An assessment of ambient air quality in Shimla city

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Air pollution in urban India has grown at an alarming rate. A vast majority of metropolitan and tier one Indian cities are experiencing acute deterioration in air quality and failing to meet health-based standards due to increased vehicular traffic and industrial sources. Studies show degradation in air quality in tier one cities but limited literature is available for tier two cities in India. The present article assesses the change in air quality in Shimla (a top tier two city) over a decade and tries to analyse the reasons for degradation in air quality. Annual and seasonal averages of major primary pollutants NO_x, $PM_{2.5}$ and SO_2 have been carried out to analyse changes in monitored concentrations. DMRB model analysis has been screened for prediction of concentrations.

Keywords: Air quality dispersion modelling, DMRB, Shimla, urban air pollution.

URBANIZATION and globalization have led to rapid economic growth in different countries of the world including India. However, this has also led to serious air pollution related problems worldwide. According to the World Health Organization (WHO)[1], air pollution is responsible for 7 million deaths worldwide every year. Urban air pollution episodes are primarily due to increased concentrations of pollutants, viz. local meteorology, emissions and dispersion conditions[2]. Traffic and industries are major sources of urban air pollution in India and are primary environmental concerns for the general public. Motor vehicles emit a variety of pollutants including nitrogen oxides (NO_x), carbon monoxide (CO), volatile organic compounds (VOC), which consist of hydrocarbons, and particulate matter (PM).

Exposure to traffic-related air pollutants results in adverse health effects like asthma and birth problems[3–5]. In view of the detrimental human health effects, monitoring stations have been set up in different countries to assess air quality on a continuous basis, measuring concentrations from both roadside and urban locations. The monitoring results are important to identify short and long term air quality monitoring objectives to determine the current air quality, and to evaluate the effectiveness of different air quality abatement programmes. Traffic-related air pollutant exposures can be estimated using several methods including long-term monitoring results. But there are several disadvantages and practical issues associated with this method, including inadequate number of monitoring stations set up in cities and inaccurate representation of spatial patterns by monitored data[6]. Alternatively, air quality dispersion models are often based on Gaussian plume models[7], hybrid models[8,9], land use regression (LUR) models[10] and receptor source models[11] to assess the spatial and temporal variations of air pollutant concentrations emanating from traffic vehicles for exposure studies.

In the Indian context, literature exists for assessment of air quality and dispersion modelling studies in metro and tier I cities like Delhi, Kolkata, Pune, etc. However studies on air quality for tier II cities like Chandigarh and Shimla are almost non-existent. We analysed the existing air quality of Shimla by assessing the change in ambient air quality for over a decade (2004–2013). Available monitoring data is used in accordance with the National Air Quality Monitoring Programmes (NAMP) criteria for stations with minimal air pollution problems. The pollutants considered in the study are SO_2, NO_x and PM_{10} as only these were monitored by the Himachal Pradesh State Pollution Control Board (HPSPCB). Annual and seasonal analyses of the monitored data were conducted to assess change in air quality over the study period in Shimla. Transportation is the predominant source. Hence air pollution in Shimla could be attributed primarily due to vehicular exhausts.

We used a screening model namely Design Manual for Roads and Bridges (DMRB, version 1.03c, 2007) to predict the concentration of NO_x and respirable suspended particulate matter (RSPM) at one of the sites and compared the monitored and modelled concentrations to evaluate the efficacy of the model. DMRB is essentially a screening model and yields quiet conservative results as it is designed to predict concentrations for the worst case scenario[12]. The DMRB model was earlier used to predict NO_2 concentrations at an intersection in Bristol, UK[13] and concentrations for different roundabouts on Leixlip town in Ireland, and these studies were successful in long and short term pollutant predictions[14].

Our main objective was to assess the change in ambient air quality of Shimla using the available monthly monitored data and a screening air quality dispersion

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model (DMRB) technique was utilized to predict pollutant concentrations.

Materials and methods

Shimla, the capital of Himachal Pradesh, is 2000 m above mean sea level (msl) in 'middle Himalayas'. The city lies in 'cold and cloudy' climate zones having fairly long winters from October to March, with severe cold spells during two months with a temperature almost 0°C. Summer months (May–June) are pleasant with a maximum temperature around 30°C. Monsoon periods (July and August) result in heavy rainfall leading to high humidity. Intervening months have a milder climate.

Station I, located on the Ridge situated in the heart of Shimla, is classified as a background site for air quality monitoring by HPSPCB primarily because (a) it experiences the least possibility of traffic pollution as no vehicles are allowed to pass through it; (b) easy site accessibility and its convenience; (c) availability of site sheltering and electrical facilities; and (d) vandal proof and protection from extreme weather (HPSPCB, pers. commun.) (Figure 1).

Station II is situated at the state bus terminal which is severely congested with heavy traffic flows during peak hours, no pedestrian pathways and vehicles moving in an unregulated pattern. This location was chosen as it exemplifies the traffic pollution at its best form (HPSPCB, pers. commun.) (Figure 2).

Monitoring was carried out according to regulations prescribed by Central Pollution Control Board (CPCB), India. Gaseous pollutants NO_x and SO_2 were monitored using the Modified Jacob and Hochheiser ($NaOHNaAsO_2$) method, and 'improved west and Gaeke method' respectively. RSPM was monitored using a high volume sampler with an average flow rate not less than 1.1 m^3/min (ref. 15).

DMRB, a screen model formulated by the former Department of Transport, UK, gives a preliminary indication of air quality near roads, and is more suited to rural motorways and trunk roads than city centre traffic conditions. Its initial algorithm was based on lookup tables and nomograms; originally published in August 1994 and revised in 1999, for making it applicable to urban situations. The main input parameters required for operation of DMRB model are vehicle flow, vehicle speed, receptor-road distances and percentage fraction of HDV and LDV. The vehicle emission rates are computed on the basis of vehicular speed. Highest emission rates of pollutants occur for low vehicle speed and congested driving conditions. In the absence of suitable vehicular speed data, the different speed limit values for different roads can be used to calculate the emission rates. It contains a useful database of vehicular emission factors for future years. Further, it is important to consider DMRB as a screening model to consider the worst case scenarios of meteorological parameters such as low wind speed and neutral atmospheric stability. The wind direction is assumed to be evenly distributed around the compass. Assumptions about background pollutant levels are included in the calculations. The most updated version of the model (version 1.03c, 2007) was utilized for predicting pollutant concentrations in Shimla.

For assessment of air quality impacts of road traffic emphasis is placed on the application of appropriate air quality models. The models predict dispersion and dilution of primary pollutants and determine road traffic concentrations using emissions and appropriate

Figure 1. Monitoring location at site I (background site).

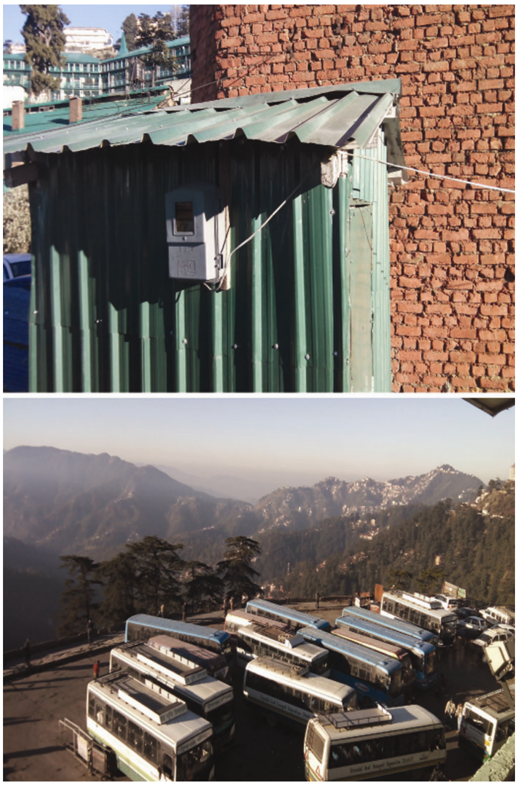

Figure 2. Monitoring location at site II (urban site).

meteorological conditions. In this study, the following assumptions have been made for determining appropriate input for the model due to lack of necessary data from local traffic authorities.

Background concentrations used in the DMRB model for prediction of PM_{10} and NO_x were obtained from monitoring station I classified as a background site by CPCB.

An important traffic input factor in the DMRB model is the actual count of annual average daily traffic (AADT) vehicles. However, no appropriate records of AADT values for the study period are available from the local traffic authorities. On repeated consultations with Transportation Department, the AADT traffic for 2013 was estimated to be 3000. The AADT values for different years were calculated assuming 10% increase every five years, applying the Transport Annual guidance (WEBTAG) Technical Guidance Unit 3.3.3 specifications. This states that 'traffic flows on all of the roads in the assessment that have been assessed will change by less than 10% as a result of the development'. This assumption was further corroborated by local traffic authorities. Hence, the AADT value used for the period 2005–2009 was 2700 and for 2010–2013 it was 3000. Due to high congestion around the monitoring station II, the annual average speed for vehicles was assumed to be 20 km/h and was used for study (Transportation Department, pers. commun.). For the study period 2004–2010 road type assumption was 'A' (motorway/highway) since Old Interstate Bus Terminal (ISBT) operated as a National Highway Road during this period. However since 2010, the road type was altered to 'B' (urban road) since the new ISBT became operational and the road running to Old ISBT was demoted to urban roads. The distance from the link centre to the receptor was measured to be 20 m and so for all the years analysed, it remains unaltered.

Daily counts of traffic vehicle around the monitoring station was absent. The percentage of Light Duty Vehicle (LDV) and Heavy Duty Vehicles (HDV) was calculated taking into account the vehicles registered with the Regional Transport Office. The data available ranged over the years 2011–2013. Similarly, it was assumed that every few year's percentage of LDV rises by 10 with respect to the WEBTAG Technical Guidance Unit 3.3.3. This assumption was discussed with the local transport authority and finally, 83% LDV values (for 2005–2009) and 93% LDV values (for 2010–2013) were used. Earth-moving vehicles were excluded from calculating the requisite percentages, as they would not be playing on daily basis at the monitoring site II.

Results and discussion

Ambient air quality was analysed for both stations in Shimla. Monthly averaged monitoring data for the study period were obtained from HPSCB for performing the analysis. Annual, seasonal and monthly analysis of monitored data was carried out to study the trends shown by pollutants in the past decade which are discussed here.

Using the air quality monitoring data annual graphs were plotted for two monitoring stations to analyse the behaviour of major pollutants. The annual graphs were analysed and evaluated to examine trends projected by these pollutants and to compare annual values to the permissible limits as set by NAMP to determine the annual change in air quality of Shimla. Figure 3 shows the variation of air quality pollutants at stations I and II. The annual average concentrations ranged from 2 to 3.73 $\mu g/m^3$ (2.73 ± 0.58) for SO_2, 6.58 to 9.39 $\mu g/m^3$ (8.07 ± 1.52) for NO_x, and 10.88 to 60 $\mu g/m^3$ (43.27 ±

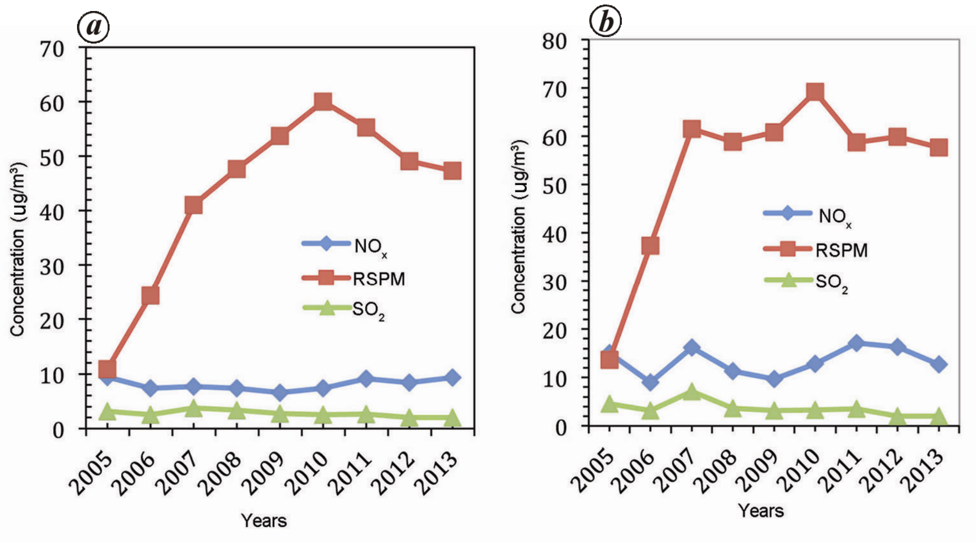

Figure 3. Annual average concentration of pollutants at (***a***) station I and (***b***) station II.

Table 1. Exceedance factors for all pollutants at both monitoring stations for the study period

	SO_2			NO_x			RSPM			
Year	Station-I	Station-II	EF	Station-I	Station-II	EF	Station-I	EF	Station-II	EF
2004–2005	0.06	0.09	L	0.23	0.38	L	0.18	L	0.23	L
2005–2006	0.05	0.06	L	0.19	0.22	L	0.41	L	0.62	M
2006–2007	0.07	0.14	L	0.19	0.41	L	0.68	M	1.03	H
2007–2008	0.07	0.07	L	0.18	0.28	L	0.79	M	0.98	M
2008–2009	0.05	0.06	L	0.16	0.24	L	0.90	M	1.01	H
2009–2010	0.05	0.07	L	0.18	0.32	L	1.00	H	1.15	H
2010–2011	0.05	0.07	L	0.23	0.43	L	0.92	M	0.98	M
2011–2012	0.04	0.04	L	0.21	0.41	L	0.82	M	1.00	H
2012–2013	0.04	0.04	L	0.23	0.32	L	0.79	M	0.96	M

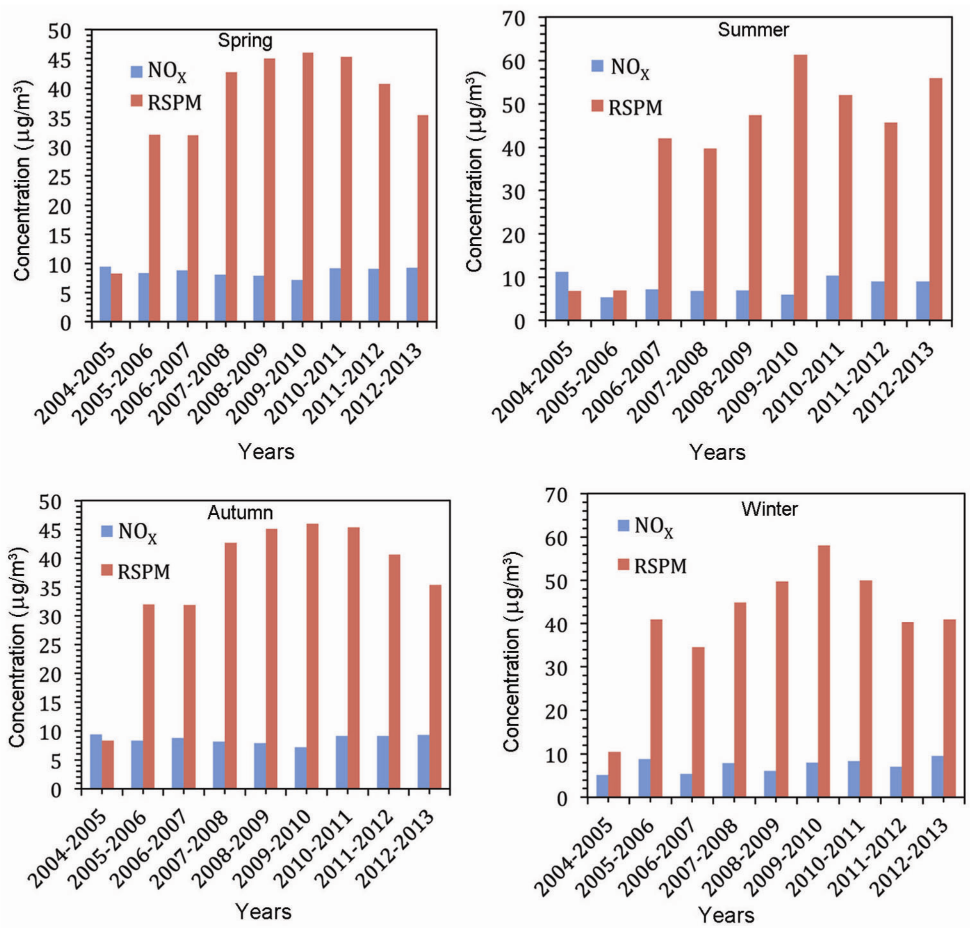

Figure 4. Seasonal variation of pollutants at monitoring station I.

15.87) for RSPM at monitoring station I. Similarly, the annual average concentrations ranged from 2 to 7.16 μg/m^3 (3.63 ± 1.55) for SO_2, 8.96 to 17.11 μg/m^3 (13.36 ± 2.99) for NO_x, and 13.63 to 69.17 μg/m^3 (53.04 ± 17.04) for RSPM at monitoring station II.

The graphs show that the concentrations of all three pollutants were higher at monitoring station II compared to monitoring station I due to the high volume of vehicular traffic. Most significantly, annual concentrations of NO_2 and SO_2 did not exceed National Ambient Air Quality Standards (NAAQS) values of 40 μg/m^3 and 50 μg/m^3 respectively, over the entire study period. The reduction in SO_2 concentrations could be attributed to various interventions that took place in recent years including reduction in sulphur content in diesel and change in domestic fuel from coal to liquified petroleum gas (LPG), compressed natural gas (CNG), etc.

Further, the low levels of SO_2 may be because there is no industry in and around Shimla. NO_2 concentration remained more or less fluctuating over the years despite

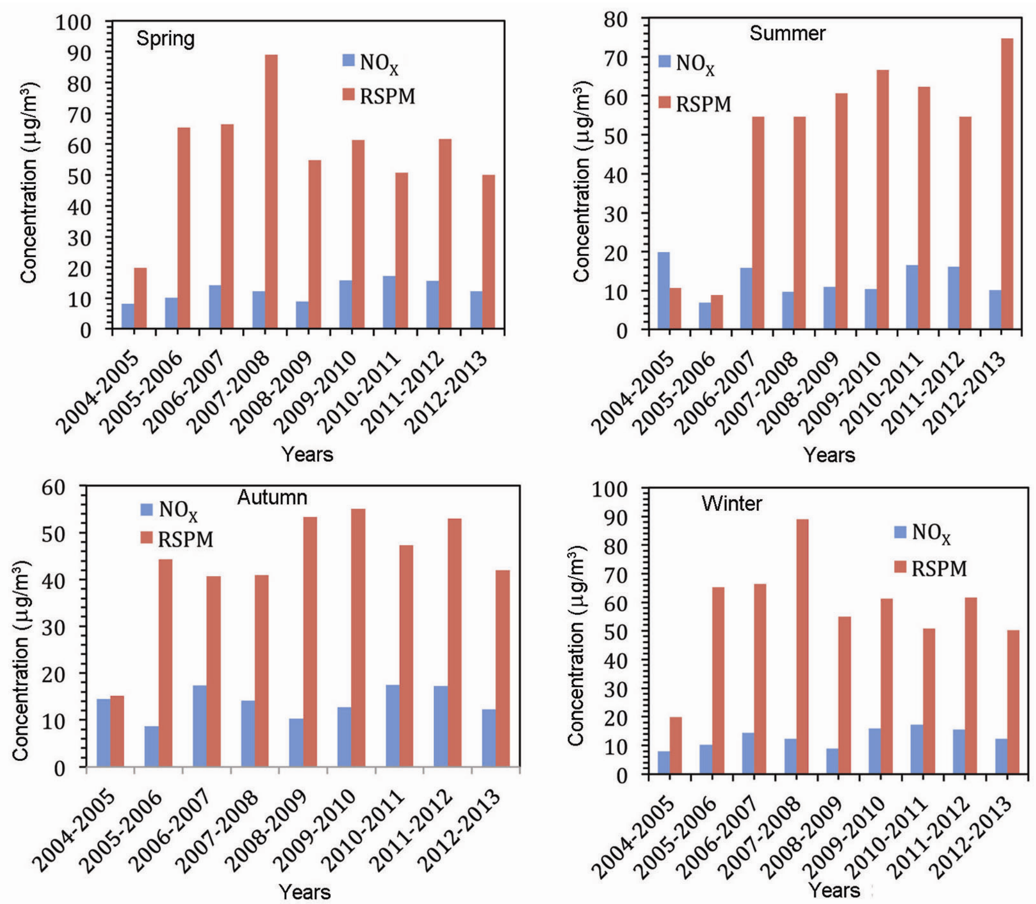

Figure 5. Seasonal variation of pollutants at monitoring station II.

Table 2. Comparison of monitored and modelled data for NO_x for the study period

Years	Monitored	Modelled
2004–2005	15.07	19.80
2005–2006	8.96	16.50
2006–2007	16.24	16.80
2007–2008	11.31	15.80
2008–2009	9.67	14.20
2009–2010	12.87	11.20
2010–2011	17.11	12.70
2011–2012	16.28	11.10
2012–2013	12.73	12.90

Table 3. Comparison of monitored and modelled data for RSPM for the study period

Years	Monitored	Modelled
2004–2005	13.63	10.09
2005–2006	37.33	25.40
2006–2007	61.54	42.15
2007–2008	58.78	48.59
2008–2009	60.75	54.50
2009–2010	69.17	60.46
2010–2011	58.67	55.66
2011–2012	59.83	49.39
2012–2013	57.64	47.74

intervention measures such as improvement in vehicle technology and other vehicular pollution control measures like alternate fuel, etc. While older vehicles have been phased out due to the Supreme Court of India norms, thereby reducing vehicular emissions, it has been balanced out by increased flow of vehicular traffic in the city over the years. Similarly, it was observed that RSPM concentrations at monitoring site II slightly exceed the standard RSPM concentration of 60 $\mu g/m^3$ and are slightly lower at monitoring station I. This is due to road congestion and increased diesel vehicles on-road. Also, a significant traffic management issue in Shimla today is high road congestion. The coverage of road network for vehicular movement is low and the existing roads are operating more than its desired capacity. Hilly regions have narrow roads and the road width is further reduced due to increasing traffic volume and increase in activity centres along the roads thus impairing traffic movement creating bottlenecks. This leads to inadequate space for movement of buses resulting in high traffic congestion. Absence of dedicated bus bays causes buses to stop on cart road for passenger boarding and alighting thereby causing traffic congestion on cart road further compounded by unregulated stopping of buses at any location.

Vehicles operate most efficiently and produce least pollution when driven in free flowing traffic at moderate speeds. Further, poor drainage systems in road lead to dust resuspension by wind and moving vehicles. Running of old vehicles and in particular heavy-duty vehicles like bus and trucks leads to higher exhaust emission of particulates. Poor road maintenance in Shimla leads to greater rate of abrasion between road and tyre resulting in higher dust production. There has been an appreciable decrease in RSPM concentrations since 2010, due to the efficient ISBT services in Shimla since 2010.

A weak correlation exists between NO_x and SO_2 at both monitoring stations. Station I shows a negative correlation ($r = -0.24$) between the pollutants whereas it is positive in station II ($r = 0.30$). A positive correlation between these pollutants indicates that they are emitted from common anthropogenic sources from both line and point sources[16].

Based on an exceedance factor (EF) which is defined as the ratio of annual mean concentration of a pollutant with that of a respective standard. NAMP[15] categorizes air quality into four: critical pollution (C), which occurs, if, EF > 1.5; high pollution (H) occurs when EF is between 1.0 and <1.5; moderate pollution (M) when EF is between 0.5 and <1.0; and low pollution (L) when EF is <0.5.

The significance that can be drawn from EF analysis is that in the first two categories the pollutants do not meet the standards. Those falling in the third category meet the NAMP standards but are likely to exceed the standards in future if pollution continues to increase. However, the locations in low pollution category have a rather clean air quality and such areas are to be maintained at low pollution level by way of adopting preventive and control measures of air pollution. For our study period 'low pollution' is designated to the pollutants NO_x and SO_2, however for RSPM it always lies between medium or high pollution levels except for the initial two years of the study (see Table 1).

From the previous assessment it is observed that the annual average concentrations of SO_2 maintain a steady rate over the entire study period and the concentration values are much lower than the prescribed standards of 50 $\mu g/m^3$. Further, since no large industry exists around Shimla city, vehicular exhaust emissions almost account for the entire pollution load of the city. Hence, further analysis of SO_2 is not needed. Seasonal analysis has been reported for pollutants NO_x and RSPM at both monitoring stations. The seasonal average concentrations ranged from 5.33 to 11.81 $\mu g/m^3$ (8.30 ± 1.87) for NO_x and 9.56 to 74.67 $\mu g/m^3$ (54.89 ± 24.56) for RSPM in spring, 5.46 to 11.22 $\mu g/m^3$ (8.05 ± 2.00) for NO_x and 6.84 to 61.33 $\mu g/m^3$ (39.74 ± 19.79) for RSPM in summer, 7.17 to 9.94 $\mu g/m^3$ (8.60 ± 0.76) for NO_x and 8.31 to 46.00 $\mu g/m^3$ (36.37 ± 11.91) for RSPM in autumn and 5.09 to 9.53 $\mu g/m^3$ (7.31 ± 1.55) for NO_x and 6.84 to 61.33 $\mu g/m^3$ (41.13 ± 13.42) for RSPM in winter at monitoring station I. Similarly, the seasonal average concentrations ranged from 8.50 to 17.93 $\mu g/m^3$ (13.92 ± 3.82) for NO_x and 13.38 to 109.22 $\mu g/m^3$ (66.38 ± 29.18) for RSPM in spring, 6.92 to 19.90 $\mu g/m^3$ (12.98 ± 4.27) for NO_x and 8.95 to 74.70 $\mu g/m^3$ (49.79 ± 23.57) for RSPM in summer, 8.71 to 17.50 $\mu g/m^3$ (13.85 ± 3.15) for NO_x and 15.20 to 55.00 $\mu g/m^3$ (43.55 ± 12.00) for RSPM in autumn and 7.99 to 17.27 $\mu g/m^3$ (12.76 ± 3.27) for NO_x and 19.79 to 89.00 $\mu g/m^3$ (57.70 ± 18.36) for RSPM in winter at monitoring station II. Figures 2 and 3 show the seasonal variation of graphs for monitoring stations I and II respectively.

Figures 4 and 5 indicate that the concentration of pollutants is comparatively higher in station II due to high volume of traffic as it is located at the state bus terminal. Seasonal variation is minimal for NO_x concentrations at both monitoring sites. Highest seasonal concentrations for NO_x occur during spring for both monitoring stations. This is primarily due to photochemical reactions between NO_x and O_3 and mixing processes in both horizontal and vertical directions[17]. Higher concentration of RSPM is also observed during spring for both monitoring stations. This can be attributed to substantial increase in floating population (i.e. tourists) due to which the traffic increases manifold in Shimla with the road network at its busiest.

Further, increase in traffic flow on roads during spring season leads to greater tire attrition, thereby causing an increase in resuspension of particulate matter on road owing to poor road conditions. Some other factors include dispersion of pollen grains from different plants during spring season which may lead to increase in RSPM concentrations.

It is observed from Table 2 that for the period 2004–2009, the modelled values overestimate the NO_x concentration in comparison to the monitored. However, the model under-predicts the monitored concentration for the study period 2010–2012. For 2013, the predicted concentration is almost similar to the monitored location. Similarly in Table 3, the modelled data underestimates the RSPM concentration values throughout the study period.

Simple descriptive statistics including mean, standard deviation and fractional bias were used to compare monitored and modelled data (Table 4). Model performance analyses are based on short-term and long-term model performance analysis. Since only monthly data (not hourly data) of pollutant concentrations were available, long-term model performance was analysed including the above mentioned parameters. The standard deviation of the modelled and monitored data set for both NO_x and RSPM is narrow. It can be stated that the high values of standard deviation for RSPM indicated that it is scattered and has a large variation about the mean. The mean monitored concentration of NO_x over the study period was 13.36 $\mu g/m^3$ and the mean predicted concentration was 14.56 $\mu g/m^3$. Similarly, the mean monitored concentration over the study period was 53.04 $\mu g/m^3$ and the mean predicted concentration was 43.78 $\mu g/m^3$ for RSPM. The

Table 4. Summary of descriptive statistics between monitored and modelled data

	NO_x		RSPM	
Parameters	Monitored	Modelled	Monitored	Modelled
Mean	13.36	14.56	53.04	43.78
Standard deviation	2.99	2.90	17.04	16.12
Fractional bias	0.00	–0.09	0.00	0.19

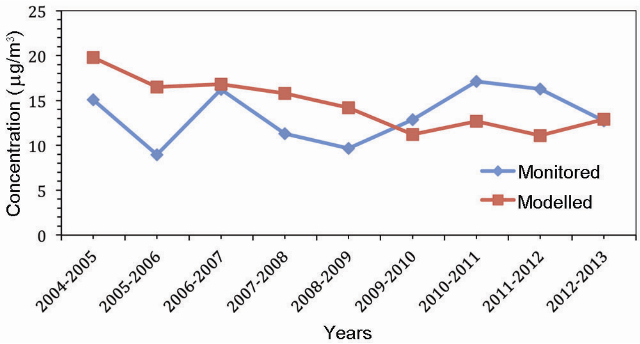

Figure 6. Annual variation of monitored and modelled concentrations for NO_x.

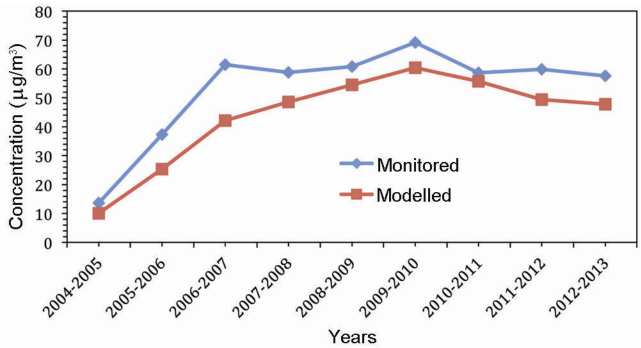

Figure 7. Annual variation of monitored and modelled concentrations for RSPM.

graphical representations of monitored modelled pollutant concentrations of NO_x and RSPM concentrations are shown in Figures 6 and 7 respectively. Though RSPM concentrations are under-predicted, the predicted concentrations show a similar trend with monitored concentrations.

Only monthly average concentration datasets were available for the study period instead of hourly data which skews the results. Hence, diurnal variations of pollutants have not been carried out in this analysis. Further, due to lack of detailed information including traffic inventory with no records on vehicle count at monitoring locations and meteorological data over the study period, detailed modelling analysis could not be carried out and a simple screening model was used for assessment. The variations in monitored and modelling data can be primarily attributed to lack of appropriate traffic data available with local transport authorities in Shimla and suitable assumptions were made to estimate AADT and percentage of LDV and HDV. However, even with the assumptions, reasonable predicted concentrations of both the pollutants were observed as seen from the fractional bias results.

Conclusions

Analysis of the annual averages of monitored data showed that concentrations of NO_x and SO_2 were below the National Ambient Air Quality Standards (NAAQS) of 40 µg/m^3 and 50 µg/m^3 respectively, while RSPM values slightly exceeded the permissible limits of 60 µg/m^3. Elevated concentrations of RSPM were primarily due to running of a large number of diesel vehicles, outdated vehicles, traffic congestion, and poor maintenance of roads causing increased tyre wear and its resuspension on the road. Low levels of SO_2 concentrations could be attributed to absence of any significant industries around Shimla. Seasonal analysis of pollutants demonstrated that most pollutant concentrations occurred during spring season due to increased traffic flow from tourists and pollen dispersion. Further, DMRB screening model was used to predict pollutant concentrations for comparison with monitored data for Shimla. Long-term model assessment parameters used for comparison showed that there was a certain degree of agreement between predicted and polluted concentrations. Further studies are in progress including preparation of detailed emission inventory for Shimla and for predicting pollutant concentrations using an appropriate air quality dispersion model.

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