Average CO₂ was high in the Ganges plain and in West Bengal region along with Brahmaputra flood plain. The values were varying from 16943 to 114480 t/yr in these areas (Figure 3). However, Deccan plateau region along with eastern part of Western Ghat were having moderate emissions ranging from 16943 to 44213 t/yr. Rest other part were having low emission ranging from 0.00229 to 16714 t/yr. Minimum values of emission were ranging from 0.00229 to 142122 t/yr (Figure 4). It was observed that the Gangetic plain is constantly contributing with high CO₂ emission values ranging from 16943 to 73267 t/yr while the Deccan plateau region along with eastern part of Western Ghat were showing moderate minimum emissions ranging from 16943 to 41213 t/yr.

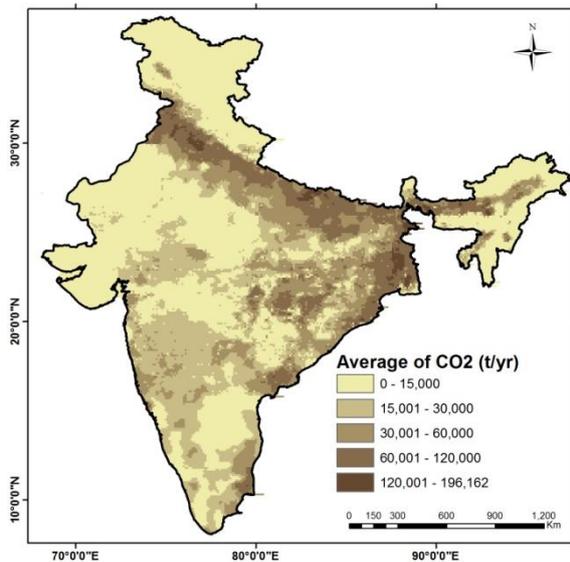


Figure 3: Average CO₂ Emitted during 1970 to 2012

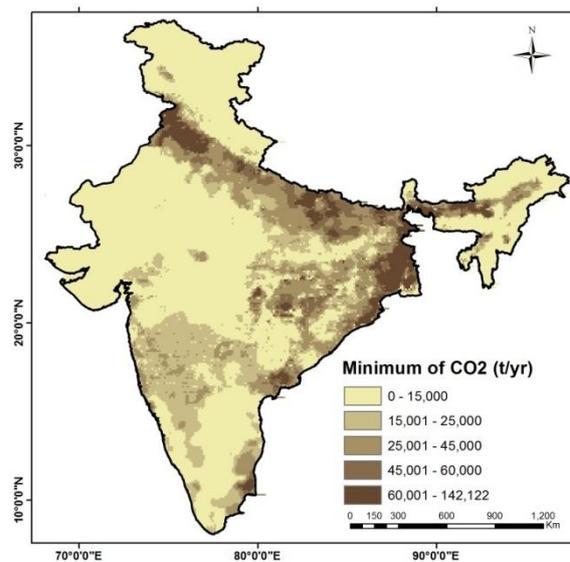


Figure 4: Minimum CO₂ Emitted during 1970 to 2012

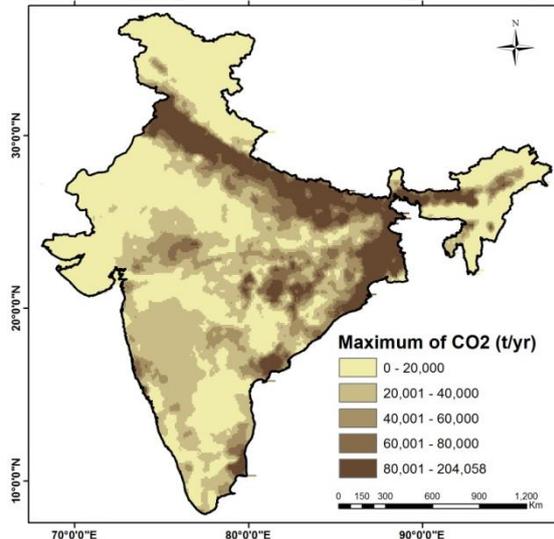


Figure 5: Maximum CO₂ Emitted during 1970 to 2012

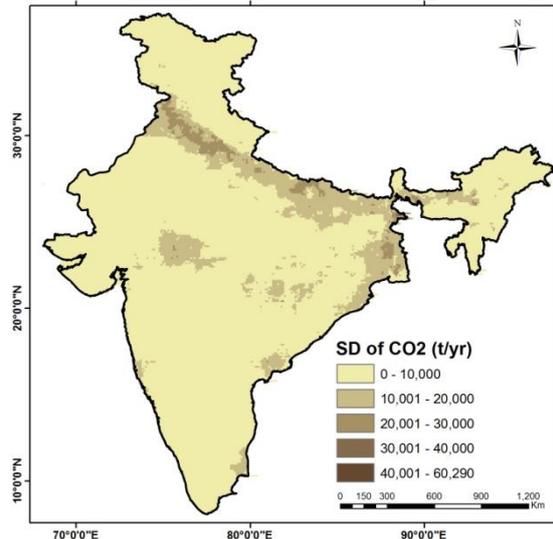


Figure 6: Standard Deviation (SD) CO₂ Emitted during 1970 to 2012

Most of the Indian region have showed maximum of CO₂ emission ranging from 16943 to 203774 t/yr (Figure 5). The vales of maximum emission during last forty-three years were distributed along the Gangetic plain, Semi-Arid region, Central Highland, Deccan plateau region and in the eastern part of Western Ghat. Part of semiarid region of Punjab and Haryana and Gangetic plain contributed maximum in the CO₂ emission as per the maximum composite values of the CO₂ in this study. The Standard Deviation (SD) values were in the range of 0.00229 to 16714 t/yr in all regions over India except, in the Semi-Arid regions of Punjab and Haryana and some part of Gangetic plain where the values of SD were varying from 16943 to 41212 t/yr (Figure 6). The

statistical parameters showed that the area with high intensity of cropping practices are contributing more in overall CO₂ emissions over India. This obvious, because in high intensity cropping areas the rice and wheat are grown extensively and farmers used to burn the stubble of wheat and rice before planting new crop. These regions are also dependent on biomass based cooking and thus high emissions of CO₂ have been observed.

3.4 Contribution of Indian States in CO₂ Emission

Over a long time period of 43 years the mean emission of CO₂ due to burning was found to be high in two major river plains of India i.e. Ganga and Brahmaputra (Figure 7). The States-wise contributions of CO₂ emission in terms of mean value were varying between 2227.78 to 88874.72 t/yr. The contribution of CO₂ emission were very low and ranging between 222.78 to 9788.27 t/yr for the states of Gujarat, Rajasthan, Chandigarh, Himachal Pradesh, Jammun and Kashmir, Sikkim, Arunachal Pradesh, Meghalaya, Mizoram, Manipur and Nagaland. The CO₂ emission for Uttarakhand (Uttaranchal earlier), Madhya Pradesh and Kerala were ranging between 9788.50 to 17140.17 t/yr and these states are seem to be contributing low in CO₂ emission in India (Figure 7). Tripura, Maharashtra, Karnataka and Andhra Pradesh have showed low to moderate contribution in the CO₂ emission during last 43 years over India with mean values ranging between 17140.40 to 22925.08 t/yr. Jharkhand, Orissa, Chhattisgarh and Tamil Nadu have showed high CO₂ emission contribution with mean values ranging between 22925.31 to 41870.37 t/yr. States of Ganges and Brahmaputra plain namely Punjab, Haryana, Uttar Pradesh, Bihar, West Bengal, Assam along with small states like Goa and Pondicherry showed very high emission with mean CO₂ ranging between 41870.60 to 88874.72 t/yr (Figure 7). The states with high to very high emission values are facing risk of health and respiratory diseases and there is strong need of management of biomass burning in these regions through the sustainable use of stubble and shift of biomass based cooking to biogas and LPG based cooking.

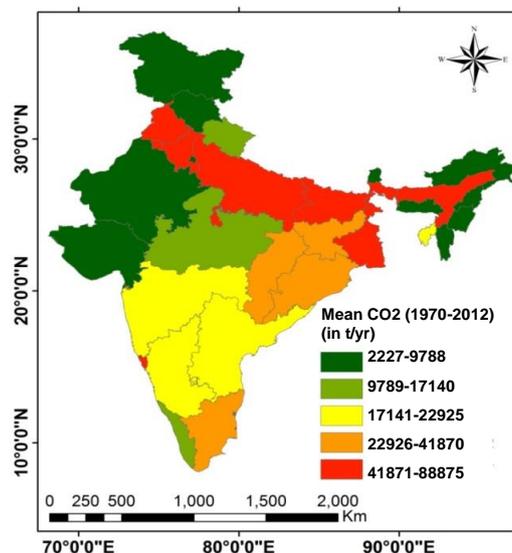


Figure 7: Contribution of Indian States in CO₂ Emission

3.5 Trend of CO₂ Emission over Indian States Since 1970 to 2012

Over all Changes in CO₂ Emission during 1970 to 2012

Trend analysis of CO₂ emission have been done using a raster based plot with year on x-axis and states on y-axis. Increasing trend of CO₂ emission is observed for all the states with highest CO₂ emission in West Bengal (73238.35 t/yr) and lowest in Nagaland (1821.61 t/yr). States like Jammu & Kashmir, Arunachal Pradesh, Chandigarh, Nagaland and Mizoram have shown less increase in emission during 1970 to 2012 (Figure 8). At the same time Punjab, Haryana, Bihar, Uttar Pradesh, West Bengal, Goa and Pondicherry have showed drastic increase in the CO₂ emission. The emissions of CO₂ for Punjab, Haryana and West Bengal were 63189.98 t/yr, 39799.66 t/yr, 73238.35 t/yr respectively, in early seventies which have increased to 117149.4 t/yr, 69905.15 t/yr and 121344.9 t/yr in the year 2012. This shows almost a twice increase in the CO₂ emission for the Punjab and Wes Bengal and 75% increase for Haryana. Interestingly Pondicherry, which had 50211.61 t/yr CO₂ emission during 1970 have showed less increase in CO₂ emission (about 67%) during last 43 years (83905.6 t/yr CO₂ emission in the year 2012) as compared to the other two states, which had high CO₂ emission in the year 1970. Assam, Jharkhand, Orissa Chhattisgarh and Dadra & Nagar Haveli have showed moderate increase in emission (Figure 8). CO₂ emissions for Punjab and West Bengal are very high and representing immediate requirement of emission management by implementing emission less policies and energy uses.

3.6 Decadal Changes in CO₂ Emission over Indian States

Change in CO₂ concentration was estimated on decadal scale. The maximum change was observed during 1980-1990 to 1990-2000 for all the states. During the decade 1970-1980 to 1980-1990 the change in CO₂ emission was highest in the state of Punjab and lowest in the state of Nagaland. The CO₂ emission in the second decade of the study period i.e. 1980-1990 to 1990-2000 was again highest in the state of Punjab (16880.99 t/yr) and lowest in the state of Nagaland (433.42 t/yr). In the third decade the change in CO₂ emission was again maximum in Punjab (8160.36 t/yr) and minimum in Maharashtra (210.87 t/yr). This shows that the change in emission was moderate during first decade for Punjab highest during second decade and lowest during last decade of the study period. This reduction in the CO₂ emission during last decades may be attributed to the implementation of biomass burning free policies like LPG utilization, electric heaters, management of stubble for biogas and other energy products. Overall increase in CO₂ emission was found in all the states with minimum increase for Arunachal Pradesh and Maximum increase for Punjab.

Alarming rate of increase in CO₂ emission as obtained from decadal change analysis showed that states like Punjab, Haryana, West Bengal, Bihar, Uttar Pradesh and Pondicherry are contributing most in the total CO₂ emission from India (Figure 8a). Thus more strong emission management policies are required for these states. However, current data on CO₂ emission may also be studied for more clear decision on type of policy effective in CO₂ emission management. Details of changes in CO₂ for each state of India during last 40 years are represented in table 1. Decadal change in CO₂ emission was consistently increasing in the states of Jammu & Kashmir, Himachal Pradesh, Nagaland, Sikkim and Rajasthan. An overall increasing trend in CO₂ emissions has been since 1970 to 2012 (Figure 8b). The CO₂ has increased from 22000 t/yr to 38000 t/yr during this time period over Indian land mass.

3.7 Rate of Decadal Changes of CO₂ Emission over Indian States

Rate of changes in CO₂ emission on decadal basis showed highest rate for emission increase in Madhya Pradesh for first and second decades and in Rajasthan in the third decade of the study period (Figure 9)). The rate of changes in emission was consistently high during the period of second decades i.e. i.e. 1980-1990 to 1990-2000 for all the states except Nagaland and Sikkim. The rates of CO₂ emission was consistently decreasing in all the decades for Karnataka and Maharashtra due to some unknown reason which needs to be studied in further research. Decrease in the CO₂ emission during last decade of the study period may be attributed to the effectiveness of Indian Government policies implemented time to time for emission management.

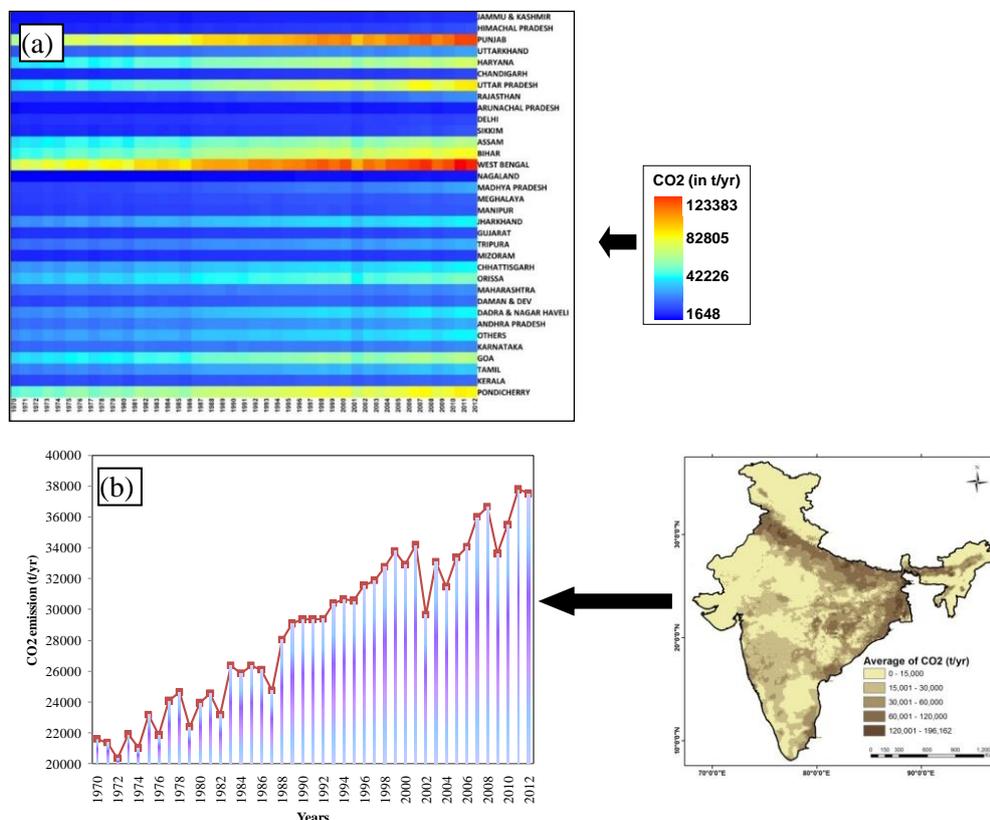


Figure 8: Variation in annual CO₂ emission for (a) Indian States and (b) average increase over India since 1970 to 2012

Table 1: Decadal Change in CO₂ Emission (t/yr)

States	1970-1980 to 1980-1990	1980-1990 to 1990-2000	1990-2000 to 2000-2010	Overall Increase
ANDHRA PRADESH	2641.97	3470.12	1504.27	9890.84
ARUNACHAL PRADESH	392.67	511.73	273.38	1566.32
ASSAM	6273.28	8391.61	3274.81	22350.85
BIHAR	7947.20	11012.52	5971.28	32662.98
CHANDIGARH	1019.56	1542.50	1040.17	4960.88
CHHATTISGARH	4043.20	5480.39	2220.91	14705.87
DADRA & NAGAR HAVELI	3994.44	6357.30	2383.93	15974.08
DAMAN	1758.64	2677.69	949.04	6752.26
DELHI	1121.45	1260.88	529.58	3862.33
GOA	6252.44	9130.47	3634.51	23951.28
GUJARAT	947.89	1371.01	1104.73	5114.97
HARYANA	7203.08	9665.55	4517.38	27715.38
HIMACHAL PRADESH	1037.19	1716.51	1921.89	7135.77
JAMMU & KASHMIR	654.83	889.05	995.06	3705.49
JHARKHAND	3952.99	5408.72	2492.92	15174.78
KARNATAKA	1644.16	1393.45	591.86	5433.22
KERALA	1292.02	1996.30	1109.31	5829.09
MADHYA PRADESH	2610.14	5426.35	4194.55	17691.51
MAHARASHTRA	1760.24	1327.74	210.87	5082.68
MANIPUR	1395.05	1888.46	907.14	5285.08
MEGHALAYA	1484.12	2039.58	1079.32	5978.15
MIZORAM	920.65	1279.89	609.49	3619.63
NAGALAND	252.77	433.42	611.55	1998.36
ORISSA	5124.12	6974.35	2858.34	18775.41
PONDICHERRY	8063.06	11943.47	4521.27	30771.54
PUNJAB	12648.90	16880.99	8160.36	48232.48
RAJASTHAN	1688.12	3532.62	4266.67	14984.06
SIKKIM	892.03	1579.37	2001.11	7031.36
TAMIL NADU	3131.71	4388.93	1721.32	11781.37
TRIPURA	2949.69	3941.78	1640.04	10608.86
UTTAR PRADESH	8692.70	15147.31	7282.99	40501.42
UTTARANCHAL PRADESH	2658.00	4311.55	2086.74	11770.60
WEST BENGAL	12174.03	16325.08	6779.51	44071.59

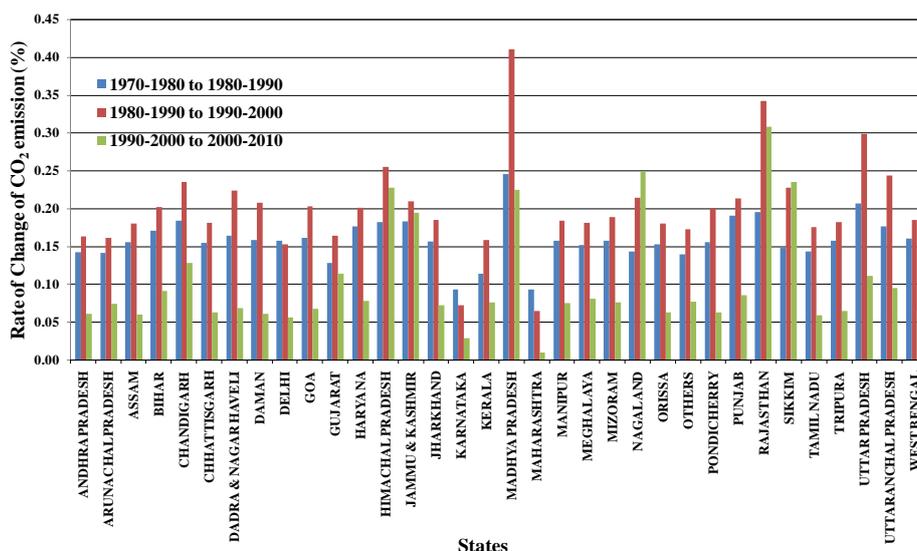


Figure 9: Rate of CO₂ emission on decadal basis for Indian States during 1970 to 2010

3.8 Comparison of CO₂ emission with biomass burning hotspot

MODIS based hotspot (developed using data from the year 2003 to 2018) analysis showed matching pattern of emission and biomass burnt both from agriculture and forest sector (Figure 10).

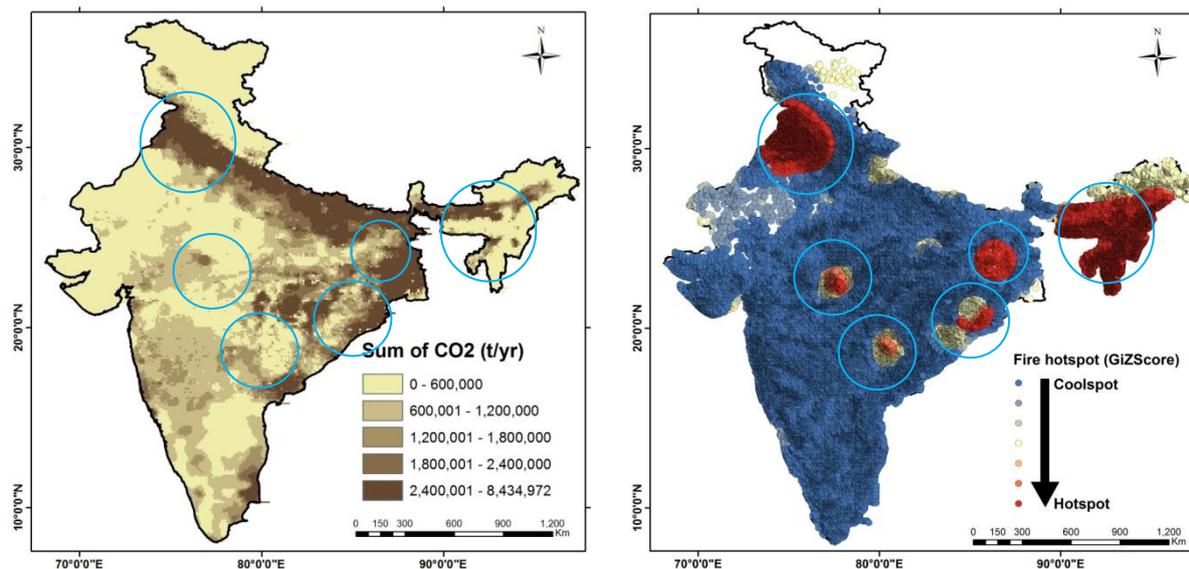


Figure 10: Comparison of EDGAR CO₂ emission pattern and satellite (MODIS) based fire hotspot

However, emissions from northeastern states are missing. The EDGAR data may have not considered the forest fire which is done for shifting cultivation in Northeastern states of India and thus interpreted less emission from this reason and a reanalysis is required to improve the emission estimates. Emission from central Indian part may be overestimated in EDGAR database as the burning hotspot are missing from this region and there is high CO₂ emission in EDGAR database. The Northwest region including Punjab and Haryana were identified as fire hotspots from MODIS data and similar results have been observed in terms of high emission in this region, however estimate need to be reanalyzed as it showed missing emission [29]. Hotspots identified in this study are similar as identified in earlier study by Vadrevu et al. [30].

4. Conclusions

Current study exploited the long-term data of CO₂ emissions (43 years, since 1970 to 2012) for assessing the individual contribution of different states of India in emission of CO₂. Statistics obtained in this study may be considered as baseline information for CO₂ related emissions in India at spatial scale such type of data is sparse especially at state level to solve the query regarding percentage of contribution of individual states in total emission of India. Further the individual states such as Goa, Pondicherry, Punjab, Haryana and West Bengal have been identified as major contributor in CO₂ emissions, though covering less area of the country. Information's obtained in this study may be used to make necessary actions and policies for the management of emissions of CO₂ in these areas which may further be used for the prioritization of states as per say for management of CO₂ emissions. The decadal changes shows that the rate of CO₂ emission was high in the second decade of the study period i.e., from 1980-1990 to 1990-2000 after that the rate of emissions have come down due to the implementation of effective management policies, technology applications, change of biomass burning based cooking system to LPG based cooking system and increase in the forest area. The study may further be extended for next decade i.e. from 2000-2010 to 2010-2020 with the provision of data availability for more clear explanation of the current findings. Alarming rate of increase in CO₂ emission for the states like Himachal Pradesh, Jammu and Kashmir, Nagaland, Sikkim, Madhya Pradesh and Rajasthan for the third decade of the study period shows an urgent need of emission management with immediate effect. The emission hotspots are matching with CO₂ emissions pattern.

References

- [1] IPCC, 2007. Climate Change, Synthesis report. Geneva, Switzerland.
- [2] National Research Council (NRC), 2011. Climate stabilization targets: emissions, concentrations, and impacts over decades to millennia. National Academies Press.
- [3] Li, K., Lin, B., 2015. Impacts of urbanization and industrialization on energy Consumption /CO₂ emissions: Does the level of development matter? *Renewable and Sustainable Energy Reviews*, 52(2015)1107–1122.
- [4] Donner, S.D., 2009. Coping with the commitment: projected thermal stress on coral reefs under different future scenarios. *PLoS ONE* 4:e5712.

- [5] Mora, C. and Sale, P.F., 2011. Ongoing global biodiversity loss and the need to move beyond protected areas: a review of the technical and practical shortcomings of protected areas on land and sea. *Marine ecology progress series*, 434, pp.251-266.
- [6] Teshager, A.D., Gassman, P.W., Schoof, J.T., Secchi, S., 2016. Assessment of impacts of agricultural and climate change scenarios on watershed water quantity and quality, and crop production. *Hydrology and Earth System Sciences*, 20(8), pp.3325-3342.
- [7] Dhanya, P., Thomas, R., 2018. Impact of climate change on stream flow. In *Emerging Trends in Engineering, Science and Technology for Society, Energy and Environment: Proceedings of the International Conference in Emerging Trends in Engineering, Science and Technology (ICETEST 2018)*, January 18-20, 2018, Thrissur, Kerala, India (p. 95). CRC Press.
- [8] Jung, T.Y., Rovere, E.L.L., Gaj, H., Shukla, P.R., Zhou, D., 2000. Structural changes in developing countries and their implication for energy-related CO₂ emissions. *Technol Forecast Soc Change* 2000;63: 111–36.
- [9] Ohlan, R., 2015. The impact of population density, energy consumption, economic growth and trade openness on CO₂ emissions in India. *Natural Hazards*, 79(2), pp.1409-1428.
- [10] IPCC, 2018. Summary for Policymakers. In: *Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Waterfield (eds.)]. World Meteorological Organization, Geneva, Switzerland, 32 pp.
- [11] Web2: <https://www.accuweather.com/en/weather-blogs/climatechange/how-rising-co2-concentrations/11855333> accessed on 10/01/2019.
- [12] Li, J., Song, H., Geng, D., 2008. Causality relationship between coal consumption and GDP: difference of major OECD and non-OECD countries. *Appl Energy* 85:421–429.
- [13] Ghosh, S., 2010. Examining carbon emissions economic growth nexus for India: a multivariate cointegration approach. *Energy Policy* 38(6):3008–3014.
- [14] Govindaraju, C.V.G.R., Tang, C.F., 2013. The dynamic links between CO₂ emissions, economic growth and coal consumption in China and India. *Applied Energy*, 104:310–318.
- [15] Tiwari, A.K., Shahbaz, M., Hye, Q.M.A., 2013. The environmental Kuznets curve and the role of coal consumption in India: cointegration and causality analysis in an open economy. *Renew Sustain Energy Rev* 18:519–527.
- [16] Duro, J.A., Teixidó-Figueras, J., Padilla, E., 2016. Empirics of the international inequality in CO₂ emissions intensity: explanatory factors according to complementary decomposition methodologies. *Environ. Resour. Econ.* 63, 57–77.
- [17] Chen, J., Cheng, S., Song, M., 2017. Decomposing inequality in energy-related CO₂ emissions by source and source increment: the roles of production and residential consumption. *Energy Policy* 107, 698–710.
- [18] Wang, H., Zhou, P., 2018. Assessing Global CO₂ Emission Inequality From Consumption Perspective: An Index Decomposition Analysis. *Ecological Economics*, 154, pp.257-271.
- [19] Garg, A., Shukla, P.R., Kankal, B., Mahapatra, D., 2017. CO₂ emission in India: trends and management at sectoral, sub-regional and plant levels. *Carbon Management*, 8(2), pp.111-123.
- [20] Sarkar, M.S.K., Begum, R.A., Sadeka, S., Pereira, J.J., 2018. Current trends and policies of energy consumption and CO₂ emission from the largest Asian economies. *International Journal of Global Warming*, 14(4), pp.417-439.
- [21] Al-mulali, U. Che Sab, C.N.B., 2018. The impact of coal consumption and CO₂ emission on economic growth. *Energy Sources, Part B: Economics, Planning, and Policy*, 13(4), pp.218-223.
- [22] Nejat P, Jomehzadeh F, Taheri M M, Gohari M and Muhd M Z 2015 A global review of energy consumption, CO₂ emissions and policy in the residential sector (with an overview of the top ten CO₂ emitting countries) *Renew. Sustain. Energy Rev.* 43 843–62
- [23] WDI, 2015. World development indicators 2015. World Bank, Washington, DC.
- [24] WDI, 2017. World development indicators 2015. World Bank, Washington, DC.

- [25] Web1: <https://gist.github.com/graydon/11198540>. accessed on 04/01/20195
- [26] Janssens-Maenhout, G., Crippa, M., Guizzardi, D., Muntean, M., Schaaf, E., Dentener, F., Bergamaschi, P., Pagliari, V., Olivier, J.G.J., Peters, J. A.H.W., van Aardenne, J. A., Monni, S., Doering, U., Petrescu, A.M.R., 2017. Global Atlas of the three major Greenhouse Gas Emissions for the period 1970-2012, Earth System Science Data, *essd-2017-79*.
- [27] Wang, S., Huang, S., Huang, P., 2018. Can spatial planning really mitigate carbon dioxide emissions in urban areas?: A case study in Taipei, Taiwan. *Landscape and Urban Planning*, 169, 22-36. <https://doi.org/10.1016/j.landurbplan.2017.08.001>.
- [28] Tamura, S., Iwamoto, S., Tanaka, T., 2018. The impact of spatial population distribution patterns on CO₂ emissions and infrastructure costs in a small Japanese town. *Sustainable Cities and Society*, 40, 513–523.
- [29] Liu, T., Marlier, M.E., Karambelas, A., Jain, M., Singh, S., Singh, M.K., Gautam, R., De Fries, R.S., 2019. Missing emissions from post-monsoon agricultural fires in northwestern India: regional limitations of MODIS burned area and active fire products. *Environ. Research Communications*, 1(1), 011007.
- [30] Vadrevu, K.P., Csiszar, I., Ellicott, E., Giglio, L., Badarinath, K. V. S., Vermote, E., Justice, C., 2012. Hotspot analysis of vegetation fires and intensity in the Indian region. *IEEE Journal of selected topics in applied Earth Observations and Remote Sensing*, 6(1), 224-238.