academicJournals

Vol. 6(2), pp. 6-12, April, 2014
DOI: 10.5897/JECE2014.0313
Article Number: 6DC19EF44504
ISSN 2141-226X

http://www.academicjournals.org/JECE

Journal of Environmental Chemistry and Ecotoxicology

Full Length Research Paper

Temporal variation of SO_2 and NO_2 concentrations around Parichha Thermal Power Plant, India

Sayar Yaseen[1], Bhat Mohd Skinder[1]*, Sheeraz Ahmad[2] and R.S. Khoiyangbam[2]

[1]Centre of Research for Development/Department of Environmental Science, University of Kashmir Srinagar (J&K) India
[2]Institute of Environment and Development Studies, Bundelkhand University, Jhansi, India.

Received 11 February, 2013; Accepted 25 April, 2014

The present study was based on monthly variation of ambient air pollution in the village located within a radius of 3 km from the Parichhna thermal power plant (Jhansi, India). Parichha thermal power plant consumes annually 3.4 million tons of coal and the annual production capacity of the plant is 2.78 billion KWh. The thermal power plant uses approximately 10,000 tons of coal and emits large amount of air pollutants like fly ash, sulphur dioxide and oxides of nitrogen. Results revealed that the range of gaseous pollutants showed slight variation within the sampling dates during the four months under study. Although the average monthly concentration SO_2 (21±2.88 μg/m^3) and NO_2 (44±5.10 μg/m^3) was within the permissible limits given for industrial and residential areas, however, they are toxic on long term basis both for human health and nearby agricultural fields. The concentration of the SO_2 ranged between 17 to 28 μg/m^3, while the concentration of NO_2 ranged between 34 to 51 μg/m^3, during the study period. It is important to note that the values of the pollutants reported are after all the mitigative measures and preventive control equipments installed and working in the thermal Power plant. It has also been revealed that concentration of both gases was found to be consistently higher in the morning hours (8.00 to 10.00 h) compared to afternoon hours (12.00 to 14.00 h) throughout the study period.

Key words: Thermal power plants, pollution, coal, sulphur dioxide, nitrogen dioxide

INTRODUCTION

Thermal power plants are major sources of air pollution. Three major air pollutants emitted from these plants are Sulphur dioxide (SO_2), Sulphur trioxide (SO_3), Oxides of nitrogen (NO_2, NO_3) and Suspended Particulate Matter (SPM). The amount of pollutants emitted from any power plant depends upon the type of the fuel used, burning method and type of control equipment. These pollutants settle in ambient air. Coal is re-emerging as the dominant fuel for power generation in various power plants (Patel and Patel, 2006). In India, coal is the only natural resource and fossil fuel available in abundance for different large and small scale industries. Consequently, it is used widely as fuel for thermal power plants producing electricity and also as a thermal energy source (Mishra, 2004). In India, power generation has increased greatly in recent years to meet the demand of the increasing population (Jamil et al., 2009). The capacity of power generation has increased tremendously from

*Corresponding Author. Email: mskbhat@gmail.com

1362 MW in 1947 to 147,403 MW in 2008. India has installed capacity for electricity generation to about 90,000 MW, of which more than 70% is produced by coal based thermal power plants. Coal is the only fossil fuel available in abundance; hence its usage will keep growing for another 2 to 3 decades at least, till there is an improvement in renewable energy sources. Availability of coal in India is of poor quality such as petcock, lignite, bituminous etc., used in power plants in which the percentage of sulphur have 6.0, 4.0 and 3.8%, respectively; also with very high ash content and low calorific value. It has been found that metallurgical industry like steel plants use good quality coal but the coal supplied to thermal power plants is of the worst quality.

A number of the coal mines are owned by private companies and they do not wish to invest on quality improvement (Mishra, 2004). The thermal power plants during the combustion of coal emits mainly carbon dioxide (CO_2), sulphur oxides (SO_x), nitrogen oxides (NO_x), chlorofluorocarbon (CFC), other trace gases and airborne inorganic particulates such as fly ash and suspended particulate matter. The two important emissions of thermal power plants that have been taken under consideration for the present study are SO_x and NO_x.

SO_x

Sulphur dioxide is one of the main products released from the combustion of sulphur containing compounds in most energy fuels having significant environmental concern. The term SO_x is a generic term describing emissions of SO_2 and SO_3. It is predictable that just about 93% of the global SO_2 emissions are emitted in the northern hemisphere and the left over 7% are emitted in the southern hemisphere (WHO, 1979). The utmost anthropogenic sources of SO_2 consequence is from the burning of fossil fuels and from the smelting sulphide ores (Weil and Sandler, 1997). Presently SO_2 is the main issue pertaining to air pollution problems in developing countries, where it contributes both to urban pollution and to regional acid depositions (Cofala et al., 2004). Among man-made sources, fuel combustion (coal) in stationary sources accounts for 74%, industries 22% and transportation 2% of the total SO_x (De, 2012). A significant feature of SO_2 is that once it is emitted into the atmosphere it can be converted through complex oxidation reactions into fine particulate sulfate and removed from the atmosphere by wet or dry deposition (De, 2012; Skinder et al., 2014). SO_2 can be oxidized in the atmosphere to form sulphate aerosols that contribute to acid deposition (Holleman and Wiberg, 2001). Thus elevated level of SO_4^{2-} concentrations in rain water are due to strong SO_2 emissions from coal fired thermal power plants (Demirak, 2007).

NO_x

This represents composite atmospheric gases, nitric oxide (NO), and nitrogen dioxide (NO_2), which are primarily involved in air pollution. Nitric oxide (NO) is a colourless, odourless gas, but NO_2 has a reddish-brown colour and pungent suffocating odour (De, 2012). The formation of NO is favoured at high temperature, usually attained during much combustion process involving air (1210 to 1763°C). The second reaction is also favoured at temperatures of about 1100°C, but the amount of NO_2 formed is usually less than 0.5% of the total NO_x at 1100°C. It is also formed by photolytic reaction; further man-made sources annually release 5×10^7 tons of NO_x (De, 2012). The NO_2 levels depend mainly on chemical reactions and not on direct emissions (Mayer, 1999). It is considered that coal-fired power plants and vehicles are the nation's largest sources of nitrogen oxides and NO_x produced in high temperature combustion processes (Memon, 2000; Emberson et al., 2001; Skinder et al., 2014).

NO_x is emitted from a variety of natural and anthropogenic sources (Al-Khalaf, 2006). Nitric oxide (NO) is by far the most important nitrogen containing species emitted into the atmosphere on a mass basis from human activities involving motor traffic, brick kilns and combustion in thermal power stations, in homes or industrial processes (Williams, 2000; Kumar and Joseph, 2006; Ali and Athar, 2006; Skinder et al., 2014). NO_x levels were found to be stabilized in residential and industrial zones but increased alarmingly at commercial zones representing higher traffic activities (Goyal et al., 2006). Moreover, NO_x concentration has been found to be at its peak during late hours of the day due to high traffic density of public and commercial vehicles (Jain and Saxena, 2002). NO_2 levels were also higher in the post monsoon season followed by winter and pre-monsoon seasons (Goyal et al., 2006).

A chemical reaction in atmosphere converts primary pollutants into secondary air pollutants. Sulfur dioxide and nitrogen dioxide goes under oxidation process and gets converted to particulate sulfate and particulate nitrates and are important features of urban air photochemistry. The rates for the formation of sulfate and nitrates in the atmosphere through conversion mechanisms are of considerable interest. It is because the conversion rates are important factors in controlling the concentrations of NO_2 and SO_2. Thus, concentration of gases decreases on temporary basis as these are transformed into secondary products. Moreover, the rate of the conversion of nitrogen oxides to nitrate affects ozone formation and ultimate fate of the nitrogen oxides in the atmosphere. The environmental effects of these secondary pollutants are associated with acidification of precipitation, visibility reduction and its deleterious effects on human health (Khoder, 2002; Skinder et al., 2014).

MATERIALS AND METHODS

Study site

The present study was carried out around Parichha thermal power station. It is situated in Jhansi district of Uttar Pradesh, India. Jhansi district lies in the Bundelkhand region. Jhansi has an area of 45.22 sq Km and a population of about 4.70 million, situated at a height of about 255 m above mean sea level (asl). Jhansi district lies between 25° 27'4"N to 25° 28'4"N latitude and 77° 38' 28"E to 77° 40' 12"E longitude in the semi arid region of the country. The power station is owned by the central government and is a coal fired station located near the National highway on the northern bank of Betwa river in Jhansi district. The power station is surrounded by villages such as Badagawn, Goramachiya, Chirgawn etc., and as per latest census report Parichha has a total population of around 2000. The average annual rainfall ranged between 800 to 930 mm in summer, furthermore, humidity during morning hours was 40 to 50% and for the rest of the day 15 to 20%. The maximum temperature during summer is 45°C and the minimum temperature is 25°C. While in winter, maximum temperature is 23°C and the minimum temperature is 4°C. It has limited vegetative cover and most of the land is used for agricultural practices.

Estimation of gaseous pollutants

Gaseous pollutants (SO_2 and NO_2) samplings were carried out every fortnightly. The gaseous pollutants were absorbed in appropriate absorbents prepared and placed in the impingers. A handy air sampler (model, PEM-HAS IB) was employed for collecting the gaseous pollutants. This model has a set of two borosilicate glass impingers (35 ml) to collect two different gaseous pollutants separately at a time. The flow rate of the air was adjusted at 1.5 L per minute (LPM). On each sampling date the instrument was ran twice for two hours between 8.00 to 10.00 h and 12.00 to 14.00 h. The impingers were covered by ice while in operation: transportation and storage of collected samples in the laboratory before the analysis. All the samples were analyzed within 3 h of the collection of the samples.

Determination of sulphur dioxide in air

The method for measuring SO_2 was adapted from West and Gaeke (1956). In this method, air-exposed samples are treated in a solution of potassium tetrachloro-mercurate (TCM). A dichlorosulphitomercurate complex is formed, which subsequently reacts with pararosaniline and formaldehyde to form the intensely coloured pararosaniline methylsulphonic acid. The absorbance of the coloured solution was measured with spectrophotometer at 560 nm, and the concentration of SO_2 was determined based on a calibration curve.

Determination of nitrogen dioxide in the atmosphere

The principle of NO_2 measurement in atmospheric samples was described by Jacob and Hochheiser (1958). Ambient nitrogen dioxide (NO_2) is collected by bubbling air through a solution of sodium hydroxide and sodium arsenite. The concentration of nitrite ion (NO_2^-) produced during sampling is determined colorimetrically by reacting the nitrite ion with phosphoric acid, sulfanilamide, and N-(1-naphthyl)-ethylenediamine di-hydrochloride (NEDA) and measuring the absorbance of the highly colored azo-dye at 540 nm.

RESULTS AND DISCUSSION

Monthly variation of ambient air pollution in the village located within a radius of 3 km from the Parichhna thermal power plant has been presented in the Table 1. Results revealed that the range of gaseous pollutants showed slight variation within the sampling dates during the four months under study. Sulphur in coal cannot be destroyed; it can only be converted from one form to another. During the combustion process, sulphur reacts with oxygen and formed SO_2 and SO_3 (Buecker, 2006; Patel and Patel, 2006). The average monthly concentration of SO_2 (21±2.88 μg/m^3) and NO_2 (44±5.10 μg/m^3) was within the permissible limits given for industrial and residential areas, Table 2. The concentration of the SO_2 ranged between 17 to 28 μg/m^3. While the concentration of NO_2 ranged between 34 to 51 μg/m^3. Although, the reported values of SO_2 and NO_2 lie within the limits, however, they are toxic on long term basis. It is important to note that the values of the pollutants reported are even after all the mitigative measures and preventive control equipments installed and working in the thermal power plant. It is considered that coal fired power plants and vehicles are the nation's largest source of nitrogen oxides (NO_x) and is produced in high temperature combustion processes (Memon, 2000; Emberson et al., 2001). While Sulphur dioxide is a prime pollutant which is released directly to the atmosphere from domestic and industrial processes, particularly those using petroleum and coal combustion (Wellburn, 1998; Emberson et al., 2001).

A temporal variation in SO_2 and NO_2 concentration was observed in all the sampling dates shown in Figures 1 and 2. Concentration of both gases was found to be consistently higher in the morning hours (8.00 to 10.00 h) throughout the study period compared to afternoon hours (12.00 to 14.00 h). The concentration of SO_2 during 8.00 to 10.00 h ranged between 19 μg/m^3 (15th April) to 28 μg/m^3 (15th March). Corresponding concentration of SO_2 on the same sampling dates during 12.00 to 14.00 h ranged between 17 μg/m^3 (15th April and 14th May) and 25 μg/m^3 (15th March).

Similarly, the concentration of NO_2 during 8.00 to 10.00 h ranged between 42 μg/m^3 (30th June) to 52 μg/m^3 (29th May). Consequent concentration of NO_2 on the same sampling dates during 12.00 to 14.00 h ranged between 36 μg/m^3 (30th June) and 45 μg/m^3 (15th March). Results also revealed that concentrations of SO_2 were lower than the NO_2 as shown in the Figure 3. These results are in consonance with the results of Cerón-Bretón et al. (2013).

The present study shows that the concentration of gases (SO_2 and NO_2) were found to be consistently higher in the morning hours throughout the study period compared to afternoon hours, it is because as the temperature increases, photochemical reactions transform NO_2 into secondary air pollutants which may lead to reduction of NO_2 in the afternoon hours

Table 1. Levels of SO_2 (µg/m^3) and NO_2 (µg/m^3) around Parichha Thermal Power Plant (India).

Sampling Date	Time (h)	Concentration of gases (µg/m^3)	
		SO_2	NO_2
15th March	08.00-10.00	28	51
	12.00-14.00	25	47
31st March	08.00-10.00	24	48
	12.00-14.00	22	41
15th April	08.00-10.00	19	39
	12.00-14.00	17	34
30th April	08.00-10.00	23	50
	12.00-14.00	18	45
14th May	08.00-10.00	21	49
	12.00-14.00	17	38
29th May	08.00-10.00	24	52
	12.00-14.00	18	45
14th June	08.00-10.00	22	49
	12.00-14.00	19	37
30th June	08.00-10.00	25	42
	12.00-14.00	18	36
Average monthly mean (µg/m^3)		21 (±2.88)*	44 (±5.10)*

*Standard deviation.

Table 2. National ambient air quality standards (NAAQS), CPCB, 2009.

Pollutants	Time weighted average	Concentration in ambient air	
		Industrial, residential, rural and other areas	Ecologically sensitive area (Notified by Central Government)
Sulphur dioxide (SO_2), µg/m^3	Annual *	50	20
	24 h **	80	80
Nitrogen dioxide (NO_2), µg/m^3	Annual *	40	30
	24 h **	80	80

*Annual Arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform intervals.**24 hourly or 8 hourly or 1 hourly monitored values, as applicable, shall be complied with 98% of the time in a year. 2% of the time, they may exceed the limits but not on two consecutive days of monitoring.

(Finlayson-Pitts and Pitts, 1993) as it receives solar radiations and the ozone is produced (Tang, 2009; Elampari et al., 2010). It has also been discussed that temperature has also significant effect on SO_2 concentrations (Salam et al., 2008). Due to the increasing temperature photochemical activities increase and also in the presence of ozone concentration (formed due to NO_x), which increase the oxidation of SO_2 and its conversion rate to sulfate (Spicer, 1986; Khoder, 1997; 2002).

Temporal variation of SO_2 and NO_2 concentration during the day, tally with the activities producing this pollutant such as thermal power plants; although the main source of SO_2 and NO_2 are thermal power plants, there are other sources as traffic flow, burning of agricultural biomass and other domestic or residential

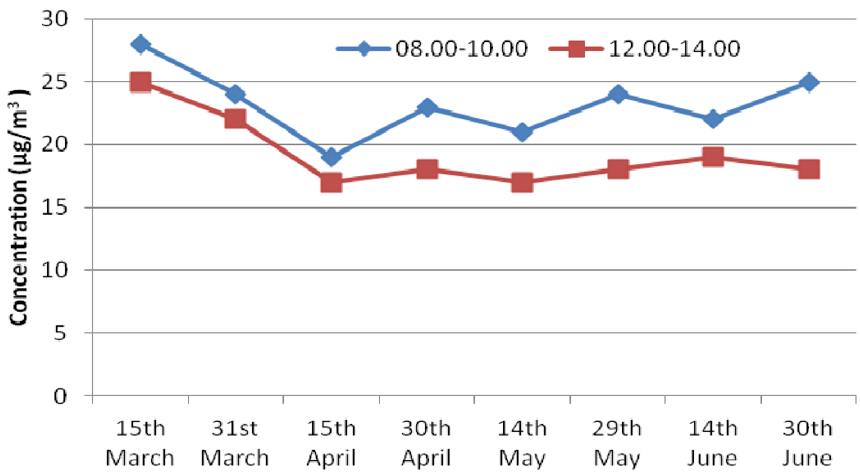

Figure 1. Time-series and bimonthly variation for SO_2 concentrations during the sampling period around Parichha Thermal Power Plant in the Year 2008.

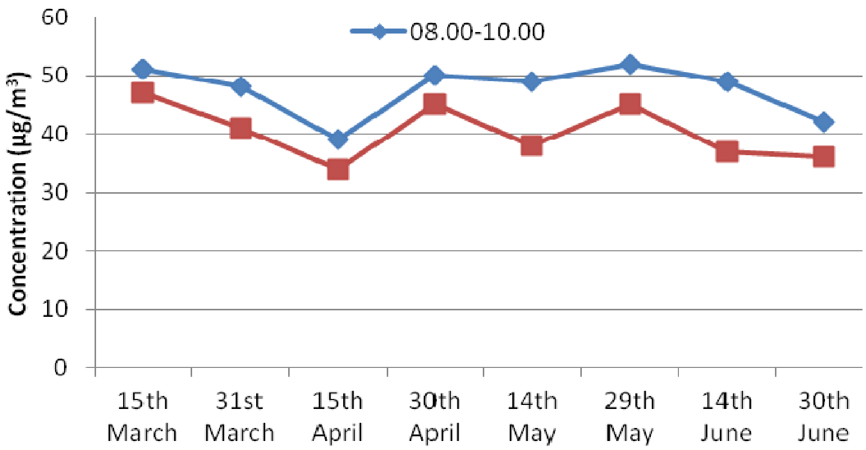

Figure 2. Time-series and bimonthly variation for NO_2 concentrations during the sampling period around Parichha Thermal Power Plant in the Year 2008.

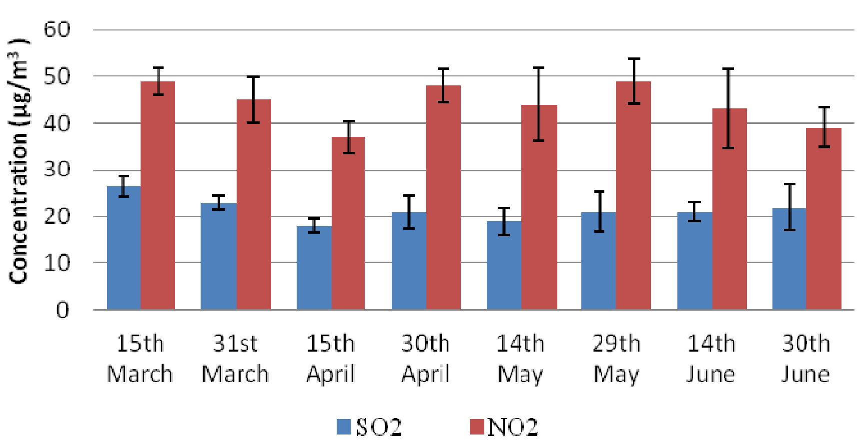

Figure 3. Comparison of SO_2 and NO_2 concentrations around Parichha Thermal Power Plant in the Year 2008.

activities. The results revealed that the values of SO_2 (within the vicinity of Parichha Thermal Power Plant) were lower than the concentration of NO_2; this variation might be attributed largely due to the proximity of the sampling site to the National High Way connecting Jhansi and Kanpur. The selected sampling sites were located just a few 100 m from the National High Way as the thermal power plant is located nearer to this highway. It is the fact that vehicular emissions contribute more NO_2 than SO_2 (Williams, 2000; Jackson, 2005a; Kumar and Joseph, 2006; Ali and Athar, 2006). Similarly, the concentration of SO_2 from motor vehicles is very low as compared to stationary sources (Williams, 2000). Thus this pattern is consistent with the observed temporal variation of NO_2 and SO_2 in the current study.

Due to continuous and long lasting emission of SO_2 and NO_2, which are the principal pollutants of coal based power plants, affecting surrounding structures, buildings, monuments of historic importance and metallic structures very badly due to corrosive reactions (Acid rain). Renowned example of this is the victimized Taj Mahal in the city of Agra which is being deteriorated due to these toxic gases (Butler et al., 2002; Dene, 2002; Pokale, 2012). Health effects caused by exposure to high levels of SO_2 include breathing problems, respiratory illness, changes in the lung's defenses and worsening respiratory and cardiovascular diseases (Skinder et al., 2014). People with asthma or chronic lung or heart diseases are the most sensitive to SO_2 (Prasad et al., 2010). The coal fired Parichha Thermal Power Plant besides emitting gaseous pollutants also emits huge quantity of fly ash particles which are deposited on surrounding agricultural lands and consequently deteriorates the soil quality in addition to vegetation (Kumari, 2009).

Conclusion

The present study showing that the concentration of gases (SO_2 and NO_2) was found to be consistently higher in the morning hours throughout the study period compared to afternoon hours. This temporal variation of SO_2 and NO_2 concentration during the day, tally with the activities producing this pollutant such as thermal power plant, traffic flow, burning of agricultural biomass and other domestic or residential activities, and it is necessary to note that the values of the pollutants reported in this study are even after all the mitigative measures and preventive control equipments installed and working in the thermal Power plant. So the government agencies related to pollution control should keep this into consideration for the proper monitoring of air quality in the coal based power plants to prevent environment from degradation.

ACKNOWLEDGEMENTS

The authors are grateful to the Head of Department, Institute of Environment and Development Studies, Bundelkhand University for providing the necessary facilities in the laboratory and transportation for the field visit and sampling.

Conflict of Interests

The author(s) declare(s) that there is no conflict of interests regarding the publication of this article.

REFERENCES

Ali M, Athar M (2006). Air polluting due to traffic, air quality monitoring along three sections of national high way N-5, Pakistan. Environ. Monit. Assess. 1(3):25-28.

Al-Khalaf AK (2006). Influence of meteorological and related factors on surface ozone pattern at Makkah station. J. Environ. Sci. 11:1-19.

Buecker B (2006). Wet lime stone scrubbing fundamentals. Power Eng. 110:32

Butler AD, Fan M, Brown RC (2002). Comparison of polymeric and conventional coagulants in arsenic removal. J. Environ. Eng. 74:308-313.

Central Pollution Control Board (CPCB) (2009). National Ambient Air Quality Standards (NAAQS), Gazette Notification, New Delhi.

Cerón-Bretón JG, Cerón-Bretón RM, Ramírez-Lara E, Rojas-Domínguez L, Vadillo-Saénz MS, Guzmán-Mar JL (2013). Measurements of Atmospheric Pollutants (Aromatic Hydrocarbons, O_3, NOx, NO, NO_2, CO, and SO_2) in ambient air of a site located at the northeast of Mexico during summer 2011. WSEAS Trans. Syst. 12(2):55-66.

Cofala J, Amann M, Gyarfas F, Schoepp W, Boudri JC, Hordijk L, Kroeze C, LI JF, Lin D, Panwar T S, Gupta S (2004). Cost-effective control of SO2 emissions in Asia. J. Environ. Manage. 72:149-161. http://dx.doi.org/10.1016/j.jenvman.2004.04.009 PMid:15251221

De AK (2012). Environmental Chemistry, (7th ed.). New Age International (P) Limited Publisher, New Delhi, p. 153.

Demirak A (2007). The Influence of a Coal-Fired Power Plant in Turkeyon the Chemical Composition of Rain Water in a Certain Region. Environ. Monit. Assess. 129:189-196. http://dx.doi.org/10.1007/s10661-006-9352-0 PMid:17057977

Dene C (2002). FGD chemistry and analytical methods handbook. Power Eng. 2:48-55

Elampari K, Chithambarathanu T, Krishna SR (2010). Examining the variations of ground level ozone and nitrogen dioxide in a rural area influenced by brick kiln industries. Indian J. Sci. Technol. 3(8):900-903.

Emberson LD, Ashmore MR, Murray F, Kuylenstierna JCI, Percy KE, Izuta T, Zheng Y, Shimizu H, Sheu BH, Liu CP, Agrawal M, Wahid A, Abdel-Latif NM, Van Tienhoven M, De-Bauer LI, Domingos M (2001). Impacts of air pollutants on vegetation in developing countries. Water Air Soil Pollut. 130:107-118. http://dx.doi.org/10.1023/A:1012251503358

Goyal SK, Ghatge SV, Nema P, Tamhane SM (2006). Understanding urban vehicular pollution problem vis-à-vis ambient air quality- a case study of a Megacity (Delhi, India). Environ. Monit. Assess. 119:557-567. http://dx.doi.org/10.1007/s10661-005-9043-2 PMid:16741810

Holleman AF, Wiberg E (2001). Inorganic Chemistry, San Diego: Academic Press, p. 21.

Jain MK, Saxena NC (2002). Air Quality Assessment along Dhanbad-Jharia Road. Environ. Monit. Assess. 79(3):239-250.

Jamil S, Abhilash PC, Singh A, Singh N, Bhel HM (2009). Fly ash trapping and metal accumulation capacity of plant, implication of for green belt around thermal power plant. J. Land Esc. Urban Plan. 92:136-147.

Khoder MI (1997). Assessment of some air pollutants in Cairo and their role in atmospheric photochemistry. Ph.D. Thesis, Ain Shams University, Egypt.

Khoder MI (2002). Atmospheric conversion of sulfur dioxide to

particulate sulfate and nitrogen dioxide to particulate nitrate and gaseous nitric acid in an urban area. Chemosphere 49:675-684. http://dx.doi.org/10.1016/S0045-6535(02)00391-0
Kumar R, Joseph AE (2006). Air pollution concentrations of PM2.5, PM10 and NO_2 at ambient and Kerbsite and their correlation in metro city Mumbai. Environ. Monit. Assess., 119:191-199. http://dx.doi.org/10.1007/s10661-005-9022-7 PMid:16541301.
Kumari V (2009). Physicochemical Properties of Fly Ash from Thermal Power Station and its Effect on Vegetation. Glob. J. Environ. Res. 3(2):102-105.
Mayer H (1999). Air pollution in cities. Atmos. Environ. 33:4029-4037. http://dx.doi.org/10.1016/S1352-2310(99)00144-2
Memon E (2000). Environmental effects of thermal power plant emissions- A case study. A thesis of Master of Engineering, Canada: Faculty of Engineering and Applied Science, Memorial University of Newfoundland.
Mishra UC (2004). Environmental impact of coal industry and thermal power plants in India. J. Environ. Radioact. 72(1-2):35-40. http://dx.doi.org/10.1016/S0265-931X(03)00183-8
Patel SKN, Patel NJ (2006). Effect of concentration in absorption of Sulphur dioxide with sodium hydroxide. Environ. Pollut. Cont. J. 9:14-18.
Prasad DSN, Sharma R, Acharya S, Saxena M, Sharma AK (2010). Removal of Sulphur Dioxide from Flue Gases in Thermal Plants. Rasayan J. Chem. 3(2):328-334.
Salam A, Hossain T, Siddique MNA, Alam AMS (2008). Characteristics of atmospheric trace gases, particulate matter, and heavy metal pollution in Dhaka, Bangladesh. Air Qual. Atmos. Health. 1:101-109. http://dx.doi.org/10.1007/s11869-008-0017-8
Skinder BM, Sheikh AQ, Pandit AK, Ganai BA (2014). Brick kiln emissions and its environmental impact: A Review. J. Ecol. Nat. Environ. 6(1):1-11. http://dx.doi.org/10.5897/JENE2013.0423
Spicer CW (1986). Patterns of atmospheric nitrates, sulfate, and hydrogen chloride in the central Ohio River valley over a one-year period. Environ. Int. 12:513–518. http://dx.doi.org/10.1016/0160-4120(86)90145-5
Tang L (2009). Regional and local surface ozone variations in relation to meteorological conditions in Sweden. Department of Earth Science, University of Gothenburg.
Weil ED, Sandler SR (1997). Sulfur Compounds. In: Kirk-Othmer Encyclopedia of Chemical Technology, John Wiley & Sons, Inc.
Wellburn A (1998). Sulfur Dioxide. In: Air Pollution and Acid rain: The Biological Impact. Longman Scientific & Technical, John Wiley & Sons. p. 23-59.
WHO (1979). Sulfur oxides and suspended particulate matter, environmental health criteria. World Health Organization, Geneva.
Williams ML (2000). Patterns of air pollution in developed countries. Department of the Environment. Transport and the Regions London, pp. 83-104.