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EXPOSURE ASSESSMENT OF TRAFFIC-RELATED AIR POLLUTION ON HUMAN HEALTH - A CASE STUDY OF A METROPOLITAN CITY

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Abstract

The present study aims to examine and model the adverse effects of vehicular emission on urban air quality and consequently on human health. It will facilitate the town planners to quantify the ill effects of vehicle generated air pollutants on human health to enable them to decide due weightage to be given to this attribute at planning level. Allahabad, a metropolitan city of India has been selected as the study area. Monitoring was conducted at various locations in the study area to evaluate the status of air pollutants e.g. NO_2, SO_2, Respiratory Suspended Particulate Matters (RSPM) and Suspended Particulate Matter (SPM). It is observed that concentration of NO_2, SO_2, RSPM, SPM are in excess of permitted levels in the study area, especially in sensitive and the residential zones. A door to door health survey was conducted, the peak expiratory flow rate (PEFR) measurements were made and the hospitalized persons from the study area were also interviewed. The acquired data was analyzed for the air quality determination and vulnerability status for assessing the pollution scenario of the study area. The data was also analyzed through the Spearman's rank correlation and Regression analyses to determine the correlation of pollutants concentration with the observed respiratory diseases like cough, asthma, breathing problem, wheezing and bronchitis in the present study. The analysis indicates that NO_2 and RSPM have relatively higher correlation with breathing problem and a moderate correlation with cough and asthma, which shows that NO_2 and RSPM are of serious concern in the study area.

Key words: air- pollution, air quality, adverse health impact, vehicular emission

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1. Introduction

In view of strict rules and regulations, pollution contribution of industries and commercial sectors in various countries have reduced markedly in recent years but the growth of vehicular traffic has increased enormously due to lack of stringent laws and scarcity of adequate public transportation system. Automobiles contribute 40-80% air pollution (Ghose, 2004) and consequently have become a serious cause of concern for the whole world. On global basis, the vehicular exhaust accounts for about 25-30% NO_x of anthropogenic total emissions. Indian scenario is further worsened due to ill maintenance of vehicles and poor road network. The huge air pollution due to vehicles results into substantial health implications as well as adverse impact on animals, plants and structures.

With unprecedented growth in vehicular population, traffic-related sources of air pollution are drawing increasing concern of exposure assessors, epidemiologists as well as toxicologists. Ground-level vehicular traffic in urban area is typically natural gas-fueled, gasoline-fueled or diesel-fueled. The physical characteristics and chemical composition of natural gas, gasoline and diesel are not the same in different regions of the world, adding to the complexity in vehicular emission. The complexity is further

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enhanced by different meteorological conditions (Capşa et al., 2016), driving habits, different maintenance as well as quality control measures (Gwilliam, 2003) for vehicles and exposure profiles (Cupitt et al., 1994) of people. The primary pollutants present in the vehicular exhaust are oxides of nitrogen (NO_x), carbon monoxide (CO), hydrocarbons (HC), lead (Pb) and particulates. Exposure to NO_2 has been reported to affect both the cellular and humoral immune system (Samet and Utell, 1999). NO_2 exposure for longer duration may affect lung function (Zeng et al., 2016) causing respiratory problems. Healthy adults exposed to high concentration of SO_2, even for small duration, results in broncho-constriction (Guleria and Wadhwa, 1997) developing asthma and allergic reaction. Respirable Suspended Particulate Matters (PM_{10}) create lung congestion (Report-All India Council for Technical Education, AICTE, 2004), and is one of the major sources of respiratory problems. It has been observed from several studies that traffic-related air pollution has both long-term and short-term effects on chronic respiratory disease in adults, even in a region with overall low levels of air pollution (Banica et al., 2017; Biswas, 2001; Bonai et al., 1994; Dennis, 1996, 2009; Slezakova et al., 2011).

The intent of the present study is to assess the concentration of vehicle generated pollutants in the study area and model their adverse effects on human health by deterioration of urban air quality. The study undertaken will provide the town planners a tool to quantify the ill effects of vehicle generated air pollutants on human health so that weightage could be assigned to this attribute at planning level.

To evaluate the adverse impact of vehicle emission on the health of residents of the study area, a fact finding study was conducted by assessment of vehicle emitted major air pollutants-NO_2, SO_2 and RSPM (PM10) and health survey in the area. The results thus obtained have been analyzed to interpret the impact.

2. Case study

2.1. Study area

The study area (Allahabad city, UP, India), situated at the confluence of three rivers Ganga, Yamuna and mythical Saraswati is located between 25°28′(N) and 81°54′(E) covering an area of 63.07 km^2 with 1.2 million population. National highways namely- NH-2, NH-27, NH-76E and NH-99 passes through the city. The vehicular population of the city is about 0.2 million (2001 census), registering an annual growth rate of 10.2% over the previous decade as per regional transport office, Allahabad, 2001. For the convenience of study, the whole city was divided into four zones, namely-sensitive zone, residential zone, commercial zone and heavy traffic zone, based on the characteristics of the areas and nature of vehicular traffic in each zone. Sensitive Zone comprises of the area whose population is highly prone to adverse health impact due to air pollution such as schools, hospitals etc. Residential Zone is identified as the area having residential dominance. Commercial Zone encompasses the area dominated by commercial establishments e.g. Markets, Official Complexes etc. and Heavy Traffic Zone identified as the area through which Heavy Traffic commutes. Pollutant monitoring locations in each zone were selected on the criteria that they should be representative of each zone type. Various locations identified for the said purpose have been mentioned in Table 1 and indicated in Fig. 1.

2.2. Methodology

To determine the air quality status of various zones, 24-hour mean concentrations of NO_2, SO_2, RSPM and SPM were monitored using high volume sampler (Envirotech APM, 430-411) along the roadside of the study locations as per the guidelines, prescribed in IS Code:5182 (Part-14) :2000.

Fig. 1. Study locations

Table 1. Locations for monitoring air pollution

Zones	*Location*
Silence zone	Patanjali School Najreth Hospital
Residential zone	Alopibagh T.B.Sapru Hospital
Commercial zone	Johnsonganj Intersection Civil Lines; Netram Intersection
Heavy traffic zone	G.T.Road (Near High Court)

Field studies have been designed to collect the data, related to traffic characteristics, meteorological parameters, road receptor geometries and air pollutants. Collection of data, related to the traffic (traffic flow, traffic speed), meteorology (wind speed, wind-road orientations and temperature), road-receptor geometries and other relevant information was done at all monitoring sites. The data required to determine the atmospheric stability such as cloud cover, visibility etc. have been collected from the nearby permanent meteorology monitoring station, located in Air Force campus, Bamrauli.

Monitoring of all above parameters was performed in both winter and summer seasons, to take maximum concentration of suspended particulates into account. Monitoring at each study location was done for one week (Monday to Friday) twice in both the seasons for continuous 16 hours a day (7AM to 11PM). The values of observed average concentration of the pollutants vis-a-vis their permissible limits as prescribed by Central Pollution Control Board (CPCB) New Delhi are presented in Table 2. For assessing the adverse impact of the air pollutants, health survey in designated study areas was conducted in two different phases. In Phase-I, a door to door visit was performed and the persons who were either resident of the study area or used to come regularly to work in that area were examined and interviewed. In order to achieve more representative results, efforts were made to cover persons of all age groups at all the locations. Only non-smokers were considered for the study as they are more prone to the pollution (Jain, 2001).

In phase-II of the survey, visits to the different hospitals of the city were made to interrogate the patients suffering from various airborne diseases. The survey data were collected through a questionnaire, prepared in the format of ATS–DLD–78 (American Thoracic Society and National Heart, Lung and Blood Institute Division of Lung Disease-78, Andrews et al., 1985) and as per the local conditions. The questionnaire has been designed to contain the information about the physiological status of the individual, such as age, height, weight, sex, nature of job, socio-economic status etc. Predominantly, it includes the information related to the past and present respiratory problems of the person suffering from cough, phlegm with heaviness in chest, bronchial asthma, whooping cough, dyspnea, wheezing etc. Few questions related to traffic were also included in the questionnaire for the sake of subsequent analysis.

It has been ensured that the sampled population be as similar as possible in respect to their socio-economic status, so that the variations in average health status of residents in different study areas could be attributed to the variation in the air quality rather than other anthropogenic sources. Each individual surveyed was thoroughly interrogated for past and present symptoms for the five common respiratory diseases viz. cough, breathing problem, wheezing, bronchitis and asthma. The survey data collected in both phases was discussed thoroughly with the concerned Medical Experts to ascertain the authenticity of the respiratory diseases observed. The people suffering from any of the respiratory diseases were treated as symptomatic. Prevalence of symptomatic and non-symptomatic persons has been defined as the percentage of symptomatic or non-symptomatic persons to the total number of person surveyed. Persons suffering from more than one respiratory problem have been considered as separate patients. The size of the population suffering from breathing problems has been presented in Table 3.

The peak expiratory flow rate (PEFR) is used to assess the ventilator capacity of the residents. Since PEFR is influenced by individual's sex, ethnic origin, age and structure of the body, the interpretation of observed PEFR values requires that they should be compared with the persons having same anthropometric characteristics. The measurement of PEFR was also made simultaneously with first phase of survey, by using peak flow meter. The PEFR for persons with normal health and different height, weight, sex and other characteristics has been predicted using regression equations (Jain et al., 1983). The health status of the population surveyed was classified into four categories, namely healthy, mildly affected, moderately affected and severely affected, based on the observed and predicted PEFR values. Persons with observed PEFR values more than 80% of the predicted one were classified as healthy whereas with PEFR values between 60-80% mildly affected, between 40-60% moderately affected and less than 40% severely affected categories. Based on the results of PEFR the health status of persons surveyed is presented in Table 4.

3. Results and discussions

The observed data for NO_2, SO_2 and RSPM concentrations presented in Table 2 have been analysed to determine the air quality status of study area. Survey data presented in Table 3 was analyzed to determine the prevalence of respiratory symptoms for five common respiratory diseases- namely cough, breathing problem, wheezing, bronchitis and asthma. The analysis of PEFR measurements (Table 4) provides the condition of lung function of the residents in study locations. In order to evaluate the stress of air pollution on the residents, the vulnerability analysis has been performed using the acquired data on pollutant's concentrations.

Table 2. Pollutant's concentrations at different study locations

Zone	Location	24-hour mean concentration of pollutants (µg/m^3)							
		NO_2		SO_2		RSPM		SPM	
		Observed concentration	CPCB standard	Observed concentration	CPCB standard	Observed concentration	CPCB standard	Observed concentration	CPCB standard
Sensitive zone	Najreth Hospital	29.15	30	13.54	30	75.13	75	133.24	100
	Patanjali School	47.09	30	oct.32	30	58.67	75	91.28	100
Residential zone	TBSapru Hospital	53.44	80	16.54	80	173.53	100	268.10	200
	Alopibagh	64.4	80	19.23	80	138.95	100	217.71	200
Commercial zone	Civil Lines	43.83	120	13.65	120	94.45	150	133.24	500
	Johnsonganj Intersection	75.71	120	40.21	120	158.97	150	239.02	500
	Netram Intersection	33.7	120	15.38	120	129.45	150	206.62	500
Heavy traffic zone	High Court	81.21	120	18.54	120	174.08	150	259.90	500

Table 3. Distribution of symptomatic persons in different study areas

Zone	Location	Total number of person surveyed	No. of Non-symptomatic persons	No. of symptomatic persons	Distribution of symptomatic persons				
					Cough	Breathing problem	Wheezing	Bronchitis	Asthma
Sensitive Zone	Najreth Hospital	90	34	56	15	23	3	5	10
	Patanjali School	70	24	46	14	18	2	2	10
Residential zone	TBSapru Hospital	112	49	63	12	29	6	3	13
Commercial Zone	Alopibagh	100	40	60	10	24	6	2	18
	Civil Lines	92	66	26	4	6	4	3	9
	Johnsonganj Intersection	118	68	50	12	21	1	4	12
	Netram Intersection	113	85	28	7	10	5	3	3
Heavy traffic zone	High Court	123	51	72	18	31	4	4	15

The data was also analyzed to establish the correlation between the concentrations of NO_2, SO_2 and RSPM emitted from the vehicles and the cases of symptomatic persons to the particular diseases. The detailed analyses of survey data and their findings have been outlined in the succeeding sections.

3.1. Air quality versus respiratory health study

The present section covers the assessment of air quality deterioration in the study areas due to vehicular emission and the extent of health damage caused by them. From Table 2 it can be observed that the concentration of RSPM has exceeded the permissible limit of CPCB in residential and heavy traffic zones. Also, the concentration of RSPM has exceeded the prescribed limit at Najreth hospital location in sensitive zone and Jonsonganj location in commercial zone. The concentration of SPM has exceeded the permissible limit in residential zone and at Najreth hospital location in sensitive zone. The observed concentration of NO_2 has exceeded the permissible limit of CPCB at Patanjali School and is on the verge to cross the limit at Najreth hospital location in sensitive zone. The concentration of SO_2 is found within the permissible limit in all zones.

The status of the air quality of the study area has been expressed in terms of air quality index (AQI) (Ratan and Kumar, 2005) for four pollutants (NO_2, SO_2, SPM, and RSPM) expressed as (Eq. 1):

$$AQI = \left[13.7 \sum_{i=1}^{4} \frac{C_i}{S_i} \right]^{1.15} \quad (1)$$

where C_i is the concentration of i^{th} pollutant (in μg/m^3) and S_i is the National ambient air quality standard for i^{th} pollutant (in μg/m^3)

In Eq. (1), the scale has been taken '10' for unpolluted background and maximum of '100' equivalent to the prescribed limits for these four pollutants by National Ambient Air Quality (India). The descriptors of AQI values are shown in Table 5 and the results of AQI are presented in Table 6. They show that the air quality indices in sensitive and residential zones are high which indicate that the air quality in these zones has deteriorated significantly and reached to an alarming stage.

The prevalence of respiratory symptoms for concerned diseases presented in Table 7 shows that a sizeable population living or working in various zones of study area are found suffering from major five respiratory diseases under consideration. It can also be observed from the Table 7 that the prevalence of symptomatic persons is highest in the sensitive zone, followed by residential, heavy traffic and commercial zones. The reason of higher prevalence of the respiratory diseases in these zones may be attributed to the deterioration of the air quality in these zones.

The results of PEFR measurements (Table 4) indicate that there is considerable deterioration in lung function of the exposed population. It can be observed from the results that the population in sensitive, residential and heavy traffic zones have been affected severely and a significant portion of the population is likely to be affected in future. Severity of exposure has also been assessed through the vulnerability analysis. It involves the identification of zones whose environment is severely damaged, causing stress on its human population.

Table 4. Status of lung function of the residents (based on PEFR Data)

Zone	*Location*	*Total number of person surveyed*	*Status of lung function of the population (% of total population surveyed)*			
			Healthy	*Mildly affected*	*Moderately affected*	*Severely affected*
Sensitive zone	Najreth Hospital	90	13	21	26	40
	Patanjali School	70	17	22	24	37
Residential zone	TBSapru Hospital	112	9	26	31	33
	Alopibagh	100	8	20	30	42
Commercial zone	Civil Lines	92	69	20	7	4
	Johnsonganj Intersection	118	34	23	20	23
	Netram Intersection	113	73	17	6	4
Heavy traffic zone	High Court	123	15	18	34	33

Table 5. Status of lung function of the residents (based on PEFR Data)

Zone	*Location*	*Air quality index*	*Air quality status*
Sensitive Zone	Najreth Hospital	93	High
	Patanjali School	89	High
Residential Zone	TB Sapru Hospital	98	High
	Alopibagh	86	High
Commercial Zone	Civil Lines	29	Good
	Johnsonganj Intersection.	58	Low
	Netram Intersection.	37	Good
Heavy traffic zone	High Court	59	Low

Table 6. Descriptors for Air Quality Index (AQI)

Range of Index	*Descriptor Categories*
< 20	Excellent
20-39	Good
40-59	Low
60-79	Moderate
80-99	High
100 and over	Critical

This analysis also provides the basis to set priorities for planning of air pollution abatement measures. The analysis is performed by developing an index called vulnerability index (VI). It is associated with the total vulnerability score (VS_T), expressed as (Eq. 2):

$$VS_T = \sum_{i=1}^{n} X_I T_i \quad (2)$$

where: X_i and T_i are the concentration and toxicity weighing factor for i^{th} pollutant respectively and n is the number of pollutants.

In the present study, VS_T has been calculated for the observed concentrations of NO_2, SO_2, RSPM and SPM. The values of toxicity weighing factors have been selected from Ghose et al. (2004). The vulnerability index has been determined on the basis of the ratio VS_T/VT_r where VT_r is the vulnerability score for threshold concentrations (i.e. the permissible limits of the concerned pollutants prescribed by CPCB) of the pollutants. Vulnerability status at different locations of various zones was decided based on VS_T/VSr and has been presented in Table 8. The descriptors for the vulnerability index, presented in Table 9 have been developed as per Ghose et al. (2004) and the results of vulnerability analysis shown in Table 9 clearly indicates that the sensitive and the residential zones of the study area are affected severely compared to other zones. Heavy traffic zone and Jonsonganj intersection of the commercial zone are moderately affected and hence require immediate mitigation measures.

To establish the correlation of pollutants concentrations with the respiratory diseases observed in the survey, Spearmen's rank correlation and regression analyses have been performed and the results are discussed in the following sections.

3.2. Spearman's rank correlation analysis

Spearman's rank correlation coefficient is used to estimate the correlation between the concentration of pollutants and symptomatic disease. The Spearman's rank correlation between the symptomatic disease to mean concentration of NO_2, SO_2 and RSPM are calculated and presented in Table 10.

Table 7. Prevalence of respiratory symptoms at different study locations

Zone	*Location*	*Non-symptomatic persons (%)*	*Symptomatic persons (%)*	*Prevalence of symptomatic disease (%)*				
				Cough	*Breathing problem*	*Wheezing*	*Bronchitis*	*Asthma*
Sensitive zone	Najreth Hospital	38	62	27	41	5	9	18
	Patanjali School	34	66	31	39	4	4	22
Residential zone	TBSapru Hospital	44	56	19	46	10	5	20
	Alopibagh	40	60	17	40	10	3	30
Commercial zone	Civil Lines	72	28	15	23	15	12	35
	Johnsonganj Intersection	58	42	24	42	2	8	24
	Netram Intersection	75	25	25	36	17	11	11
Heavy traffic zone	High Court	42	58	25	44	5	5	21

Table 8. Vulnerability status at different study locations

Zone	*Location*	*VS_T (μg/m^3)*	*VSr (μg/m^3)*	*VS_T/VSr*	*Vulnerability status of the locations*
Sensitive zone	NajrethHospital	217.75	244.50	0.9	High
	PatanjaliSchool	279.16	244.50	1.1	Very High
Residential zone	TBSapru Hospital	419.81	562.00	0.7	Moderate
	Alopibagh	441.78	562.00	0.8	High
Commercial zone	Civil Lines	301.35	843.00	0.4	Very Low
	Johnsonganj Intersection	540.06	843.00	0.6	Moderate
	Netram Intersection	289.69	843.00	0.3	Very Low
Heavy traffic zone	High Court	548.07	843.00	0.7	Moderate

Table 9. Descriptors for Vulnerability Index (VI)

VS_T/VS_r	*Vulnerability Index*
>1	Very high
1-0.75	High
0.74-0.60	Moderate
0.59-0.45	Low
<0.45	Very Low

Rank correlation for SPM is not reported separately because RSPM, (the finer constituent of SPM) is mainly responsible for respiratory diseases. At 95% confidence level and for the number of sample areas (N) equal to 8, the critical value of 'p' is found as 0.715. It can also be observed from Table 10 that for RSPM, the value 'p' is positive and greater than the critical value for diseases such as cough, breathing problem and asthma. It shows that there is a good rank order relationship between these variables and mean concentration of RSPM. A significant correlation can also be observed between cough and NO_2 concentrations. SPM does not show any significant correlation with the diseases.

3.3. Regression analysis

In order to quantify the extent of correlation observed in the Spearman's rank analysis, linear and multiple-regressions have been performed between the air pollutants (NO_2, SO_2 and RSPM) and the prevalence of diseases under consideration. The results of linear and multiple-regressions with coefficients of determination (R^2) have been presented in Table 11. It can be observed that the value of R^2 is relatively higher (0.780) for RSPM with breathing problems indicating that the breathing problem is reasonably well correlated with mean concentration of RSPM. The correlation equation of linear regression obtained is as (Eq. 3):

$$Y = X_1 + 20.74 \quad (3)$$

where: Y is the prevalence of breathing problem (%) and X_1 is the observed concentration of RSPM (in μg/m^3) in the study area.

The observed concentration of RSPM shows a moderate correlation with cough and asthma. NO_2 concentration also indicates a moderate correlation with cough. SO_2 concentration shows insignificant correlation with all the diseases under consideration. This is in consonance with the fact that SO_2 concentrations are well within the CPCB standards. Multiple-regressions have been performed between the prevalence of symptomatic diseases (cough, breathing problem, wheezing, bronchitis and asthma) to NO_2, SO_2 and RSPM.

It can also be observed from Table 11 that a higher degree of correlation exists between the combination of observed concentrations of NO_2 and RSPM with the breathing problem and asthma, than other diseases. The correlation thus obtained in the multiple- regression can be expressed as (Eq. 4):

$$Y = -0.0113\, X_1 + 0.13 X_2 + 20.93 \quad (4)$$

where: Y is the prevalence of breathing problem (%); X_1 and X_2 are the observed concentrations of RSPM and NO_2 (in μg/m^3) respectively in the study area.

Table 11 also shows that the coefficient of correlation for NO_2 and RSPM combination is better compared to these pollutants considering separately for diseases under consideration. This could be probably due to the synergistic effect of NO_2 and RSPM combination (Gupta, 1999). The multiple-regression of SO_2 and RSPM combination shows a moderate correlation with cough and breathing problem. Multiple-regressions of NO_2, SO_2 and RSPM combination, shows a moderate correlation with cough, breathing problem and asthma. For all other cases no significant correlation is observed in this study.

Table 10. Spearmen's rank correlation between symptomatic disease and mean concentration of pollutants

S.N	*Disease*	*No of sample areas (N)*	*Spearman's rank correlation coefficient (p)*		
			NO_2	*SO_2*	*RSPM*
1	Cough	8	0.534	0.215	0.741
2	Breathing problem	8	0.380	0.425	0.779
3	Wheezing	8	-0.285	-0.119	0.071
4	Bronchitis	8	-0.404	-0.190	-0.238
5	Asthma	8z	0.476	0.380	0.721

Table 11. Results of multiple-regression analysis

Polluant/ Polluant-combination (μg/m^3)	*Coefficient of determination (R^2) of symptomatic disease*				
	Cough	*Breathing problem*	*Wheezing*	*Bronchitis*	*Asthma*
NO_2	0.521	0.421	0.043	0.16	0.189
SO_2	0.242	0.211	0.035	0.05	0.235
RSPM	0.670	0.780	0.164	0.011	0.694
NO_2 and SO_2	0.441	0.324	0.053	0.104	0.195
SO_2 and RSPM	0.690	0.675	0.315	0.441	0.491
$NO_2$and RSPM	0.712	0.890	0.031	0.267	0.700
NO_2, $SO_2$and RSPM	0.610	0.692	0.112	0.246	0.561

4. Conclusions

The present study reveals that the status of air pollution in major parts of Allahabad city has reached to an alarming stage and need immediate remedial measures to protect the population of the city from respiratory diseases. The concentration of RSPM has exceeded the permissible limits in residential and high traffic zones and is reaching the limit in sensitive zone. NO_2 concentration also has acquired the alarming stage in sensitive zone.

The vulnerability analysis and PEFR results show that the sensitive and the residential zones of the study area are severely affected compared to other zones. The results of Spearman’s rank correlation indicate that the breathing problem has a better correlation with RSPM concentrations whereas cough and asthma show a moderate one.

The result is further supported by linear regression analysis. The multiple-regression analysis indicates that NO_2 and RSPM combination has a higher correlation with breathing problem compared to the individual and other combinations of the pollutants considered for different diseases. NO_2, SO_2 and RSPM combination indicates a moderate correlation with cough, breathing problem and asthma whereas SO_2 alone does not show significant correlation with any one of the diseases considered in the present study.

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