Journal of Chemical Health Risks
www.jchr.org
JCHR (2024) 14(2), 2935-2944 | ISSN:2251-6727

Photochemical Smog in Delhi: Impact, Analysis and Future trends

Dr Nidhi Sharma[1], Dr Shweta Taneja[2], Dr Bhawna Suri[3], Savneet Kaur[4], Arshita Bhatt[5]
[1]Department of Applied Science
VIPS-Technical Campus
Delhi-110084
[2,3]Department of Computer Science & Engineering
Bhagwan Parshuram Institute of Technology
Rohini, Delhi-110085.
[4]Department of Information Technology, Guru Tegh Bahadur Institute of Technology, New Delhi, India.
[5]ZS Associates, Gurugram, Haryana 122002.

(Received: 07 January 2024 Revised: 12 February 2024 Accepted: 06 March 2024)

KEYWORDS
Volatile Organic Compounds (VOC), AutoRegressive Integrated Moving Average (ARIMA) model, Particulate Matter (PM), Time series forecasting

Abstract
Smog is the haze that envelopes the ambient atmosphere of urban cities. It is generated due to chemical reaction between Nitrogen Oxides (NO_X) and volatile organic compounds(VOC) catalyzed by solar UV radiation which leads to formation of ground level Ozone and PAN (Peroxyacyl Nitrate) as the main products of smog. In recent years Delhi has been facing very frequent episodes of this visible type of air pollution. This brought us to study the Smog formation in Delhi.

In this work, data is collected for the period of seven years, from 2016 to 2022 from Central Pollution Control Board (CPCB, GOI) website. We have used correlation and linear regression analysis along with descriptive analysis to analyse and predict the trend of smog generating pollutants i.e., volatile organic compound (VOC), Nitrogen Oxides (NO and NO_2), Ground level ozone(O_3), suspended particulate matter and respirable suspended particulate matter (PM10 and PM 2.5), and certain environmental factors like wind direction and speed, relative humidity and atmospheric temperature. The formation of smog shows seasonal variability and also the weather characteristics influence smog formation along with anthropogenic reasons. Smog formation has deleterious health effects. In pandemic times the spell of fog decreased appreciably indicating that smog is controllable by human interventions. Smog not only causes severe health disorders but ozone is detrimental for vegetation too.

1. Introduction

The National Capital of India, Delhi is facing a major crisis pertaining to air pollution. Rapid construction of modern estate with all hi-tech facilities, industrialization & modernization led to a massive deterioration of the immediate air we breathe. Such circumstances are detrimental for the health of the huge population that resides here.

One of the visible pieces of evidence of increasing pollution levels is Smog. Smog- the word is formed from smoke and fog. Smog, in scientific terms, can be defined as the formation of a blanket of fog which mainly comprises particulate matter and ground-level ozone formed by reaction of primary pollutants in the ambient air.

Smog is formed due to high temperature and stagnant wind. These primary pollutants mainly include NO_x and volatile organic compounds (VOC) majorly attributed to vehicular emissions. Photochemical smog is the smog formed due to a complex photochemical reaction in the atmosphere in these pollutants which are called "precursors" in the presence of sunlight [1]. In Los Angeles in the 1940s, photochemical smog was first observed. Many other cities like Manila and Mexico, Australia, Greece, Japan, India and the UK were also affected by the same [2]. This fog which exceedingly decreases the visibility of the surrounding is generally observed with maximum concentration and frequency after monsoon season expires (October-November) and in cold winter months (December - January) that too during nights and early mornings. This type of smog causes severe health effects, shortness of breath, irritation in eyes, nausea, asthma attack, heart and cardiovascular ailments. Due to the severe pollution in Delhi, 18,600 premature deaths are estimated per year [3].

Journal of Chemical Health Risks
www.jchr.org
JCHR (2024) 14(2), 2935-2944 | ISSN:2251-6727

1.1. Causes of SMOG formation

Photochemical smog formed in Delhi is majorly due to primary pollutants released by following processes:

1.1.1. Vehicular Emission

With increase in number of vehicles on road, there was a significant increase observed in NOx emission since 2005 as due to CNG's high flash point more nitrogen reacts with oxygen thus increasing NOX emission and increment in VOC is also assessed which comes from the exhaust of 2 wheelers and passenger cars [3].

1.1.2. Stubble Burning in Adjoining States

An estimated 35 million tons of residual stubble are burnt in the state of Punjab and Haryana, which account fior up to 60 percent of air pollution in Delhi. In general, photochemical smog is formed away from the site which is the source of its precursor. Moreover, the flow of air in Delhi is from west to east due to the stubble smoke that reaches here and in winter due to stagnant air it leads to formation of smog.

1.1.3. Industrial Exhaust

The smoke from various industries and power plants comprises total suspended particulate matter SOX and NOx , main pollutants forming the smog .

1.1.4. Other Factors

Some other factors leading to smog formation may include continuous construction and demolition activities which cause suspension of dust in air, Burning of municipal solid waste , road dust , and diesel generators[4].

1.2 Pollutant forming the SMOG

A. Particulate matter (PM 10 and PM2.5):-The particulate matter released in the form of smoke and soot from vehicular and industrial exhaust and also due to burning of fossil fuels, such as suspended particulate matter and respirable suspended particulate matter remain in the air in the form of suspensions.

B. NO_X:-The main pollutant released from vehicular exhaust and industrial smoke act a primary pollutant which consist of NO and NO_2 reacts in atmosphere to form secondary pollutants.

C.VOC (Volatile Organic Compounds):- these are the organic compounds present in the ambient air such as benzene, toluene, percholoethylene etc which is the major contributor to smog formation as they are primary pollutants.

D. PAN:- Peroxyacyl nitrate is the nitrate that formed from VOC in the presence of NO_2 and light it is an eye irritant and are mutagenic.

E. OZONE:- ozone in troposphere is known as bad ozone formed during the photochemical reaction between the primary pollutants VOC, NOX etc. which is the primary constituent of the photochemical smog . ozone causes severe health effects

1.3 Effects of SMOG

Increase in air pollution and smog is causing an emergency like situation in Delhi which not only causes the severe health effects but also affects the local vegetation, flora and fauna. Starting from mild ailments like cough and cold , shortness of breath, eye irritation , watering of eyes, to acute diseases such as, frequent asthma attacks, ischemic heart disease, chronic pulmonary obstructive disease, pneumonia, cardio-vascular and other pulmonary diseases in worst cases it may lead to lung cancer and heart attack[5].

In plants, ozone has a detrimental effect on plants such as reduction in leaf area and flowering decrease in photosynthesis water use efficiency which primarily affect horticulture plants and commercial crops. It may cause a direct effect too such as making plants susceptible to fungi and pathogen attack.

1.4 Study area

Delhi lies in the northern part of India with an area of 1483 km2 with latitude and longitudinal coordinates 28°35'N, 77°12'E, respectively. Considering the geography and the climatic condition Delhi is a semi arid region with scorching summers, average rainfall and chilly winters. It lies 160 km to the south of Himalayas at an elevation of 216 km from sea level[6].

Journal of Chemical Health Risks
www.jchr.org
JCHR (2024) 14(2), 2935-2944 | ISSN:2251-6727

Figure 1. Geographical division of Delhi

The figure1 shows the geographical division of Delhi and in our study we have taken Anand Vihar station into consideration.

In section 2, the work done related to this is discussed. The materials and methods to prove the work is mentioned in section 3 subsequently followed by section 4 in which results are shown. The paper is concluded in section 5.

2. Related Work

Ever since pollution in Delhi has become a major issue of concern for all, various researchers have done work to get a deep understanding of the problem and how to curb it.

Rati Sindhwani, Pramila Goyal have assessed the trends of gaseous and particulate emissions generated by traffic and trends over Delhi (2000–2010) [3]. The authors have studied past trends of gaseous and RSPM (PM 2.5) emission estimates over Megacity Delhi (2000-2010) and estimated the emission in (2011-2020) [7]. In [8], authors have used Descriptive analysis and predictive analysis techniques to analyze the trends of various air pollutants like suspended particulate matter (PM), sulphur dioxide (SO2), ozone (O3) carbon monoxide (CO), nitrogen dioxide (NO2), and predict the future trend. The authors in [9] have tried to analyze the quality of human life with respect to air pollution in different states of India using time series analysis and correlation. They have concluded that Delhi NCR has the lowest quality of human life due to severe concentration of pollutants in air.

Iva Hunova and Vít Baumelt have studied Observation-based trends in ambient ozone in the Czech Republic over the past two decades[10]. Pawan Gupta et al. have studied satellite remote sensing of particulate matter over global cities by studying the correlation between AOT(Aerosol Optical Thickness) and particulate matter.[11].

Humaib Nasir et al. have studied the NAQI data and reviewed the air quality monitoring system in India [12]. David Hu and Juyuan Jiang have studied the formation of PM 2.5 from various pollutants causing smog and compared the control of PM2.5 pollutant control strategies in the USA and that in China [13]. Mattias Hallquist et al. have studied air quality policies related to photochemical smog, the scientific challenges thereof and implications in China [14].

Sanjay Tyagi, Suresh Tiwari and Anuradha Mishra have studied the decreased visibility over New Delhi due to air pollution and winter fog by analyzing the mass distribution of particulate matter during the month of January in the year 2014 and 2015[15]. Suresh Tiwari, Swagata Payra and Deewan Singh Bisht have studied visibility degradation during spell of fog due to urban aerosols of anthropogenic origin at Delhi, India by using meteorological parameters [16]. B.R. Gurjar et al. have studied primary pollutant emission source and future trends (1990–2000) for megacity Delhi and consequences.[17].

3. Materials and Methods used

3.1 Data set used

To conduct our study, data was collected from the Central Pollution Control Board (CPCB, GOI) website[18].

The dataset snapshot is shown in figure 2. Fourteen attributes relevant to smog were studied: season, NO, NO2, NOx, benzene, toluene, O3, PM10, PM2.5, wind speed and direction, atmospheric temperature, relative humidity and ambient temperature. The data was collected for 7 years, 2016 to 2022. It was observed everyday and segregated into seasons further. Dataset contains concentration of pollutants and fluctuations in environmental factors.

Journal of Chemical Health Risks
www.jchr.org
JCHR (2024) 14(2), 2935-2944 | ISSN:2251-6727

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Date	Season	Benzene	Toluene	NO	NO2	NOx	PM2.5	PM10	RH	WS	WD	Ozone
2	31-01-2016	Winter	12.59548	30.05903	197.2729	97.66484	355.7645	330.1148	580.8171	62.70968	1.033548	193.2681	17.4271
3	29-02-2016	Winter	27.62414	71.66793	142.749	86.64379	271.8762	177.0159	296.8948	49.75034	1.417586	202.1555	28.62621
4	31-03-2016	Summer	24.15452	57.19677	128.1213	84.96129	250.6852	136.6442	287.9	42.51968	1.571935	232.7771	27.17452
5	30-04-2016	Summer	18.703	42.16867	159.617	95.73267	301.7623	144.8507	393.8453	23.22533	1.969667	234.9733	32.46333
6	31-05-2016	Summer	11.93903	34.72032	56.94226	67.70903	138.0787	100.469	427.1345	36.91484	2.838387	142.3284	27.77581
7	30-06-2016	Monsoon	9.907	40.09233	39.9	56.468	104.7983	92.93833	328.1673	49.945	2.768333	140.928	24.50633
8	31-07-2016	Monsoon	6.809032	33.16903	50.25774	47.37452	110.8706	58.1029	196.2106	69.4029	1.839032	154.229	23.60387
9	31-08-2016	Monsoon	5.046774	36.75903	46.5271	42.53452	101.4313	45.26194	182.2439	68.30097	2.070323	138.9794	23.87387
10	30-09-2016	Post-Mon	5.434333	22.29	63.344	54.094	134.6097	69.68033	332.5803	54.502	1.315667	180.984	30.92033
11	31-10-2016	Post-Mon	11.73613	37.6429	204.0168	103.1971	369.5906	201.0361	583.1435	47.43258	0.767097	207.0061	38.91774
12	30-11-2016	Winter	17.12233	50.20033	287.8823	137.3347	505.1357	333.8697	801.5673	46.31233	0.686	215.8243	34.837
13	31-12-2016	Winter	16.69452	40.57226	165.9152	81.74677	289.2987	295.1584	634.7745	60.80258	0.808065	193.3029	16.71645
14	31-01-2017	Winter	12.69548	29.76097	152.2071	84.26258	270.6132	179.1203	399.3355	59.52677	0.94871	219.0139	19.85065
15	28-02-2017	Winter	8.144286	20.40321	143.2432	103.6114	279.7179	133.1254	443.3429	49.55607	0.839643	223.4125	14.46
16	31-03-2017	Summer	7.667742	16.83935	72.26452	96.20677	179.8606	109.4903	432.5123	38.53258	0.993871	215.4855	17.13484
17	30-04-2017	Summer	6.316667	19.38633	123.7117	111.2343	260.6897	128.4943	507.078	24.97867	1.503667	207.312	41.43567
18	31-05-2017	Summer	0.815806	6.052581	97.91516	90.33677	201.9619	151.2174	466.3713	34.05516	1.520323	179.0858	65.52677
19	30-06-2017	Monsoon	0.67	3.91	51.61433	97.536	153.1457	54.854	375.848	48.27333	3.933333	124.689	30.40133
20	31-07-2017	Monsoon	0.67	3.91	23.3	91.4	108.88	41.11	336.17	52.27	4.67	98.45	27.22
21	31-08-2017	Monsoon	0.67	3.91	23.3	91.4	108.88	41.11	336.17	52.27	4.67	98.45	27.22
22	30-09-2017	Post-Mon	0.67	3.91	23.3	91.4	108.88	41.11	336.17	52.27	4.67	98.45	27.22
23	31-10-2017	Post-Mon	1.500323	4.457742	45.97194	105.6887	278.2	102.0377	410.251	50.53323	2.526452	111.9487	33.87516

Figure. 2. Dataset details

3.2 Proposed Approach

The Proposed approach is shown in figure 3. Data gathered from CPCB is cleaned and preprocessed. In preprocessing, methods like noise removal, elimination of redundancy, scaling, date parsing etc. were carried out. Next, Time series forecasting is implemented using the ARIMA model. Also, Anaconda distribution[19] and Tableau[20] were used to carry out the descriptive analysis of the refined dataset for different stations.

3.3 Techniques Used

1. Statistical Description: The insight of the dataset can be statistically analyzed and visualized graphically using descriptive analysis for the interpretation of the collected data.

2. Time Series Forecasting : It is a method of predicting or forecasting future values based on present values over a period of time. In this work, uni-variate time series forecasting is considered, using the past time series data to predict future trends. The algorithm used is ARIMA i.e, AutoRegressive Integrated Moving Average' model, aims to study the past time series data and predict the future values[21].

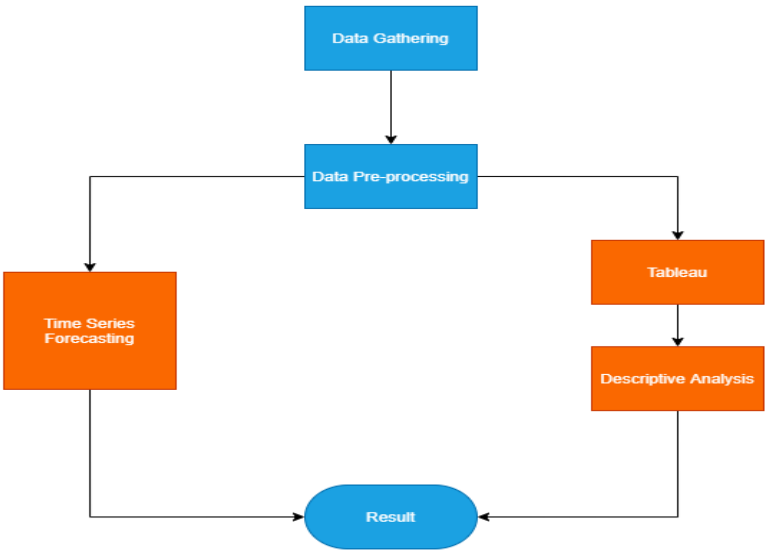

Figure 3. Proposed Approach

Journal of Chemical Health Risks
www.jchr.org
JCHR (2024) 14(2), 2935-2944 | ISSN:2251-6727

4. Results

The result section consists of two sub sections, namely descriptive analysis results and forecasting future trends of different compounds.

4.1 Descriptive analysis results

Resulted smog in Delhi has been divided into seasonal study for better observations. Seasons that have been considered are: summer (March to May), monsoon (June to September), Post monsoon (October and November)and winter (December to February).

The trends of volatile organic compounds are shown in Fig 4, Toluene and Benzene. Decreased level of volatile compounds is shown from summer to monsoon and sudden increase at post monsoon which contributes to winter smog.

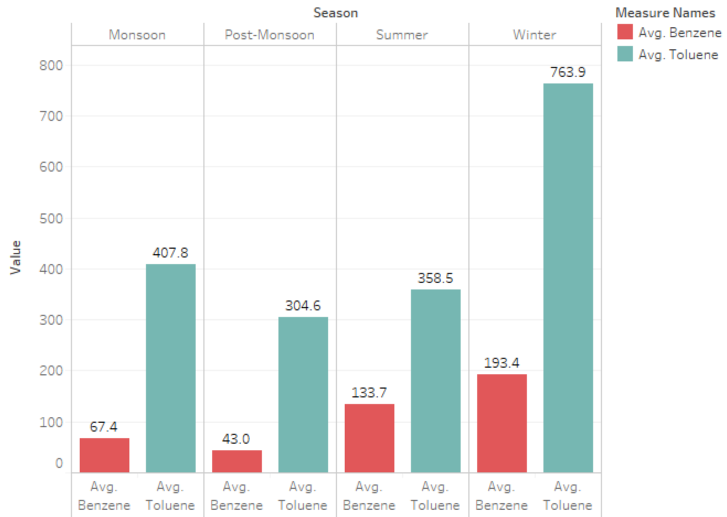

Figure 4: Trend of volatile organic compounds

Figure 5 represents the distinct concentration of NOx for entire seasons. The variations in the level of NOx can be seen by the different sized circles in the figure. Oxides of nitrogen that seem to be in less fluctuating levels contribute to the smog created for the entire year though post monsoon concentration is relatively high which directly is associated with the haze created. Figure 6 further shows the oxides of nitrogen separately, NO2 and NO. Again the drastic increase in the concentrations can be seen in the post monsoon.

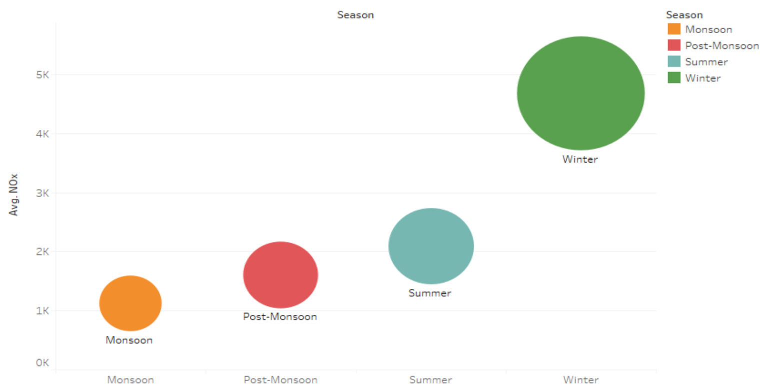

Figure 5. Oxides of Nitrogen visualization

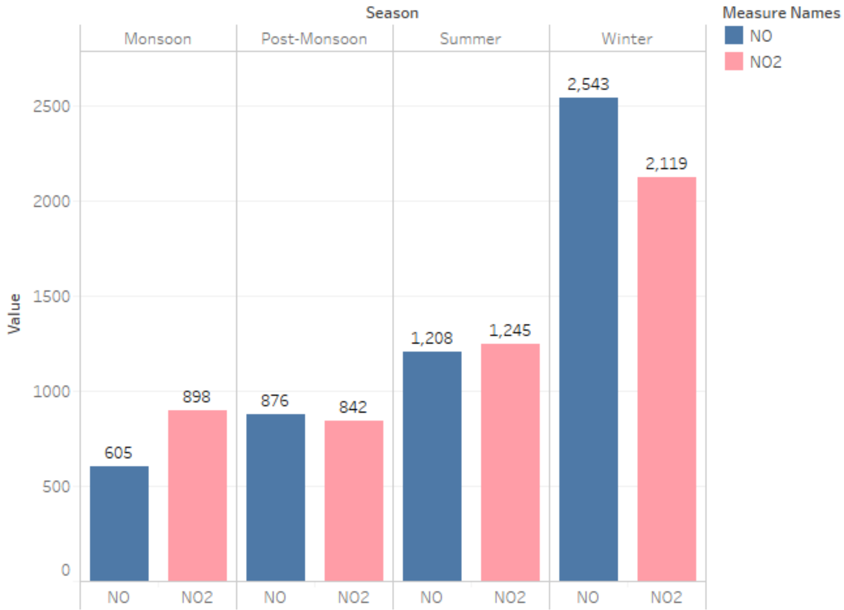

Figure 6. NO_2 and NO trend over different seasons

Figure 7, represents the seasonal trend of ozone. Formation of ozone in summer is the highest due to the radiations from the sun that eventually shows the correlation of ozone and temperature.

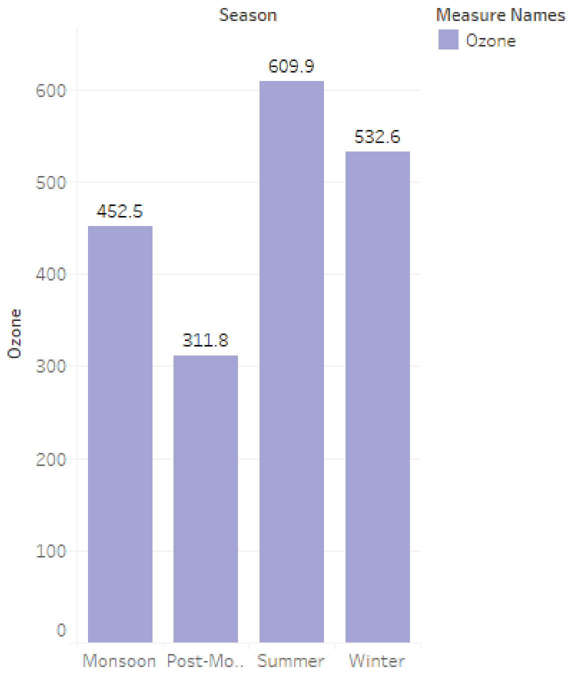

Figure 7. Concentration of Ozone

Journal of Chemical Health Risks
www.jchr.org
JCHR (2024) 14(2), 2935-2944 | ISSN:2251-6727

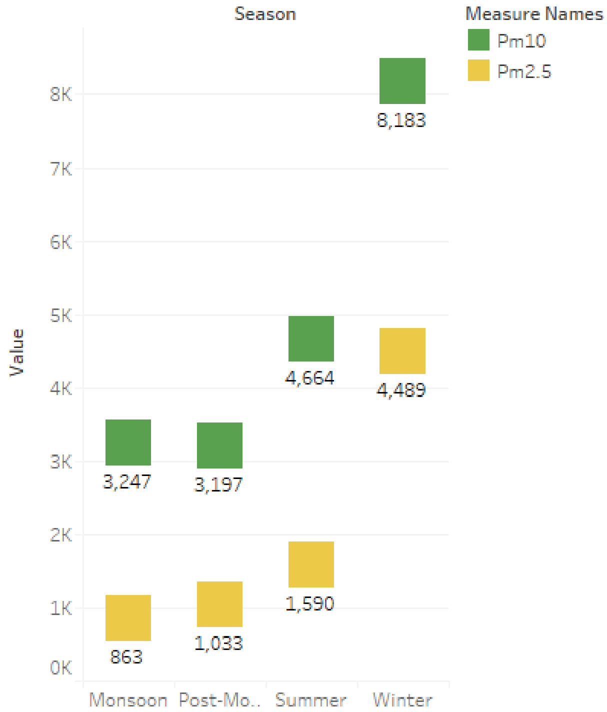

Figure 8. Particulate Matter average visualization

Figure 8 indicates the PM(10&2.5) concentration in different seasons. The lightest shade presents the least values during monsoon and most dense value in post monsoon. Different environment factors, like temperature, relative humidity, wind speed and wind direction are observed. In figure 9, variations in these factors are observed in different seasons.

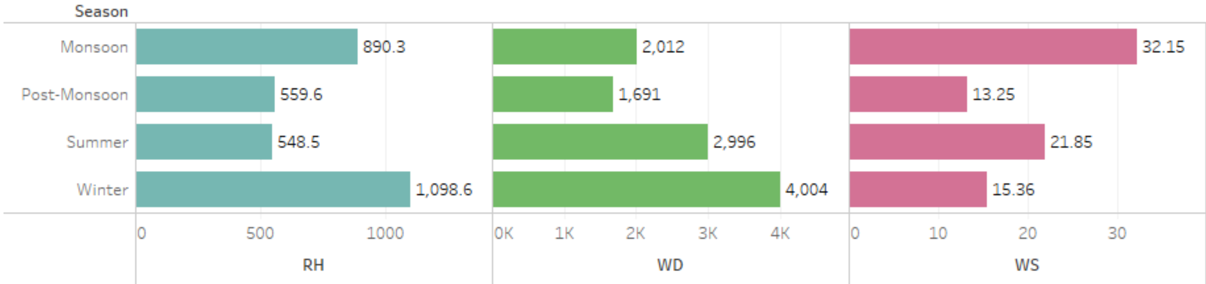

Figure 9. Study of environmental factors

4.2 Forecasting future trends

Using the ARIMA model we have obtained a forecast for gaseous and particulate matter involved in smog formation, for the upcoming years.

In Fig 13, oxides of nitrogen show to increase in initial months of the next year i.e the winter duration that is around 177 ug/m3 as also show certain seasonality in the trends, hence they are likely to spike around winter months (December to February). Similar seasonality based trends can be observed for particulate matter i.e PM10 and PM2.5 which spike around winter season and are at their lowest for the period between monsoon and post-monsoon. As shown in Fig 10 and Fig 11, for upcoming months PM10 and PM2.5 is likely to increase 330 ug/m3 and 580ug/m3.

Journal of Chemical Health Risks
www.jchr.org
JCHR (2024) 14(2), 2935-2944 | ISSN:2251-6727

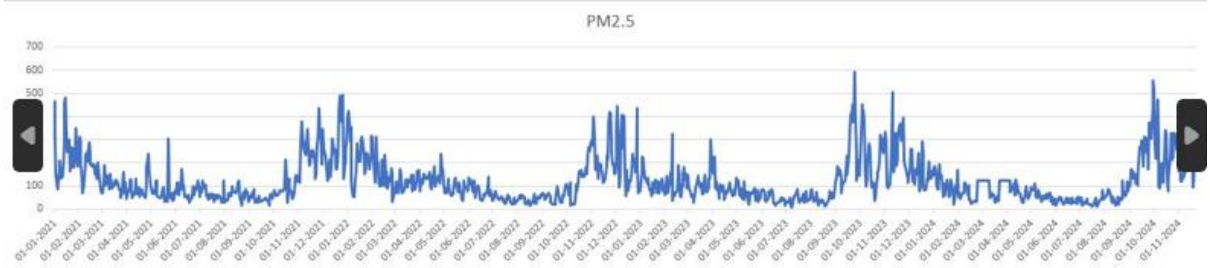

Figure. 10. Forecast of PM 2.5 levels

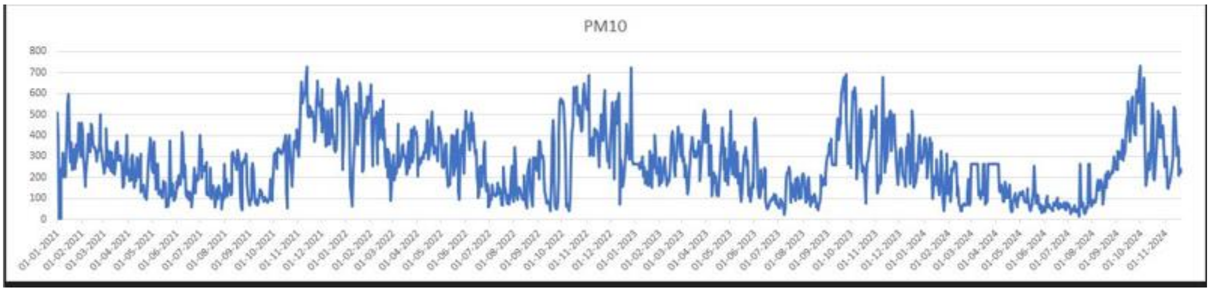

Fig. 11. Forecast of PM 10 levels

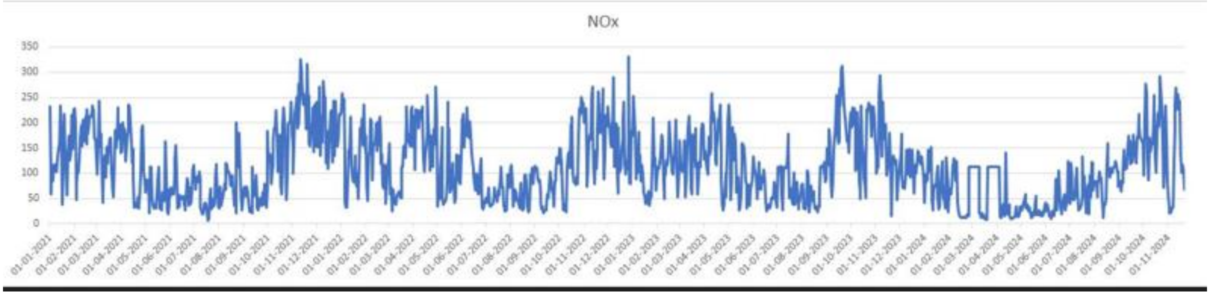

Figure 12. Forecast of NOx levels

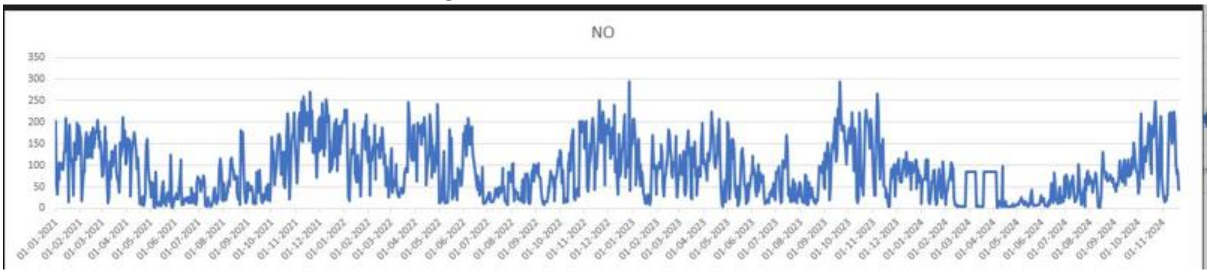

Figure 13. Forecast of NO levels

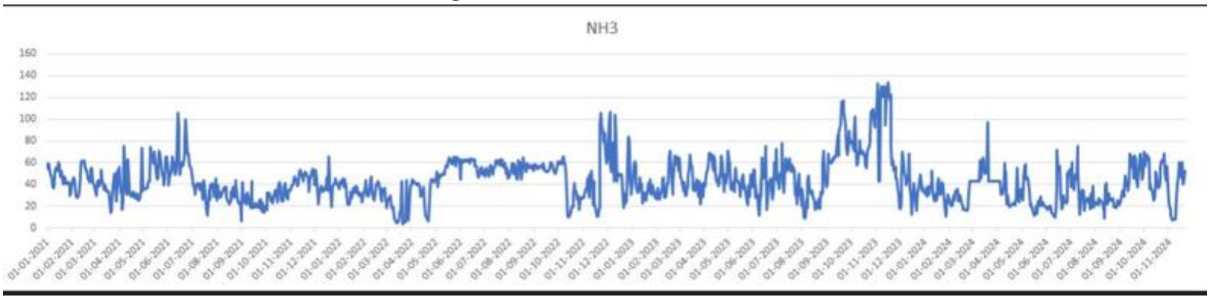

Figure 14. Forecast of Wind Speed levels

5. Conclusion and Future Scope

This study indicates that the aggravation of Smog related pollution in recent times can mainly be attributed to Particulate pollution. The buildup of smog is increased in the winter season due to low temperature and stagnant air along with high NOx pollution. Contribution of fossil fuel to smog cannot be negated as in spite of government guidelines on usage of fossil fuel, the amount of hydrocarbons in the form of Volatile organic Compounds in air are almost permanent in the post monsoon season. Smog, being the major pollution indicator in industrial cities on a global scale, is also responsible for health problems like COPD, asthma and allergic conditions. However, a negligible smog built up during first lockdown and significantly low smog during second lockdown indicates that restrictions, if imposed on emissions, increased usage of public transport and reduced road congestion can remarkably reduce smog load. Environmentally Intelligent methods to curb toxic air emissions as well as Smog built up monitoring in real time is the need of the hour to combat Smog in industrialized cities. To achieve this Government-Private partnership is required. Public should be able to gauge the toxic emissions in surrounding air to understand the impact of Air pollution and subsequent smog formation.Government subsidies on startups working on pollution abatement will further help in improving air quality and maintaining a sustainable future

References

1. Sawlani, R., Agnihotri, R., Sharma, C., Patra, P. K., Dimri, A. P., Ram, K., & Verma, R. L. (2019). The severe Delhi SMOG of 2016: A case of delayed crop residue burning, coincident firecracker emissions, and atypical meteorology. Atmospheric Pollution Research, 10(3), 868-879.
2. Rani, B., Singh, U., Chuhan, A. K., Sharma, D., & Maheshwari, R. (2011). Photochemical Smog Pollution and Its Mitigation Measures. Journal of Advanced Scientific Research, 2(4).
3. Sindhwani, R., & Goyal, P. (2014). Assessment of traffic-generated gaseous and particulate matter emissions and trends over Delhi (2000–2010). Atmospheric pollution research, 5(3), 438-446.
4. Sharma, M., & Dikshit, O. (2016). Comprehensive study on air pollution and green house gases (GHGs) in Delhi. A report submitted to Government of NCT Delhi and DPCC Delhi, 1-334.
5. Yang, L. E., Hoffmann, P., & Scheffran, J. (2017). Health impacts of smog pollution: The human dimensions of exposure. The Lancet Planetary Health, 1(4), e132-e133.
6. Geographical location of Delhi. https://www.mapsofindia.com/. Last accessed on 5th May, 2021
7. Sindhwani, R., Goyal, P., Kumar, S., & Kumar, A. (2012). Assessment of gaseous and respirable suspended Particulate matter (PM10) emission estimates over megacity Delhi: past trends and future scenario (2000-2020). Center for atmospheric sciences, 123-140.
8. Sharma, N., Taneja, S., Sagar, V., & Bhatt, A. (2018). Forecasting air pollution load in Delhi using data analysis tools. Procedia computer science, 132, 1077-1085.
9. Nidhi Sharma, Shweta Taneja & Arshita Bhatt (2020) Empirical analysis of life quality based on air pollution in states of India, Journal of Statistics and Management Systems, 23:7, 1213-1226, DOI: 10.1080/09720510.2020.1799579
10. Hůnová, I., & Bäumelt, V. (2018). Observation-based trends in ambient ozone in the Czech Republic over the past two decades. Atmospheric Environment, 172, 157-167.
11. Gupta, P., Christopher, S. A., Wang, J., Gehrig, R., Lee, Y. C., & Kumar, N. (2006). Satellite remote sensing of particulate matter and air quality assessment over global cities. Atmospheric Environment, 40(30), 5880-5892.
12. Nasir, H., Goyal, K., & Prabhakar, D. (2016). Review of air quality monitoring: case study of India. Indian Journal of Science and Technology, 9(44), 1-7."
13. David, H., & Juyuan, J. (2013). A study of smog issues and PM 2.5 pollutant control strategies in China. Journal of Environmental Protection, 2013.
14. Hallquist, M., Munthe, J., Hu, M., Wang, T., Chan, C. K., Gao, J., ... & Thynell, M. (2016). Photochemical smog in China: scientific challenges and implications for air-quality policies. National Science Review, 3(4), 401-403.
15. Sanjay Tyagi ,Suresh Tiwari ,Anuradha Mishra , (1970) " Impact of Air Pollution on Visibility Over New Delhi, India: A Case Study of Winter Fog " , International Journal of Advances in Science, Engineering and Technology(IJASEAT) , pp. 215-218,
16. Tiwari, S., Payra, S., Mohan, M., Verma, S., & Bisht, D. S. (2011). Visibility degradation during foggy period due to anthropogenic urban aerosol at Delhi, India. Atmospheric Pollution Research, 2(1), 116-120.
17. Gurjar, Bhola R. et al. , "Emission estimates and trends (1990–2000) for megacity Delhi and implications." Atmospheric Environment 38, no. 33 (2004): 5663-5681.

Journal of Chemical Health Risks
www.jchr.org
JCHR (2024) 14(2), 2935-2944 | ISSN:2251-6727

18. Air Quality Monitoring, Emission Inventory and Source Apportionment Studies –Delhi http://cpcb.nic.in/Delhi.pdf
19. Anaconda distribution. https://www.anaconda.com/products/distribution
20. Tableau Software. (2018). Tableau Desktop. [Online] Available at: https://www.tableau.com/products/desktop [Accessed 16 Jan. 2018].
21. Carta, S., Medda, A., Pili, A., Reforgiato Recupero, D., & Saia, R. (2018). Forecasting e-commerce products prices by combining an autoregressive integrated moving average (ARIMA) model and google trends data. Future Internet, 11(1), 5.