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Impact of Air Pollutants on Atmospheric Visibility in Delhi

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Abstract: ***The air pollution problem has been serious in Delhi due to the rapidly expanding economic, industrial and vehicular developments. It has significant influences on atmospheric visibility, whose degradation dominates in urban areas. Increased air pollution in urban area may lead to the atmospheric reactions, resulting into the formation of secondary pollutants similar to cloud the condensation processes. Northern regions of India experience severe visibility degradation conditions during the peak of winter season (December-January) each year. In this study, air pollutants concentration, meteorological parameters and atmospheric visibility in Delhi during 2006-2011 peak winter season of the years have been studied. In order to study the impact of air pollutants on visibility at IGI airport of Delhi during the winter season (December and January), the daily data of visibility and meteorological parameters like dry bulb temperature , humidity , wind speed , Dew point temperature have been collected and a study is carried out to correlate these parameters and air quality in terms of the concentration of CO , NOx , SO_2 and O_3 with the observed visibility. The analysis is carried out in two different ways to find the impact of air pollutants as well as other meteorological parameters on visibility. At first stage the normalized values of daily observed concentration of air pollutants and averaged values of daily visibilities along with other meteorological parameters are studied. Secondly, the analysis of hourly normalized data of the 7440 observations of hourly visibility and daily averaged visibility in the above said period is found to be 1636.9 meters and 1625.1 meters respectively. The regression analysis of daily averaged visibility using empirical model demonstrates that higher the concentration of air pollutants (CO, NOx, SO_2, O3), lower the visibility. Because air pollutants have a significant impact on atmospheric visibility, it is also observed that a targeted reduction of air pollutants in Delhi would improve the visual range.***

Keywords: about four key words separated by commas.

1. Introduction

Meteorological phenomena such as humidity, wind speed etc. are natural causes of changes in visibility in the atmosphere. Man made pollutants from combustion, construction, mining, agriculture and welfare are increasingly significant in the air pollution. Air pollution in India is reported to cause 527, 700 deaths a year. According to the WHO, the capital city of New Delhi is one of the top ten most polluted cities in the world. Declining regional air quality means visibility has also decreased dramatically. At the IGI airport, Delhi, the 700 flights on an average depart and arrive daily with the maximum numbers of flights in night and morning hours during winter, when the chances of dense pollutants are also high. Due to which the susceptible visibility degradation may be there. The thick blanket of pollutants remains till afternoon and sometimes shows no sign of abating for a few consecutive days which decreases visibility and affects aviation severely at the IGI airport. During winter season, several flights are cancelled and diverted due to visibility impairment. The visibility impairment for a couple of hours can delay or stop air traffic both locally and nationwide, causing substantial monetary loss. Most of activity in the tourism is based on sightseeing and visiting places. Unfortunately, many visitors are not able to see the spectacular vistas they expect. Generally it is found that high concentration of pollutants decreases the visibility, which is an important aspect of ambient air quality. Visibility impairment is probably the most easily recognized effect of air pollution and it is caused by scattering and absorption of light by particles and gases in air. Visibility degradation is the loss of contrast between the object and the background and arises from the attenuation of light by fine partials and gaseous pollution (Trijonis 1982).

Atmospheric pollution due to coal combustion, vehicle exhaust, and industry, the primary emission sources of particles over urban area, was considered to be the main cause of visibility degradation (Chanand Yao, 2008). Ambient aerosols, especially fine particles, played a dominant role in visibility reduction in different regions (Chanetal., 1997; Christoforouetal., 2000). Sometimes, the sky is so smoggy due to air pollutants that visibility is limited. It happens most often in large cities with many people, but these pollutants can also travel to other areas with the help of the wind. When pollutants are in the sky, sunlight can have trouble shinning through it. As a result, the climate of the area can be changed by pollutants. A reduction in sunlight may not be the only thing air pollution reduces. Scientists are researching the possibility that it may also inhibit rainfall. More clouds usually mean more rain, but not always, especially with certain specks of air pollution. Recent research findings report that particles of soot are often too small to produce raindrops large enough to hit the ground. This is unfortunate, because rain is one way to wash dust, soot, and chemicals from polluted air and allow mountains and buildings near and afar to be seen. For now, however, more research needs to be done. Air pollution and its harmful effects are visibility, rain, climate, and so much more. Gas molecules and atmospheric particles are smaller than the wavelengths of visible light. When light hits a gas molecule, the molecule absorbs and scatters the light in different directions. This is why at night we can see the beam of a torch even if we are not in the light's path. Visibility is reduced when atmospheric particles between the observer and the object absorb or scatter light from the sun. Light scattering by particles is the most important phenomenon responsible for impairment of visibility. Light can also be absorbed by atmospheric constituents: for example, elemental carbon (soot) and NO2 are particularly effective at absorbing light. The size, concentration and chemical characteristics of the particles affect atmospheric visibility. The finest particles (particularly those between 0.1 and 1 µm) are most efficient at reducing visibility. These small particles are mostly of human origin.

Air pollution that reduces visibility is often called haze or smog. The term smog originally meant a mixture of smoke and fog in the air, but today it refers to any mixture of air pollutants that can be seen. Smog typically starts in cities or areas with many people, but because it travels with the wind, it can appear in rural areas as well. One consequence of smog over any given area is that it can change the area's climate. Smog reduces the amount of the Sun's energy reaching the Earth's surface. In some cities, this reduction has been as high as 35 percent on particularly smoggy days. The reduction is greatest when the sun is low on the horizon because the sunlight has to travel through a greater amount of polluted air as its angle drops.

Particulates in the air often form condensation nuclei that attract water vapor. When enough moisture accumulates around natural dust particles for example, droplets of rain typically fall. But certain specks of air pollution, such as black carbon, can be too small to produce raindrops big enough to hit the ground. Since rain flushes dust, soot, and chemicals from polluted skies, atmospheric visibility could also be negatively impacted as a consequence.

2. Material and Methodology

2.1 Data

Central Pollution Control Board (CPCB) has mainly four monitoring stations at ITO, Delhi College of Engineering (DCE), East Arjun Nagar, and Siri Fort. Increased traffic density seems to have resulted into the worst air quality at Delhi. Since the nearby station of IGI airport is Siri Fort, we have taken air quality data of Siri Fort (The concentration of Carbon Monoxide (CO), Sulphur Dioxide (SO_2), Oxides of Nitrogen (NO_x) and Ozone (O_3) which are being monitored regularly. These hourly and daily pollutants observations are taken from CPCB for the years 2006-2011. The hourly and daily meteorological parameters like wind speed (WS), relative humidity (RH) and depression temperature (DT) (difference between dry bulb temperature and dew point temperature) are taken from Indian Meteorological Department (IMD) for years 2006-2011.

FIGURE-1

2.2 SOFTWARE USED:

The data obtained from the sources mentioned above was converted into Microsoft Excel -2007 format by using MS-Office -2007.The missing data values were obtained by using SPSS(Statistical Package For Social Science)-7.5 for Windows .The analysis of data was carried out using MS- Excel-2007.

2.3 LINEAR REGRESSION:

Much of statistical weather forecasting is based on the statistical procedure known as linear, least-squares regression.

MULTIPLE LINEAR REGRESSION

A forecast can be expressed as a function of a certain number of variables that determine its outcome. In multiple linear regression (MLR) technique, there is one dependent variable to be predicted and two or more independent variables in the form of multiple linear regression can be expressed as:

$$Y = b_1 + b_2 X_2 + \dots\dots\dots\dots + b_k X_k + e, \qquad (1)$$

where Y (AQI) is dependent variable X_2, X_3.........., X_k (previous day's AQI and meteorological variables) are independent variables, b_1, b_2.........., b_k are linear regression parameters, e is an estimated error term, which is obtained from independent random sampling from the normal distribution with mean zero and constant variance. The task of regression modeling is to estimate the b_1, b_2.........., b_k, which have been done using least square technique. In order to avoid the asymptotic effect, the input and output data are normalized between -1 to +1 before any preprocessing using the minimum and maximum of the time series as follows:

$$x_{normalized} = \frac{2 \times (x - x_{min})}{(x_{max} - x_{min})} - 1.$$

Eq. (1) can also be written in this form

$$Y = X\,b + e \qquad (2)$$

where $Y = \begin{bmatrix} Y_1 \\ Y_2 \\ : \\ : \\ Y_n \end{bmatrix}$, $X = \begin{bmatrix} 1\,X_{21}\;X_{31}\;....\;X_{k1} \\ .... \qquad\qquad .. \\ 1\,X_{2n}\;X_{3n}\;....\;X_{kn} \end{bmatrix}$, $b = \begin{bmatrix} b_1 \\ b_2 \\ : \\ : \\ b_k \end{bmatrix}$ and

$e = \begin{bmatrix} e_1 \\ e_2 \\ : \\ : \\ e_n \end{bmatrix}$

So Y is an n x 1, X is an n x k, b is a k x 1 and e is an n x 1 matrix.

After using the least square technique, the solution has been obtained as $b = \left(X'X\right)^{-1}\left(X'Y\right)$, where X' is transpose of X. The resulting model has been used to forecast future observations.

3. Results and Discussion

Relationships between visibility, meteorological variables and concentration of pollutants

(A) Daily Data: The correlation of daily averaged visibility, meteorological variables and concentration of air pollutants have been studied and analyzed as shown in Table 1. It has been found that visibility has negative correlation (inversely proportional) with CO, NO_x, SO_2, O3 and RH. It has also been found that visibility has positive correlation (directly proportional) with variables such as PDVV, WS and Depression temperature.

Table 1: Correlation matrix of average daily visibility, previous day visibility, meteorological parameters and air pollutants in Delhi for 2006-2011 peak winter seasons

	VV	PDVV	WS	RH	CO	NOx	SO2	O3	DT
VV	1								
PDVV	0.687	1							
WS	0.221	0.001	1						
RH	-0.493	-0.456	0.008	1					
CO	-0.193	-0.063	-0.422	0.041	1				
NOx	-0.107	0.023	-0.303	-0.226	0.229	1			
SO2	-0.105	-0.020	-0.153	-0.078	0.236	0.283	1		
O3	-0.139	-0.133	-0.238	-0.047	0.149	-0.055	-0.009	1	
DT	0.384	0.405	-0.099	-0.862	0.046	0.191	0.087	0.158	1

(A) Hourly Data: The correlation of hourly visibility, meteorological variables and concentration of air pollutants have been studied and analyzed as shown in Table 2. Similarly to table 1, it has been found that hourly visibility has negative correlation (inversely proportional) with CO, NO_x, SO_2, O3 and RH. It has also been found that visibility has positive correlation (directly proportional) with variables such as PDVV, WS and Depression temperature (DT).

Table 2: Correlation matrix of hourly visibility, previous hour visibility, meteorological parameters and air pollutants in Delhi for 2006-2011 winter seasons

	VV	PDHV	WS	RH	CO	Nox	SO_2	O3	DT
VV	1								
PHVV	0.940	1							
WS	0.524	0.430	1						
RH	-0.789	-0.739	-0.432	1					
CO	-0.124	-0.042	-0.327	0.030	1				
Nox	-0.093	-0.034	-0.224	0.033	0.274	1			
SO2	-0.026	-0.016	-0.085	-0.035	0.219	0.035	1		
O3	-0.134	-0.070	-0.105	-0.240	-0.140	-0.187	-0.033	1	
DT	0.791	0.729	0.455	-0.977	-0.060	-0.050	0.022	0.254	1

VV: Visibility, PDVV: Previous Day Visibility, PHVV: Previous Hour Visibility, WS: Wind Speed, RH: Relative Humidity, [CO]: Concentration of carbon monoxide, [NO_x]: Concentration of oxides of Nitrogen, [SO_2]: Concentration of sulphur dioxide, [O_3]: Concentration of Ozone, DT: Depression Temperature

4. Comparison of Simulated and Observed Visibility :

Empirical relationships have been formed between atmospheric visibility, concentration of air pollutants and meteorological parameters on daily as well as hourly basis using the MLR technique:

A) From data on daily basis: The forecasting of daily visibility, based on air pollutant concentration and meteorological variables, has been carried out by using MLR techniques during winter season for the years 2006–2010. The model's daily visibility for the year 2011 has been validated with observed data for the same year.

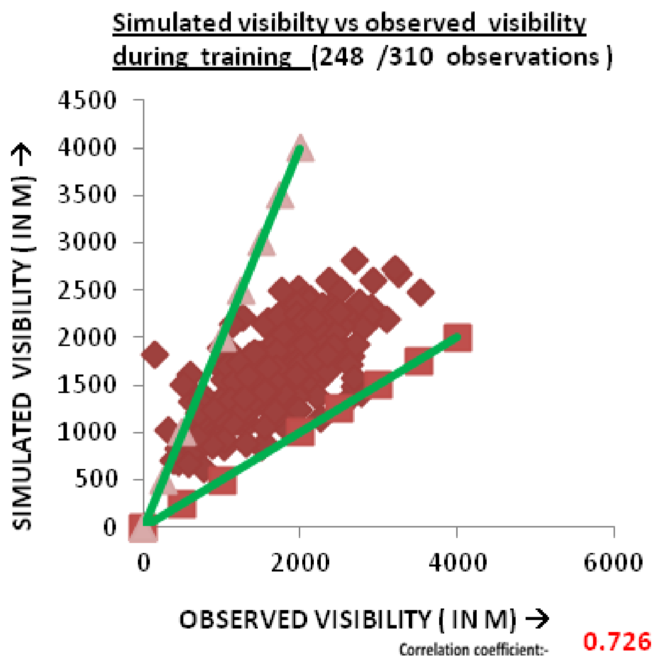
$$VV= -0.203 +0.540\,PDVV + 0.116\,WS -0.311RH - 0.044[CO] - 0.103[NO_X] - 0.116[SO_2]$$

$$-0.078[O_3]+0.093DT \qquad (3)$$

The above equation (3) is used to forecast daily visibility in the year 2011, which has been compared with observed daily visibility of 2011, which has been analyzed through statistical error analysis as shown in Table 3. This indicates that model is performing satisfactory with respect to the Normalized Mean Square Error (NMSE) and Root Mean Square Error (RMSE). However, the model is over-predicting with respect to Fractional bias. The Coefficient of correlation (R) has been found 0.726 in training period. The model's training for the years 2006-2010 and validation in 2011 between observed and forecasted values have been shown graphically in Figures 2 (a) and 2(b) respectively. The above discussion reflects the satisfactory performance of the MLR model for daily visibility.

Table 3: Comparison of daily model simulated visibility and observed visibility

S. No.	DAILY (310 observations)				
		RMSE	NMSE	Correlation Coefficient	Fractional Bias
1	Training	440.215 m	.073293	0.726	-0.00039
2	Validation	358.317 m	0.044184	0.885	0.030153



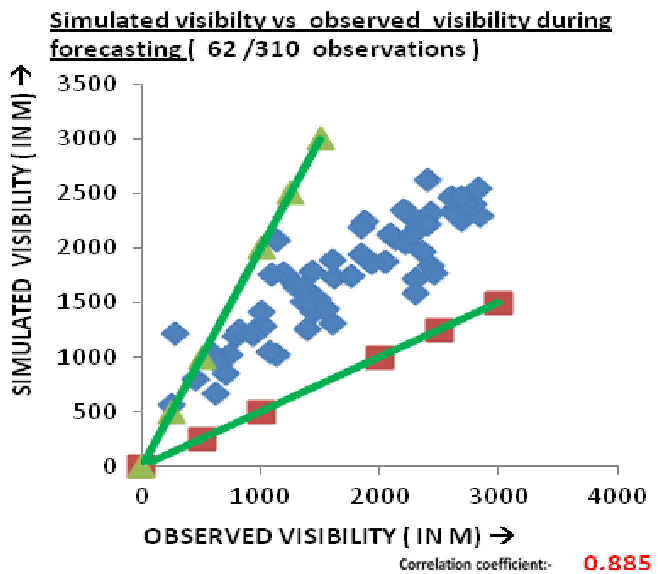


Figure 2: Scatter plots between daily observed and MLR model forecasted visibility in (a) training, (b) validation period

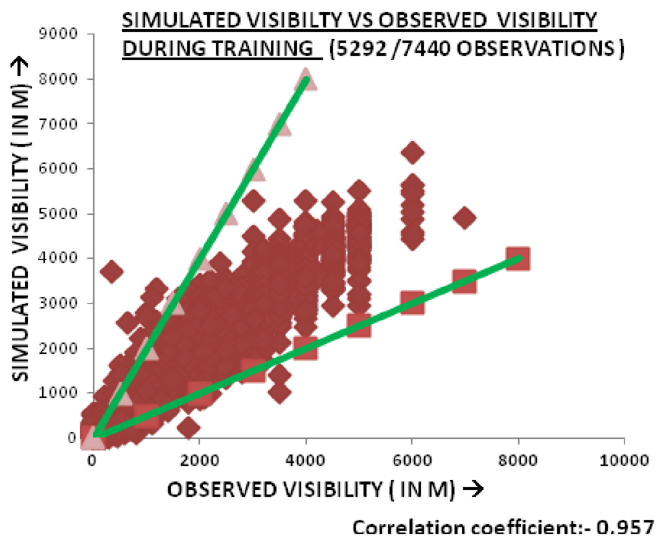
B) From data on hourly basis: The forecasting of hourly visibility, based on air pollutant concentration and meteorological variables, has been carried out by using MLR techniques during winter season for the years 2006–2010. The model's hourly visibility for the year 2011 has been validated with observed data for the same year.

$$VV= -0.104 +0.762\ PHVV +0.089\ WS -0.122\ RH- 0.099\ [CO]- 0.030\ [NO_X] - 0.032\ [SO_2] -0.017\ [O_3] + 0.003\ DT \quad (4)$$

The above equation (4) is used to forecast hourly visibility in the year 2011, which has been compared with observed hourly visibility of 2011, which has been analyzed through statistical error analysis as shown in Table 4. This indicates that model is performing satisfactory with respect to the Normalized Mean Square Error (NMSE) and Root Mean Square Error (RMSE). However, the model is under-predicting with respect to Fractional bias. The Coefficient of correlation (R) has been found 0.957. The model's training for the years 2006-2010 and validation in 2011 between observed and forecasted values have been shown graphically in Figures 3 (a) and 3(b) respectively. The above discussion reflects the satisfactory performance of the MLR model for hourly visibility.

Table 4: Comparison of hourly model simulated visibility and observed visibility

S. No.	HOURLY (7440 observations)				
		RMSE	NMSE	Correlation Coefficient	Fractional Bias
1	Training	353.938 m	0.048014	0.957	0.001079
2	Validation	359.962 m	0.048195	0.963	-0.03463



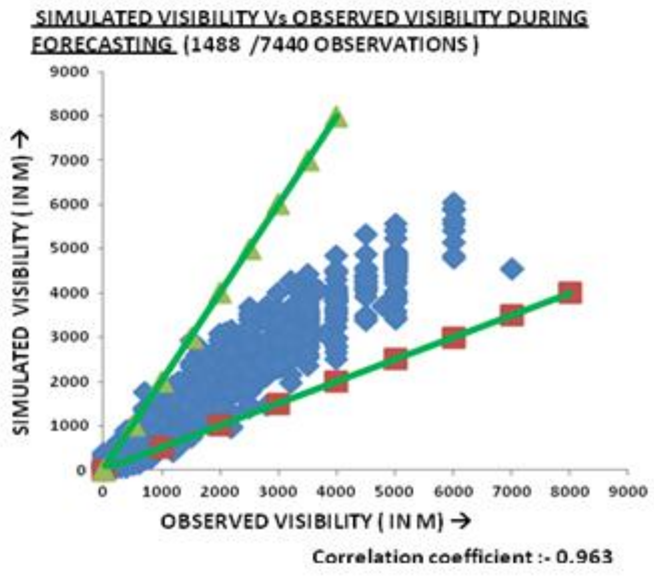


Figure 3: Scatter plots between hourly observed and MLR model forecasted visibility in (a) training, (b) validation period

Out of these two analysis, regression analysis of hourly data performs better than daily one.

Impact of reduction of air pollutants on daily visibility: The impact of reduction of air pollutants on daily visibility is showing in Table 5, which is showing that after deducing the half of CO, NOX SO_2 and O_3 one by one, the visibility is improving 16.30, 36.7, 45.5 and 13.7 m respectively. The visibility is improving 112.2 m after reducing the half of all the pollutants at one time

Table 5: To assess the impact of reduction of air pollutants on atmospheric visibility

IMPACT ASSESSMENT:- (DAILY BASIS)	
REDUCTION	VISIBILITY IMPROVEMENT (Meters)
0.5 [CO]	16.30
0.5 [NO_X]	36.7
0.5[SO_2]	45.5
0.5[O_3]	13.7
0.5 {[CO]+ [NO_X]+ [SO_2]+ [O_3]}	112.2

5. Conclusion:

The atmospheric visibility is positively related to the prevailing wind speed of the place of observations. So, one can say that atmospheric visibility improves, if the wind speed becomes high and vice-versa. Reason being that the, if wind speed is high it will carry away the air pollutants with it and will help in improving the visibility of the place and reverse will happen in case of low wind speed.

The depression temperature (or depression in dew point temperature) i.e. the difference between dry bulb temperature and dew point temperature of a place is related positively with atmospheric visibility. Visibility degradation is more likely with increasing dew point and decreasing dew point depression (Temperature – Dew point Temperature), as expected (Roach, 1994). Humidity of a place is negatively related to atmospheric visibility i.e. when humidity increases which leads to formation of tiny droplets suspended in air which reduces the atmospheric visibility by inhibiting the solar radiations reaching the Earth's surface.

While comparing Simulated and observed visibility values, MLR model based on average daily data during forecasting showed RMSE of 358.3m , NMSE=0.044184 and correlation coefficient=0.885, implies that model is performing well.

MLR model based on hourly data during forecasting showed RMSE of 359.96 m, NMSE=0.048195 and correlation coefficient=0.963,implies that model is also performing well and better than the model based on daily data.

The concentration of air pollutants is related negatively to the atmospheric visibility and affects the atmospheric visibility by absorption and scattering of light reaching the Earth's surface and can lead to visibility impairments . The impact of reduction (50%) of the average daily concentration of pollutants, on visibility improvement is significant (≅ 112 m)

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