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Methane Emission from Wetland Paddy Fields and Its Forecasting for India and China

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Abstract Methane is a trace gas, which is once among the major contributor for global warming by capturing outgoing radiation from earth. According to a report of Intergovernmental Panel on Climate Change, Methane's global warming potential on mass basis is nearly around 28 times more than that of carbon dioxide [CO_2] over the 100 year time horizon. Methane is formed in anaerobic condition by methanogenic bacteria both by natural phenomena and human practices. Water logged paddy cultivation is a major source of anthropogenic factors in methane emission from agriculture sector. India and china are the top countries which are producing rice to feed their growing population and hence thereby emitting more methane in recent times. Forecasting methane emission for these two countries from their cultivated paddy fields can be made by using ARIMA (0,1,1) model, which fitted best for these countries using time series data from FAO statistics. The Model fitted, forecast methane emission value for the year 2020 to 4782.73 and 5413.41 Giga grams per year for India and China respectively. It was also observed that China will be the major emitter relatively as compared to India for the projection period considered. It was also noticed that the methane that the methane emission values is expected to increase over forecasting period for both China and India. The present investigation is a modest attempt to forecast the emission of methane using ARIMA modeling technique. The results are alarming and should take the attention of policy makers in China and India.

Keywords ARIMA , Forecasting, Methane emission, Paddy cultivation.

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Introduction

Global warming is on burning talks in recent times at many international and national forums. One of the significant gas that is contributing for global warming today is methane, chemically denoted by CH_4. According to a report of Intergovernmental Panel on Climate Change [1], Methane's global warming potential on mass basis is nearly around 28 times more than that of carbon dioxide [CO_2] over the 100 year time horizon. Methane concentration has been increased from 715 ppb during pre-industrial period to 1774 ppb in 2005 to global atmospheric pool [2]. Methane emission is taking place by both natural phenomena and human activities. The organic matter degradation which is taking place under anaerobic conditions are producing the methane gas and among them agricultural wetlands are the major sources of emission as anthropogenic concept [3]. The water logged paddy cultivating fields, in the absence of molecular oxygen, high organic substrates and high moisture creates the ideal favorable anaerobic conditions for mthanogenic microbes to produce methane through degradation of dissolved organic carbon (DOC) [4]. The irrigated paddy cultivation are considered to contribute about 70-80% of methane emission from global rice fields.Numerous studies found that methane flux under continuously waterlogged environment is almost 10 times more prominent than that of non-flooded conditions. The global total methane emissions from paddy cultivation alone was estimated to be around 20 to 40 Tg per year [$1Tg=10^{12}g$], which is nearly contributing around 11% of the total methane emission from global anthropogenic factors [5]. China and India are the major countries which are culltivating paddy in the world. These two countries bear nearly 40% of world human population having with rice as their staple food. According to FAO statistics, China and India rank first and second respectively in the paddy cultivation. China is one of the most important rice-producing country in the world, accounting for 20% of the world's paddy cultivating area [6]. In India out of total 44 million hectare of rice area, nearly 18.8 million hectare is under rainfed condition and rest is under irrigated condition [7]. The global rice production is expected to increase by folds in the coming years to feed its exploding population and so as the emission of methane can be anticipated in huge quantum. There is a requisite to know the early estimates of methane emission for the future so that its reduction can be planned in present time.

Till date many field measurements and model studies have focused their attention on CH_4 emissions from rice paddies in China and India. A study by Zheng et al. [8] found that chinese rice paddies bestowing to a total CH_4 estimate of 6—10 Tg per year in 1990s . Using region-specific methane emission factors, Yan et al. [5] estimated that the global methane emission to 28.2 Tg CH_4 per year by rice fields. Asia continent accounts for 25.1 Tg CH_4 per year, of which 7.67 Tg CH_4 per year is emitted from China and 5.88 Tg CH_4 per year from India respectively. With this alarming facts and figures of methane gas and its role in global warming, the present investigation made modest attempt to forecast the methane emission upto 2020 for India and China from their paddy fields. The present investigation makes use of time series ARIMA modeling technique to forecast the methane emission based on FAO published time series data. The results may stand in help for Chinese and Indian policies formulation so as to reduce or cut of their methane emission in the future days.

Materials and Methods

The data for the present investigation is used from the official website of Food and Agriculture Origination (FAO). The amount of methane [in Giga grams] emitted from the cultivated area of paddy annually both for India and China was collected for a period of 1961-2012. The annual time series data is then subjected for testing the presence of significant outliers by using the Grubbs test [9] [through http://graphpad.com]. the presence of outliers will influence the actual findings of the study and deviate the results from statistical point of view. So if any such cases of outliers suspected and proved for its statistical significance, then the respective extreme data point [outlier] will be replaced by the median value of that series. The outlier free data was then actually used for the analysis purpose. Anand et al. [10] used system dynamic approach for estimating the methane emissions from rice fields in India till the year 2020. To forecast the methane emission from paddy cultivation from both China and India, Box and Jenkins ARIMA model [11] was employed in the present study which is a different approach than other studies. Many studies used ARIMA modeling technique for the purpose of forecasting based on historical time series data . Naveena et al. [12] used ARIMA modeling for forecasting time series coconut production data for India . ARIMA abbreviated as "Auto Regressive Integrated Moving Average". Lags of the differenced series appearing in the forecasting equation are called "auto-regressive" termss, lags of the forecast errors are called "moving average" terms and a time series which needs to be differenced to be made stationary is said to be an "integrated" version of a stationary series. The future values of the time series will be more reliable when the statistical model used for forecasting is a better fit. In its general form, the ARIMA model expressed as follows [13] :

$$\text{ARIMA } (p,d,q)\,(P,D,Q)_s$$

Where, p=Order of non-seasonal auto regression (AR), d= Order of non-seasonal difference, q = Order of non-seasonal moving average (MA), P=Order of seasonal AR, D = Order of seasonal difference, Q = Order of seasonal MA, s = Length of season (=4 in quarterly data, 12 in monthly data and so on).

Auto regressive process
(p,0, 0) or AR (p)

If the observation Y_1 in the series depends on its own preceding observation (Y_{t-j}, j = 1,2,3 ...,p, where p is the order of Auto regressive part) and error term e_t (often referred as white noise) that it is called auto regressive process (AR process). Mathemattically AR (p) can be expressed as

$$Y_t = \mu + p_1 Y_{t-1} + p_2 Y_{t-2} + \ldots + p_j Y_{t-j} \ldots + p_p Y_{t-P} + e_t$$

Where, p_1, p_2, ...p_p are the parameters of the model, "μ" is the constant term and "*t*" is time. Auto regressive co-efficient values are restricted to lie between – 1 and + 1.

Moving average process
(0,0,q) or MA (q)

If the observation Y_t dependss on the error term e_t and onone or more previous error terms (e_{t-i}, i=1,2,3,....,q, where q is the order of moving average) then we have moving average (MA) process. Mathematically MR (q) can be expressed as

$$Y_1 = c + \theta_1 e_{t-1} + \theta_2 e_{t-2} + \ldots + \theta_t e_{t-i} \ldots + \theta_P e_{t-q} + e_t$$

where, θ_1, θ_2, ...,θ_q are the parameters of the model, "*c*" is the constant term and "*t*" is time. Again Moving average co-efficient values are restricted to lie between – 1 and + 1.

Autoregressive Moving Average
model or ARIMA (p,q)

The notation ARIMA (*p,q*) refers to the model with *p* autoregressive terms and *q* moving average terms. This model contains the AR (*p*) and MA (*q*) models,

$$Y_t = K + \varepsilon_\tau \sum_{j=1}^{p} p_j Y_{t-j} + \sum_{i=1}^{q} \theta_t \varepsilon_{\tau-t}$$

where *K* is the constant term in the ARIMA (p,q).

ARIMA (p,d,q)

Since ARIMA model refers only to a stationary time series, the first stage of Box-Jenkins model is to reduce the non-stationary series Y_t to a stationary series X_t by taking first differencing (d=1) as follows.

$$X_t = \Delta Y_t,\ X_t = Y_t - Y_{t-1},\ X_t = Y_t - BY_t\ ,\ X_t = (1-B)\,Y_t$$

Where, B = backward shift operator, Y_t = original time series and X_t = differenced series.

The backward shift operator is convenient to describe process of differencing. To define B such that

$$B^I Y_t = Y_{t-i} \qquad i = 1,2,3, \ldots\ldots$$

Suppose the first difference of the series does not become stationary then, second order differencing is done as follows :

$X_1 + \Delta(\Delta Y_t)$

Which give rise to

$X_t = (1–B)^2 Y_t$

In general, if it takes a d^{th} order difference to achieve stationarity, we will write : d^{th} order difference $=(1–B)^d Y_t$

The general ARIMA (0,d,0) model will be :

$(1–B)^d Y_t = e_t$

Where, e_t is the error term distributed normally with $E(e_t) + 0$ and $V(e_t) = e_t$ and cov (e_i, e_j)

$=0$ for all t $(i \neq j)$.

To identify the appropriate ARIMA model for a time series, one begins by identifying the order(s) of differencing (d=?) needing to stationarize the series. The auto correlation function (ACF), the partial auto correlation function (PACE), and the resulting correlograms, are used to identify the appropriate values of "p", "q". Estimation of parameters of the model are based on simple least squares technique. Among the competitive Box-Jenkins model best model is selected on the basis of maximum R_2, minimum root mean square error (RMSE), minimum mean absolute percentage error (MAPE), minimum of maximum average percentage error (MaxAPE), minimum of maximum absolute error (MaxAE), minimum of Normalized BIC. Any model which has fulfilled most of the above criteria is selected.

After estimating the parameters of a tentatively identified ARIMA model, it is requisite to go for diagnostic check to get affirmation that the model is adequate. Ljung and Box [14] 'Q' statistic was used to know whether the auto correlations for those residuals are significantly different from zero or not. This diagnostic checking helps to spot the differences in the model identified, so that the model could be subjected to modification if so required. After diagnostic checks the best fitted model was used for forecasting of emission of methane from wetland paddy purpose till the period of 2020.

Results and Discussion

The preliminary examination of series for outliers using Grubbs test revealed that there was no significant outliers at 5% level of significance. When the series is then used to obtain auto correlations and partial auto correlations, it was found that the tme series datais not stationary. First order differencing [d=1] of the series both in the case of China and India was sufficient to obtain stationarity. After knowing the order of differencing [i.e, d=1], we tried many combination of p and q starting from ARIMA (0,1, 0) to identify the best model. It was found that ARIMA (0,1,1) fitted best for methane emission series data both in the case for China and India.

Table 1 gives the best fitted models with model fit statistics and 'Q' statistics for China and India. In case of India ARIMA (0,1,1) found to be best fit having co-efficient of determination 0.84, which means 84% of variation in response is explained by the

Table 1. Model Fit statistics and Ljung-Box Q statistics.

				Model Fit statistics							Ljung-Box Q		
Country	Model	Number of outliers	Number of predictor	R-squared	RMSE	MAPE	MAE	MaxAPE	MaxAe	Normalized BIC	Statistics	DF	Sig.
India	ARIMA (0,1,1)	0	0	0.84	122.25	2.06	88.01	9.34	406.10	9.77	19.54	17.00	0.30
China	ARIMA (0,1,1)	0	0	0.90	145.58	1.94	106.74	7.92	398.11	10.12	10.42	17.00	0.88

Table 2. ARIMA model parameters.

Country	Model	Parameters	Estimate	Standard error	*t*-value	Significance
India	ARIMA (0,1,1)	CONSTANT	18.07	5.98	3.02	0.004
		Difference	1.00			
		MA (Lag 1)	0.67	0.12	5.75	0.000
China	ARIMA (0,1,1)	CONSTANT	11.65	26.92	0.43	0.667
		Difference	1.00			
		MA (Lag 1)	-0.30	0.14	-2.16	0.036

model. In case of China also ARIMA (0,1,1) found fitted best with coefficient of determination explaining about 90% of variation in the dependent variable. For both India and China, Ljung-Box 'Q' statistic proved that there is no auto correlation in residual error terms. The residual error terms found independently, identically and normally distributed and also among all the models fitted for India and China, ARIMA (0,1,1) model disclosed low values for RME, MAPE, MAE, Max APE, Max AE and Normalized BIC.

The parameter estimates of ARIMA (0,1,1) for India and China are given in Table 2. It is found that all the model parameters for both India and China are found significant except in case of constant term which exhibited non significance in China case.

Table 3 provides the forecasted values of methane emission from paddy fields in terms of Giga grams per year from India and China upto year 2020. The model fitted forecast methane emission value for the year 2020 to 4782.73 and 5413.41 Giga grams per year for India and China respectively. The forecasted values are also presented in Figure 1. We can observe that there is increasing figures over forecasting period considered. The results are alarming and should take the attention of policy makers in China and India. The strategies for the action of reducing the methane emission in the near future should be framed and taken utmost importance in the above discussed countries. The alternative technologies should be given attention and adopted in case of waterlogged paddy cultivation which support our environment and its quality. Studies like in India, Tyagi et [15] observed that there was 9% less methane flux when drainage was done at tillering stage of paddy cultivation. It was also evidenced by Tyagi et al. [15] that the multiple drainage and mid-season drainage brought done methane flux by 41 and 36.7% ,respectively. In determining the activity of methanogenic bacteria the release of soluble C compounds from decomposing organic substrates in soil may be an essential factor. Methane emission can be mitigated by controlling the anaerobic decomposition of organic substrate. Pramanik and Kim [16] also found that emission of methane can be reduced almost to 20% in paddy cultivation by application of compost. However, the Intergovermental Panel on Climate Change (IPCC) has recommended 8% reductions of in anthropogenic methane fluxes to stabilize atmospheric concentrations. The results of the present study may stand in help for policy framers of both countries to plan and reduce their methane emission. The planning at macro level can more likely reduce so called global warming.

Table 3. Forecasted values of methane emission from China and India upto 2020. [in Giga grams/year].

Year Particulars	2011 Observed values	2011 Predicted value	2012 Observed values	2012 Predicted value	2013	2014	2015	2016	2017	2018	2019	2020
					Predicted value							
India	4641.4732	4620.13	4476.7996	4638.19	4656.26	4674.33	4692.39	4710.46	4728.53	4746.59	4764.66	4782.73
China	5325.1923	5308.54	5340.4202	5320.19	5331.84	5343.49	5355.15	5366.8	5378.45	5390.1	5401.75	5413.41

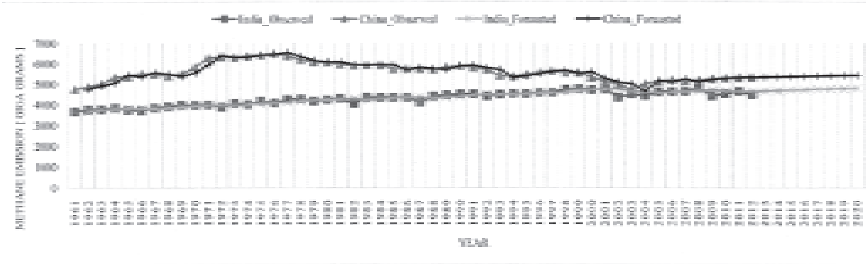

Fig. 1. Forecasted values of methane emission for china and India upto 2020 [in Giga grams/years].

Conclusion

Methane is a trace gas, which is one among the major contributor for global warming by capturing outgoing radiation from earth. Methane is formed in anaerobic condition by methanogenic bacteria both by natural phenomena and human practices. Water logged paddy cultivation is a major source of anthropogenic factors in methane emission from agriculture. India and China are the top countries which are producing rice to feed their growing population and hence there by emitting more methane. Forecasting methane emission for these two countries can be made by using ARIMA (0,1,1) model which fitted best for these countries using time series data from FAO. The projected values says that in near future the emission is expected to increase further and it is alarming. Policy makers at national level should make formulations to cut off their emission level to sustain the environment of mother earth. The alternative technologies and mitigation options studied over time by many researchers can be used to curtain the methane emission which includes rice production management, using varieties of rice of low methane emission, water management and fertilizer amendment. Using high yielding rice varieties together with efficient cultivation practices may certainly contribute in curbing of the methane emission fluxes to atmosphere.

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