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Modeling and Forecasting of Carbon Dioxide Emissions in Bangladesh Using Autoregressive Integrated Moving Average (ARIMA) Models

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Abstract

In the present paper, different Autoregressive Integrated Moving Average (ARIMA) models were developed to model the carbon dioxide emission by using time series data of forty-four years from 1972-2015. The performance of these developed models was assessed with the help of different selection measure criteria and the model having minimum value of these criteria considered as the best forecasting model. Based on findings, it has been observed that out of different ARIMA models, ARIMA (0, 2, 1) is the best fitted model in predicting the emission of carbon dioxide in Bangladesh. Using this best fitted model, the forecasted value of carbon dioxide emission in Bangladesh, for the year 2016, 2017 and 2018 as obtained from ARIMA (0, 2, 1) was obtained as 83.94657 Metric Tons, 89.90464 Metric Tons and 96.28557 Metric Tons respectively.

Keywords

Carbon Dioxide, Modeling, Forecasting, Time Series, ARIMA, Bangladesh

1. Introduction

Generally, emission of carbon dioxide (CO_2) from living animals, humans, wetlands, volcanoes, and other sources is nearly balanced by the same amount being removed from the atmosphere by plant photosynthesis and by the oceans. Human activity is disturbing this equilibrium by generating increased CO_2 from fossil fuels like as coal, gas, and petroleum products; and combustion via electricity generation, transportation, industry, and domestic use. The results of these imbalances are believed to be greenhouse effects: global warming, melting of polar ice sheets and caps, a rise in sea levels and subsequent coastal inunda-

tions, and damage to agriculture and natural ecosystems, among others. There is an increasing trend of greenhouse gas (GHG) emissions worldwide due to human activities, which indicates a substantial increase in atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) (EPA, 2014) [1]. IPCC (2007) [2] shows that carbon dioxide is the most dominant GHGs (greenhouse gases) which accounted 77% of the total global GHG emission where CH_4, N_2O and other gases contributed 14%, 8% and 1% respectively.

Climate change as a result of global warming has become one of the most important issues in the recent years. Reddy *et al.* (1995) shows that global mean temperature will also rise to 3˚C - 4˚C with doubling of the CO_2 concentration [3]. In 2007, the Intergovernmental Panel on Climate Change reported that there would be an estimated rise in the average global temperature between 1.1˚C and 6.4˚C within the next 100 years [2]. Lau *et al.* (2009) shows that a meager 2˚C increase in temperature would greatly hamper many ecosystems and would cause an increase in the sea-level that would adversely impact the lives of people living in coastal zones [4].

The developed countries have a much higher share in global emissions than the developing ones. Nakicenovic (1994) [5] studied the perspectives of GHG emission on a regional basis. He stated that the developing countries are responsible for less than 16% of the CO_2 concentration due to their past consumption of fossil energy. The developed countries have a much higher share in global emissions than the developing ones. In Bangladesh, the power sector alone contributes 40% of the total CO_2 emissions [6] [7]. Sarkar *et al.* (2015) has shown that the growth of CO_2 emission found 6.7% per year which is higher than the growth of GDP and energy consumption in Bangladesh [8]. According to the third Assessment Report of IPCC (2007) [2], Bangladesh is the most vulnerable region of the world to climate change impacts [6] [9] [10] [11] [12]. Global warming has caused fundamental changes to our climate. According to the IPCC (2001) [13], a 45cm sea-level rise could cause a potential land loss of 10.9% and a one meter sea-level rise a loss of 20.7%. Recently, the IPCC, in its Fifth Assessment Report, has suggested a 1.5 mm sea-level rise per year for Bangladesh. According to the IPCC (2007) Bangladesh will loose about 8% of its rice and 32% wheat production by the year 2050. The UNDP (2007) [14] predicts that 11% of the population will be directly threatened by a one meter sea-level rise. Rahman *et al.* (2015) [15] shows that in Bangladesh the maximum temperature increased significantly by 0.021 degree Celsius per year in Cox's Bazar and Sylhet region which is alarming for Bangladesh.

2. Materials

In the present study, time series secondary data on carbon dioxide emissions in Bangladesh were considered for the period 1972 to 2015 from Boden *et al.* (2016), UNFCCC (2016), BP (2016) [16] [17] [18]. The time series secondary

data were analyzed with the help of various ARIMA models and have forecast using the appropriate model which was selected using the minimum selection criteria.

3. Methods

ARIMA is one of the most traditional methods of non-stationary time series analysis. In contrast to the regression models, the ARIMA model allows time series to be explained by its past or lagged values and stochastic error terms. The models developed by this approach are usually called ARIMA models because they use a combination of autoregressive (AR), integration (I) - referring to the reverse process of differencing to produce the forecast and moving average (MA) operations [19].

The ARIMA model is denoted by ARIMA (p, d, q), where "p" stands for the order of the auto regressive process, "d" is the order of the data stationary and "q" is the order of the moving average process. The general form of the ARIMA (p, d, q) can be written as [20],

$$\Delta^d y_t = \delta + \theta_1 \Delta^d y_{t-1} + \theta_2 \Delta^d y_{t-2} + \cdots + \theta_p y_{t-p} + e_{t-1} \alpha e_{t-1} - \alpha_2 e_{t-2} \alpha_q e_{t-2} \quad (1)$$

where, Δ^d denotes differencing of order d, *i.e.*, $\Delta y_t = y_t - y_{t-1}$, $\Delta^2 y_t = \Delta y_t - \Delta y_{t-1}$ and so forth, $y_{t-1}, \cdots, y_{t-p}$ are past observations (lags), $\delta, \theta_1, \cdots, \theta_p$ are parameters (constant and coefficient) to be estimated similar to regression coefficients of the Auto Regressive process (AR) of order "p" denoted by AR (p) and is written as,

$$Y = \delta + \theta_1 y_{t-1} + \theta_2 y_{t-2} + \cdots + \theta_p y_{t-p} + e_t \quad (2)$$

where, e_t is forecast error, assumed to be independently distributed across time with mean θ and variance $\theta_2 e, e_{t-1}, e_{t-2}, \cdots, e_{t-q}$ are past forecast errors, $\alpha_1, \cdots, \alpha_q$ are moving average (MA) coefficient. While MA model of order q (*i.e.*) MA (q) can be written as,

$$Y_t = e_t - \alpha_1 \alpha_{t-1} - \alpha_2 e_{t-2} - \cdots - \alpha_q e_{t-q} \quad (3)$$

Seasonal ARIMA model is to denoted by ARIMA (*p*, *d*, *q*) (P, D, Q), where P denotes the number of seasonal autoregressive components, Q denotes the number of seasonal moving average terms and D denotes the number of seasonal differences required to induce stationarity [21]. The steps which are followed in order to define an ARIMA model as stated by Box & Jenkins:

a) Identifying a model;

b) Estimating the parameters of the model;

c) Diagnostic checking.

In the present paper, time series yearly data on emissions of carbon dioxide in Bangladesh were considered so there is no seasonal variation in the data which means non-seasonal ARIMA (*p*, *d*, *q*) models are applicable only. Comparison among family of different parametric combination of ARIMA (*p*, *d*, *q*) was done on the basis of minimum value of selection criteria which are Root mean

squared error (RMSE), Mean percentage error (MPE), Mean absolute percentage error (MAPE), Mean absolute error (MAE), Maximum absolute percentage error (MAPE), Maximum absolute standard error (MASE) and Bayesian information criteria (BIC) [22] [23].

4. Result and Discussion

In Figure 1, from the autocorrelation (ACF) and partial autocorrelation (PACF), it is clear that there is no significant spike in the original series which also indicates that there are no significant effects of Auto-Regressive and Moving Average in the original series, that is, the carbon dioxide emission series is stationary without any difference.

After making the series stationary, different parametric combinations of ARIMA (p, d, q) model were tried to analyze the forty-four-year data (1972 to 2015) of carbon dioxide emission and the best fitted model is accepted on the basis of minimum value of all selection criteria as mentioned above in methodology. The results of performance of developed ARIMA (p, d, q) model is presented in Table 1. Table 1 exposed the performance of twenty ARIMA Models out of which ARIMA (0, 2, 1) was best out of all. ARIMA (0, 2, 2) and ARIMA (1, 2, 1) ranks second and third respectively while remaining ARIMA Models are not as good as these three.

Therefore, it was concluded that the appropriate model for forecasting the carbon dioxide emission in Bangladesh during 2015 was ARIMA (0, 2, 1) having minimum value of all selection criteria as compared to remaining nineteen models.

Table 2 shows the forecasted value of carbon dioxide emission using the best fitted model ARIMA (0, 2, 1). The forecasted value of carbon dioxide emission in Bangladesh, for the year 2016, 2017 and 2018 as obtained from

ARIMA (0, 2, 1) was obtained as 83.94657 Metric Tons, 89.90464 Metric Tons and 96.28557 Metric Tons with Upper emission limit (UEL) and Lower emission limit (LEL) are 92.21431 Metric Tons and 75.96045 Metric Tons, 98.72545 Metric Tons and 81.13923 Metric Tons, 105.90164 Metric Tons and 87.02782 Metric Tons respectively.
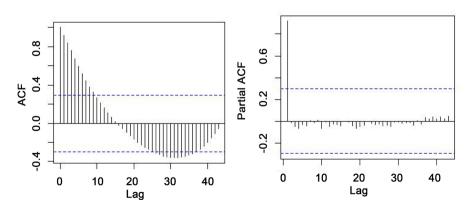

Figure 1. Autocorrelation and Partial Autocorrelation graph.

Table 1. Performances of different ARIMA (p, d, q) models of carbon dioxide in Bangladesh.

Models	Model Selection Criteria						
	RMSE	MAE	MPE	MAPE	MASE	AIC	BIC
ARIMA (0, 1, 0)	2.3425	1.7402	6.6104	7.1229	0.9773	198.22	199.98
ARIMA (0, 1, 1)	1.9891	1.4639	4.7313	6.5207	0.8221	186.35	189.88
ARIMA (0, 1, 2)	1.5460	1.1544	3.1398	5.6675	0.6483	168.01	173.29
ARIMA (0, 1, 3)	1.4824	1.1296	2.5420	5.6682	0.6344	166.91	173.96
ARIMA (1, 1, 0)	1.5956	1.2749	1.8421	6.2357	0.7159	168.03	171.55
ARIMA (1, 1, 2)	1.4660	1.14591	2.1419	5.8150	0.6435	165.74	171.55
ARIMA (2, 1, 0)	1.4060	1.1035	1.1014	5.4728	0.6197	159.71	164.99
ARIMA (2, 1, 1)	1.4021	1.1024	1.1528	5.5165	0.6191	161.5	168.55
ARIMA (2, 1, 2)	1.3333	0.9679	1.0146	4.8551	0.5436	159.86	168.67
ARIMA (2, 1, 3)	1.2603	0.9817	0.8985	5.1329	0.5513	157.32	167.88
ARIMA (0, 2, 0)	1.6744	1.3174	-0.0317	6.3415	0.7398	166.44	168.18
ARIMA (0, 2, 1)	1.3216	0.9600	0.4590	4.6932	0.5391	149.42	152.9
ARIMA (0, 2, 2)	1.3212	0.9558	0.4602	4.6698	0.5368	151.41	156.62
ARIMA (0, 2, 3)	1.2666	1.0051	0.3100	5.1614	0.5644	150.1	157.05
ARIMA (1, 2, 0)	1.4139	1.1248	0.0158	5.4194	0.6317	154.57	158.05
ARIMA (1, 2, 1)	1.3211	0.9547	0.4604	4.6638	0.5361	151.41	156.62
ARIMA (1, 2, 2)	1.3079	0.9478	0.4499	4.5701	0.5323	152.59	159.54
ARIMA (1, 2, 3)	1.2481	0.9741	0.3619	4.9698	0.5470	150.78	159.47
ARIMA (2, 2, 1)	1.3140	0.9719	0.4336	4.7371	0.5458	152.9	159.85
ARIMA (2, 2, 3)	1.1497	0.9081	0.3649	4.6018	0.5101	149.43	159.85

Table 2. Forecast of carbon dioxide emission in Bangladesh using ARIMA (0, 2, 1) during 2016 to 2018.

Year	Forecast	LEL*	UEL*
2016	83.94657	75.96045	92.21432
2017	89.90464	81.13923	98.72545
2018	96.28557	87.02782	105.90164

*95% confidence interval.

5. Conclusion

This paper aimed to model the emission of carbon dioxide during 2015 in Bangladesh, by Autoregressive Integrated Moving Average (ARIMA) approach. On basis of results obtained, it is concluded that ARIMA (0, 2, 1) model having minimum value of all measures of selection criteria was found to be the appropriate model amongst all for predicting the carbon dioxide emission in Bangladesh. The model showed a good performance in case of explaining variability in

the data series and, it's predicting ability. Using the model ARIMA (0, 2, 1) we obtained the emission as 83.94657 Metric Tons, 89.90464 Metric Tons and 96.28557 Metric Tons in the year 2016, 2017 and 2018. However, the forecasting of carbon dioxide can help the government of Bangladesh and world leaders as well as the policy makers for taking the appropriate plan for reducing the future emission of carbon dioxide in Bangladesh.

Acknowledgements

Conflicts of Interest

The authors declare no conflict of interest.

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