

Diurnal Variation of Ambient NH₃ in Relation with Agricultural Activities and Meteorological Factors at a Rural Site in North India

SUDESH and U. C. KULSHRESTHA*

School of Environmental Sciences, Jawaharlal Nehru University, New Delhi 110067, India.

Abstract

Ammonia is a chemically active gas which accelerates particulate matter formation by combining with nitrate (NO₃⁻) and sulphate (SO₄²⁻) in acid cloud droplets, thereby reducing air quality. Since pre-industrial times, NH₃ emissions have more than doubled globally, owing to increase in agricultural activities and fertilizer usage. In this study, ambient NH₃ monitoring was done during selected periods on event basis in summer season (kharif crop) at a rural site of Jhajjar district of Haryana. Collected gaseous NH₃ samples in absorbing solution (1.4ml H₂SO₄ in 1 litre water) at a flow rate of 1 LPM were prepared with the indo phenol-blue method and analyzed using spectrophotometer at 630nm. Here, we present the day-night variation in ambient NH₃ concentrations emitted from various agricultural activities such as synthetic fertilizers, animal manure, biological N-fixation, the crop residue in the field after harvest, biomass burning, etc in relation with meteorological parameters. Its emission was recorded as 1 to 45; 63 to 190; 98 to 187 and 56 to 249 µg m⁻³ during sowing, fertilizer addition, grain filling and biomass burning respectively. Concentration of NH₃ during the sowing period i.e. 1 to 45 µg m⁻³ can be considered as baseline values. The Concentration of ambient NH₃ reached its maxima at night and minima during midday. NH₃ concentration was observed to be high during night time which might be due to reduced dispersion as the atmospheric conditions are stable at night. Concentration of NH₃ is majorly influenced by wind speed and wind direction & its dependency on these meteorological parameters suggested a local source influence indicating that the nearby agricultural



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CONTACT U. C. Kulshrestha ✉ umeshkulshrestha@gmail.com 📍 School of Environmental Sciences, Jawaharlal Nehru University, New Delhi 110067, India.



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fields might be the major NH_3 contributors at the observational site. This study suggests that the knowledge of NH_3 levels measured at various stages can help in implementing N efficient management system and emissions can be reduced by minimizing the Nitrogen (N) input during different stages. These measurements are also helpful in making fertilizer policy, and guidelines for farmers.

Introduction

The biogeochemical cycling of nitrogen is of vital importance due to the role of nitrogen in both aquatic and terrestrial ecosystems. However, global nitrogen cycle is being disturbed by the unchecked increase in food and energy production resulting in the accumulation of Reactive Nitrogen (Nr) in various environmental matrices. Generally, Nr refers to any form of nitrogen compound that is biologically active, photochemically reactive and radioactively active in the biosphere and atmosphere of the earth.¹⁻² Nr includes inorganic reduced form of N (NH_3 , NH_4^+), inorganic oxidized forms (NO_x , NO_3^- , N_2O , HONO) & organic nitrogen compounds.³ However, these Nr species are extremely important in atmospheric chemistry. Henceforth, the monitoring of Agricultural nitrogen air emissions and understanding their behaviour in atmosphere is crucial due to impending environmental and human health concern of the latter. One of the major sources of the incessant increase in the nitrogen air emissions is the agriculture activities followed by livestock, human waste, transport sector. Ammonia is one of the most important reactive Nitrogen (Nr) compounds emitted from agricultural sources. Other minor anthropogenic sources of atmospheric NH_3 emissions include animal manure, slash burning and industries⁴ along with the natural sources such as forest fires, soils and oceans.⁵⁻⁶ In India, the Indo-Gangetic plain (IGP) has been reported as hotspot of both NH_3 and NH_4^+ emissions due to intense agricultural activities in the region.⁷ The major contributor for NH_3 emissions in agricultural systems includes inorganic fertilizers, livestock manure, increased biological N-fixation, biomass burning and residue added to the field after crop harvesting. For instance, as reported by Misselbrook *et al.*,⁸ agricultural sector alone is responsible for about 90% of the total atmospheric NH_3 emissions. According to Vitousek *et al.*,⁹ human interventions have approximately doubled the fluxes of Nr species viz NH_3 , NO_x , NH_4^+ , NO_3^- , and N_2O .¹⁰ Human activities contribute approximately

170 Tg year^{-1} of Nr into agroecosystems, where inorganic fertilizer additions account for about 80 Tg Nr annually.¹¹ For Indian Scenario, Aneja *et al.*,¹² reported the highest contribution of fertilizer application and livestock towards NH_3 as 2696.6 Gg and 1704.8 Gg respectively. Among various inorganic fertilizers, urea is the most widely used N fertilizer in south Asia.¹³ Furthermore, urea is the highest contributor (~ 94%) of NH_3 because of its large scale use and nitrogen content is maximum among all other fertilizers being used in India.¹⁴ Urea alone contributes 2481.5 Gg NH_3 whereas di-ammonium phosphate (DAP), NPK, ammonium phosphate contributes 124.8 Gg, 89.7 Gg and 0.6 Gg NH_3 respectively, annually. Also, the rate of increase of urea in agricultural fields is estimated to be 92% per year, thus adding to the Nr budget.¹³ 45-55% of these Nr inputs are recovered by crop biomass whereas remaining is lost from agricultural systems via leaching, erosion (32–45 Tg N year^{-1}) and denitrification (26–60 Tg N year^{-1}).¹⁰⁻¹¹ Hence directly or indirectly influences the Nitrogen cycle.

A remarkable portion of N-fertilizer or excess reactive soil N (Nr) is lost through volatilization in the form of ammonia (NH_3) and surface run off which significantly contributes to the Nitrogen loss. Bouwman *et al.*,¹⁵ reported that 10–30% of the applied N fertilizer is lost through volatilization process. Once NH_3 is applied to the soil by fertilizer addition, NH_4^+ gets retained on the exchange sites. NH_4^+ is either nitrified to nitrate (NO_3^-), or decomposed to NH_3 , depending on soil and environmental conditions. High temperature inhibits the nitrification process as reported by Grunditz and Dalhammar,¹⁶ and hence, ammonia volatilization increases with increase in temperature. In agroecosystems, NH_3 emissions can be reduced by minimizing the N input, increasing the efficiency of N fertilizers.¹⁷

Some studies have been carried out by research groups for NH_3 inventories in Asian region¹⁸ which

mainly relied on emission factors. However, no country-specific emission factor for NH_3 is available, there is high uncertainty in the emission estimates of NH_3 in India.¹⁹ As reported by Parashar *et al*²⁰ NH_3 emissions from fertilizers and livestock are estimated to be 1175 Gg and 1433 Gg, respectively. According to the estimates given by Yang *et al*,²¹ the annual concentration of gaseous ammonia measured in an agricultural field varied from 1.3 to 17.2 $\mu\text{g m}^{-3}$ and observed to be higher in summer than in winter season.

Fate of atmospheric ammonia (NH_3) is highly variable. NH_3 is the most abundant alkaline constituent in the atmosphere²² and a precursor molecule for secondary aerosol formation causing severe air pollution in East and South Asia by contributing ambient levels of fine particulate matter ($\text{PM}_{2.5}$).²³ Transformation of atmospheric NH_3 into NH_4^+ via chemical processes of precursor gases (NH_3 , SO_2 , NO_x) occurs either by condensation or by direct nucleation. The major inorganic compounds formed through the gas-to-particle formation process are ammonium bisulfate (NH_4HSO_4), ammonium sulfate ($(\text{NH}_4)_2\text{SO}_4$), ammonium nitrate (NH_4NO_3) and ammonium chloride (NH_4Cl). Due to the substantial increment in atmospheric NH_3 emissions and its transformation, more ammonium (NH_4^+) is returned to terrestrial and aquatic ecosystems via dry and wet deposition mechanisms. In temperate regions, precipitation is the main scavenging mechanism whereas in dry regions (with no or little rainfall) dry deposition is the dominating mechanism for the removal of atmospheric pollutants. Since, in India ~ 90 % of precipitation occurs during monsoon period (June to September), dry deposition is the dominating mechanism for the scavenging of atmospheric pollutants throughout the year.²⁴ Moreover, the fate of N species is determined by atmospheric acidity, particulate loading, land use dynamics, and photochemistry of the atmosphere.²⁵ The deposition of NH_3 and NH_4^+ in various compartments across the globe causes a cascade of environmental problems such as eutrophication of terrestrial and aquatic ecosystem, biodiversity loss, forest damage, water and soil acidification.²⁶⁻²⁷ Hence its role in atmospheric phenomenon such as neutralisation of cloud water, precipitation and aerosol formation typically in the fine particle size range is pivotal.²⁸

In addition, the formation of ammonium particulates increases the residence time of NH_3 in the atmosphere thereby influencing the geographic distribution of acidic species. Also, deposition of these fine particles deep into the lungs causes morbidity and mortality in humans, alterations in visibility and climate.²⁹ Henceforth, the monitoring of atmospheric NH_3 in agricultural fields is one of the decisive parameters that needs to be considered. For this the study was conducted at a rural site in Jhajjar district of Haryana with the following objectives- i). to quantify the NH_3 concentration and its variation during different growing stages of crops sown in our study area and ii). to study the effect of meteorological parameters in order to identify the possible transformations of NH_3 . The NH_3 emission rate from various agricultural activities and its downwind concentration mainly depends on meteorological conditions. There exists a positive relationship between incident solar radiation/ air temperature and NH_3 emission from surface-applied fertilizers.³⁰⁻³² The Solar radiation increases the NH_3 emission by increasing the atmospheric turbulence and hence, NH_3 evaporates from the surface. Apart from that evaporation of water due to increasing air temperature increases the total N concentration at the surface. Consequently, the NH_3 at the surface is transported upwards by atmospheric turbulence and sideways, by advection. Hence, NH_3 emission levels are related to wind speed, relative humidity and temperature.³² Higher humidity and lower temperature favours the formation of NH_4^+ aerosols in presence of NO_2 and SO_2 .

Methodology

Site Description

A study was conducted at a rural site in Chhuchhakwas village of Jhajjar district in Haryana (Fig. 1). It lies between 28°22' - 28°49' North latitudes, and 76°18' -76°59' East longitudes. The village is located at a 13 kms from Jhajjar district which lies in the south-east part of the Haryana state covering total geographical area of 1834 sq.km. The climate characteristics of this area are hot summer, cold winter and moderate rainfall of about 444 mm. This area comprises approximately 87.03% land under agriculture and 6.77% build up area, indicating very less development in terms of urbanization. The district covers an forest area of 41 km², net sown

area of 1670 km² and cultivable area of 1760 km² (Agriculture department Jhajjar). The sampling site

represents a typical rural atmosphere surrounded by agricultural fields in all directions.

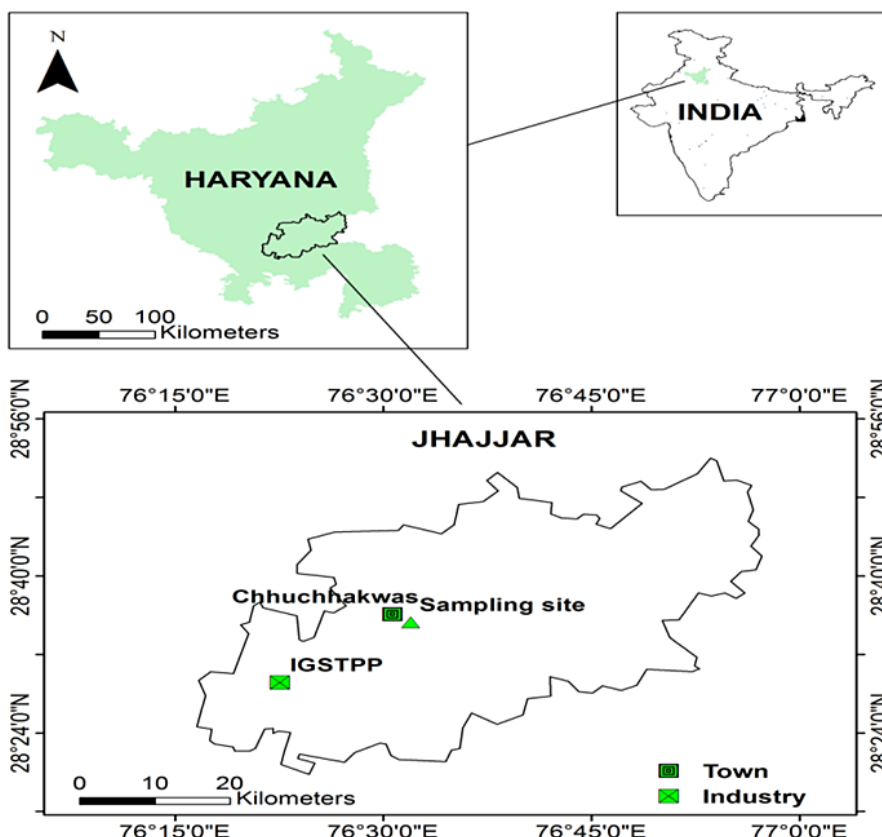


Fig. 1: Map of the sampling site

Table 1: Monthly variation of temperature, wind speed and relative humidity during the sampling period

Month	Temperature (°C)	Wind speed (mph)	Relative humidity (%)
July, 2017	37.40	9	39.46
August, 2017	35.83	7	52.13
September, 2017	35.28	4	38.06
October, 2017	34.86	3	32.40

Meteorological Data

The Temperature, relative humidity and wind data of the study region for every month (July to October) were downloaded from the world weather online.com. Table 1 shows the mean values of all above mentioned meteorological parameters during the sampling period.

Experimental Setup

Collection of gaseous NH₃ samples was performed on 6 hr basis during both daytime and night time (8am-2pm and 10pm-4am) from July to October 2017 using a sampling assembly (Fig. 2) consisting of a low volume pump operating at a flow rate of 1 LPM. Ammonia gas was absorbed in absorbing

solution (20 ml of 25 mM H₂SO₄) in a standard impinger for 6 hours.³³ The aerosol samples were collected on the PTFE filters (diameter 47 mm and pore size 0.2µm) placed upstream to the impingers. Filter pack was connected to the impinger through silicon tubing. Collected gaseous NH₃ samples in absorbing solution were transferred into centrifuge tubes, preserved in refrigerator and analyzed by catalyzed Indophenol-blue method. It includes photometric determination of NH₃ which is based on reaction with phenol and hypochlorite producing

Indophenol, intensely blue in alkaline medium which is further analysed using spectrophotometer at 630nm. The collection efficiency of impinger technique for NH₃ capture was estimated by using two impingers in series (Fig. 2), using the formula:

$$\text{Collection efficiency} = \eta_2 * 100 / (\eta_1 + \eta_2) \quad \dots(1)$$

where η_1 and η_2 are the values of optical density in impingers 1 and 2, respectively (Fig. 2)

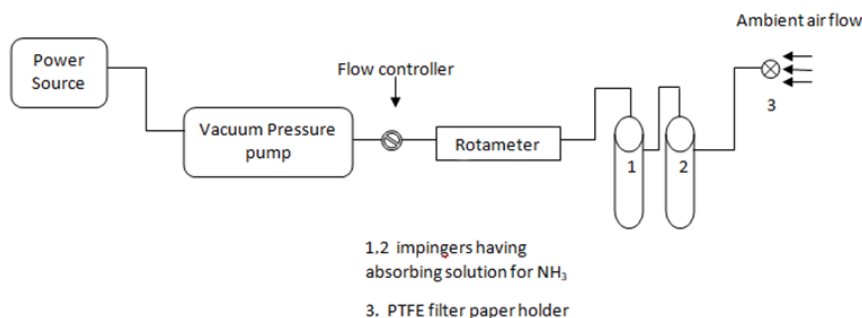


Fig. 2: Flow diagram of sampling assembly

Hence, the collection efficiency of NH₃ using this method was estimated to be 67%. Furthermore, certainty and reliability in data collection was maintained by rejection of daily samples in case of any disruption or reduction of post-sampling flow rate by more than 10% of the pre-sampling flow rate.

Agriculture and Cropping Pattern

The farming practices in Jhajjar district are dominated by agriculture activities and animal husbandry. The main crops sown in this region are Kharif crops and Rabi crops. Kharif crops also known as monsoon or autumn crops, are cultivated at the onset of the monsoon season around June and harvested by September or October. *Oryza Sativa* (Paddy), pearl millet (bajra), *Gossypium* (cotton), *Cyamopsis tetragonoloba* (guar) etc. and Rabi crops are agricultural crops that are sown in winter in month of November and harvested in March. *Triticum aestivum* (Wheat), *Brassica juncea* (mustard), *Hordeum Vulgare* (barley), etc.

Results and Discussion

Concentration of NH₃ Over the Study Period

Table 2 gives the concentration of NH₃ over various periods (growing, post-fertilizer, grain filling, post-

harvest) for the kharif crop (mainly pearl millet in our study area). Growing period in the month of July shows the least NH₃ concentration with an average value 29.68 µg m⁻³ as compared to all other time phases. These values can be assumed as background values. Nitrogen fertilizer can either be incorporated into the soil (basal dressing) before growing the crop or applied to the soil surface (top dressing). In basal dressing, nitrogen fertilizer is placed below the soil layer which limits the rates of nitrification, denitrification, volatilization and therefore, enhance efficiency of N fertilizer use.³⁴ As Diammonium phosphate (DAP) fertilizer is mainly used in basal dressing (30 kg/hectare) prior to growing, the levels were very less as compared to the levels after top dressing (commonly urea) fertilizer application. The levels increased markedly after urea was applied on the soil surface on 1st August with an application rate ~100kg/hectare. Among various fertilizers being used in India, the NH₃ concentrations peaked in conjunction with the application of urea. Contribution from application is highest not only because of its excessive usage in Indian agriculture but also due to the large emission factor for NH₃

emissions.³⁵ The average were measured as 96 $\mu\text{g m}^{-3}$ and 149 $\mu\text{g m}^{-3}$ during day and night time respectively. The levels of NH_3 are very high during grain filling and post-harvest period. As plant uptake of soil-N decreases towards maturity,

NH_3 volatilization from soil increases. This may be responsible for higher NH_3 emission towards maturity. For further analysis during these months, variation of NH_3 was related with wind directions as described below (Fig. 7).

Table 2: Day-Night concentration of NH_3 over various time periods of the kharif crop (pearl millet in our study area)

Date	Sampling periods	Day time NH_3 conc. (μgm^{-3})	Night time NH_3 conc. (μgm^{-3})
09 July 2017		1	-
10 July 2017		34	-
11 July 2017	Sowing period	41	-
12 July 2017		45	-
13 July 2017		25	-
02 Aug 2017		115	163
03 Aug 2017	Post-fertilizer addition	122	88
04 Aug 2017		84	190
05 Aug 2017		63	154
12 Sept 2017	Grain filling	141	170
13 Sept 2017		187	139
14 Sept 2017		125	144
15 Sept 2017		98	121
08 Oct 2017	Post-harvest	56	176
09 Oct 2017		104	234
10 Oct 2017		117	249
11 Oct 2017		151	184

Diurnal Variation of NH_3 Over the Study Period

Fig.3 shows the diurnal variability in NH_3 concentration over the study period. NH_3 concentration is higher during night time as compared to the day time. Similar variation in NH_3 emissions were also reported by other researchers.³⁶ During day time NH_3 concentration varied from 1 to 187 μgm^{-3} and during night time it lies in the range 88 to 249 μgm^{-3} . The mean concentration of NH_3 for the day and night time was found to be 89 and 168 μgm^{-3} respectively. Fig.4 shows the variation of average day and night time concentration of NH_3 over the sampling months. Higher NH_3 concentrations observed during night time might be due to stable atmospheric conditions (less turbulence) which resulted in reduced dispersion of gaseous NH_3 in

the atmosphere because of the accumulation and inefficient vertical mixing within a relative shallow boundary. This pattern is in consistent with the studies by other researchers.³⁷⁻³⁸

Meteorological Data

The Mean temperature during the sampling periods over the month of July, August, September, October observed to be 37.4°C, 35.83°C, 35.28°C and 34.86°C respectively whereas the average relative humidity levels were found to be 39.46%, 52.125%, 38.06% and 32.40% respectively. The prevailing wind speed and directions were mostly in the range 2–7 mph with distinct patterns in W, E, NW and ESE directions.

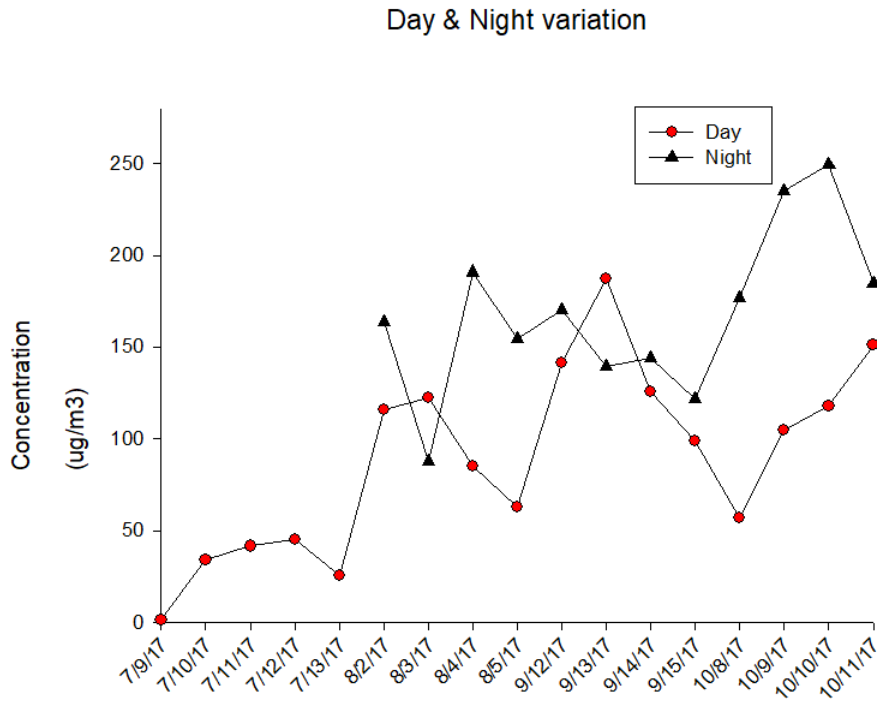


Fig. 3: Diurnal variation of NH₃ concentration over the study period.

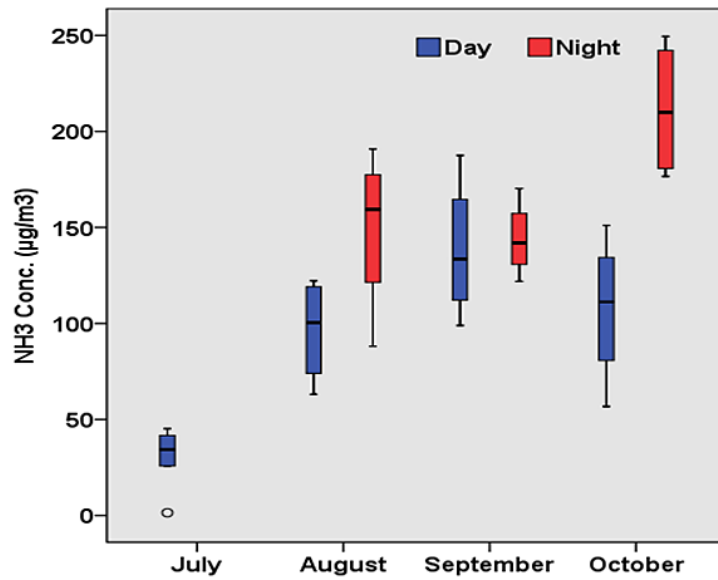


Fig. 4: Average day- night time variation of NH₃ over the sampling months.

Variation of NH₃ with temperature and relative humidity is as represented in Fig. 5. There was no significant correlation observed between NH₃ concentration with temperature and relative humidity in our catchment (Fig. 6). The Levels of

NH₃ are negatively correlated with temperature and relative humidity during day time. In contrast, NH₃ concentration are positively correlated with temperature & negatively with relative humidity during night time. The relation can be explained

on the fact that high temperature and low relative humidity conditions favours the formation of NH_3 from NH_4^+ . The reason being, in summer, particulate

ammonium nitrate is volatile, and hence, NH_4NO_3 will be in gaseous phase.³⁹

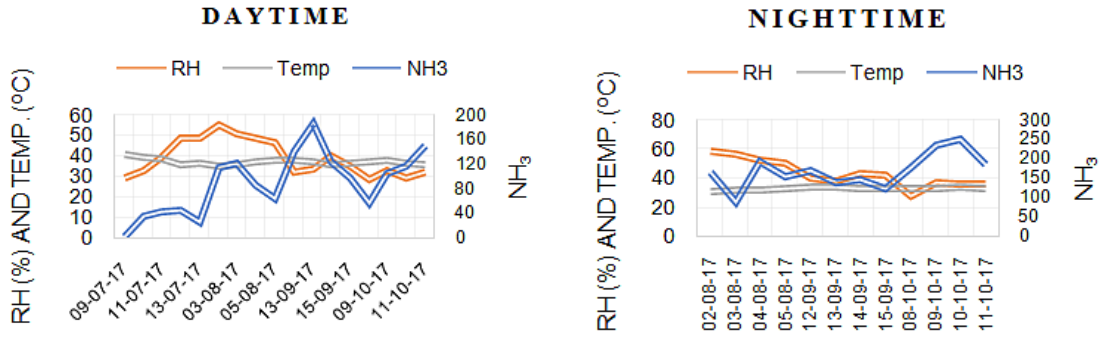


Fig. 5: Variation of NH_3 ($\mu\text{g m}^{-3}$) with RH (%) and temperature ($^{\circ}\text{C}$) during day time and night time

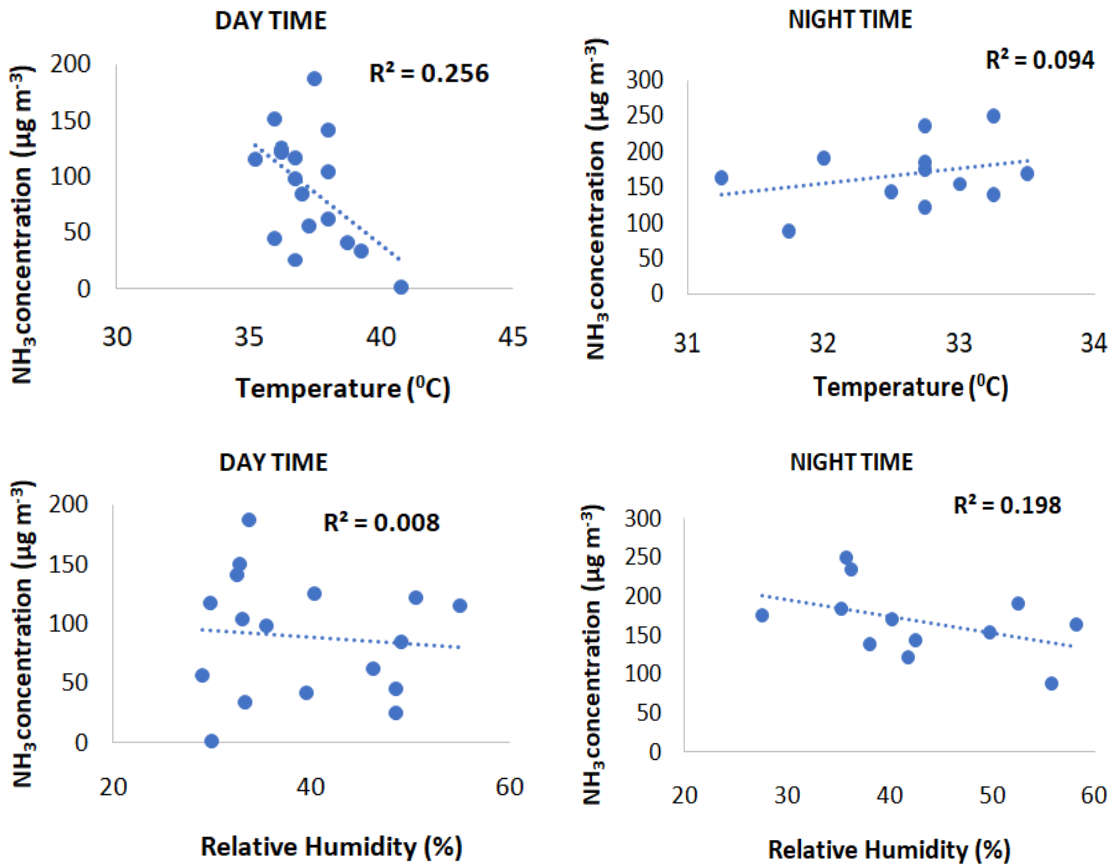


Fig. 6: Correlation of NH_3 ($\mu\text{g m}^{-3}$) with RH (%) and temperature ($^{\circ}\text{C}$) during day time and night time

Possible Sources of NH_3

Since, NH_3 is either subjected to dry deposition or readily converted to NH_4^+ . Therefore, high levels

of gaseous NH_3 are expected close to the surface and at less distance from the emission sources.⁴⁰⁻⁴¹ Hence, there might be some local emission sources

near the observation site. The wind rose plots suggested higher concentration from the west direction of the sampling site in the month of July and August (Fig.7). Application of large amount of inorganic nitrogen fertilizers in the nearby agricultural fields might be contributing to ambient NH₃ concentration in these sampling months. Several researchers from various parts of the world also reported similar observations.⁴²⁻⁴³ During the grain filling period, in the month of September, the level of

ammonia was considerably high, and the prevailing wind direction was mainly northwest (Fig.7c). As the village is in the northwest direction of the sampling site, livestock population, solid waste generation might be contributing towards higher NH₃ levels. In addition, wind was very diverse majorly from E and ESE direction during post harvest period in October. In addition to biomass burning, there might be various sources like animal waste, solid waste, etc. from nearby areas.

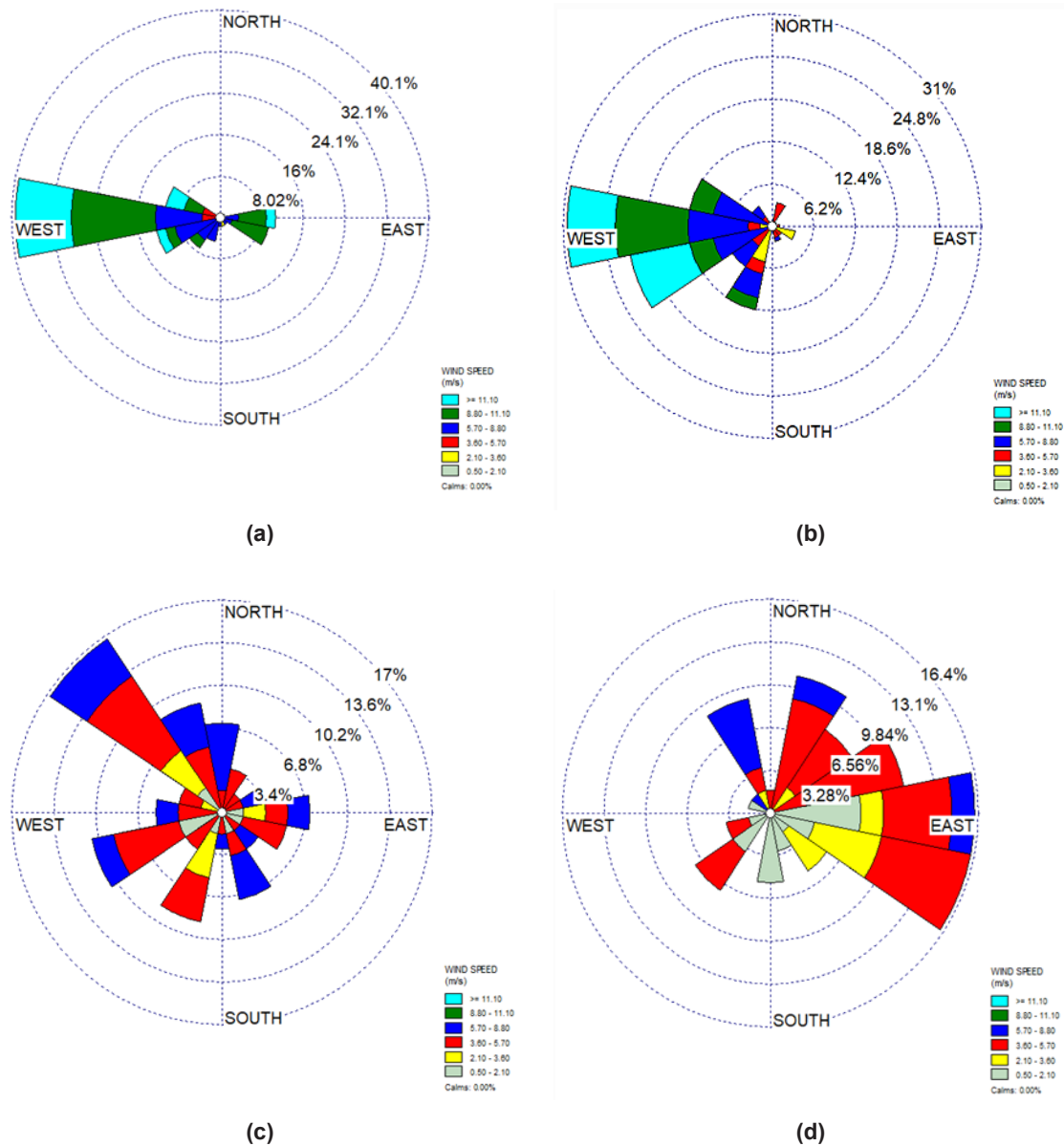
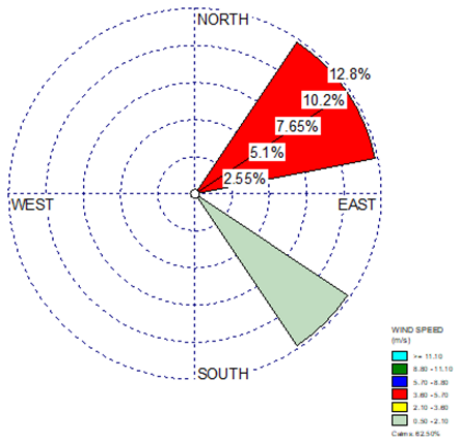
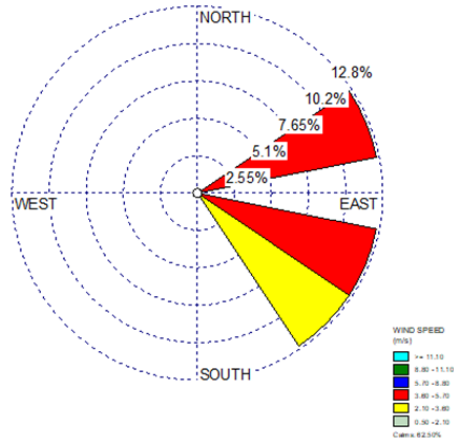


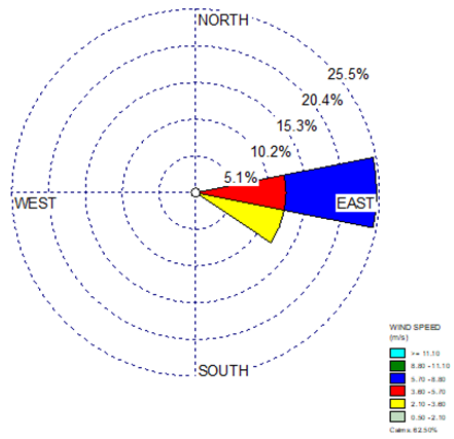
Fig. 7: Wind rose plot a) July 2017 b) August 2017 c) September 2017 d) October 2017



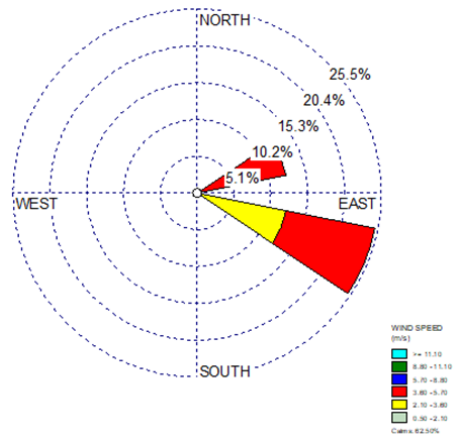
(e)



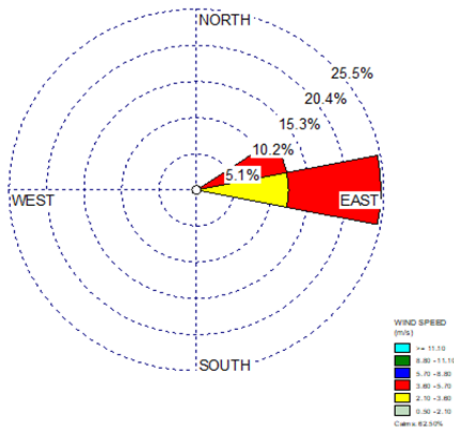
(f)



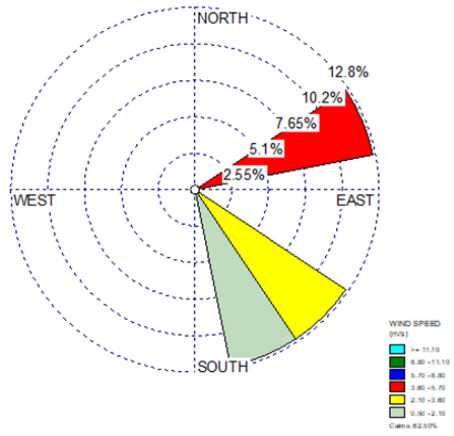
(g)



(h)



(i)



(j)

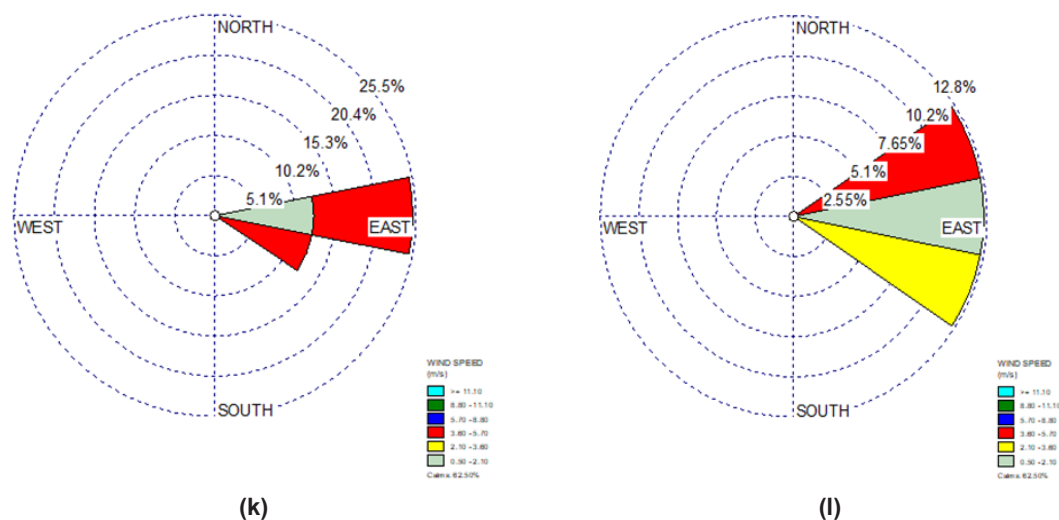


Fig. 8: Day & night wind rose plots (e, f) 8 October 2017 (g,h) 9 October 2017 (i, j)10 October 2017 (k, l) 11 October 2017, respectively

It is observed that the NH₃ concentration during day & night time on 8 October, 2017 was 56µg m⁻³ & 176 µg m⁻³ (Table 2). Wind rose diagrams were plotted to understand the significant gap between the diurnal values on this particular day (Fig.8). It can be inferred that there were only minor changes in wind directions

during day and night time. Hence, the high NH₃ levels starting from night time (8 October, 2017) can be attributed to the onset of biomass burning during post harvest period. However, to rule out any other possibility further investigation is required.

Table 3: Comparison of ambient NH₃ concentrations at various characteristic sites worldwide

Site	Background	Period	NH ₃ (µg m ⁻³)	Reference
North Carolina (USA)	Agricultural	July-September 2004	11.1	Wilson and Serre ⁴⁴
Dongbeiwang (China)	Suburban-agricultural		9.5	Shen <i>et al.</i> ⁴⁵
Beijing (China)	Urban	August 2007	24.3	Lanniello <i>et al.</i> ⁴⁶
Dhangadi (Nepal)	Regional	September 1999 -June 2001	14.6	Carmichael <i>et al.</i> ⁴⁷
Agra (India)	Urban	July-September November-February (1997-1998)	10.8	Parmar <i>et al.</i> ⁴⁸
Okhla, New Delhi (India)	Urban industrial	October 2012 -September 2013	40.7	Singh and Kulshrestha ¹⁴
Mai, U.P (India)	Rural-agricultural	October 2012 -September 2013	50.5	Singh and Kulshrestha ¹⁴
Chhuchhakwas, Haryana (India)	Rural-agricultural	July 2017 Aug 2017 Sept 2017 Oct 2017	29.7 122.9 141.2 159.5	Present study

Comparison of Concentrations of Gaseous NH₃ With other Studies

Generally, the level of atmospheric NH₃ is higher in tropical regions as compared to temperate regions. This is probably due to high temperature in tropical regions resulting in higher evaporation rates of gaseous NH₃ from agricultural soils, animal waste and other sources. In addition, abundance of alkaline dust in tropics favours the existence of alkaline NH₃ in its gaseous form. In contrast, dominance of H₂SO₄ in acidified atmosphere in most of the temperate areas results in the formation of NH₄⁺ and SO₄²⁻ aerosols.³⁸ Table 3 gives a comparison of NH₃ concentrations at various sites worldwide.

Conclusion

The average NH₃ level in the growing period, when DAP was incorporated into the soil was very less i.e. 29.68 μg m⁻³. This is because addition into the soil increases the efficiency of fertilizer use. The concentration reached to considerably high levels, 96.53 μg m⁻³ and 149.40 μg m⁻³ during day and night time respectively, after addition of N-fertilizer (urea) on the soil surface. The wind direction indicated nearby agricultural fields to be the main source of these high levels. Average NH₃ concentration during day and night time were observed to be 138.41 μg m⁻³ and 144.01 μg m⁻³ respectively prior to crop harvesting. Such high

levels might be due to the contribution from livestock, sewage, etc. as the winds were predominantly from North-west (village) direction during this sampling period. Ambient NH₃ concentration reached its maxima at night and minima during midday.

The study suggested that to reduce anthropogenic forcing of N cycle globally, there is need to address the inefficiency of N fertilization. In addition, there is a need to examine the formation of ammonium aerosols in the air around the agricultural areas in a comprehensive manner to address the health and climate issues related to ammonium aerosols.

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Conflict of Interest

The authors do not have any conflict of interest.

References

- Galloway, J. N., Dentener, F. J., Capone, D. G., Boyer, E. W., Howarth, R. W., Seitzinger, S. P., & Karl, D. M. Nitrogen cycles: past, present, and future. *Biogeochemistry*. 2004;70(2):153-226.
- Phoenix, G. K., Hicks, W. K., Cinderby, S., Kuylenstierna, J. C., Stock, W. D., Dentener, F. J., & Ashmore, M. R. Atmospheric nitrogen deposition in world biodiversity hotspots: the need for a greater global perspective in assessing N deposition impacts. *Global Change Biology*. 2006; 12(3): 470-476.
- Hertel, O., Skjoth, C. A., Reis, S., Bleeker, A., Harrison, R. M., Cape, J. N., & Kulmala, M. Governing processes for reactive nitrogen compounds in the European atmosphere. *Biogeosciences*. 2012; 9:4921-54.
- Sutton, M. A., Dragosits, U., Tang, Y. S., & Fowler, D. Ammonia emissions from non-agricultural sources in the UK. *Atmospheric Environment*. 2000; 34(6):855-869.
- Bouwman, A. F., Lee, D. S., Asman, W. A. H., Dentener, F. J., Van Der Hoek, K. W., & Olivier, J. G. J. A global high-resolution emission inventory for ammonia. *Global biogeochemical cycles*. 1997; 11(4):561-587.
- Lee, S., Baumann, K., Schauer, J. J., Sheesley, R. J., Naeher, L. P., Meinardi, S., & Clements, M. Gaseous and particulate emissions from prescribed burning in Georgia. *Environmental science & technology*. 2005; 39(23):9049-9056.
- Mishra, M., Kulshrestha, U.C. Extreme air pollution events spiking ionic levels

- at urban and rural sites of Indo-Gangetic plain. *Aerosol and Air Quality Research*. 2020; 20:1266-1281.
8. Misselbrook, T. H., Van Der Weerden, T. J., Pain, B. F., Jarvis, S. C., Chambers, B. J., Smith, K. A., Phillips, V.R.&Demmers, T. G. M. Ammonia emission factors for UK agriculture. *Atmospheric Environment*. 2000; 34(6): 871-880.
 9. Vitousek, P. M., Aber, J. D., Howarth, R. W., Likens, G. E., Matson, P. A., Schindler, D. W., Schlesinger, W.H. & Tilman, D. G. Human alteration of the global nitrogen cycle: sources and consequences. *Ecological applications*. 1997; 7(3):737-750.
 10. Galloway, J. N., & Cowling, E. B. Reactive nitrogen and the world: 200 years of change. *AMBIO: A Journal of the Human Environment*. 2002; 31(2): 64-71.
 11. Smil, V. Nitrogen in crop production: An account of global flows. *Global biogeochemical cycles*. 1999; 13(2): 647-662.
 12. Aneja, V. P., Schlesinger, W. H., Erisman, J. W., Behera, S. N., Sharma, M., & Battye, W. Reactive nitrogen emissions from crop and livestock farming in India. *Atmospheric Environment*. 2012; 47:92-103.
 13. Schwab, G. J., & Murdock, L. W. Nitrogen transformation inhibitors and controlled release urea. Extension Report. Lexington, KY: University of Kentucky College of Agriculture. 2005.
 14. Singh, S., Kulshrestha, U.C. Rural versus urban gaseous inorganic reactive nitrogen in the Indo-Gangetic plains (IGP) of India. *Environmental Research Letters*. 2014; 9(12):125004.
 15. Bouwman, A. F., Boumans, L. J. M., & Batjes, N. H. Estimation of global NH₃ volatilization loss from synthetic fertilizers and animal manure applied to arable lands and grasslands. *Global Biogeochemical Cycles*. 2002; 16(2):8-1.
 16. Grunditz, C., & Dalhammar, G. Development of nitrification inhibition assays using pure cultures of *Nitrosomonas* and *Nitrobacter*. *Water research*. 2001; 35(2):433-440.
 17. Van Egmond, K., Bresser, T., & Bouwman, L. The European nitrogen case. *AMBIO: A Journal of the Human Environment*. 2002; 31(2):72-78.
 18. Zhao, D. W., & Wang, A. P. (1994). Estimation of anthropogenic ammonia emissions in Asia. *Atmospheric Environment*, 28, 689–694. [https://doi.org/10.1016/1352-2310\(94\)90045-0](https://doi.org/10.1016/1352-2310(94)90045-0)
 19. Beusen, A. H. W., Bouwman, A. F., Heuberger, P. S. C., Van Drecht, G., & Van Der Hoek, K. W. (2008). Bottom-up uncertainty estimates of global ammonia emissions from global agricultural production systems. *Atmospheric Environment*, 42(24), 6067-6077.
 20. Parashar, D. C., Kulshrestha, U. C., & Sharma, C. (1998). Anthropogenic emissions of NO_x, NH₃ and N₂O in India. Nutrient cycling in agroecosystems, 52(2-3), 255-259.
 21. Yang, R., Hayashi, K., Zhu, B., Li, F., & Yan, X. (2010). Atmospheric NH₃ and NO₂ concentration and nitrogen deposition in an agricultural catchment of Eastern China. *Science of the Total Environment*, 408(20), 4624-4632.
 22. Aneja, V.P., Schlesinger, W.H., Knighton, R., Jennings, G., Niyogi, D., Gillam, W., Duke, C. Proc. Of the workshop on agricultural air quality: State of Science; Potomac, MD, North Carolina state University, Raleigh, NC. 2006.
 23. Xu, R. T., Pan, S. F., Chen, J., Chen, G. S., Yang, J., Dangal, S. R. S., & Tian, H. Q. (2018). Half-century ammonia emissions from agricultural systems in Southern Asia: Magnitude, spatiotemporal patterns, and implications for human health. *GeoHealth*, 2(1), 40-53.
 24. Naseem, M., & Kulshrestha, U. C. (2017). An Overview of Atmospheric Reactive Nitrogen Research: South Asian Perspective. *Current World Environment*, 14(1), 10.
 25. Vet R., Artz R. S., Carou S., Shaw M., Ro C.U., Aas W. & Hou A. A global assessment of precipitation chemistry and deposition of sulfur, nitrogen, sea salt, base cations, organic acids, acidity and pH, and phosphorus. *Atmospheric Environment*. 2014; 93:3-100
 26. Bouwman, A. F., Van Vuuren, D. P., Derwent, R. G., & Posch, M. A global analysis of acidification and eutrophication of terrestrial ecosystems. *Water, Air, and Soil Pollution*. 2002; 141(1-4):349-382.
 27. Bouwman, A. F., Lee, D. S., Asman, W. A. H., Dentener, F. J., Van Der Hoek, K. W., & Olivier, J. G. J. A global high-resolution

- emission inventory for ammonia. *Global biogeochemical cycles*. 1997; 11(4):561-587.
28. Aneja, V. P., Chauhan, J. P., & Walker, J. T. Characterization of atmospheric ammonia emissions from swine waste storage and treatment lagoons. *Journal of Geophysical Research: Atmospheres*. 2000; 105(D9):11535-11545.
 29. Asman, W. A., & van Jaarsveld, H. A. A variable-resolution transport model applied for NH_x in Europe. *Atmospheric Environment. Part A. General Topics*. 1992; 26(3): 445-464
 30. Sommer, S. G., Olesen, J. E., & Christensen, B. T. Effects of temperature, wind speed and air humidity on ammonia volatilization from surface applied cattle slurry. *The Journal of Agricultural Science*. 1991; 117(1):91-100.
 31. Braschkat, J., Mannheim, T., & Marschner, H. Estimation of ammonia losses after application of liquid cattle manure on grassland. *Zeitschrift für Pflanzenernährung und Bodenkunde*. 1997; 160(2):117-123.
 32. Sommer, S. G., Friis, E., Bach, A., & Schjørring, J. K. Ammonia volatilization from pig slurry applied with trail hoses or broadcast to winter wheat: effects of crop developmental stage, microclimate, and leaf ammonia absorption. *Journal of Environmental Quality*. 1997; 26(4):1153-1160.
 33. Tiwari, R., Kulshrestha, U. Winter time distribution and atmospheric interactions of reactive nitrogen species along the urban transect of Delhi – NCR. *Atmospheric Environment*. 2019; 209: 40-53.
 34. Linquist, B. A., Hill, J. E., Mutters, R. G., Greer, C. A., Hartley, C., Ruark, M. D., & Van Kessel, C. Assessing the necessity of surface-applied preplant nitrogen fertilizer in rice systems. *Agronomy Journal*. 2009; 101(4):906-915.
 35. Sharma, C., Tiwari, M. K., & Pathak, H. Estimates of emission and deposition of reactive nitrogenous species for India. *Current Science*. 2008; 1439-1446.
 36. Walker, J.T., Whittall, D.R., Robarge, W., & Paerl, H.W. Ambient ammonia and ammonium aerosol across a region of variable ammonia emission density. *Atmospheric Environment*. 2004; 38: 1235–1246.
 37. Burkhardt, J., Sutton, M. A., Milford, C., Storeton-West, R. L., & Fowler, D. Ammonia concentrations at a site in southern Scotland from 2 yr of continuous measurements. *Atmospheric Environment*. 1998; 32(3):325-331.
 38. Singh, S., Kulshrestha, U. C. Abundance and distribution of gaseous ammonia and particulate ammonium at Delhi, India. 2012; 9(12):5023-5029.
 39. Seinfeld, J.H., Pandis, S.N. *Atmospheric Chemistry and Physics*. Wiley-Interscience, New York. 1998.
 40. Ferm, M. Atmospheric ammonia and ammonium transport in Europe and critical loads: a review. *Nutrient Cycling in Agroecosystems*. 1998; 51(1):5-17.
 41. Lee, S., Baumann, K., Schauer, J. J., Sheesley, R. J., Naeher, L. P., Meinardi, S., Blake, D.R., Edgerton, E.S., Russell, A.G. and Clements, M. Gaseous and particulate emissions from prescribed burning in Georgia. *Environmental science & technology*. 2005; 39(23):9049-9056.
 42. Sakurai, T., Fujita, S. I., Hayami, H., & Furuhashi, N. A case study of high ammonia concentration in the nighttime by means of modeling analysis in the Kanto region of Japan. *Atmospheric Environment*. 2003; 37(31):4461-4465.
 43. Whitehead, J. D., Longley, I. D., & Gallagher, M. W. Seasonal and diurnal variation in atmospheric ammonia in an urban environment measured using a quantum cascade laser absorption spectrometer. *Water, air, and soil pollution*. 2007; 183:317-329.
 44. Wilson, S. M., & Serre, M. L. Use of passive samplers to measure atmospheric ammonia levels in a high-density industrial hog farm area of eastern North Carolina. *Atmospheric Environment*. 2007; 41(28):6074-6086.
 45. Shen, J. L., Tang, A. H., Liu, X. J., Fangmeier, A., Goulding, K. T. W., & Zhang, F. S. High concentrations and dry deposition of reactive nitrogen species at two sites in the North China Plain. *Environmental Pollution*. 2009; 157(11):3106-3113.
 46. Ianniello, A., Spataro, F., Esposito, G., Allegrini, I., Rantica, E., Ancora, M. P., Hu, M., & Zhu, T. Occurrence of gas phase ammonia in the area of Beijing (China). *Atmospheric Chemistry and Physics*.

- 2010; 10(19):9487-9503.
47. Carmichael, G. R., Fern, M., Thongboonchoo, N., Woo, J. H., Chan, L. Y., Murano, K., Viet, P.H., Mossberg, C., Bala, R., Boonjawat, J., & Upatum, P. Measurements of sulfur dioxide, ozone and ammonia concentrations in Asia, Africa, and South America using passive samplers. *Atmospheric Environment*. 2003; 37(9-10):1293-1308.
48. Parmar, R. S., Satsangi, G. S., Lakhani, A., Srivastava, S. S., & Prakash, S. Simultaneous measurements of ammonia and nitric acid in ambient air at Agra (27 10' N and 78 05' E)(India). *Atmospheric Environment*. 2001; 35(34):5979-5988.