AATCC Review

24 April 2024: Received
30 May 2024: Revised
26 June 2024: Accepted
16 August 2024: Available Online

https://aatcc.peerjournals.net/

Review Article

Open Access

Agriculture development and its Impact: A Comprehensive Time series analysis of Climate Variables

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ABSTRACT

Climate change poses significant challenges that necessitate the development of policies to manage aggregate input and social costs. To formulate such policies, an analysis of the factors and their current trends must be conducted. This study explores the factors influencing climate change and provides insights into their impacts through changes in arable land and greenhouse gas (GHG) emissions in India from 1990 to 2020. Utilizing time series analysis, this study examined trends in GHG emissions from agriculture and developed a simulation model to estimate overall GHG emissions through methane and nitrous oxide emissions. The results indicate that enteric fermentation and agricultural soil are major contributors to methane and nitrous oxide emissions, respectively, with enteric fermentation contributing approximately 69.33% and agricultural soil contributing approximately 97.66% to methane and nitrous oxide emissions, respectively. Additionally, a higher growth rate was observed for nitrous oxide emissions than for methane emissions, with nitrous oxide emissions showing a 161% increase from 1960 to 2010. Furthermore, a positive correlation (r=0.587) between GHG emissions and changes in the annual mean temperature underscores the direct impact of agricultural emissions on climate dynamics in India, with a regression coefficient factor of 0.176. It is estimated that the overall GHG emissions from agriculture through methane and nitrous oxide emissions will be approximately 695.87 to 818.73 MMTCDE in the year 2030, while the change in annual mean temperature is estimated to be approximately 1.65 ± 0.58o C from 1990 to 2030 in India. This study faces challenges such as uncertainties in long-term climate projections and emission estimates, variability in regional agricultural practices, and the need for more granular data. These findings highlight the urgent need for effective mitigation strategies within the agricultural sector to address the growing threat of climate change.

Keywords: *Greenhouse gases (GHGs), methane, nitrous oxide, emission, temperature, climate change.*

Introduction

Agriculture, which accounts for approximately 42.86% of India's workforce (World Bank, 2022), contributes significantly to the country's economy, with its Gross Value Added (GVA) at current prices reaching about 18.3% in FY-23, and total food grain production reaching approximately 3296.87 lakh tonnes[c]. Not only does agriculture ensure self-sufficiency in feeding the population, but it also boosts exports. India has witnessed substantial growth in agricultural exports, with fruit and vegetable exports increasing by 18.94%, oilseed exports by 32.83%, oil meal exports by 34.24%, and rice exports by 5.38% in July 2023 compared to July 2022, underscoring the success of agricultural production in the country.

However, despite this growth, the sustainability of this trajectory would be questioned if social cost were to be accounted for. The exponential increase in production has led to a significant rise in Greenhouse Gas (GHG) emissions, primarily methane, nitrous oxide, and carbon dioxide [14], emanating from the agriculture sector in India.

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DOI: https://doi.org/10.21276/AATCCReview.2024.12.03.99

Previous studies have shown that enteric fermentation by livestock and rice cultivation are major contributors to GHG emissions [17]. Similarly, recent assessments of GHG emissions from crop cultivation over the past 50 years in India indicated a 161% increase from 1960 to 2010[18].

Studies by Vetter *et al.* have highlighted the changing Indian diet and its implications for GHG emissions from food production, with rice cultivation and ruminant products being significant contributors[20]. Additionally, the burning of agricultural residue and savannas has seen a 75% increase in GHG emissions since 2011 across India [7]. Nitrogen fertilizers, a key component of agricultural practices, have been found to contribute significantly to GHG emissions, with a considerable portion being lost to the environment[6][9].

The surge in GHG emissions has led to observable climate change, with estimates suggesting a rise in Earth's temperature by 1.8-4.0°C by the end of the century [1]. Predictions also indicate an annual temperature increase of 0.7 to 1.0°C by 2040 compared to the 1980s, resulting in more frequent extreme weather events such as floods, droughts, and glacier melting [2] [13].

This paper aimed to analyze the trend and time-series data of GHG emissions in India in relation to changes in arable land. It also seeks to identify the factors driving the surge in nitrous oxide (N_2O) and methane (CH_4) emissions from agriculture, two major GHGs.

Furthermore, a model was developed to understand the relationship between the overall GHG production and nitrous oxide (N_2O) & methane (CH_4) emissions from agricultural and allied activities in India. Finally, it correlates and estimates a model for annual mean temperature changes in India with GHG emissions over the past 28 years (1990-2018). It is noteworthy that this study does not consider the parameters of carbon dioxide emissions (CO_2) from agricultural activities because of its overall negative contribution to the total GHG emissions from agriculture.

Methodology

Greenhouse gases emitted per capita in Turkey were estimated to be about 7.2 to 8.0 tons in 2030 based on emissions from various sectors [16]. This study used both linear and logarithmic models to estimate the findings. Drawing from the references derived from the log-linear regression model was developed[10], and expressed as:

$$Y = \exp\left(C + \sum_i w_i f_i(X)\right)$$

Where $f_i(X)$ represents quantities that are potential functions of variable X, and is generally a vector of values, while C and w_i refer to the model parameters; Subsequently, a model for greenhouse gas (GHG) emissions from agriculture in India was developed. The study involves the analysis of secondary time-series data extracted from the Organization for Economic Cooperation and Development (OECD) for the years between 1990 and 2020 [b] [5], focusing on the Agri-Environment and other relevant indicators. The model transformed the data into logarithmic form and a linear regression model was fitted to derive a model for estimate total greenhouse gas emissions through agriculture *($TGHG_{Agri}$)*. The model is represented as follows:

$$\log(TGHG_{Agri}) = 0.294_{(\pm 0.13)} + 0.757_{(\pm 0.02995)} \log(TCH4_{Agri}) + 0.233_{(\pm 0.00791)} \log(TN20_{Agri})$$

Where $TCH4_{Agri}$ represents total methane emissions from agriculture, and $Tn20_{Agri}$ represents total nitrous oxide emissions from agriculture. To further analyze the climate variables, a second model was estimated using the same process to examine the relationship between annual mean temperature ($Mean_{Avg}$) and $TGHG_{Agri}$. The secondary data for this model were extracted from the time-series data catalog accessed from the National Data Sharing and Accessibility Policy (NDSAP) for the years 1990 to 2018[a]. The model is described as follow:

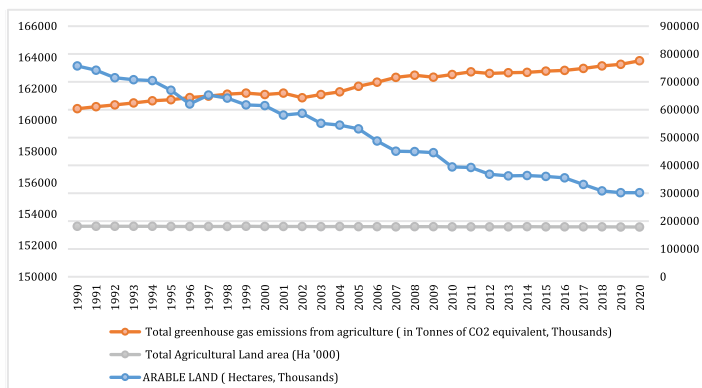
$$\log(Mean_{Avg}) = 0.366_{(\pm 0.2799)} + 0.176_{(\pm 0.0480)} \log(TGHG_{Agri})$$

Both models were estimated with a confidence interval of 95% for accuracy

Results & Discussion

1) GHG emission and arable land in India

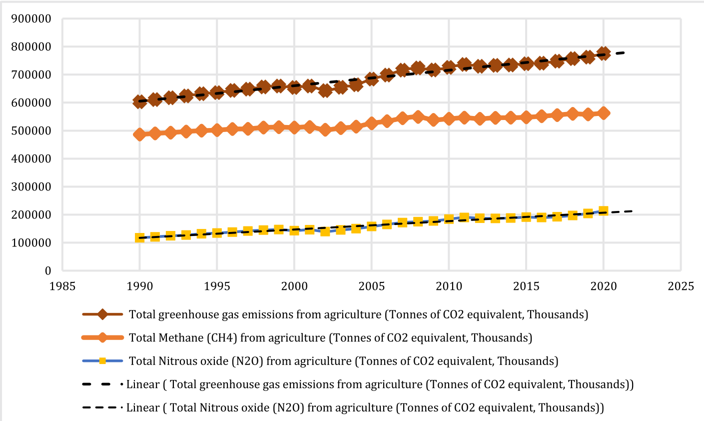
Graph 1 further illustrates this relationship further, displaying a negative trend line for arable land and a positive trend line for GHG emissions. Additionally, Table 1 shows a strong negative correlation (r = -0.986) between the total arable land and overall GHG emissions. This indicates a significant decline in total arable land and an increase in GHG emissions from agriculture between 1990 and 2020[5][11]. The reduction in arable land can be attributed to various factors, including increased livestock production (as estimated by increased enteric fermentation), excessive fertilizer usage, rice cultivation, and burning of agricultural residues. It is important to note that the definition of arable land includes areas used for temporary crops, meadows, market or kitchen gardens, and temporary fallow land, excluding areas abandoned due to shifting cultivation.



Graph . Trend line between Total GHGs emission, Total agricultural land & ARABLE LAND from 1990-2020.

		ARABLE LAND	Total greenhouse gas emissions from agriculture	Total Agricultural Land area
ARABLE LAND	Pearson's r	—		
	p-value	—		
Total greenhouse gas emissions from agriculture	Pearson's r	-0.986	—	
	p-value	< .001	—	
Total Agricultural Land area	Pearson's r	0.979	-0.965	—
	p-value	< .001	< .001	—

From Table 1.1, a model was developed to analyze the contributions of methane and nitrous oxide to the total GHG emissions ($TGHG_{Agri}$). The model indicated that methane emissions ($TCH4_{Agri}$) had a higher coefficient of estimation (β1 = 0.757) than nitrous oxide (β2 = 0.233), suggesting a greater contribution of methane to the total GHG output



However, Graph 1.1 revealed that the total emission through methane was much greater, while the trend line for nitrous oxide exhibited a steeper slope than methane emission ($\Delta N_2O/N_2O > \Delta CH_4/CH_4$), indicating a higher rate of nitrous oxide emission growth between 1990 and 2020. This increase in nitrous oxide emissions can be attributed to excessive fertilizer and chemical usage in agricultural soil, leading to increased microbial activities, such as denitrification, ammonification, and other losses, such as volatilization [21].

Graph 1.1. Trend lines of Total GHG emission, Total Methane (CH4) emission & Total Nitrous oxide (N2O) emission in India.

Table 1.1. Model Coefficients - TGHG $_{Agri}$ – Transform

Model Coefficients - TGHG_Agri - Transform 2				
Predictor	**Estimate**	**SE**	**t**	**P**
Intercept	0.294	0.13089	2.25	0.034
TCH4_Agri - Transform 3 (**β1**)	0.757	0.02995	25.28	< .001
TN2O_Agri - Transform 3 (2) (**β2**)	0.233	0.00791	29.45	< .001

The analysis further identified the specific sources contributing to methane and nitrous oxide emissions. Graph 1.2 illustrated an upward trend in methane emissions from the field burning of agricultural residue [8][12] and enteric fermentation [19], while emissions from rice cultivation and manure management remained relatively constant.

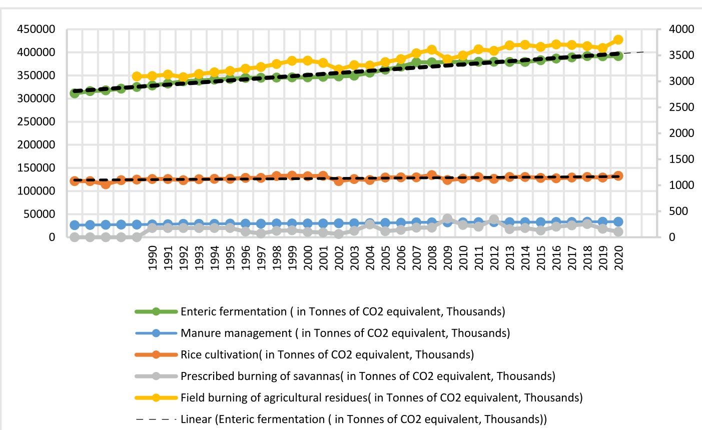
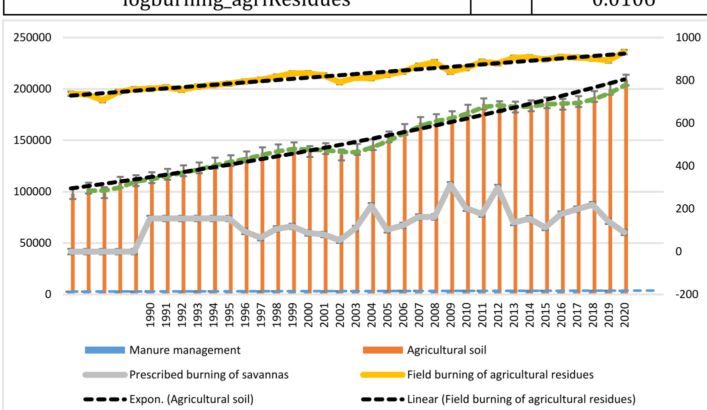


Table 1.2 provided model coefficients indicating that enteric fermentation had the highest contribution to methane emissions (*logEnteric_ferment*=0.6933), followed by rice cultivation (*logRice_- cult*=0.2441) and burning of agricultural residue (*logburning_agriResidues*=0.0106). These findings corroborated with previous studies indicating a shift in dietary habits towards increased consumption of animal-based products in India [20].

Graph 1.2. Total Methane emission from different sources of agriculture in India (1990-2020)

Table 1.2. Model Coefficients for logCH4

Predictor	**Estimate**	**SE**	**t**	**p**
Intercept	0.3549	0.01694	20.96	< .001
logEnteric_ferment	0.6933	0.01020	67.96	< .001
logManure_mgt	0.0503	0.01097	4.59	< .001
logRice_cult	0.2441	0.00272	89.87	< .001
logburning_savannas	4.75e-4	1.24e-4	3.83	< .001
logburning_agriResidues	0.0106	0.00310	3.42	0.002



Graph 1.3 depicts the total nitrous oxide emissions from various sources in Indian agriculture between 1990 and 2020. It was an upward trend in emissions from agricultural soil and field burning of agricultural residue, with a significant increase observed over the period [8][12].

Graph 1.3. Total Nitrous oxide emission from different sources from agriculture in India (1990-2020)

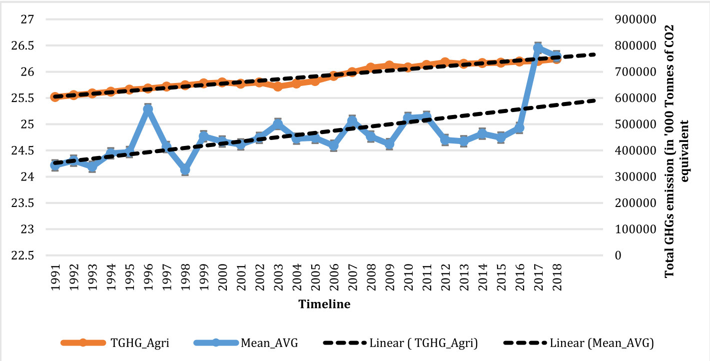
The model coefficients from Table 1.3 confirmed that agricultural soil had the highest contribution to nitrous oxide emissions (*logAgri_soil*=0.97657), followed by manure management[4] (*logManure_mgt*=0.01476).

Table 1.3. Model Coefficients - logN2O

			95% Confidence Interval						95% Confidence Interval
Predictor	**Estimate**	**SE**	**Lower**	**Upper**	**t**	**p**	**Stand. Estimate**	**Lower**	**Upper**
Intercept	0.07476	0.00395	0.06664	0.08289	18.916	< .001			
logManure_mgt	0.01476	0.00187	0.01091	0.01861	7.885	< .001	0.00585	0.00433	0.00738
logAgri_soil	0.97657	0.00105	0.97441	0.97873	927.899	< .001	0.99305	0.99085	0.99525
logburning_savannas	9.02e-4	7.43e-5	7.49e-4	0.00105	12.131	< .001	0.00209	0.00174	0.00244
logburning_agriResidues	0.00168	0.00180	-0.00203	0.00538	0.930	0.361	6.06e-4	-7.34e−4	0.00194
Overall, the results highlight the impact of increased fertilizer usage in agricultural soil on GHG emissions, particularly nitrous oxide, by providing more substrate to microbes and contributing to processes, such as ammonification and denitrification [21]. Additionally, unwanted nitrogen losses through volatilization also play a significant role in GHG emissions from agricultural soil [9].									

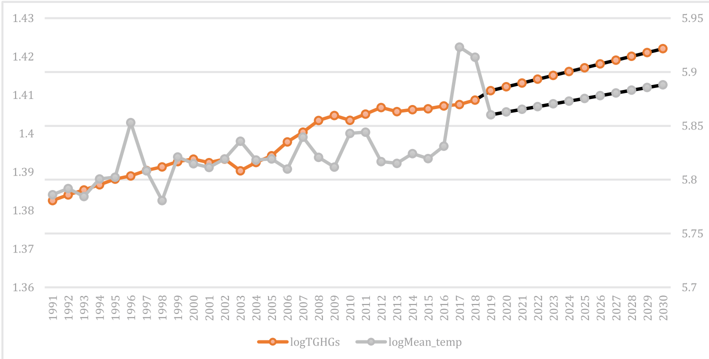
1) GHG emission and annual mean temperature change

The examination of greenhouse gas (GHG) emissions and annual mean temperature change unveiled an upward trend for both factors from 1990 to 2018, as illustrated in Graph 2. Although some fluctuations were noted in the annual mean temperature trend line for India, an overarching shift towards higher annual mean temperatures was apparent, suggesting a general increase [1][2][5].



Graph 2. Total GHG emission & Annual Mean Temperature Change in India

Graph 2.1 illustrates the observed and estimated values for GHG emissions and annual mean temperature, which were predicted through the model developed by the time series analysis of logarithmically transformed values for total GHG emissions and annual mean temperature[16].



Graph 2.1. Observed and Estimated Values of log(TGHGs) & log(Mean_temp)

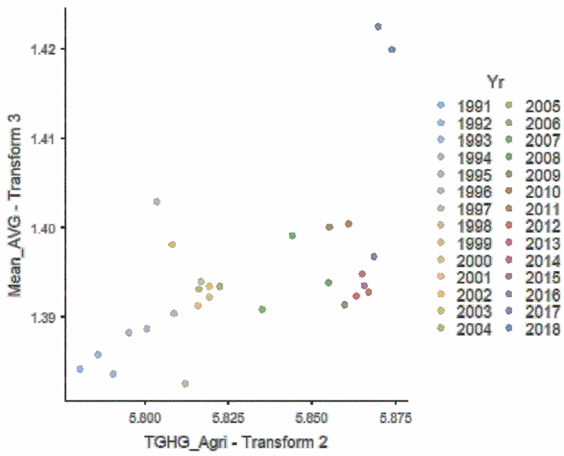
Table 2. Parameter Estimates for log (annual mean temperature)

Model Fit Measures		
Model	**R**	**R^2**
1	0.585	0.342

Model Coefficients - Mean_AVG - Transform 3				
Predictor	**Estimate**	**SE**	**t**	**p**
Intercept	0.366	0.2799	1.31	0.202
TGHG_Agri - Transform 2	0.176	0.0480	3.67	0.001

Table 2, which estimates the model coefficients for annual mean temperature, shows a positive coefficient for total GHG emissions from agriculture [7]. This model explained 99.2% of the variance in the dependent variable ($logMean_{AVG}$), indicating a strong relationship between agricultural GHG emissions and their contribution to temperature change in India.

Graph 2.2 illustrates a scatterplot diagram of the estimator with the actual values obtained for the given period. It can be observed that the estimator responds with a 95% accuracy to the original data.



Graph 2.2. Scatterplot diagram of Actual and Predicted Values of Annual Mean Temperature from 1990 to 2018

Thus, it can be inferred that there is a direct relationship between GHG emissions from agriculture[4] and their impact on temperature change in India, with agriculture playing a significant role in influencing the observed changes in temperature[11].

Conclusion

The following conclusions were drawn from this study:

- Despite agriculture in India emitting a larger overall amount of methane, the rate of nitrous oxide emission was significantly higher.
- Enteric fermentation emerged as the primary contributor to methane emissions, consistent with previous studies [19]. Additionally, nitrous oxide emissions from agricultural soils were identified as major contributor to GHG emissions, corroborates with the previous findings[3].
- A direct relationship between overall GHG emissions and annual mean temperature in India was observed. With an increase in the total GHG emissions, the average annual mean temperature also increased, with a coefficient factor of 0.176. This study revealed that GHG emissions from agriculture directly impacted climate change in India between 1990 and 2020. Moiceanu and Dinca conducted similar investigations in Romania [15].
- According to the national greenhouse gas (GHG) inventory, the agriculture sector in India currently emits 408 million metric tons (MMT) of CO_2 equivalent. However, projections from a model suggest that GHG emissions from agricultural activities, primarily from methane and nitrous oxide emissions, will increase significantly by 2030. These emissions are estimated to range between 695.87 to 818.73 million metric tons of CO_2 equivalent (MMTCDE) by 2030.

Additionally, projections indicate a notable increase in annual mean temperature in India. Specifically, the temperature is expected to rise by approximately 1.65 ± 0.58 ^{0}C from 1990 to 2030. This temperature rise could have significant implications for various aspects of the environment, agriculture, and human activities in India.

These conclusions underscore the significant role of agricultural activities in contributing to GHG emissions and their subsequent impacts on climate change, highlighting the need for effective mitigation strategies within the agricultural sector.

Limitations of Study: The study analysed only GHG emissions from agriculture and did not account for emissions from industries and other sources related to human activities. Therefore, a thorough analysis of all the sources is required to obtain a more comprehensive understanding. This will also help determine per capita emissions in India and forecast future emissions. This information will help policymakers formulate better strategies and assess their mitigation efforts.

Scope of Study: To assess the impact of the suggested measures on greenhouse gas (GHG) emissions, a comparative experiment was conducted. It will involve two sites, where one of which will follow conventional agricultural practices, while the other will be untouched by modern farming technologies. After implementing silage feeding for livestock and direct seeded rice practices, methane and nitrous oxide emissions from both sites were monitored. This will enable us to examine the effects of these practices under varying conditions and their correlation with soil emissions.

Source codes: (Rgui 4.2.2 Version)

```
jmv::linReg(
   data = data,
   dep = Mean_AVG - Transform 3,
   covs = TGHG_Agri - Transform 2,
   blocks = list(
      list(
         "TGHG_Agri - Transform 2")),
   refLevels = list())

jmv::linReg(
   data = data,
   dep = TGHG_Agri - Transform 2,
    covs = vars(TCH4_Agri - Transform 3, TN2O_Agri - Transform
3 (2)),
   blocks = list(
      list(
         "TCH4_Agri - Transform 3",
         "TN2O_Agri - Transform 3 (2)")),
   refLevels = list(),
   r2Adj = TRUE,
   ci = TRUE,
   stdEst = TRUE,
   ciStdEst = TRUE,
   norm = TRUE,
   resPlots = TRUE,
   durbin = TRUE)

jmv::corrPart(
   data = data,
   vars = vars(Mean_AVG, TGHG_Agri),
   controls = vars(),
   sig = FALSE)

gamlj::gamljGzlm(
     formula = `Mean_AVG - Transform 3` ~ `TGHG_Agri -
Transform 2`,
   data = data,
   showParamsCI = TRUE,
   showExpbCI = FALSE,
   eDesc = TRUE,
   custom_family = "poisson")


jmv::linReg(
   data = data,
   dep = TGHG_Agri - Transform 2,
    covs = vars(TCH4_Agri - Transform 3, TN2O_Agri - Transform
3 (2)),
   blocks = list(
      list(
         "TCH4_Agri - Transform 3",
         "TN2O_Agri - Transform 3 (2)")),
   refLevels = list(),
   r2Adj = TRUE,
   ci = TRUE,
   stdEst = TRUE,
   ciStdEst = TRUE,
   norm = TRUE,
   resPlots = TRUE,
   durbin = TRUE)

scatr::scat(
   data = data,
   x = Mean_AVG - Transform 3,
   y = Predicted values,
   group = Yr)
```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