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Morning Visibility Reduction and Air Quality in Raipur, India

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This paper presents an observational study on the air quality and horizontal visibility in Raipur city of India. The air quality in Raipur city is deteriorated on account of large number of iron steel industries and increasing vehicular and population pressure. The paper presents interplay between suspended particulate matter (SPM), ultrafine particles (DUST), meteorological parameter and the horizontal visibility in a yearlong study. Observations were carried out a long traffic corridor between Bhilai and Raipur city. Air quality parameters [SPM and DUST] were found to be more important than the meteorological parameter for the visibility reduction in the study area. The visibility at both Raipur and Bhilai location has shown strong negative correlation with the SPM in air which translates into the fact at higher SPM is causing reduction in the visibility. This correlation in case of DUST is not as strong in case of SPM, which proves that SPM by being able to remain suspended in air for longer time plays a greater role in visibility reduction. It is also clear that the air visibility observation can an effective indication of the air quality prevailing in a particular area.

Keywords: Visibility, Particulate matter, Wind speed, Relative humidity.

INTRODUCTION

Ambient air is a dynamic matrix and its quality depends on the level of the contaminants, meteorological and topographical conditions of the place. The visibility of the air is an observable phenomenon for any human eye. The ability of the human eye to see long distances clearly is the simplest definition of the visibility. The World Meteorological Organization (WMO) has defined the visibility or meteorological visibility (by day) and meteorological visibility at night are defined as the greatest distance at which a black object of suitable dimensions (located on the ground) can be seen and recognized when observed against the horizon sky during daylight or could be seen and recognized during the night if the general illumination were raised to the normal daylight level [1,2].

Meteorologically the visual range is the distance at which the contrast of a given object with respect to its background is just equal to the contrast threshold of an observer. The meteorological visibility or meteorological optical range (MOR) is expressed in metres or kilometres. The measurement range varies according to the application [1]. For daytime observations, the visual estimation of visibility gives a good approximation of the true value of MOR.

It is a known fact that all over the world the clear sky visibility over land has decreased globally over the past 30 years which is indicative of an increase in aerosols, or airborne particulates. The urban air visibility is considered as a important visual indicator of air pollution level, thus the reduction in the visibility has been correlated with the poor air quality. Visibility reduction in urban area is an indicator of poor air quality or presence of excessive pollutant in ambient air which can cause severe health impacts also.

Indian cities are witnessing heavy vehicular movements, rapid industrialization, fast paced urbanization and the large consumption of fossil fuels for various activities. These factors are responsible for the increased levels of suspended particulate materials (SPM), ultrafine particle (DUST), oxides of sulphur (SOx), oxides of nitrogen (NOx) and other such pollutants in ambient air. The increasing levels of these pollutants are responsible for decreasing urban air visibility [3]. Many studies exist in the literature that connects visibility with aerosol properties [4]. However, only a few studies have been carried out in the Indian subcontinent, where the visibility has reduced rapidly over the last 30 years period [5]. The increase in number of low visibility days has also been reported [6]. The rapid decrease in the visibility has been attributed to the increase in aerosol concentration due to the rise in anthropogenic emissions.

This is reported to resulting into a concomitant reduction in the surface reaching solar radiation [7].

The northern India is particularly suffering from winter fog situation where the meteorological conditions aided by high aerosol concentration [8] lead to frequent fog formation resulting in a very low visibility [9]. Normally the visibility of an area is determined by the meteorological parameter such as wind velocity and relative humidity, however, with the advancement in knowledge it is also established that pollutant characteristics in terms of size, shape, concentration and composition in the lower troposphere can change the frequency and mathematics of fog formation [1]. Fog formation in northern India is reported to be caused by aerosol radiative cooling [10]. This feature is further compounded by low wind speed and high relative humidity (RH) [11]. Fine airborne particles with diameter of 2.5 μm and less are also responsible for reduction of visibility because they are good light absorber as well as light scatterer. The fine airborne particles are reported to be associated with temperature change in air and they are also good absorber of humidity [12]. Visibility is a critically important parameter, because low visibility can disrupt the traffic movement, public safety and tourism industry.

The studies from China have reported that visibility in the country was degrading rapidly due to increased fossil fuel usage [13]. Visibility degradation in Hong-Kong has been found to be mostly due to fine sulphate particles [14,15]. The study of Syed *et al.* [11] has clearly shown that winter fog frequency over the Indo-gangetic plain has increased over the last 35 years due to increased loading of aerosols from the coal power plants, factories and inhabitants in this region [16].

The visibility in Delhi has been reported decreased rapidly at a rate of 0.11 km year per between 1980-2000 and is reported to have been stabilized after the year 2000. The adoption of CNG in the public transport sector from diesel/petrol from the year 2001 is reported as the major reason for the stabilization of visibility levels [17].

Apart from the above, there are almost no other reports on the visibility and aerosol levels from other urban locations in India. This paper attempts to provide the information from Raipur city, which is an important urban-industrial location in central east India. Raipur is the capital city of a young state of Chhattisgarh. It is particularly important city as it is undergoing fast urbanization and industrialization together. The major aim of this study was to understand the air pollution status at Raipur through the systematic study on the visibility and the levels of atmospheric particulates. In India, most of the studies on urban air quality generally focus only on the particulates/gases and their chemical composition. In our opinion, it is more important to understand the interplay of the pollutants and the meteorological factors. Accordingly this paper reports the urban particulate levels prevailing in the city of Raipur then it has examined the effect of these levels on the atmospheric visibility depending on the prevailing meteorological conditions.

EXPERIMENTAL

The capital city of state of Chhattisgarh *i.e.* Raipur is considered as one of the fastest growing city of India. The Raipur District is situated between 22° 33' N to 21°14'N Latitude and 82° 6' to 81°38'E Longitude. Area of the district is about 13083 square kilometres and it is surrounded by Bilaspur district in the North, Dhamtari district in the South, Durg district in the west, Janjgir-Champa district and Mahasamund district in the East and the Nabarangpur district of Orissa state in the South. The population of the city is 1,010,087 with a population density of 4500 persons per square kilometre. The city is getting increasingly industrialized and urbanized which is resulting in increasing pollution level in the city.

In this work the meteorological data was obtained from meteorological station of the Indian Meteorological Department (IMD) and our own observation. The visibility data in this study was recorded by trained observers every day in accordance with the standard operating procedure (SOP) developed for the purpose. This standard operating procedure was prepared based on the guideline as given in the Guide to Meteorological Instruments and Methods of Observation. In brief, the visual estimation of the meteorological optical range (MOR) was done by a meteorological observer using natural or man-made objects (groups of trees and building towers). For each observational station a plan of the action and the reference objects was pre-decided. The accurate distances and bearings from the observer were also recorded before the measurement. This paper measured only the daytime MOR and the night time (due to artificial light sources) MOR was not measured in order to avoid the measurement biases. The directional variations of MOR were ruled out by prior estimations; MOR observation has been made by trained observer who was having a normal vision. No optical aid *viz.* binocular *etc.*, was used in estimation. During the measurement the observer was standing at a normal height above the ground and the eyes alignment was approximately 1.5 m above the ground. Only black or dark objects were chosen as objects and the observations were made using these objects subtending an angle of no less than 0.5° at the observer's eye. The observer was having a normal vision.

Air quality, temperature, relative humidity and wind speed were also recorded including the concentration of SPM and DUST with a minimum frequency of twice a week.

The quality assurance (QA) and the quality control (QC) procedure included regular instrument calibration throughout the period, use of internal and external standards and duplicate analysis, wherever possible. The High Volume Sampler used was Envirotech Model APM 460 BL with size selective inlet for PM10 and automatic volumetric flow control. This equipment is designed to separate the bigger air-borne particles in a cyclone before the passing of the air through the filter media. The filter media used was Whatman quartz microfiber Filter (GFF) of 20.3 × 25.4 cm (8 × 10 in) size. The filters used were moisture free, prepared and stored as per the SOP. During sampling both SPM and DUST were collected separately. The dust cup attached to the cyclone gave the measurement of the DUST. The glass microfiber filter paper collected SPM on the 20.3 × 25.4 GFF filters. The particulate mass concentration was obtained gravimetrically by accurately weighing the particles collected and measuring the total volume of air sampled. The filter papers were kept in desiccators for at least 24 h before and after the sample collection. Blank GFF filter samples were routinely analyzed for PM_{10} to evaluate analytical bias and precision.

The sampling was done in a linear fashion covering the major trunk road passing almost through the middle of the city. The sampling locations were also chosen keeping the ease of observation and collection of visual data. Sampling locations were not affected by any near source or anthropogenic activity. A total five sampling sites were selected along the National Highway NH-6, starting from Bhilai area which is about 33 kilometres away.

The details of the sampling locations are as follows:

1. Site R-1 (Tatibandh over bridge): This sampling site passes through the Tatiabndh area of Raipur which is characterized by relatively denser population and an aerial proximity to the Urla-Silatara industrial area of Raipur.

2. Site R-2 (Indoor stadium): Indoor Stadium is comparatively open area with heavy traffic of two wheeler or domestic wheelers. The heavy or loaded traffic is not allowed here.

3. Site R-3 (Pachpedi naka): this location is on nearby national highway no 6, so heavy and loaded traffic is easily occurs in this region with crowed housing and little vegetation.

4. Site R-4 (Naya Raipur): developing ultra modern city with advance techniques but recently it has almost nil population and traffic zone.

Site B-1 (Power house Bhilai over bridge): This sampling location is situated about 25 km. distance from sampling location R-1. This site was chosen as a comparison point for comparison of the mean data of Raipur city with the data of Bhilai. Only one sampling station was chosen, as the Bhilai is a comparatively smaller city and the sampling site was free from any very near source effect.

RESULTS AND DISCUSSION

This study was carried out from December 2014 to November 2015 and the morning visibility was estimated in kilometres by measuring the light attenuation by human observation between a strictly followed time-window of 8 AM to 8.30 AM. In measurement terms it translated into identifying the farthest distance a trained human observer can see through. Thus the visibility data reported here are the horizontal visibility rather than the vertical or horizon observation. The horizontal visibility data were measured at five stations. Four of them namely, Tatibandh (R-1), Indoor Stadium (R-2), Pachpedi Naka (R-3), Naya Raipur (R-4) are located in Raipur city and the observation point was located at Power House area in Bhilai city. This station B-1 was treated as reference Station. The analysis was carried out in the four season of an actual year *i.e.* winter (December to February), pre monsoon (March to June), monsoon (July to September) and Post monsoon (October to November).

Based on the yearly analysis of data it can be seen the Bhilai observation point showed average horizontal visibility is 1.49 km compared to the 1.19 km average visibility of Raipur location. At both locations the minimum visibility was observed in the winter season (December to February) when the average visibility at Bhilai was 0.83 km and at Raipur it was 0.65 km. As expected the visibility distance kept on increasing from winter to pre-monsoon (March to May) with average visibility value as 1.48 km for Bhilai location and 1.16 km for Raipur location.

It was also observed (Table-1) that on the days of rain event there was a marked increase in the visibility in the same season. This increased visibility can be explained by the wash out effect of the rain.

TABLE-1
THE DATA OF MORNING VISIBILITY IN KM FOR FULL YEAR STARTING FROM DECEMBER 2014 TO NOVEMBER 2015

Month	R-1	R-2	R-3	R-4	B-1
January	0.47	0.70	0.57	0.93	0.77
February	0.49	0.61	0.50	0.85	0.87
March	0.53	0.78	0.71	1.08	1.09
April	1.00	1.80	1.44	2.26	2.04
May	0.72	1.22	0.88	1.50	1.32
June	0.69	1.48	1.08	1.74	1.53
July	1.14	2.14	1.88	2.75	2.50
August	0.99	2.06	1.63	2.50	2.19
September	1.00	2.00	1.50	2.40	2.17
October	0.67	1.39	1.06	1.66	1.40
November	0.57	0.87	0.83	1.23	1.18
December	0.50	0.69	0.61	0.96	0.85
Average	0.74	1.31	1.06	1.66	1.49

R-1: Tatibandh; R-2: Indoor stadium; R-3: Pachpedi naka; R-4: Naya Raipur; B-1: Bhilai

Industrial and urban profile of study area

Raipur is one of the highly industrialized district of Chhattisgarh state. The total number of industrial units in Raipur is 10,150 out of which registered industrial units in the district is 6,442. Out of these units the registered heavy and large units are 140. The estimated number of people employed in small scale industries is 86,395. Whereas the number of people employed in large industries are 23,906. There are two areas earmarked as industrial area which house medium to heavy industries. They are named as Urla industrial area and Siltara industrial area.

The Bhilai location is also an industrial location with a large integrated steel plant of 10 million ton capacity. This location is also having two cement plants and host of iron and steel based industries. The troika of three adjoining urban areas of Raipur-Bhilai-Durg is considered as one of the most advanced industrial belt in eastern India.

The location R-4 in this study is situated at Naya-Raipur (New Raipur) which is being developed as the new, well planned capital city of the Chhattisgarh state.

Meteorological parameter: As the visibility is affected by many parameters among them the most important are meteorological parameter such as wind, humidity, cloud cover, temperature and also the pollutants of anthropogenic origin such as urban particulates. Accordingly the complete data collection of all major meteorological parameter and urban particulate pollution was carried out throughout the study period.

As the studied location is a tropical climate region, accordingly the winter season (December to February) showed an average temperature of 21.22 °C, pre-monsoon (March to June) was 31.05 °C, the monsoon (July to September) was having a temperature of 27.44 °C and the post monsoon (October to

November) was having a temperature of 24.9 °C. As the studied locations are situated within an aerial distance of about 30 Km therefore; no significant variation was noted in meteorological parameters at both locations (Table-2).

TABLE-2
THE MONTHLY AVERAGE VALUE OF ALL METEOROLOGICAL PARAMETER AT BOTH STUDIED LOCATION*

Month	Relative humidity (%)	Wind speed (Km/h)	Temp. (°C)	Precipitation (mm)
December	63.06	3.76	18.50	16
January	71.52	1.95	20.46	10
February	37.09	7.30	24.72	17
March	48.73	6.60	26.46	14
April	41.38	12.83	30.20	13
May	26.11	12.61	37.30	18
June	68.38	16.26	30.23	239
July	80.92	13.42	28.30	383
August	87.88	13.38	27.40	364
September	80.26	9.70	26.63	197
October	68.32	7.17	25.53	50
November	66.00	2.10	24.40	11

*The results are average of monthly sampling.

It was observed that the relative humidity (RH) peaked in the monsoon season (July to September) and the average humidity level was 83.02 % and the lowest relative humidity was measured in summer season (March to May) with the value of 38.74 % (Table-2).

The wind movement pattern also showed the similar profile with maximum wind speed of 12.16 km/h was noted in the monsoon season and the minimum wind speed of 4.33 km/h was noted in the winter season (December to February). The urban particulates play an important role in attenuation of light. The studied region is predominantly an industrial region of the state of Chhattisgarh. Therefore it can be expected that the urban particulates will be playing a major role in the visibility pattern of the region. To assess the role of urban particulates we carried out weekly air sampling initially at all sampling locations. The results established (Table-2) that the location R-1 was maximum polluted by particulates and very high value of both suspended particulate matter (SPM) and ultra fine particle (DUST), were noted here. In this work we have considered R-1 (Tatibandh) location as the maximum polluted location and the pollution data of this location was used for the study.

The urban particulate pollution shows an immense increase in concentration during the winter season with SPM 330.95 μg/m^3. The particulate air pollution measurement was not carried out during rainy season as the particulate pollution value were on a very low site due to the obvious effect of rain out or wash out phenomenon (Table-3).

It was also observed that in the months of December, January and March and October the fine particulate (SPM) concentration was significantly higher than the coarse particles (> 10 μm) (Table-3). To account for this anomaly the meteorological parameters were minutely studied. In this study it was observed that the average wind speed of these months was lower (3.76, 1.95, 6.6, 7.17 km/h respectively) as compared to other studied month when higher wind velocities were observed. Therefore it can be surmised that the prevailing lower wind speed and greater inversion possible in these months were responsible for greater concentration of SPM. The low wind speed in these months led to a lower dispersion due to lower mixing depths and hence higher concentration of the SPM. This observation assumes greater significance as the pollution levels go significantly higher in winter months at Raipur city.

TABLE-3
SUSPENDED PARTICULATE MATTER CONCENTRATION (μg/m^3)

Month	R-1	R-2	R-3	R-4
January	298.40	103.58	124.33	57.50
February	283.60	107.27	118.17	63.11
March	129.73	43.92	52.00	25.88
April	167.20	56.80	73.04	44.00
May	158.78	55.44	66.16	50.09
June	197.60	62.33	75.03	36.94
October	120.47	43.48	52.17	30.00
November	165.32	59.75	80.27	87.86
December	410.86	136.69	177.74	76.12
Average	214.66	74.36	90.99	52.39

A correlation study was carried out to find out the intercorrelation between meteorological parameters, visibility and urban particulates parameter. We have taken the maximum SPM concentrations observed at Raipur (average of R-1, R-2 and R-3 location) and New Raipur for the correlation calculation (Table-4). It was found that suspended particulate matter (SPM) showed negative correlation with wind speed in all two locations, which means that greater wind speed results in lower particulate concentration. Relative humidity (RH) and visibility at both locations showed a negative correlation (-0.13). This means that when the humidity increases there is a considerable decrease in the visibility and *vice versa*. Strong positive correlation (0.61) between temperature and visibility is understandable because higher temperature results in lower relative humidity thus give higher visibility.

TABLE-4
CORRELATION STUDY

	SPM (R)	SPM (NR)	Raipur	NR	RH	WS	Temp.
SPM (R)	1						
SPM (NR)	0.6	1					
Raipur	-0.58	-0.44	1				
NR	-0.58	-0.44	1	1			
RH	0.19	0.11	-0.13	-0.13	1		
WS	-0.42	-0.56	0.72	0.72	-0.41	1	
Temp.	-0.67	-0.43	0.61	0.61	-0.65	0.8	1

SPM: Suspended particulate matter, NR: Naya Raipur

However, it is worthwhile to note that the Tatibandh location (R-1) has shown lowest visibility on any observed date among all monitored locations. This fact assumes a greater significance from the human health and traffic visibility considerations. To explain the phenomenon the prevailing wind direction in various seasons was considered. Based on this analysis it was observed that the Tatibandh location (R-1) is tangentially downwind to the Urla and Siltara industrial area in winter season. As this industrial area is having large number of small to medium industries the particulate and smoke emission in the area is higher. Another factor which may be contributing to the influx of some humidity is the proximity to a small river called Kharun. Hence it can be concluded that both of these parameters are causing a higher particulate concentration and slightly higher humidity. The two combined are causing stronger smog conditions at Tatibandh compared to any other monitored location.

Comparison with other reported area: As this research is the first ever reporting of the visibility in the studied region, there is no benchmark to compare the status of visibility. Therefore, the data obtained from the Raipur and Bhilai location were compared with the some other reported area such as Beijing, Guangzhou in China and Delhi in India which are also highly affected by the SPM pollution. The reported visibility range is shown in Table-5. The comparison makes it clear that the visibility range of Raipur and Bhilai area are approaching to that of other mentioned cities at least in the morning time.

TABLE-5
COMPARISON WITH PREVIOUS RECORDS

Location	Visibility (km)	Year	Ref.
Beijing (China)	0.58	2005-2009	[12]
Guangzhou (China)	0.83	2005-2009	[12]
Delhi (India)	0.11	1980-2000	[17]
Raipur (India)	0.62	2013-2105	This study
Bhilai (India)	0.83	2013-2105	This study

Conclusion

In this work, the relation between visibilities and related parameters obtained from experimental observation were determined. High SPM concentration were always associated with decrease in visibility, this is observed in central area between Raipur and Bhilai *i.e.* Tatibandh (R-1). Tatibandh (R-1) location is downwind area so the concentration of SPM and DUST were always in higher side in this location. So the visibility of this area is always in lower side. It was commonly observed in winter season.

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