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Indoor and Outdoor Air Quality Assessment of SO_2 and NO_2 in Suburban Schools in Imphal, Manipur

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Abstract

Air quality assessments for NO_2 and SO_2 levels in indoor and outdoor environments were conducted in three suburban schools in Imphal. Season-wise, the highest NO_2 and SO_2 concentrations were observed during winter, while the lowest occurred during the monsoon. The concentration of SO_2 in the indoor air was comparatively cleaner than in the outdoor air. Similarly, indoor air was found to be cleaner than outdoor air with respect to NO_2. The overall concentration obtained for the entire study period for SO_2 was 4.9±1.5 μg m^{-3}, and for NO_2, it was 9.2±3.0 μg m^{-3}. The concentrations of the two gases obtained during the study were below the NAAQs and WHO permissible limits. Seasonal variation of SO_2 concentrations between the pre-monsoon period and monsoon months and also between the monsoon period and winter months (*at* $p<0.001$) was significant. For NO_2, seasonal variation in the concentrations between the monsoon and winter (at $p<0.001$) was found significant. The estimated I/O ratios for the two studied gases, which were below one, plus the positive correlation between the classroom and campus environment concentrations of NO_2 (r=0.96), and SO_2 (r=0.96), reflected the influence of the indoor air quality by outdoor pollution sources. Data on similar studies for the country's northeastern region, in particular, is scanty, and that's why it may provide valuable insights to the scientific world.

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Introduction

Intensification of air pollutant levels in urban areas has become a significant problem with fast economic growth, especially in metropolitan cities.[1] Majority of air pollution fatalities occur in developing countries, where laws are not adequately enforced and emission standards are less stringent.[2] In India, traffic emissions are a significant source of air pollution and associated damage to human health.[3] Vehicle emissions are problematic for human health, road safety, and the global environment.[4] However, there is uncertainty in vehicle emission estimations

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in India due to the lack of reliable emission factors representing real-world driving data.[5] The complicated impacts of urban-scale urban forms on air pollution are poorly understood.[6] Air quality in the indoor environment is a critical determinant of the level of comfort, health status, and well-being of the building residents.[7] Understanding the importance of good Indoor Air Quality (IAQ) in school is the backbone of developing an effective IAQ program.[8] Good air quality in classrooms becomes an essential need for children in their learning ability and benefits their health. Students, teachers, and staff working in classrooms with poor air quality may develop chronic and acute health issues. Although clean air may be a fundamental human right, many school children worldwide do not access it, posing an increased risk of sickness and pollution.[9] Microclimate in the classroom is one of the crucial indicators of whether the environment is healthy or unhealthy.[10] Children are highly vulnerable to air pollutants that impact their respiratory system, leading to asthma, allergic rhinitis, and eczema due to their air-breathing pattern and lower body mass index.[11] As per the World Health Organisation (WHO) report,the primary air pollutants, such as SO_2, NO_2, CO_2, O_3, and Particulate Matter (PM), affect human health, causing severe diseases among various age groups.[12] Sulphur dioxide is one of the primary gaseous effluents released from the combustion of sulphur-containing fuels, and the pollutant is the main issue of air pollution problems in developing countries.[13] Sources of air pollutants in urban areas include transportation sectors, power plants, industrial boilers, incinerators, petrochemical plants, aircraft, and ships.[14] Oxides of nitrogen are detrimental to the human respiratory system, and NOx is directly or indirectly involved in ozone and particulate formation.[15] Exposure to high levels of air pollutants poses a higher risk of developing chronic illnesses like cardiovascular disease in children, creating complicated health issues later in life.[16] Children who attend schools near roadways face the potential risk of exposure to various contaminants arising from roads, thereby, are more prone to hazardous health impacts.[17] As a result of a poor public transport network, residents in Imphal increasingly rely on private vehicles in and around Imphal city.[18] The current investigation aimed to evaluate the concentrations of NO_2 and SO_2 in three suburban roadside schools situated along the National Highways passing through Imphal city.

Table 1: Some characteristics of the schools under study

Parameters	SU-1	SU-2	SU-3
Location	Residential	Residential	Residential
Distance from NH	~10 m	~5 m	–
Educational Standard	1st to 12th	11th and 12th	Pre-nursery to 10th
Total No. of students	~ 950	~ 450	~ 400
Source of pollutants	Transportation & Domestic	Transportation & Domestic	Domestic
Details of Air Monitoring Room			
Standard	3rd Standard	11th Standard	1st Standard
No.of occupants during sampling	28±05	43±05	22±05
Type of Room	Classroom	Classroom	Classroom
Building type (Floor)	Concrete (Ground floor)	Concrete (Ground floor)	Concrete (Ground floor)

Materials and Methods

Study Area

Manipur is a hilly state on the Indo-Myanmar border in northeastern India. Imphal, the capital city (24.721^0 N & 24.883^0 N and 93.887^0 E & 93.982^0 E) of Manipur, is situated in a small mountain valley embedded in the offshoot hilly tract of the Himalayas. Imphal valley occupies about 10% of the state's geographical area, situated at 786 m a.m.s.l. By catering to administrative, commercial and other local needs, Imphal serves as the gateway city, connecting mainland India with the Southeast Asiatic countries. The present study was conducted in three suburban schools in Imphal. The schools taken up for the current study are SU-1: Manipur Public school, Koirengei, SU-2: Standard Robarth Higher Secondary school, Canchipur, and SU-3: Children's Training school, Langol in Imphal. Out of the three, the first two schools are situated along the National Highway (SU-1 and SU-2 are located along the NH-2 and NH-102, respectively), while the third is located in a residential area.The study was conducted for eleven months (March 2018 – February 2019), covering three seasons, *viz*. the pre-monsoon, monsoon and winter. The instrument was run for eight hours on each air sampling day, starting from 8 am to 4 pm. Sampling campaigns were reported twice a month, covering 22 samplings in each school in the eleven months study period. The main air pollution sources in the suburban areas of Imphal include vehicular emissions, small enterprises, diesel-powered electric backup generators (especially in commercial and settlement zones), diesel-runmobile tower generators, domestic activities, etc.

Sampling and Analysis

Measurements of NO_2 and SO_2 were conducted parallelly inside the classroom and in the outside environment of the schools. The NO_2 and SO_2 concentrations in the air were measured using portable gaseous samplers (Envirotech APM 433). The concentration of SO_2 was analysed following the standard methods described by the Improved West and Gaeke method.[17] The airborne NO_2 level was analysed following Modified Jacob and Hochheiser method.[19] The respective absorbing solution (30 mL) for the two gases was lodged in separate midget impingers for carrying out the sampling. The sampling air was bubbled through the respective absorbing agent at the rate of 1 Litre Per Minute (LPM). The NO_2 and SO_2 content in the air was determined colourimetrically (Genesys 180) at 540 nm and 560 nm wavelengths respectively.

Statistical Analysis

The variation in the concentrations of NO_2 and SO_2 during the study period was evaluated using the One-way ANOVA with Tukey (HSD) Post Hoc test. SPSS software was employed for the statistical calculations.

Table 2: Seasonal SO_2 concentrations in the suburban schools

Schools	Indoor(μg m^{-3})			Outdoor(μg m^{-3})		
	Pre-monsoon (N=18)	Monsoon (N=24)	Winter (N=24)	Pre-monsoon (N=18)	Monsoon (N=24)	Winter (N=24)
	Avg±SD	Avg±SD	Avg±SD	Avg±SD	Avg±SD	Avg±SD
SU-1	5.2±1.8	3.2±0.5	6.2±0.4	5.6±1.9	3.8±0.9	7.3±0.7
SU-2	6.2±0.8	4.6±0.9	5.4±0.5	6.8±0.7	4.6±0.7	6.3±0.6
SU-3	4.3±0.8	3.0±0.2	4.2±1.0	4.8±1.0	3.5±0.4	4.5±1.2
All-SU	5.2±1.4	3.6±0.9	5.3±1.1	5.7±1.5	4.0±0.8	6.0±1.4

Results and Discussion

The results obtained during our assessment of SO_2 and NO_2 in the suburban schools of Imphal are presented in Tables 2 and 3. In the three suburban schools, the concentrations of indoor SO_2 for the entire study period ranged between 2.5 and 7.7 μgm^{-3}, and the mean was 4.7±1.1 μg m^{-3}. The corresponding level of SO_2 in outdoor air during the same period ranged between 2.7 and 8.4 μgm^{-3} with a mean of 5.2±1.2μg m^{-3}. For NO_2, the indoor concentrations ranged between 5.0 and 13.9 μgm^{-3}, while the outdoor concentration ranged between 5.0 and 15.1 μg m^{-3}. The mean SO_2 and NO_2 content in the indoor and outdoor air for the three schools for the entire study period were 4.9±1.5 μg m^{-3} and 9.2±3.0 μg m^{-3}. Dambajamts *et al.*(2019).[20] reported that the two-year mean levels of SO_2 in schools in Ulaanbaatar, Mongolia ranged between 4.4 ppb and 10.1 ppb, while the highest concentrations ranged between 36 ppb and 63 ppb.Salonen *et al.*(2019).[21] concluded that the average levels of NO_2 in schools ranged between 6.00 and 68.5 µg m^{-3}, and concentration in office environments ranged between 3.40 and 56.5 µg m^{-3}. The levels of the two studied gaseous pollutants in the classroom reported by these authors are comparatively higher than the observations obtained in the current study. Clean air is a concern in the mega cities in India, as the content of fine particulates, SO_2, and NO_2, are frequently found to exceed the limits of the National Ambient Air Quality Standards (NAAQS).[22] However, many authors claimed that air pollutants like NO_2 and SO_2, even at low concentrations, may cause harmful effects on human health.[23-25] Children are most at risk for health problems related to air pollution.[26]

Table 3: Seasonal NO_2 concentrations in the suburban schools

Schools	Indoor(µg m^{-3})			Outdoor(µg m^{-3})		
	Pre-monsoon (N=18)	Monsoon (N=24)	Winter (N=24)	Pre-monsoon (N=18)	Monsoon (N=24)	Winter (N=24)
	Avg±SD	Avg±SD	Avg±SD	Avg±SD	Avg±SD	Avg±SD
SU-1	8.1±1.1	6.8±1.4	13.0±0.6	9.3±1.3	7.9±1.4	14.2±0.7
SU-2	10.3±1.9	8.9±1.9	10.8±1.1	12.9±1.9	9.8±2.3	11.9±1.8
SU-3	6.7±1.1	5.9±0.6	7.0±2.6	7.0±1.7	6.5±0.9	7.7±3.2
All-SU	8.4±2.0	7.2±1.8	10.3±3.0	9.7±2.9	8.1±2.1	11.3±3.4

The mean concentrations of the two air pollutants were recorded as highest during the winter, and the concentrations decreased consecutively in the following two seasons. During the winter, the SO_2 in classrooms ranged between3.0 and 6.7 µg m^{-3}. The NO_2 content in the classrooms during the same season ranged between 5.0 and 13.9 µg m^{-3} (Table 2 & 3). The outdoor concentrations of the two gases during winter ranged between 3.0 and 8.4 µg m^{-3}(SO_2) and 5.0 and 15.1 µg m^{-3}(NO_2). Seasonal concentration of the two respective gases during winter was 6.0±1.4 µg m^{-3} and 11.3±3.4 µg m^{-3}. The content of SO_2 and NO_2 in the classroom during the pre-monsoon was between 2.8 and 7.7 µg m^{-3} and 5.4 and 12.8 µg m^{-3}. The corresponding levels of the two gases in the campus ambient air during pre-monsoon were between 3.1 and 8.4 µg m^{-3} and between 5.0 and 14.5 µg m^{-3}, and the average gaseous content in the air was 5.7±1.5 µg m^{-3} and 9.7±2.9 µg m^{-3}. In monsoon, the content of SO_2 in the air ranged between 2.5 and 5.7 µg m^{-3}, and for NO_2, it ranged between 5.1 and 11.1 µg m^{-3}. In the same period, the SO_2 in the outdoor environment was from 2.7 to 5.4 µg m^{-3}) while the content of NO_2 ranged between 5.1 and 14.5 µg m^{-3} with respective mean values of 4.0±0.8 µg m^{-3} and 8.1±2.1 µg m^{-3}. Lower gaseous pollutants in the schools during monsoon and pre-monsoon seasons might be due to persistent rainfall and the prevailing turbulent meteorological conditions. In contrast, ambient air is considerably drier during winter, and the washout of pollutants by precipitation is almost non-existent. Mukta *et al.*(2020).,[27] in a study at Gazipur, Bangladesh, observed mean seasonal NO_2 values of 45.1 ppb, 33.5 ppb, and 13.9 ppb, respectively, during winter, pre-monsoon, and monsoon. The researchers claimed that the washout effect of precipitation lowered the gas concentration during the rainy season. Bodor *et al.*(2020)[28] believed that seasonal fluctuations in energy usage and air stability influence lower concentrations of air pollutants during warmer times and higher concentrations during the winter. Chutia *et al.*(2020)[29] also observed a pronounced ambient SO_2 seasonality over India, with the maximum occurring during winter and a minimum during the monsoon. The authors attributed the winter-maximum concentrations to weaker chemical sink, stagnant meteorological conditions, and elevated emissions. In a satellite-derived correlation, Lin *et al.*(2019)[30] concluded that higher temperature and relative humidity favour the condensation of SO_2 and NO_2 into sulfate and nitrate aerosols. The temporal variations (monthly and seasonal) of SO_2 and NO_2 concentrations in indoor and outdoor environments are presented in Figure 1.

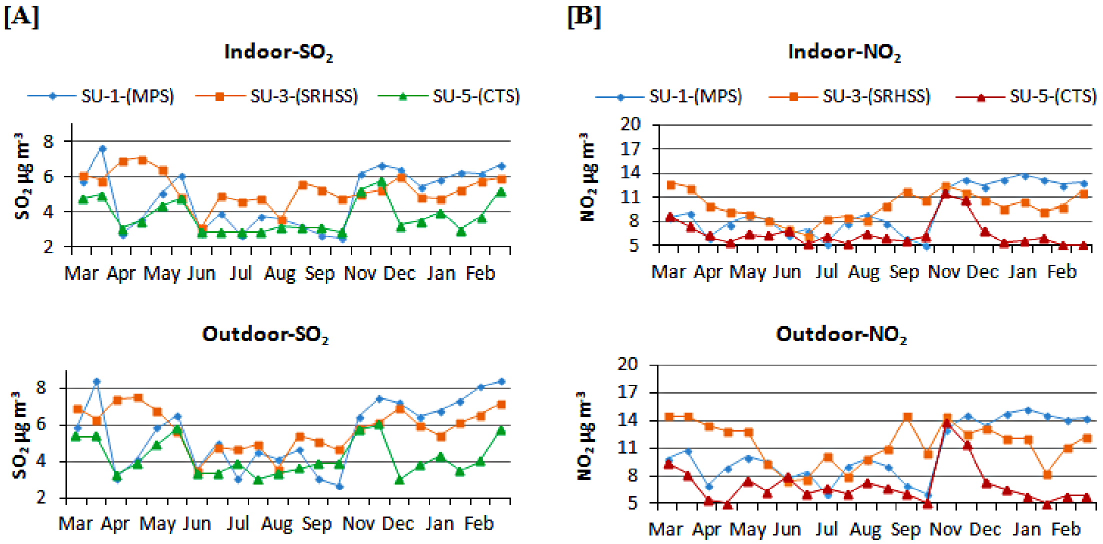

Fig. 1:Temporal variations of: [A] SO_2 and [B] NO_2 concentrations

The monthly variations of the two pollutants in the classrooms and the ambient air of the three schools are depicted in Figure 1. The highest indoor concentration of SO_2 (7.7 µg m^{-3}) occurred during March. However, the peak outdoor concentration (8.4 µg m^{-3}) occurred in two months (March and February) in SU-1. The comparatively higher SO_2 and NO_2 concentrations obtained in the current study during the pre-monsoon and winter might be due to high temperatures and low humidity. A significant seasonal variation in the concentrations of SO_2 was observed between the pre-monsoon and monsoon samplings(at $p< 0.001$) and also between the monsoon months and winter months (at $p< 0.001$). For NO_2, a significant variation in the concentrations of the gas was observed only between the monsoon and winter (at $p< 0.001$).

The lowest SO_2 concentrations in the schools were observed during September for the indoor (2.5 µg m^{-3}) as well as outdoor (2.7 µg m^{-3}) environments, both were observed in the SU-1. Similarly, for the NO_2, the highest concentration was observed during January in both the indoor (13.9 µg m^{-3}) and outdoor air (15.1µg m^{-3}) of the SU-1. During the study, the lower most indoor air pollutant levels (5.0 µg m^{-3}) occurred during February in the SU-3, while the lowermost outdoor pollutant levels (5.0 µg m^{-3}) occurred in January and April in SU-3. The SU-1 is located along the road, while the school SU-3 is situated in a rural residential area. Dandotiya *et al.*, (2019)[31] observed that the adverse health consequences of air contaminants were lower in well-vegetated areas than in high-traffic metropolitan areas. It is noteworthy to mention here that the overall mean concentrations of the SO_2 (4.9±1.5 µg m^{-3}), as well as NO_2 (9.2±3.0 µg m^{-3}), were well below the prescribed limit recommended by NAAQS (SO_2 – 50 µg m^{-3} annual and 80 µgm^{-3} 24-hrs mean, NO_2 – 40 µg m^{-3} annual and 80 µgm^{-3} 24-hrs)[19] and the WHO[32] (40 µg m^{-3} 24-hrs mean for SO_2, and 25 µg m^{-3} 24-hrs mean for NO_2). Salonen *et al.*(2019)[21] reported that the concentrations of NO_2 in the school and the office were well below the WHO-recommended concentrations.

I-O Relationship

The indoor and outdoor relationship of the two gases was deduced with the help of linear regression (Figure2). The mean I/O ratio was well below one for both the SO_2 (0.89±0.07) and NO_2 (0.90±0.09). Analysis of the classroom and campus air contaminations of the two gases exhibit a positive correlation, SO_2 (r= 0.96), and NO_2(r= 0.96), and was significant ($p < 0.001$), showing that outdoor air pollutant sources influenced the air quality in the classrooms. The concentrations of NO_2 in the outdoors may be considered a reliable predictor of indoor NO_2 levels.[21] Majd *et al.*(2019)[33] opined that pollutants significantly contributing to indoor exposure were mainly related to outdoor sources, indicating a strong correlation between indoor concentrations with outdoor sources.

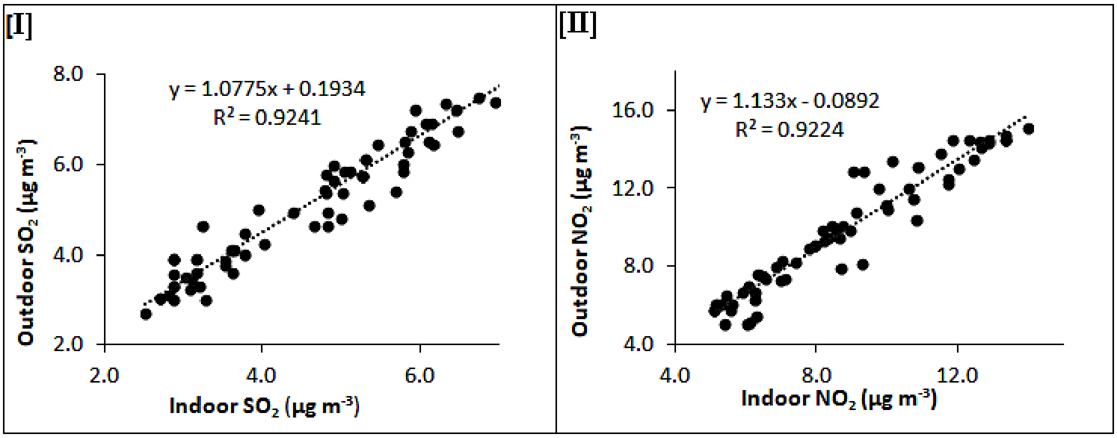

Fig. 2: Gaseous concentration in the classroom versus outdoor air of SO_2 [I] and NO_2 [II]

Conclusion

In modern times, proper monitoring of air quality in schools has become highly necessary due to a host of multiple underlying factors. Some of the pertinent reasons compelling air quality analysis in schools are the ever-increasing traffic volume near schools, mushrooming of schools near the roadside, children's sensitivity to air contaminants, the time children spend in the schools, the crowded working space in classrooms, etc. The current study investigated the status of air quality in the schools in the suburban area of Imphal city with respect to the content of SO_2 and NO_2. The peak SO_2 (7.7 µg m^{-3}), as well as NO_2 (13.9 µg m^{-3}) in classroom air, were observed in a school (SU-2) located very close to a heavy-traffic road. In contrast, the lowest concentration of the two gases in the classroom was observed in a school (SU-3) in a suburban residential area. Air pollutants released from transportation remain the primary cause of air contamination in the city and its surrounding suburban areas. Season-wise, the classrooms' highest concentrations of SO_2 and NO_2 were observed in winter, while the lowest concentrations of the gases were observed during the rainy season. The higher concentrations of gaseous pollutants in the schools during winter might be due to decreased humidity and the prevailing atmospheric conditions. The levels of gaseous pollutants in the campus and classrooms of the schools were found to be positively correlated. The I/O ratio indicated that the outdoor polluting sources of the two gases influenced indoor air concentrations. However, the levels of the two gaseous pollutants observed during the current study were within the safe concentration range recommended by the WHO and NAAQS Standards.

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Conflict of Interest

The authors do not have any conflict of interest.

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