Archives of Environmental Contamination and Toxicology
https://doi.org/10.1007/s00244-019-00689-8

ORIGINAL RESEARCH

Influence of Vehicular Emissions (NO, NO_2, CO and NMHCs) on the Mixing Ratio of Atmospheric Ammonia (NH_3) in Delhi, India

Garima Kotnala[1,2] · S. K. Sharma[1,2] · T. K. Mandal[1,2]

Received: 2 September 2019 / Accepted: 11 November 2019

Abstract

Mixing ratios of atmospheric ammonia (NH_3), nitric oxide (NO), carbon monoxide (CO), nonmethane hydrocarbons (NMHCs), and methane (CH_4) were measured to investigate the vehicular emissions, which are a dominant source of atmospheric NH_3 in urban sites of Delhi, India from January 2013 to December 2014. The annual average mixing ratios of NH_3, NO, CO, NMHCs, and CH_4 were 21.2 ± 2.1 ppb, 21.2 ± 6.1 ppb, 1.89 ± 0.18 ppm, 0.67 ± 0.21 ppm and 3.11 ± 0.53 ppm, respectively. Considering NO as a tracer of vehicular plume, ambient NH_3 was correlated with NO during peak traffic hour in the morning (7:00–10:00 h) and evening (17:00–19:00 h) and observed significant positive correlation between them. Result reveals that the mixing ratio of atmospheric NH_3 significantly positive correlated with traffic related pollutants (NO, CO, and NHHCs) during all the seasons (winter, summer, and monsoon). During winter, the average mixing ratio of atmospheric NH_3 was increased by 1.2–3.5 ppb in the morning peak hour, whereas increased by 0.3–1.6 ppb in the evening peak hour. Similarly, an increase in NH_3 mixing ratio was observed during summer (morning: 1.2–2.7 ppb and evening: 1.5–1.6 ppb) and monsoon (morning: 0.4–3.6 ppb and evening: 0.9–1.4 ppb) seasons. The results emphasized that the traffic could be one of the dominant source of ambient NH_3 at the urban site of Delhi, as illustrated by positive relationships of NH_3 with traffic related co-pollutants (NO, CO and NMHCs).

Ammonia (NH_3) is the third most abundant nitrogen containing gas in the atmosphere after N_2 and N_2O (Seinfeld and Pandis 1998; Aneja et al. 2000) and principal reduced nitrogen components in the atmosphere (Chang et al. 2016). It plays a strong role in local as well as regional tropospheric chemistry and air quality by serving as a precursor to particulate formation (Seinfeld and Pandis 2006; Sharma et al. 2018). As a primary alkaline gas in ambient air, NH_3 can neutralize nitric acid and sulphuric acid gases to form ammonium nitrate and sulphate (Pinder et al. 2007; Sharma et al. 2014; Jain et al. 2019), which are important constituents of airborne fine particles or $PM_{2.5}$ (Chow et al. 1994; Aneja et al. 2001; Huang et al. 2011a, b; Saraswati et al. 2019). The most recent consideration for NH_3 emissions on the global scale is linked to climate change based on its ability to form $PM_{2.5}$, specifically ammonium particulates (Aneja et al. 2001). The need to better understand the role of this particular air pollutant has been underscored in recent years as its atmospheric concentration increases day by day. Effective management strategies are essential to mitigate the pollutants over public health concern and to enhance visibility (Brunekreef and Holgate 2002; Wang et al. 2012).

Major anthropogenic sources of ambient NH_3 are agricultural practices, livestock, transport, and industrial activities (Sutton et al. 2000; Li et al. 2006; Sharma et al. 2010), along with natural sources, such as forest fires and emissions from soil (Olivier et al. 1998; Lee et al. 2005). Although agriculture is the dominant source of atmospheric NH_3 at continental to global scales (Sutton et al. 2013), in urban areas a significant NH_3 source is gasoline vehicles equipped with three-way catalysts (TWC). The reduction of NO compounds in TWC converters of automobile exhaust and industrial power stations emissions are significant contributors to atmospheric NH_3 in urban environments ($2NO + 2CO + 3H_2 \rightarrow 2NH_3 + 2CO_2$

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00244-019-00689-8) contains supplementary material, which is available to authorized users.

✉ S. K. Sharma
sudhir.npl@nic.in; sudhircsir@gmail.com

[1] Environmental Sciences and Biomedical Metrology Division, CSIR-National Physical Laboratory, Dr. K.S. Krishnan Road, New Delhi 110012, India

[2] Academy of Scientific and Innovative Research (AcSIR), Ghaziabad 201002, India

Published online: 12 December 2019

or $2NO + 5H_2 \rightarrow 2NH_3 + 2H_2O$) (Gandhi and Shelef 1991). Because of the growing efficiency of TWC to reduce NO_x emissions and recent introduction of selective catalytic reduction (SCR) systems in diesel vehicles, NH_3 is now a dominant-reactive nitrogen species emitted by vehicles (Stritzke et al. 2015). Correlation matrix of NH_3 with CO also suggested the dependency of NH_3 on the traffic intensity and air temperature (Perrino et al. 2002; Meng et al. 2011). Li et al. (2006) observed spikes in the NH_3 time-series that was correlated with the spikes in the CO and inferred that the NH_3 came from nearby traffic. Limited efforts had been done to explore the vehicle-emitted NH_3 to the urban atmosphere of India (Sharma et al. 2017). Therefore, more efforts are needed to elucidate the contribution of vehicle-emitted NH_3 to the urban atmosphere.

In the previous study, we reported the diurnal, seasonal, temporal, spatial, and annual variations in mixing ratio of ambient NH_3 and its interaction with other trace gases (NH_3, NO, NO_2, CO, SO_2, and HNO_3) under the prevailing meteorological conditions of the observational site of Delhi and reference therein (Sharma et al. 2010, 2014, 2017; Saraswati et al. 2018; 2019). The purpose of this study was to determine whether pollutants (NO, NO_2, CO, NMHCs, and CH_4) emitted from roadside traffic are the source of atmospheric NH_3 over the urban site of megacity Delhi, India? Hence, in this paper, we present the influence of vehicular emissions on the mixing ratio of NH_3 in the urban atmosphere of megacity Delhi, India.

Experimental Methods

Delhi, the capital of India, is considered one of the most polluted megacities of the world due to its geographical origin, rapid urbanization, overcrowding, and vehicular emissions (Nagpure et al. 2013; Sharma et al. 2018). The mixing ratios of ambient NH_3, NO, CO, NMHCs, and CH_4 were measured at the CSIR-National Physical Laboratory, New Delhi (28°38′ N, 77°10′ E; 218 m amsl) from January 2013 to December 2014 (Fig. 1). The observational site represents a typical urban atmosphere, amenable to free wind flow from all the directions and is surrounded by huge roadside traffic. Detailed descriptions of the observational site, including general meteorology (temperature, RH, wind speed, and wind directions) during the observational period are available in Table S1 (in Supplementary Information) and Saraswati et al. (2018).

Mixing ratios of ambient NH_3 and NO were measured using a NH_3-Analyzer (AC32M&CNH$_3$, Environment SA, Paris, FR), operating on a chemiluminescence method (accuracy: ± 1.0 ppb) from January 2013 to December 2014. NH_3 analyzer was calibrated periodically using Pure Air Generator (Model: PAG-003, M/s. ECO Physics AG, Switzerland, accuracy ± 0.01 ppb) and NIST certified NO span gas (500 ppb ± 5%). Mixing ratio of CO was recorded using a non-dispersive infrared (NDIR) gas filter correlation analyzer (Model 48C; Thermo Fisher Scientific, Waltham, MA). CO-Analyzer was calibrated using NIST traceable certified CO gas (8.1 ppm ± 5%) and Pure Air Generator. NMHCs and CH_4 were measured using flame ionization detection (FID) based Hydrocarbon analyzer (APHA-360; Horiba, Japan) from April to December 2014. Zero and span gas of hydrocarbon analyzer were calibrated using Pure Air Generator and NIST certified Propane and Methane gases (Sharma et al. 2017). Statistical analysis of these trace gases (NH_3, NO, CO, NMHCs, and CH_4) were performed using standard recommended methods.

Results and Discussion

Mixing Ratios of NH_3, NO, CO, NMHCs and CH_4

The annual average mixing ratios of ambient NH_3, NO, CO, NMHCs, and CH_4 were 21.2 ± 2.1 ppb; 21.2 ± 6.1 ppb, 1.89 ± 0.18 ppm, 0.67 ± 0.21 ppm, and 3.11 ± 0.53 ppm, respectively from January 2013 to December 2014 (Table 1). Seasonal average of ambient NH_3, NO, CO, NMHCs, and CH_4 are tabulated in Table 1 with maxima during winter season. Figure 2 showed the average diurnal variations in mixing ratios of NH_3, NO, CO, and NMHCs during winter (NDJF), summer (MAMJ), and monsoon (JASO) seasons. Kapoor et al. (1992) reported the average NH_3 mixing ratio of NH_3 as 47.3 ± 13.6 ppb in Delhi, whereas Sharma et al. (2010) reported the average mixing ratio of ambient NH_3 as 20.23 ± 2.71 ppb. Zutsi et al. (1970) reported the NH_3 mixing ratio as 50.7 ppb at Mumbai, whereas Sharma et al. (2016) reported the NH_3 mixing ratio as 43.4 ± 7.0 ppb at Kolkata, India. The diurnal, seasonal, annual, and spatial variations in mixing ratio of ambient NH_3 and its interaction with other trace gases (O_3, NO, NO_2, CO, SO_2, and HNO_3) under the prevailing meteorological conditions at Delhi (same site) and other locations of India are already discussed in our previous studied (Sharma et al. 2010, 2014, 2017; Saraswati et al. 2018, 2019) and compared with other studies (Sharma et al. 2014).

Diurnal Profiles of NH_3 and Insight Into Sources

Hourly measurements over long-term periods offer a unique opportunity to provide the robust diurnal profiles for each season. Figure 2 showed the average diurnal profiles of NH_3, NO, CO, and NMHCs mixing ratios during winter, summer, and monsoon seasons. On road vehicular exhaust contributes 36% of NO_x, whereas 83% of CO to the ambient air of Delhi (Sharma and Dikshit 2016). In Fig. 2, CO, NO, and

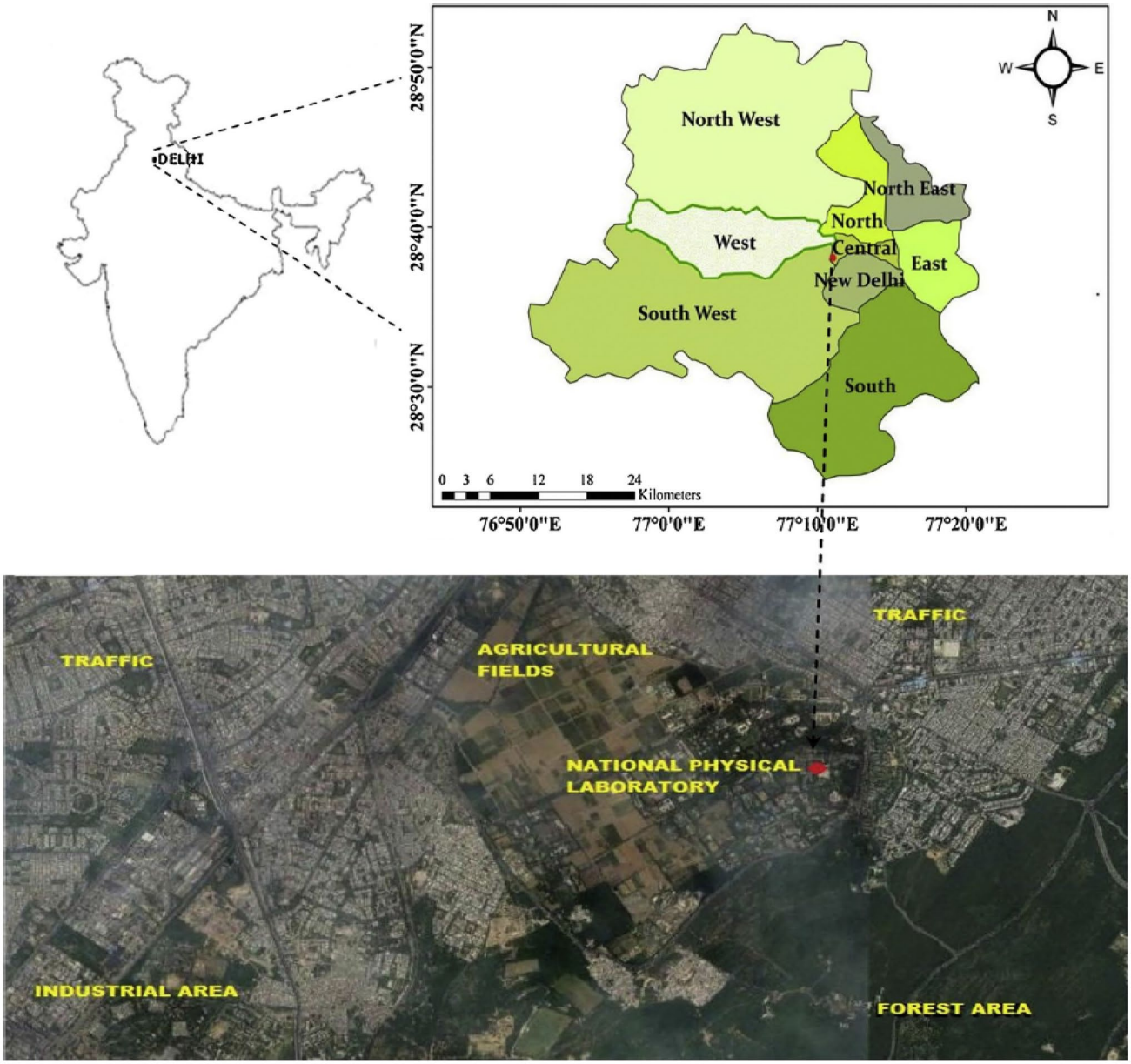

Fig. 1 Map of observational site. *Source*: Google map

NMHCs shows a bimodal diurnal profile, with maxima in the morning (starting at 06:00 IST; Indian Standard Time) and the evening (starting at 17:00 IST), consistent with the traffic flow in Delhi (peak hours and non-peak hours). Therefore, variation in NO and CO mixing ratios can be used as a potential indicator of vehicular emissions. NH_3 mixing ratio also shows a clear bimodal diurnal profile during all the seasons, similar to the NO and CO diurnal profile, suggesting a significant influence of on-road traffic emissions (NO and CO) on the ambient mixing ratio of NH_3 in the urban area of Delhi. During winter, the average mixing ratio of ambient NH_3 was increased by 1.2–3.5 ppb in morning peak hour (starting at 06:00 IST), whereas increased by 0.3–1.6 ppb in evening peak hour (starting at 17:00 IST). Similarly, increase in NH_3 mixing ratio was also observed during summer (morning: 1.2–2.7 ppb and evening: 1.5–1.6 ppb) and monsoon (morning: 0.4–3.6 ppb and evening: 0.9–1.4 ppb) seasons (Table 2). NO and CO are also showing the same trend during winter, summer and monsoon seasons (Fig. 2), indicating the influence in mixing ratio of ambient NH_3.

The hypothesis that traffic exhausts (NO and CO) could be the dominant source of ambient NH_3 at urban site is supported by the good correlation between NH_3 versus CO and NO (Meng et al. 2008; Chan and Yao 2008). The correlation

Table 1 Average mixing ratios of NH_3, NO, CO, NMHC, and CH_4 during winter, summer, and monsoon seasons at Delhi

Seasons	NH_3 (ppb)	NO (ppb)	CO (ppm)	NMHC (ppm)	CH_4 (ppm)
Winter	25.1 ± 2.3	22.9 ± 5.5	2.01 ± 0.23	0.79 ± 0.24	3.13 ± 0.53
Summer	21.8 ± 2.0	19.5 ± 5.7	1.75 ± 0.12	0.54 ± 0.15	3.07 ± 0.56
Monsoon	16.8 ± 1.9	21.2 ± 7.2	1.92 ± 0.17	0.68 ± 0.28	3.11 ± 0.50
Average	21.2 ± 2.1	21.2 ± 6.1	1.89 ± 0.18	0.67 ± 0.21	3.11 ± 0.53

± Standard deviation

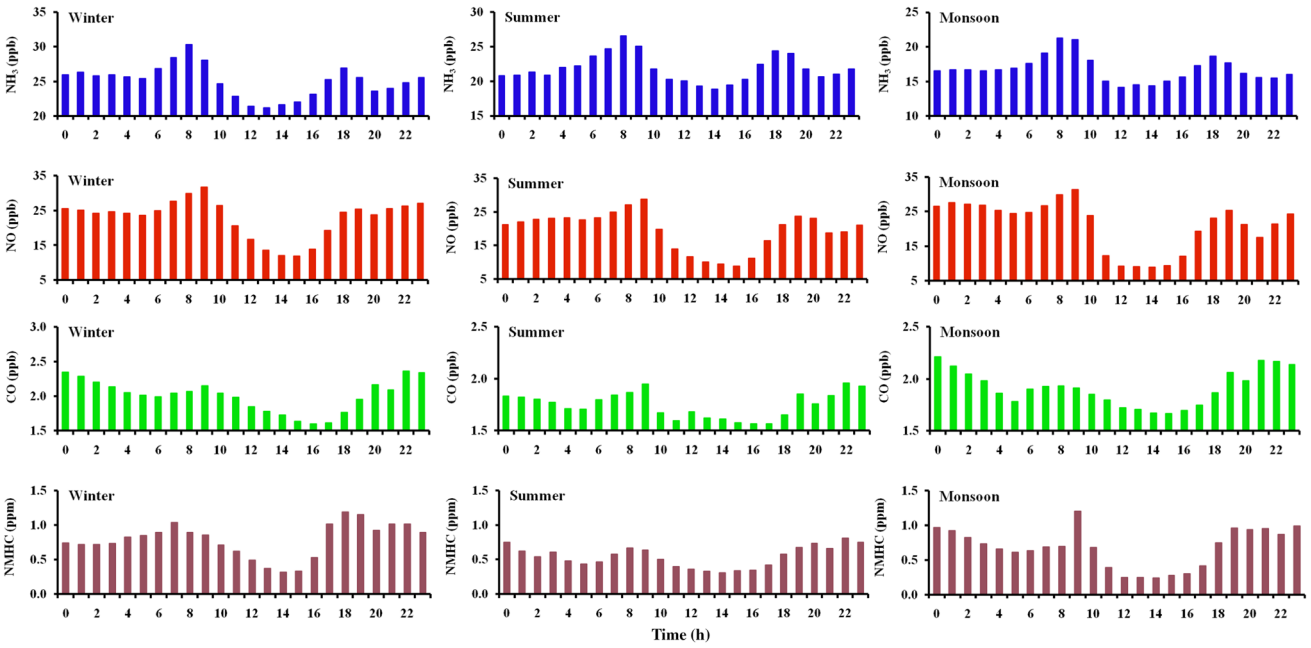

Fig. 2 Average diurnal variations of NH_3, NO, CO, and NMHCs during winter, summer, and monsoon seasons

matrix between NH_3 & NO, NH_3 & CO, and NH_3 & NMHCs are summarized in Table 3 along with CH_4. The correlation matrix of NH_3 with NO shows good correlation during winter ($r^2 = 0.84$), summer ($r^2 = 0.80$) and monsoon ($r^2 = 0.78$) seasons, respectively. The positive linear correlation between NH_3 and NO during winter season at Beijing was also reported by Meng et al. (2011) and considered that traffic was one of major sources of ambient NH_3 over Beijing, China. The strong links was also observed between NH_3 emissions and traffic in roadside measurements in the United Kingdom (Capr et al. 2004) and Europe (Kirchner et al. 2012; Perrino et al. 2002). Ianniello et al. (2010) also reported good correlation of NH_3 with NO_X ($r^2 = 0.65$) and CO ($r^2 = 0.67$) in winter season and attributed traffic as one of the major source at the observational site. However, the insignificant correlation of NH_3 with CO ($r^2 = 0.29$) during monsoon season suggests that other non-traffic sources may become more important (other biological sources like human, sewage treatment, and agriculture) (Whiteland et al. 2007; Fu et al. 2013).

In order to identify the possible local sources of ambient NH_3 and trace gases (O_3, NO, NO_2, CO, SO_2, and HNO_3) using surface wind speed and wind direction alongwith trace gases had already been discussed in our previous papers and references therein (Sharma et al. 2014; Saraswati et al. 2018, 2019). The highest NH_3 mixing ratio was observed during the lowest wind speed (1–2 m s^{-1}) from downwind direction indicates the possible nearby sources (roadside traffic in SW, NE, and SE directions) (Saraswati et al. 2018). The higher NH_3 mixing ratio was recorded during winter season may also be due to the lowest wind speed which associated with local sources from SE and SW direction (Fig. S1; in supplementary information) may be due to major influence of on-road traffic.

Table 2 Hourly changes in mixing ratios of NH_3, NO, CO, NMHC, and CH_4 when compared with average mixing ratios at 06:00h and 17:00h

Time (in h)	NH_3 (ppb)	NO (ppb)	CO (ppm)	NMHCs (ppm)	CH_4 (ppm)
Winter					
06:00	26.9	24.9	2.00	0.90	3.50
07:00	1.6	2.7	0.05	0.14	0.06
08:00	3.5	5.0	0.07	0.02	0.07
09:00	1.2	6.8	0.16	0.06	−0.33
10:00	−2.2	1.6	0.05	−0.19	−0.62
17:00	25.3	19.3	1.61	1.02	2.49
18:00	1.6	5.3	0.15	0.17	0.30
19:00	0.3	6.1	0.34	0.13	0.70
Summer					
06:00	23.6	23.2	1.80	0.47	3.45
07:00	1.1	1.7	0.05	0.11	0.11
08:00	2.9	4.0	0.07	0.20	−0.18
09:00	1.4	5.7	0.15	0.17	−0.70
10:00	−1.8	−3.3	−0.13	0.04	−1.07
17:00	22.5	16.4	1.57	0.42	2.47
18:00	1.5	4.8	0.09	0.15	0.12
19:00	1.6	7.3	0.29	0.25	0.40
Monsoon					
06:00	17.6	24.8	1.90	0.63	3.55
07:00	1.5	1.9	0.02	0.06	−0.02
08:00	3.6	5.1	0.03	0.07	−0.25
09:00	3.4	6.5	0.01	0.58	−1.41
10:00	0.4	−1.0	−0.05	0.04	−1.07
17:00	15.0	19.3	1.75	0.42	2.54
18:00	1.4	3.8	0.12	0.34	0.32
19:00	0.9	6.0	0.31	0.55	0.51

Table 3 The correlation matrix of NH_3 and other trace gases during winter, summer, and monsoon seasons

Seasons		NH_3	NO	CO	NMHC	CH_4
Winter	NH_3	1				
	NO	0.84*	1			
	CO	0.44*	0.75*	1		
	NMHC	0.67*	0.75*	0.36	1	
	CH_4	0.64*	0.83*	0.89*	0.62*	1
Summer	NH_3	1				
	NO	0.80*	1			
	CO	0.48*	0.74*	1		
	NMHC	0.42	0.70*	0.85*	1	
	CH_4	0.21	0.65*	0.71*	0.66*	1
Monsoon	NH_3	1				
	NO	0.78*	1			
	CO	0.29	0.63*	1		
	NMHC	0.52*	0.81*	0.85*	1	
	CH_4	0.02	0.52*	0.69*	0.46*	1

*Significant at $p < 0.05$

Conclusions

Mixing ratios of ambient NH_3, NO, CO, NMHCs, and CH_4 were measured to investigate the vehicular emissions are dominant source of atmospheric NH_3 in urban site of Delhi, India, from January 2013 to December 2014. The annual average mixing ratios of NH_3, NO, CO, NMHCs, and CH_4 were 21.2 ± 2.1 ppb, 21.2 ± 6.1 ppb, 1.89 ± 0.18 ppm, 0.67 ± 0.21 ppm, and 3.11 ± 0.53 ppm, respectively. Result reveals that the mixing ratio of ambient NH_3 significantly positively correlated with traffic-related pollutants (NO, CO, and NHHCs) during all the seasons. The results emphasized that the traffic could be one of the dominant source of ambient NH_3 at the urban site of Delhi, as illustrated by positive correlations of NH_3 with traffic related co-pollutants. However, it is still unknown whether small fraction of NH_3 emissions from vehicles in Delhi is just the result of its local traffic composition or they are generally true worldwide.

Acknowledgements The authors thank the Director, CSIR-National Physical Laboratory, New Delhi and Head, Environmental Sciences and Biomedical Metrology Division, CSIR-NPL, New Delhi for their encouragement and support. The authors also acknowledge Council of Scientific and Industrial Research (CSIR), New Delhi (CMM project; CSIR-EMPOWER Project: OLP-102132), and Department of Science and Technology, New Delhi (Grant No.: SR/S4/AS:12/2008) for financial support.

References

Aneja VP, Chauhan JP, Walker JT (2000) Characterization of atmospheric ammonia emissions from swine waste storage and treatment lagoons. J Geophys Atmos 105:11535–11545

Aneja VP, Roelle PA, Murray GC, Southerland J, Erisman JW, Fowler D (2001) Atmospheric nitrogen compounds II: emissions, transport, transformation, deposition and assessment. Atmos Environ 35:1903–1911

Brunekreef B, Holgate ST (2002) Air pollution and health. Lancet 360:1233–1242

Capr JN, Tang YS, van Dijk N, Love L, Sutton MA, Palmer SCF (2004) Concentrations of ammonia and nitogen dioxide at roadside verges and their contribution to nitrogen deposition. Environ Pollut 132:469–478

Chan CK, Yao X (2008) Air pollution in mega cities in China. Atmos Environ 42:1–42

Chang Y, Liu X, Deng C, Dore AJ, Zhuang G (2016) Source apportionment of atmospheric ammonia before, during, and after the 2014 APEC summit in Beijing using stable nitrogen isotope signatures. Atmos Chem Phys 16:11635–11647

Chow JC, Watson JG, Fujita EM, Lu Z, Douglas R, Lawson DR, Lowell, Ashbaugh LL (1994) Temporal and spatial variations of $PM_{2.5}$ and PM_{10} aerosol in the Southern California air quality study. Atmos Environ 28:2061–2080

Fu X, Wang S, Zhao B, Xing J, Cheng Z, Liu H, Hao J (2013) Emission inventory of primary pollutants and chemical speciation in 2010 for the Yangtze River Delta region China. Atmos Environ 70:39–50

Gandhi HS, Shelef M (1991) Effect of sulphur on noble metal automotive catalysts. Appl Catalyst 77:175–186

Huang C, Chen CH, Li L, Cheng Z, Wang HL, Huang HY, Streets DJ, Wang YJ, Jhang GF, Chen YR (2011a) Emission inventory of anthropogenic air pollutants and VOC species in the Yangtze River Delta region China. Atmos Chem Phys 11:4105–4120

Huang X, Qiu R, Chan CK, Kant PR (2011b) Evidence of high $PM_{2.5}$ strong acidity in ammonia-rich atmosphere of Guangzhou, China: transition in pathways of ambient ammonia to form aerosol ammonium at $[NH_4^+]/[SO_4^{2-}] = 1.5$. Atmos Res 99:488–495

Ianniello A, Spataro F, Esposito G, Allegrini I, Rantica E, Ancora MP, Zhu T (2010) Occurrence of gas phase ammonia in the area of Beijing (China). Atmos Chem Phys 10:9487–9503

Jain S, Sharma SK, Srivastava MK, Chaterjee A, Singh RK, Saxena M, Mandal TK (2019) Source apportionment of PM_{10} over three tropical urban atmospheres at indo-gangetic plain of India: an approach using different receptor models. Arch Environ Contam Toxicol 76(1):114–128

Kapoor RK, Singh G, Tiwari S (1992) Ammonia concentration viš a viš meteorological conditions at Delhi, India. Atmos Res 28:1–9

Kirchner PB, Bales RC, Musselman KN, Molotch NP (2012) Undercanopy snow accumulation and ablation measured with airborne scanning LiDAR altimetry and in situ instrumental measurements, southern Sierra Nevada, California. Fall Meeting, American Geophysical Union, December 2012. Abstract C14B-08

Lee S, Baumann K, Schauer JJ, Sheesley RJ, Naeher LP, Meinardi S, Blake DR, Edgerton ES, Russel AG, Clements M (2005) Gaseous and particulate emissions from prescribed burning in Georgia. Environ Sci Technol 39:9049–9056

Li Y, Schwab JJ, Demerjian KL (2006) Measurement of ambient ammonia using a tunable diode laser absorption spectrometer: characteristics of ambient ammonia emissions in an urban area of New York City. J Geophy Res 111:D10. https://doi.org/10.1029/2005jd006275

Meng ZY, Ding GA, Xu XB, Xu XD, Yu HQ, Wang SF (2008) Vertical distributions of SO_2 and NO_2 in the lower atmosphere in Beijing urban areas China. Sci Total Environ 390:456–465

Meng ZY, Lin WL, Jiang XM, Yan P, Wang Y, Zhang YM, Jia XF, Yu XL (2011) Characteristics of atmospheric ammonia over Beijing, China. Atmos Chem Phys 11:6139–6151

Nagpure AS, Sharma K, Gurjar BR (2013) Traffic induced emission estimates and trends (2000–2005) in megacity Delhi. Urban Clim 4:61–73

Olivier JGJ, Bouwman AF, Van der Hoek KW, Berdowski JJM (1998) Global air emission inventories for anthropogenic sources of NO_x, NH_3 and N_2O in 1990. Environ Pollut 102:135–148

Perrino C, Catrambone M, Bucchianico ADM, Allegrini I (2002) Gaseous ammonia in the urban area of Rome, Italy and its relationship with traffic emissions. Atmos Environ 36:5385–5394

Pinder RW, Adams PJ, Pandis SN (2007) Ammonia emission controls as a cost-effective strategy for reducing atmospheric particulate matter in the Eastern United States. Environ Sci Technol 41(2):380–386

Saraswati, Sharma SK, Mandal TK (2018) Five-year measurement of ambient ammonia and its interaction with other trace gases at an urban site of Delhi, India. Meteo Atmos Phys 130(2):241–257

Saraswati, George MP, Sharma SK, Mandal TK, Kotnala RK (2019) Simultaneous measurements of ambient NH_3 and its relationship with other trace gases, $PM_{2.5}$ and meteorological parameters over Delhi, India. MAPAN-JMSI 34(1):55–69

Seinfeld JH, Pandis SN (1998) Atmospheric chemistry and physics from air pollution to climate change. Wiley, New York, p 1326

Seinfeld JH, Pandis SN (2006) Atmospheric chemistry and physics: from air pollution to climate change. Wiley, New York

Sharma M, Dikshit O (2016) Comprehensive study on air pollution and green house gases (GHGs) in Delhi. A report submitted to Government of NCT Delhi and DPCC Delhi. 2016;1–334

Sharma SK, Datta A, Saud T, Saxena M, Mandal TK, Ahammed YN, Arya BC (2010) Seasonal variability of ambient NH_3, NO, NO_2 and SO_2 over Delhi. J Environ Sci 22:1023–1028

Sharma SK, Kumar M, Gupta NC, Rohtash Saraswati, Saxena M, Mandal TK (2014) Characteristics of ambient ammonia over Delhi India. Meteorol Atmos Phys 124:67–82

Sharma SK, Rohtash, Mandal TK, Deb NC, Pal S (2016) Measurement of ambient NH_3, NO and NO_2 at an urban area of Kolkata, India. MAPAN-JMSI 31:75–80

Sharma SK, Saraswati Mandal TK, Saxena M (2017) Inter-annual variation of ambient ammonia and related trace gases in Delhi India. Bull Environ Contamin Toxicol 99(2):281–285

Sharma SK, Mandal TK, Sharma A, Jain S, Saraswati (2018) Carbonaceous species of $PM_{2.5}$ in megacity Delhi, India during 2012-2016. Bull Environ Contamin Toxicol 100:695–701

Stritzke F, Diemel O, Wagner S (2015) TDLAS-based NH_3 mole fraction measurement for exhaust diagnostics during selective catalytic reduction using a fiber-coupled 2.2-µm DFB diode laser. Appl Phys B 119:143–152

Sutton MA, Dragosits U, Tang YS, Fowler D (2000) Ammonia emissions from non-agricultural sources in the UK. Atmos Environ 34:855–869

Sutton MA, Reis S, Riddick SN, Dragosits U, Nemitz E, Theobald MR et al (2013) Towards a climate-dependent paradigm of ammonia emission and deposition. Philos Trans R Soc B Biol Sci 368:20130166

Wang XM, Ding X, Fu XX, He QF, Wang SY, Bernard F, Zhao XY, Wu D (2012) Aerosol scattering coefficients and major chemical compositions of fine particles observed at a rural site in the central Pearl River delta, south China. J Environ Sci 24:72–77

Whitehead JD, Longley ID, Gallagher MW (2007) Seasonal and diurnal variation in atmospheric ammonia in an urban environment measured using a quantum cascade laser absorption spectrometer. Water Air Soil Pollut 183(1–4):317–329

Zutshi PK, Sequeira R, Mahadevan TN, Banerjee T (1970) Environmental concentrations of some of the major inorganics pollutants at the Barc site Trombay. Indian J Meteorol Geophys 21:473–478