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Study on Particulate Matter Pollution in Jaipur City

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Abstract

This paper presents a trend analysis of respirable suspended particulate matter (PM_{10}) and suspended particulate matter ($PM_{2.5}$) in Jaipur city, Rajasthan, India from year 2005 to 2015. The concentration of particulate matters in the air is compared with national air quality standards for year 2005 to 2015. The analysis covers six air quality monitoring stations in Jaipur It is found that every year recorded mean values of particulate matters ($PM_{2.5}$ and PM_{10}) are very much higher than the specified limit by NAAQS. The PM_{10} and $PM_{2.5}$ values were lower in monsoon season compared to winter and summer season. A seasonal ARIMA (SARIMA) model of time series analysis is used for analysis and forecasting of air pollutants. The data set of $PM_{2.5}$ and PM_{10} good fitted with respective seasonal ARIMA model as per Ljung –Box test. The cross validation of model is done using residual analysis. The residual of difference between observed value and forecasted value of PM_{10} is not significant for the period 2016-2017.

Keywords: Air pollution, Forecasting, Particulate matter, Time series analysis, SARIMA.

1. INTRODUCTION

Air is the mixture of gases that fills the atmosphere, giving life to the human, plants and animals that make Earth as a living planet. Air is almost entirely made up of two gases (78.09% nitrogen and 20.85% oxygen), with a few other gases such as carbon dioxide (0.04%) and argon (0.93%). Air pollution is the condition when the chemical composition of air changes due to certain substance. In general air naturally maintains its chemical composition by dispersing the pollutant when they mixed with it. With insanely use of natural resources in the name of development to make human society affluent cause series of problem like deforestation, release of toxic materials and solid waste which results in scarcity of pure and clean environment. These problems become severe in all metro cities of the world. In last decade the air quality of most of metro cities in world is poorest [1]. Globally every year, 7 million people die because of exposure to high level of air pollutants [2].

Urbanization is unavoidable process in developing nation which gives accelerating growth in the transport sector, a booming construction industry, and a growing industrial sector. In India most of metro cities are unplanned one which leads to higher population density towards the city centre [3]. The high population density result in more transportation activities [4] and improper maintenance of vehicles [5,6] worsen air quality and human health[7]. This increased level of air pollutants result in adverse effect on health of human being as well as animals [8-14]. The impact of gaseous and particulate pollutants on human and ecosystem health varies with season, hence; seasonality has always been a factor for determining the concentration of pollution in the lower atmosphere [15].

Since last decade a rapid economic growth and geographical expansion have been observed in the Jaipur city of Rajasthan State. Simultaneously with growth factors and high population the air pollution is also increasing day by day. Jaipur stands at 33rd in the list of most polluted city in the world, report released by WHO in May 2016.

There have been many studies published[16-23] for assessment and forecast/prediction of air pollution for various cities in the world using different statistical concept like spatial, time series analysis etc.

Pan et al. (2008) analysis the air quality data of Taiwan using autoregressive fractionally integrated moving-average (ARFIMA) model and fount it is better than ARIMA models to predict the air quality data [24]. Seetharam & Simha (2009) attempted to assess trend of ambient air quality status of Bangalore city for $PM_{2.5}$, NO_x and SO_2 using time series analysis[1].

Naveen & Anu (2017) studied ambient air quality data of Thiruvanantpuram District, Kerala, India using ARIMA and SARIMA method and found that ARIMA model gave better forecasting than the SARIMA model [23]. Xile et al. (2012) analysed the concentrations of SO_2,NO_2 and PM_{10} during 1996 to 2008, in Zhengzhou city of China using non-parametric Mann-Kendall test [25]. Sharma et al. (2012) used the extreme value theory to predict level of different pollutant in Delhi [26]. Kumar & Jain (2010) used ARIMA model to forecast the value of different pollutant for the ITO Delhi location. Ahmad & Bano (2015) using spatial temporal method found that value of that $PM_{2.5}$ and PM_{10} remain higher than NAAQS standard in Firozabad city [27]. Panday (2016) also showed that value of PM_{10} in Indore city was higher than NAAQS, 2009 [28]. Table 1 shows the National Ambient Air Quality Standards.

Table 1: National Ambient Air Quality Standards (2009)

Pollutants	Time weighted Average	Concentration in Ambient Air	
		Industrial , Residential, Rural and other areas	Ecologically sensitive Area (Notified by Central Government)
Nitrogen Dioxide (NO_2) ($\mu g/m^3$)	Annual	40	30
	24 Hours	80	80
Sulphur Dioxide (SO_2) ($\mu g/m^3$)	Annual	50	20
	24 Hours	80	80
$PM_{2.5}$ ($\mu g/m^3$)	Annual	40	40
	24 Hours	60	60
PM_{10} ($\mu g/m^3$)	Annual	60	60
	24 Hours	100	100

Dadhich et al. (2016) evaluated air quality of Jaipur city using geo-spatial and geo-statistical techniques and estimate the seasonal and temporal variation (2004-2015) of gaseous and particulate pollutants. It was found that $PM_{2.5}$ and PM_{10} is the major contributor to the deterioration of air quality in Jaipur city, while NO_x and SO_2 concentrations were below as per the NAAQS, 2009 [29]. The main objective of this study is to evaluate the temporal and seasonal variation in concentration of air pollutants of Jaipur city.

2. MATERIALS AND METHODS:

2.1 Study area

Jaipur the capital of Rajasthan state is known as the "Pink City" and is famous for it’s Rajputana culture and forts. Jaipur District has total area of 11,117 sq. km. with an average population density of 470 people per sq. km. Jaipur city lies on the geographical coordinates of 26° 55' 0" N, 75° 49' 0" E and covers an area of 200.4 sq. km.

2.2 Air monitoring infrastructure:

The daily data of air pollutants was collected from CPCB, Delhi for Jaipur city which has six manual stations (Table 2) for air quality monitoring. Air pollutants $PM_{2.5}$, PM_{10} concentrations are expressed in microgram per cubic meter ($\mu g/m^3$).

2.3 The data Set:

The data used in this study consists of daily observations of PM_{10} and $PM_{2.5}$ for the period 2005-2017 taken from Central Pollution Control Board (CPCB), Delhi. The maximum daily values were obtained by extracting the maximum pollutant levels of a dataset of hourly concentrations through a 24 hour period.

Table 2: Air Quality Monitoring stations

S. No.	Station Code	Station Name	Category
1	297	Vishwakarma Industrial Area (VKIA)	Industrial
2	296	Ajmeri Gate	Residential/Commercial
3	408	Chandpole	Residential/Commercial
4	298	Rajasthan Pollution Control Board (RPCB) Office,Jhalana	Residential/Commercial
5	409	Regional Office, RPCB, North Jaipur, Sikar Road	Residential/Commercial
6	410	RIICO office, Malaviya Industrial Area(MIA)	Industrial

2.4 Time Series Modelling Procedure:

The seasonal ARIMA model is used for trend analysis of air pollutant data for the period of January 2005 to December 2015. The seasonal ARIMA model incorporates both non-seasonal and seasonal factors in a multiplicative model. One shorthand notation for the model is ARIMA $(p, d, q) \times (P, D, Q)S$, Where p = non-seasonal AR(Autoregressive) order, d = non-seasonal differencing, q = non-seasonal MA (Moving Average) order, P = seasonal AR order, D = seasonal differencing, Q = seasonal MA order, and S = time span of repeating seasonal pattern. The lack of fit and forecast performance of proposed time series model is done by L-jung Box test. The subsequent 2 years data January 2016 to December 2017 were used for the validation of proposed model.

3. RESULTS & DISCUSSION

3.3 Particulate matter ($PM_{2.5}$ and PM_{10})

Particulate matters ($PM_{2.5}$ and PM_{10}) in the atmosphere produced as a result of chemical reactions involving particulate matter forming (precursor) gases: SO_2, NO_x, NH_3 and non-methane volatile organic compounds. Airborne particulate matter represents a complex mixture of organic and inorganic substances(Guerreiro et al. 2014). PM poses the greatest risk, as it penetrates into sensitive regions of the respiratory system and can lead to health problems and premature mortality (Krzyzanowski & Cohen 2008; Hosamane & Desai 2013).

3.3.1 Respirable Suspended Particulate Matter (PM_{10})

The Figure 1 represents the graphical presentation of mean PM_{10} values for every month from year 2005 to 2015. It is observed from the Figure 1 that during study period 2005-2015, mean PM_{10} values has been increased considerably after year 2009. The range for mean PM_{10} values for years 2005-2009 was 50-200$\mu g/m^3$ whereas it was 50-300$\mu g/m^3$ 2010 to 2015 which is higher than the NAAQ standard 60 $\mu g/m^3$ annually. It is also observed from the Figure 1 that mean PM_{10} value was lowest in monsoon season and higher values are observed during winter and summer season.

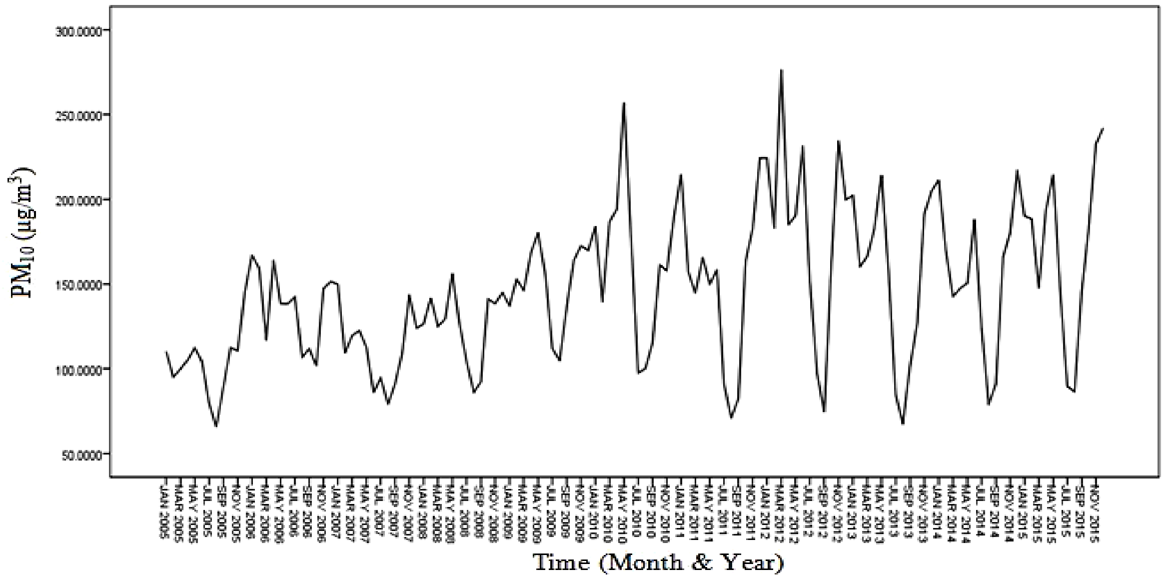

Figure 1: Graphical presentation of mean PM_{10} values from year 2005 to 2015

The ARIMA(0,0,2)(0,1,1) model is used for analysis and forecasting of mean PM_{10} value. It is observed from Table 3 that in Ljung-Box test significance value is 0.249 which is greater than p = 0.05(significance level for comparison). So proposed model does not does not exhibit lack of fit. Moreover, Stationary R-squared is 0.589 which is large enough and Normalised BIC is small as compared with other models, which is desirable. So the proposed model is good fitted and acceptable.

Figure 2 shows the forecasting of mean PM_{10} values for the period of 2016-2018.The bold black line represents the observed values and blue line shows model fitted values in figure 2. The dotted lines represents upper control limit (UCL) and lower control limit (LCL) for PM_{10} at 95% confidence level. The model shows good fit for Mean PM_{10} as predicted values are between 95% Confidence limits. The cross-validation of forecasted value is done with observed values for year 2016 and 2017.

Table 3 : Model Statistics for mean PM_{10} value

Model	Number of Predictors	Model Fit statistics				Ljung-Box Q(18)			Number of Outliers
		Stationary R-squared	RMSE	MAPE	Normalized BIC	Statistics	DF	Sig.	
PM_{10} levels ARIMA(0,0,2)(0,1,1)	0	.589	24.301	13.836	6.620	18.256	15	.249	2

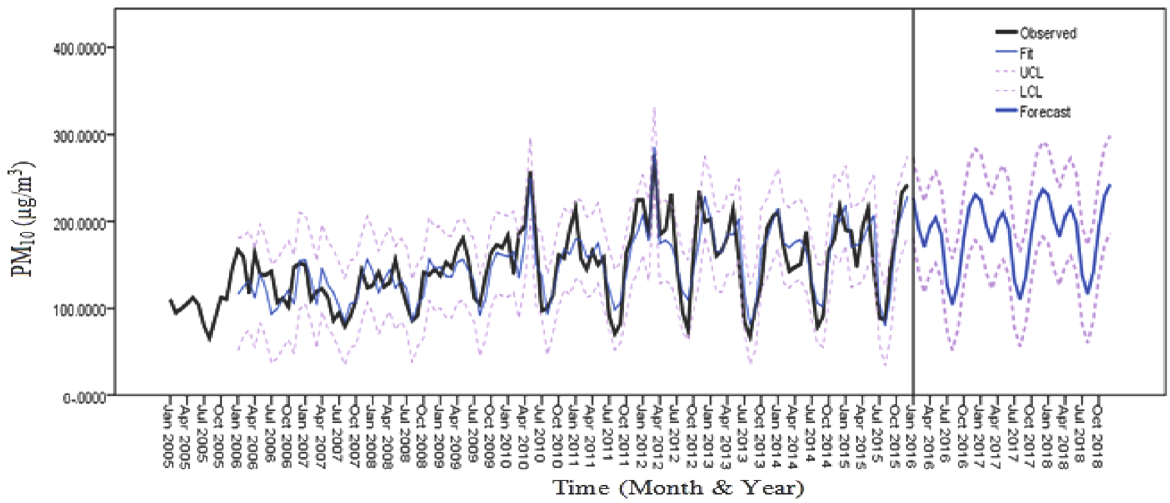

Figure 2: Forecasting of Mean PM_{10} value for period 2016-2018

The forecast values with upper control limit (UCL) and lower control limit (LCL) for PM_{10} are given in Table 4 at 95% confidence level for every month of year 2016 to 2018 as proposed model. It is also observed that forecasted values are very much near to observed values and all are between 95% confidence intervals.

Table 4: Forecasting of Mean PM_{10} value for year 2016-2018

	Jan 2016	**Feb 2016**	**Mar 2016**	**Apr 2016**	**May 2016**	**Jun 2016**	**Jul 2016**	**Aug 2016**	**Sep 2016**	**Oct 2016**	**Nov 2016**	**Dec 2016**
Observed	236.3333	195.1667	199.3333	222.00	246.00	211.8333	85.16667	79.33333	176.1667	226.3333	276.5	300.3333
Forecast	227.1158	191.4044	170.4791	193.5074	204.2391	185.9020	126.3224	104.2774	129.9197	180.7057	217.2531	230.6687
UCL	273.1521	242.7256	222.9681	245.9964	256.7281	238.3909	178.8113	156.7664	182.4087	233.1947	269.7419	283.1565
LCL	181.0795	140.0831	117.9902	141.0184	151.7501	133.4130	73.8334	51.7884	77.4307	128.2167	164.7644	178.1809
	Jan 2017	**Feb 2017**	**Mar 2017**	**Apr 2017**	**May 2017**	**Jun 2017**	**Jul 2017**	**Aug 2017**	**Sep 2017**	**Oct 2017**	**Nov 2017**	**Dec 2017**
Observed	303.3333	220	181.5	230.5	241.5	165.5	109.6667	124.6667	178.8333	222.3333	184.6667	192.1667
Forecast	224.3224	195.2166	176.5159	199.5442	210.2759	191.9387	132.3591	110.3141	135.9565	186.7425	223.2899	236.7055
UCL	278.3029	249.5542	230.9373	253.9656	264.6973	246.3601	186.7805	164.7355	190.3779	241.1639	277.7111	291.1257
LCL	170.3419	140.8790	122.0945	145.1228	155.8545	137.5173	77.9377	55.8927	81.5350	132.3211	168.8687	182.2852
	Jan 2018	**Feb 2018**	**Mar 2018**	**Apr 2018**	**May 2018**	**Jun 2018**	**Jul 2018**	**Aug 2018**	**Sep 2018**	**Oct 2018**	**Nov 2018**	**Dec 2018**
Forecast	230.3592	201.2533	182.5526	205.5809	216.3126	197.9755	138.3959	116.3509	141.9932	192.7792	229.3266	242.7422
UCL	286.2204	257.4591	238.8383	261.8666	272.5983	254.2611	194.6815	172.6365	198.2788	249.0649	285.6121	299.0272
LCL	174.4979	145.0476	126.2670	149.2953	160.0270	141.6898	82.1103	60.0653	85.7076	136.4936	173.0411	186.4572

The validation of model is done for using year 2016 and 2017. The forecast values with upper control limit (UCL) and lower control limit (LCL) are given in Table 4 at 95% confidence level for every month of year 2016 to 2018 as proposed model. Auto correlation function (ACF) and partial auto correlation function (PACF) for residuals are shown in Figure 3. The lag is shown along the vertical line and the autocorrelation is on the horizontal. The border line indicates boundary for statistical significance. It can be concluded from the Figure 3 that purposed model is good, as all residuals are not significant.

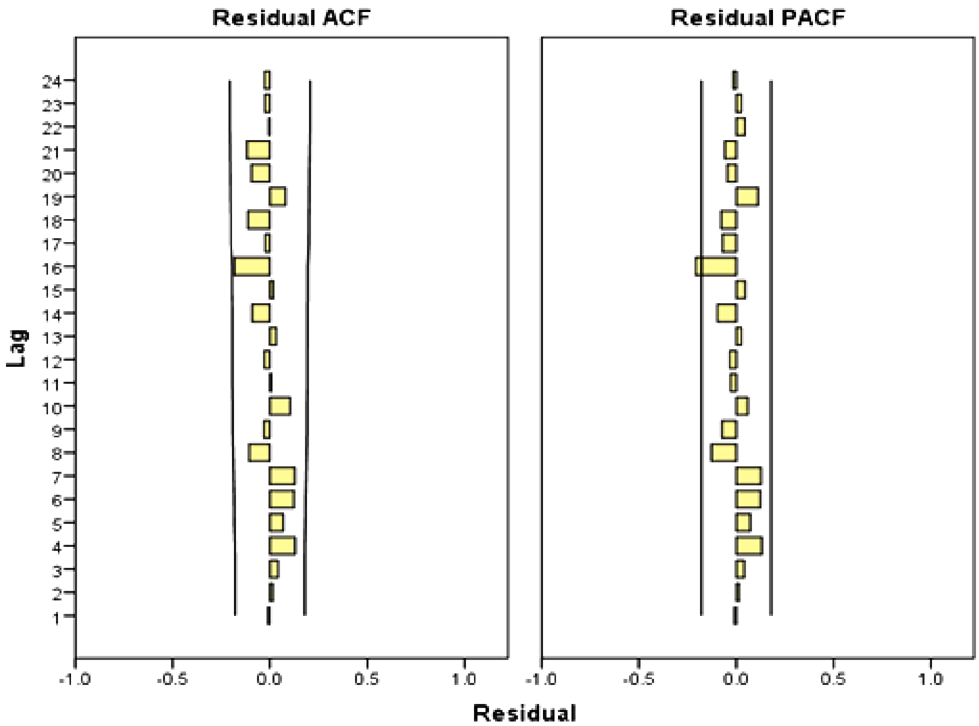

Figure 3: Residual ACF and PACF Plots

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Figure 4: Comparison with national standards

On Comparing with NAAQ Standards it is found that every year recorded mean values are very much higher than the specified limit 60µg/m^3 yearly.

3.3.2 Suspended Particulate Matter $PM_{2.5}$

Graphical presentation of Mean $PM_{2.5}$ values from year 2005 to 2015 is given in Figure 5. It is observed from figure 5 that there is seasonal variation in the mean value of $PM_{2.5}$. The range of monthly mean $PM_{2.5}$ value was same every year except years 2010 and 2012 where a maximum value is increased significantly. The range for mean value of $PM_{2.5}$ was 150-450µg/m^3. But in year 2010 and 2012 it raised up to 600 and 700µg/m^3 respectively. $PM_{2.5}$ levels are very much high in comparison to NAAQ standard 40µg/m^3 annually. Since year 2011 every year, a decrease has been recorded in the minimum pollutant level. In monsoon season (July to September) $PM_{2.5}$ levels are lowest and in winter and summer season these levels are high. Highest values are recorded during summer season in months of April and May every year.

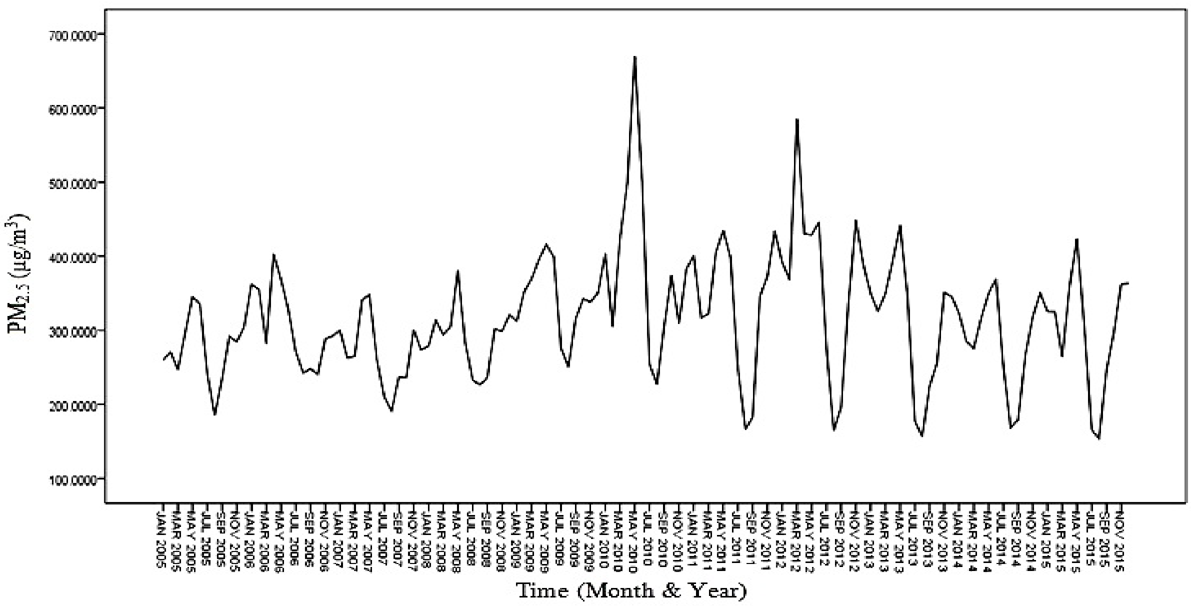

Figure 5: Graphical presentation of Mean $PM_{2.5}$ values from year 2005 to 2015

ARIMA(0,0,1)(1,1,0) model is used for analysis and forecasting. It is observed from the Table 5 that in Ljung-Box test significance value is 0.839 which is greater than p = 0.05(significance level for comparison). So proposed model does not does not exhibit lack of fit. Moreover, Stationary R-squared is 0.653 which is large enough and Normalised BIC is small as compared with other models, which is desirable. So the proposed model is good fitted and acceptable. Figure 6 shows the forecasting of mean PM $_{2.5}$ values for the period of 2016-2018.

The bold black line represents the observed values and blue line shows model fitted values in Figure 6. The dotted lines represents upper control limit (UCL) and lower control limit (LCL) at 95% confidence level. The model shows good fit for Mean PM $_{2.5}$ as predicted values are between 95% Confidence limits. Cross-validation cannot be completed due to unavailability of data of $PM_{2.5}$ for years 2016 onwards.

Table 5: Model statistics for mean $PM_{2.5}$ value

Model	Number of Predictors	Model Fit statistics				Ljung-Box Q(18)			Number of Outliers
		Stationary R-squared	RMSE	MAPE	Normalized BIC	Statistics	DF	Sig.	
PM2.5 level ARIMA(0,0,1)(1,1,0)	0	.653	42.072	10.739	7.718	10.509	16	.839	4

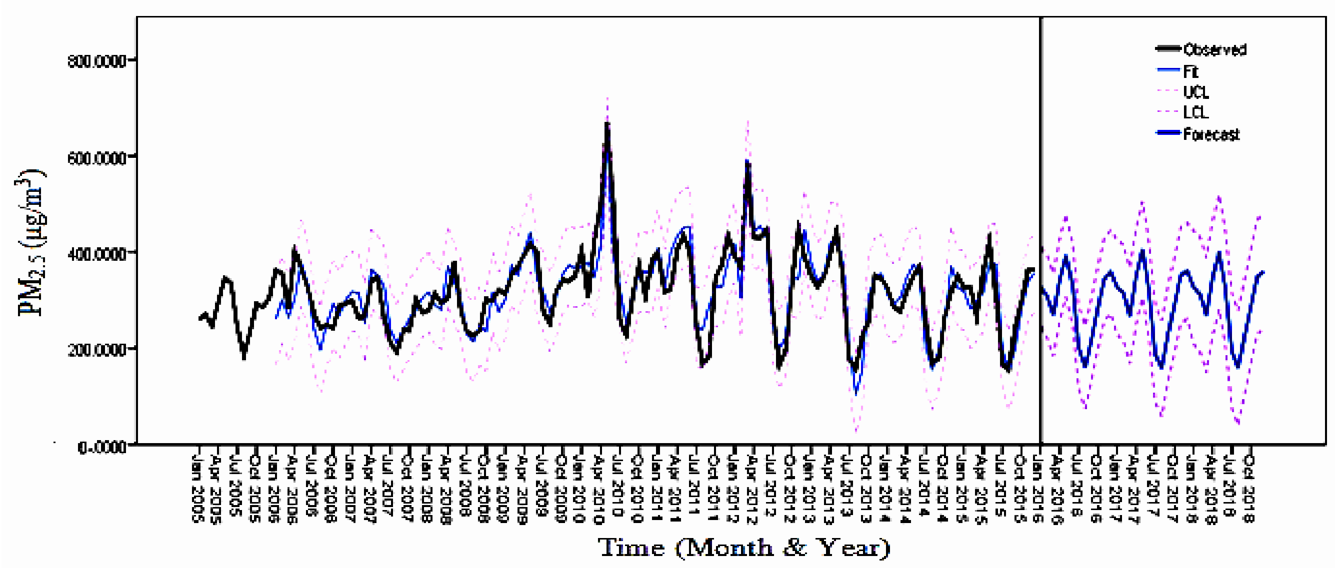

Figure 6: Forecasting of Mean PM $_{2.5}$ for period 2016-2018

The forecast values with upper control limit (UCL) and lower control limit (LCL) for $PM_{2.5}$ are given in Table 6 at 95% confidence level for every month of year 2016 to 2018 as proposed model. Auto correlation function (ACF) and partial auto correlation function (PACF) for residuals are shown in Figure 7. The border line indicates boundary for statistical significance. It can be concluded from the figure 7 that proposed model is good, as all residuals are not significant except at lag 24.

Table 6 : Forecasting of Mean $PM_{2.5}$value for year 2016-2018

	Jan 2016	**Feb 2016**	**Mar 2016**	**Apr 2016**	**May 2016**	**Jun 2016**	**Jul 2016**	**Aug 2016**	**Sep 2016**	**Oct 2016**	**Nov 2016**	**Dec 2016**
Forecast	326.5726	308.4522	268.8348	341.9446	392.6670	331.0462	201.7488	159.8543	217.8727	284.0677	343.7945	357.9055
UCL	408.6639	394.4950	354.8776	427.9874	478.7098	417.0890	287.7916	245.8971	303.9155	370.1105	429.8373	443.9483
LCL	244.4812	222.4093	182.7920	255.9018	306.6242	245.0034	115.7060	73.8115	131.8299	198.0249	257.7517	271.8627
	Jan 2017	**Feb 2017**	**Mar 2017**	**Apr 2017**	**May 2017**	**Jun 2017**	**Jul 2017**	**Aug 2017**	**Sep 2017**	**Oct 2017**	**Nov 2017**	**Dec 2017**
Forecast	326.0590	315.3788	266.8312	349.3579	405.3754	319.7689	186.8651	157.2210	229.3217	289.2198	351.4081	360.2239
UCL	424.6200	415.0889	366.5413	449.0679	505.0855	419.4790	286.5751	256.9311	329.0318	388.9298	451.1182	459.9340
LCL	227.4980	215.6688	167.1211	249.6478	305.6653	220.0589	87.1550	57.5109	129.6116	189.5097	251.6981	260.5138
	Jan 2018	**Feb 2018**	**Mar 2018**	**Apr 2018**	**May 2018**	**Jun 2018**	**Jul 2018**	**Aug 2018**	**Sep 2018**	**Oct 2018**	**Nov 2018**	**Dec 2018**
Forecast	326.2718	312.5083	267.6615	346.2858	400.1089	324.4423	193.0330	158.3122	224.5771	287.0847	348.2530	359.2631
UCL	443.7758	431.6227	386.7759	465.4002	519.2233	443.5567	312.1474	277.4266	343.6915	406.1991	467.3674	478.3775
LCL	208.7678	193.3940	148.5471	227.1714	280.9945	205.3279	73.9186	39.1979	105.4627	167.9703	229.1386	240.1487

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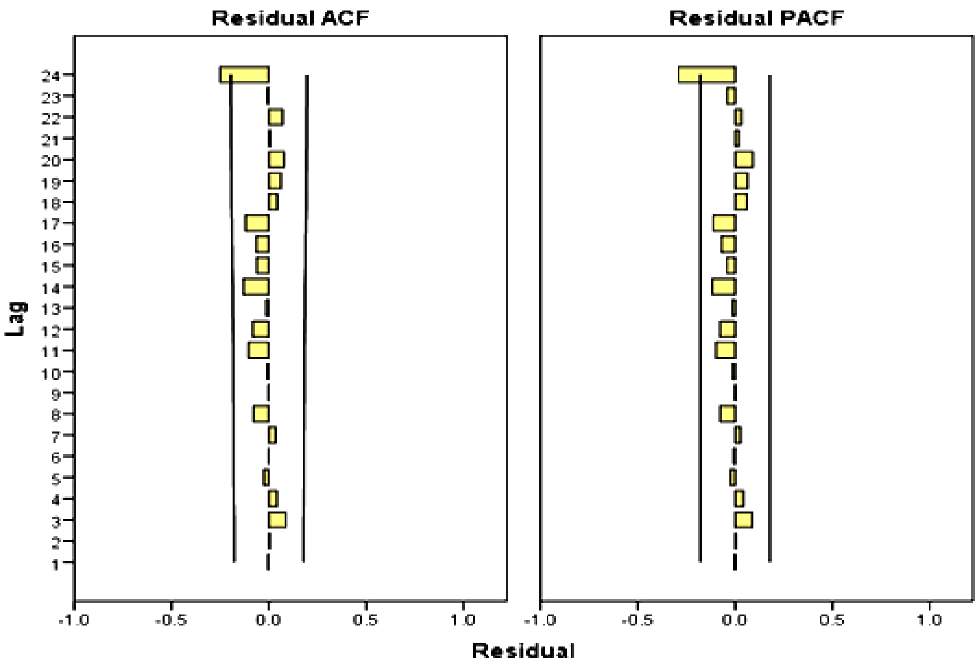

Figure 7: Residual ACF and PACF Plots

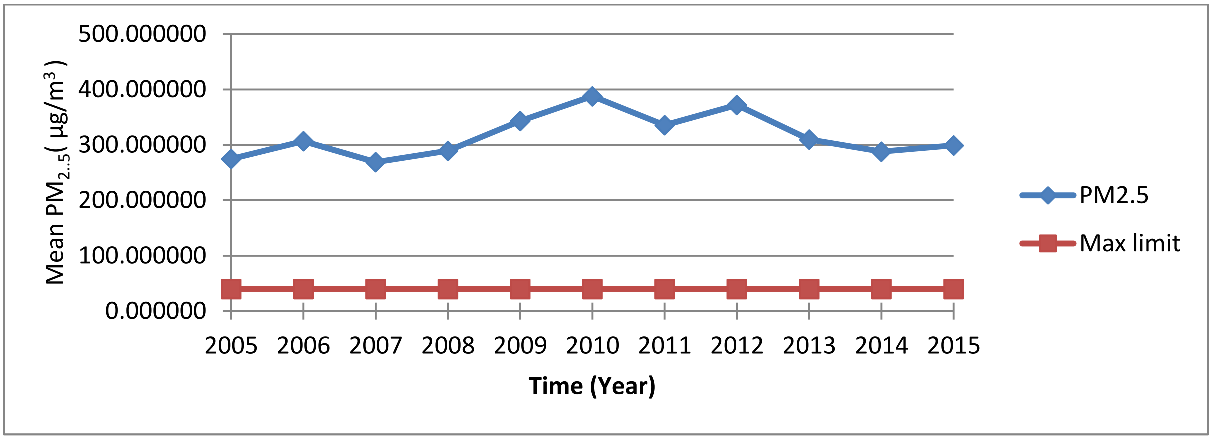

Figure 8: Comparison with national standards

On Comparing with NAAQ Standards it is found that every year recorded mean values are very much higher than the specified limit 40µg/m^3 yearly. It is observed from Figure 8 that values were eight times higher than the permissible maximum limits.

4. CONCLUSION

The present study highlights that the air pollution become a major problem for the Jaipur city during last decade. This study reveals that both the particulate pollutants, PM $_{10}$ and $PM_{2.5}$ are mostly above permissible limits at study site It is observed that there is no gradual increasing or decreasing trend in the studied air pollutants i.e. PM_{10} and $PM_{2.5}$. PM_{10} and $PM_{2.5}$ values varies seasonally and decreases in monsoon season between months July to September, in rest of the months in winter and summer season every year observed values shows considerable increase in pollutant level. It is observed that $PM_{2.5}$ values are highest in the summer season. ARIMA model fitted the observed value with good correlation coefficient for duration 2005 to 2015. The residuals are also very small for the ARIMA model for forecasting the level of PM_{10} for the year of 2016 to 2017.

The findings of this study may provide a comprehensive database for framing an appropriate strategy for necessary preventive measures. In addition to above, public awareness for environment protection should be adopted and green plantation along highway and within industries should be encouraged. It may, thus be concluded that strict implementation of environmental regulations and adoption of adequate pollution control measures is need of the hour.

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