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Assessment of gaseous air pollutants motility in Khulna City of Bangladesh using direct sense probes

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Abstract: The atmosphere surrounding Bangladesh is being polluted day by day in short order due to harmful activities strongly related to air pollution. This study was carried out in Khulna City of Bangladesh located in the southern part of the country. Gaseous air pollutants concentrations at specific eight locations were measured and analysed using real-time monitoring equipment. Time series analysis, diurnal and seasonal variations in mass concentration and variation in total mass concentration of SO_2, CO, and NOx were analysed. This study reveals the highest average concentrations of SO_2, CO, and NOx as 224 μg/m^3, 3,104 μg/m^3, and 116 μg/m^3 consecutively. Significant diurnal and seasonal variation of pollutants can be sanctioned by the adjustable working scenario of concerning locations. Air pollution controlling provisions can be directed considering this baseline study in Bangladesh and other similar Asian countries.

Keywords: Khulna City; air quality; gaseous pollutants; SO_2; CO; NOx; AQI.

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Kazi A.B.M. Mohiuddin is one of the pioneers of air pollution research in Bangladesh. Currently, he is working as a Professor in the Department of Civil Engineering at Khulna University of Engineering & Technology (KUET). He received his PhD in Air Pollution Engineering from Macquarie University, Sydney, Australia in 2014.

1 Introduction

Several air pollutions events have occurred which increased mortality since the beginning of the last century. Meuse Valley in 1930, Donora in 1948, London in 1952, Malaysian haze in 2005 and Southeast Asian haze in 2013 are some examples of air pollution events. Urban air quality has become an essential domain to be investigated. Depending upon the severity of air pollution events, a growing body of researchers was found worldwide to investigate urban air quality during last decades (Hosseinibalam and Hejazi, 2012). Since air pollution has been mainly caused by rapid industrialisation, air pollution has been identified as the price of industrialisation for some cities and air pollution caused by automobiles has been indicated as the disease of wealth (Rao and Rao, 2000; Ganguly and Broderick, 2013). The common gaseous air pollutants in urban areas are sulphur dioxide (SO_2), carbon monoxide (CO), nitrogen oxides (NOx), and ozone (O_3). In addition, depending upon the land use pattern of different areas there could be a wide range of other pollutants (Roy and Adhikari, 2009).

Air pollution by coal-fired power plants in developing or least developed countries are great concern because of producing 85% of total emissions containing PM, SO_2 and NOx (Chen et al., 2020). Reducing the emission level of gaseous air pollutants has become significant as thermal power plants emit a considerable volume of pollutants into the atmosphere (Lalljith et al., 2020; Hamidzadeh et al., 2020). Gaseous air pollutants such as SO_2, NOx, CO, O_3, etc., dispersed in air are identified as the major sources of air pollution disease (Sarasamma and Narayanan, 2014). As per WHO's assertion in 2016, 58% of premature death caused by air pollution happened due to heart disease, strokes, chronic pulmonary disease, respiratory infection and lung cancer, and they claimed SO_2 and NOx after particulate matter as a threat to human health (WHO, 2018). Though in Bangladesh, particulate matter pollution is more severe than gaseous pollution (Begum et al., 2014), gaseous pollutants also have specific contribution to the detriment of human health.

SO_2 is one of the principal constituents of air pollution which is strongly responsible for the contamination of air (Rao and Rao, 2000). Manmade sources are responsible for generating about 99% of the sulphur dioxide in air (Kim et al., 2010). Industrial activity is the main source of sulphur dioxide in the air that processes materials containing sulphur as example, the generation of electricity from oil, coal, or gas that contains sulphur. Sulphur is contained by some mineral ores and sulphur dioxide is released when they are processed. In addition, other important sources of sulphur dioxide are industrial activities that burn fossil fuels. The environmental pollution caused by power plants operating based on fossil fuel are visualised as the deterioration of air quality. Gaseous pollutants production from these industries can be reduced considering the volume by following different environmental dispatch approach (Goudarzi et al., 2020). Sulphur dioxide is also present in motor vehicle emissions, as the result of fuel combustion (DEHA, 2005).

SO_2 can harm the human respiratory system and make breathing difficult with short-term exposures to it. SO_2 also causes eye irritation. The respiratory system and pulmonary functions can be also affected (Li et al., 2015). Inflammation of the respiratory tract causes coughing, mucus secretion, aggravation of asthma and chronic bronchitis and makes people more prone to infections of the respiratory tract (Padula et al., 2013). Some studies conclude that people with asthma may experience changes in lung function and respiratory symptoms after periods of exposure to SO_2 in just 10 minutes (Gonzalez-Barcala et al., 2013). Hospital admissions for cardiac disease and mortality found to be increased day by day with higher level exposure of SO_2. Sulphur dioxide is one of the main industrial pollutants that can have specific effects on the development of Crohn's disease, particularly in adults employed in the industries (Li et al., 2009) and ulcerative one's colitis, respectively. Increasing concentrations of SO_2 can also be considered as a risk factor for maternal depressive symptoms. The increase SO_2 levels can induce acute development of maternal emotional stress (Lin et al., 2017). A secondary effect is the formation of sulphates aerosol or ultrafine airborne particles, which can make up a significant proportion of the particulate matter and have been associated with increased asthma attacks, heart and lung disease and respiratory problems in susceptible population groups (EGCSA, 2019).

NOx is produced during combustion particularly at high temperatures by the reaction of nitrogen and oxygen gases in the air. The amount of nitrogen oxides emitted into the atmosphere as a result of air pollution can be significant in areas with high motor vehicle traffic, such as in large cities. When combustion occurs in the presence of nitrogen such as car engines, NOx gases are produced naturally by lightning, too (Noxite, 2015).

Nitrogen oxides have specific contribution to the detriment of human health. It spreads through the capillary vessels of lungs and the alveolar cells which makes a disruption to the alveolar structures and their functions in lung (Miriam, 2012). Nitric oxide (NO) is very much poisonous and it is less soluble in water. Because of its low solubility, it diffuses through all parts of the respiratory system rapidly. Nitrogen dioxide (NO_2) is a highly reactive gas with a reddish-brown colour. It has also a suffocating door and acts as an oxidising agent. Because of its delaying ability to chemical pneumonitis and causing pulmonary oedema, NO_2 is recognised as highly toxic and hazardous compound (Baukal, 2004).

Carbon monoxide (CO) is a colourless, odourless and non-irritating but very poisonous gas (Sulaymon et al., 2018). The haemoglobin which is responsible in carrying oxygen in human body bounded by CO can make the body to face a lack of oxygen supply. Different incomplete combustion produces carbon monoxide. Also, its major source is road transport (Kampa and Castanas, 2008). The main source of CO in vehicles is the incomplete combustion of petrol in the engine cylinders.

CO emissions affect human health by influencing the blood's ability to transport O_2 into body tissues. It easily crosses the alveolar epithelium to enter the blood as CO is inhaled, where it binds to haemoglobin to form carboxyhaemoglobin (COHb), a beneficial marker for predicting the health effects of CO. Since CO has a haemoglobin brace that is more than 200 times greater than O_2, the presence of CO in the lungs displaces O_2 from haemoglobin (Interim Report, 2002). In other words, the presence of CO in the lungs renders it difficult for haemoglobin to achieve 100% O_2 saturation. Toxicity of the central nervous system and heart, chest pain, diminished performance on basic psychological tests, and arithmetic, and lack of time judgment is certain particular symptoms of carbon monoxide exposures. The previous discussion strongly clarifies the adverse effect of gaseous air pollutants to human health.

Khulna is the third largest city of Bangladesh situated in southwest region of the country. This city contains numerous industries covering agriculture-based industries, heavy metal industries, cement industries, forest-based industries, frozen food industries, etc. Khulna City is also connected to six intercity transport routes. The requirements of these industries and intercity connection routes are causing heterogeneous motorised vehicles movement in the city. The total number of vehicles operating in Khulna City was found more than 20,990. The motorised vehicles revise their count with an average annual growth rate of 15% (Kabir et al., 2016). Truck-lorry, truck, bus, minibus, pickup, private car, easy bike, motorbike, etc. are the common types motorised vehicles in the city. The operation of these motorised vehicles requires considerable amount of fuel burning. Air pollutants emission from vehicles and industries is one of the great concerns for most of the megacities (Srimuruganandam and Nagendra, 2013; Adebayo et al., 2016). Industrial and vehicular emissions are polluting the airshed of this city by increasing the air pollutants emission.

This study was conducted to assess the concentration of different gaseous air pollutants in Khulna City. Only one continuous air monitoring station established by Department of Environment (DoE), Bangladesh; is not sufficient to represent the urban air quality in Khulna City. Khulna City was selected for this study because no previous study was found to assess the variation and trend of gaseous air pollutants (SO_2, CO and NOx) concentration using real-time monitoring equipment. Evaluation of the concentration of gaseous air pollutants from specific eight locations was performed to find out which pollutant is mainly responsible for polluting the airshed of this city and which place is mostly polluted. This study can be considered as baseline study for further application in a great context. Moreover, the main findings of this study may assist to develop future provisions in order to regulate urban air pollution.

2 Research methods

2.1 Monitoring locations

Eight monitoring locations in Khulna City were carefully selected to monitor the concentration of gaseous air pollutants. Selection of locations for monitoring was performed covering residential zone (2 nos), educational institute (1 nos), commercial zone (1 nos), and public places (4nos). The locations in four public places are bus stand, market, ferry ghat and rail station. The location KUET campus was monitored both in winter and monsoon seasons. Table 1 presents the detail description of monitoring locations and monitoring periods. Acronyms of each considered monitoring location are mentioned besides their actual name.

Table 1 Description of monitoring locations

SL.	*Location*	*Latitude and longitude*	*Monitoring period*	*Site condition*
L1	Sonadanga (SD)	22° 49' 01.7574" N 89° 32' 32.8122" E	24-10-18 and 25-10-18	Central bus terminal
L2	Nirala RA (NRA)	22° 48' 02.6814" N 89° 33' 10.3248" E	15-11-19 and 16-11-19	Residential area
L3	Newmarket (NM)	22° 49' 31.2306" N 89° 33' 03.2430" E	22-12-18 and 23-12-18	Market place
L4W	KUET Campus (Winter) [KUET (W)]	22° 53' 57.9660" N 89° 30' 06.8220" E	06-12-18 and 07-12-18	Educational institute
L4M	KUET Campus (Monsoon) [KUET (M)]	22° 53' 57.9660" N 89° 30' 06.8220" E	23-07-19 to 26-07-19	Educational institute
L5	Banargati RA (BRA)	22° 48' 17.8452" N 89° 32' 46.2696" E	06-07-19 and 08-07-19	Residential area
L6	Khulna Rail Station (KRS)	22° 49' 13.1622" N 89° 33' 26.9424" E	22-06-19 and 01-08-19	Inter city rail station
L7	Bagmara CA (BCA)	22° 47' 27.0738" N 89° 35' 12.5736" E	01-02-19 and 02-02-19	Commercial area
L8	Rupsha ghat (RG)	22° 48' 06.7716" N 89° 34' 49.6050" E	03-02-19 to 05-02-19	Ferry ghat

2.2 Measurement of gaseous pollutants

Concentration of gaseous pollutants (SO_2, CO and NOx) from eight locations were measured. Advanced Sense TM Pro an environmental test meter was used for gaseous pollutants measurements. The environmental test meter equipped with direct sense probes can measure continuous data as micrograms per cubic metre ($\mu g/m^3$) Available backup power system of this equipment assist the continuous monitoring without interruption for three hours. One minute averaging time was set for monitoring. The increasing number of monitoring locations could assist the evaluation process in other ways. Continuous monitoring programs at specific locations might offer even more clarification in the assessment of the polluting scenarios.

2.3 Operation of environmental test meter

Firstly, two direct sense probes are made to be connected with environmental test meter as at instant only two probes are allowed to be connected. Next step becomes the placement of equipment at the selected monitoring locations. Afterward, the equipment is started by clicking power button and selected log and run the auto name log. Setting the log name, average time interval assists to press on 'start log' option, which makes the instrument start counting readings. Counted data reading then can be shown in the screen in accordance with probe number as different probes are used to measure different parameters. After monitoring eight hours continuously for one location in the day time, started log made to be stopped by clicking on the option 'stop log'. Measured data were saved to the internal storage of the equipment automatically. Concentration was measured by using 1-minute to 5-minute average for at least 8 hours in a day and three consecutive days in each selected location for this study. Also, the test meter was placed at 5.0 ft above the existing ground surface which is the average nose heights. After completing the monitoring campaign of any selected locations, stored data can be transferred and downloaded using a software named 'Wolf Sense PC' which is provided with the environmental test meter. However, the transfer process also requires 'Windows Mobile Device Centre' in order to connect the test meter with prescribed software.

2.4 Assessment of gaseous pollutants

Many statistical methods have been used to analyse the air pollutants in recent years. Time series analysis is being used as a useful tool for better understanding the cause, effect relationship of air pollutants (Hosseinibalam and Hejazi, 2012). In this study, variation in daily mass concentration of gaseous pollutants was observed through time series analysis. Daily variation showed the peak daily values and as well as the lowest value of a certain pollutant in a specific location. The increasing and decreasing trends of pollutants concentration was made to understand from the time series analysis. Time-series model usually asserts a relationship in between a certain number of temporal sequences or time series. The simple regression model of time series analysis is given by equation 1. Here, $y(t) = \{yt; t = 0, \pm1, \pm2, \ldots\}$ is an order, indexed by the time symbol t, which is a conjunction of an observable order $x(t) = \{xt\}$ and an unobservable order $\varepsilon(t) = \{\varepsilon t\}$ of independent and identical delivered random variables (Lima et al., 2009).

$$y(t) = x(t)\beta + \varepsilon(t) \tag{1}$$

Spatial variation of mass concentration was also observed. The box-whisker plot was incorporated in order to identify the extremes and outliers concentration (Lima et al., 2009). It helped to exhibit the spatial variation of gaseous pollutants which was performed with the help of a software named as 'origin 2018'. The source apportionment of considered air pollutants could help to understand the exact sources and scenario of emission though it was not performed. The evaluation methods incorporated in this study are similar to Lima et al. (2009), Mukherjee et al. (2013), Ganguly and Broderick (2013), Wang et al. (2014) and Zhao et al. (2016).

2.5 Air quality index

Air quality index (AQI) is used to expose the condition of air within a short order to whom are going experience the air of a specific region. The higher AQI value contains more severity and the lower value of AQI indicates a positive sign of good air. The higher the AQI, the greater is the air pollution level and thus indicates greater public health concern (CASE, 2018). Generally, this index is derived using the following formula:

$$AQI = \frac{\text{Measure data reading of pollutants}}{\text{Standard limit of pollutants}} \times 100 \tag{2}$$

Though, different formulas are available for calculating the index according to different agencies, this study used the above depicted equation (2) for calculating the air quality index. The AQI standard for Bangladesh is given in Table 2. There are five ranges of AQI values indicating air quality as good to extremely unhealthy. Different colours signs are also added to the AQI index of Bangladesh for different ranges of AQI values. Colour signs vary as green, yellow green, yellow orange, red and purple where green reflects good and purple reflects extremely unhealthy air quality.

Table 2 Air quality index for Bangladesh

Air quality index (AQI)	*Category*	*Colour*
0–50	Good	Green
51–100	Moderate	Yellow Green
101–150	Caution	Yellow
151–200	Unhealthy	Orange
201–300	Very unhealthy	Red
301–500	Extremely unhealthy	Purple

Source: CASE (2018)

3 Results and discussion

3.1 Average concentration of gaseous pollutants

The average concentrations of SO_2, CO and NOx at eight observed locations are placed in Table 3. The highest concentration of SO_2 found as 224 $\mu g/m^3$ at Nirala residential area whereas the lowest concentration of SO_2 found at KUET campus as 77 $\mu g/m^3$ which was measured in monsoon. The pace of motor vehicles, construction works and solid waste burning at Nirala residential area might lead the concentration of SO_2 to be highest among all nine locations. The highest concentration of CO found as 3,104 $\mu g/m^3$ at Newmarket area whereas the lowest concentration found at KUET campus as 1,036 $\mu g/m^3$. Newmarket is well known as very busy place in Khulna City where many people come for shopping by riding various types of motor vehicles which could be the reason of the rising concentration. Rupsha ghat and Bagmara commercial area were found to carry the highest NOx concentration as 116 $\mu g/m^3$ and 114 $\mu g/m^3$ respectively where Banargati residential was found to carry the lowest average concentration as 11 $\mu g/m^3$. Emissions from ice factories, sea food processing industries, shrimp processing industries, motor vehicles, motor vessels, ship yard and crematorium could be responsible for the highest concentration of NOx at Rupsha ghat and Bagmara commercial area. On the other hand, less air pollution activities were observed at Banargati residential area which supports to have lowest concentration. Though the highest and lowest average concentrations of SO_2, CO and NOx were discussed, no average concentrations were found to cross the Bangladesh National Ambient Air Quality Standards (BNAAQS) except the NOx concentrations at Rupsha ghat and Bagmara commercial area. After averaging all the measured concentration of SO_2, CO and NOx in the selected monitoring locations, concentrations of SO_2, CO and NOx are found within the range of BNAAQS. The concerned authorities can take air pollution control measures to mitigate and control the current scenario of pollution in Khulna City. Specifically, controlling the emission from mentioned industries and other sources can improve the air quality of the city.

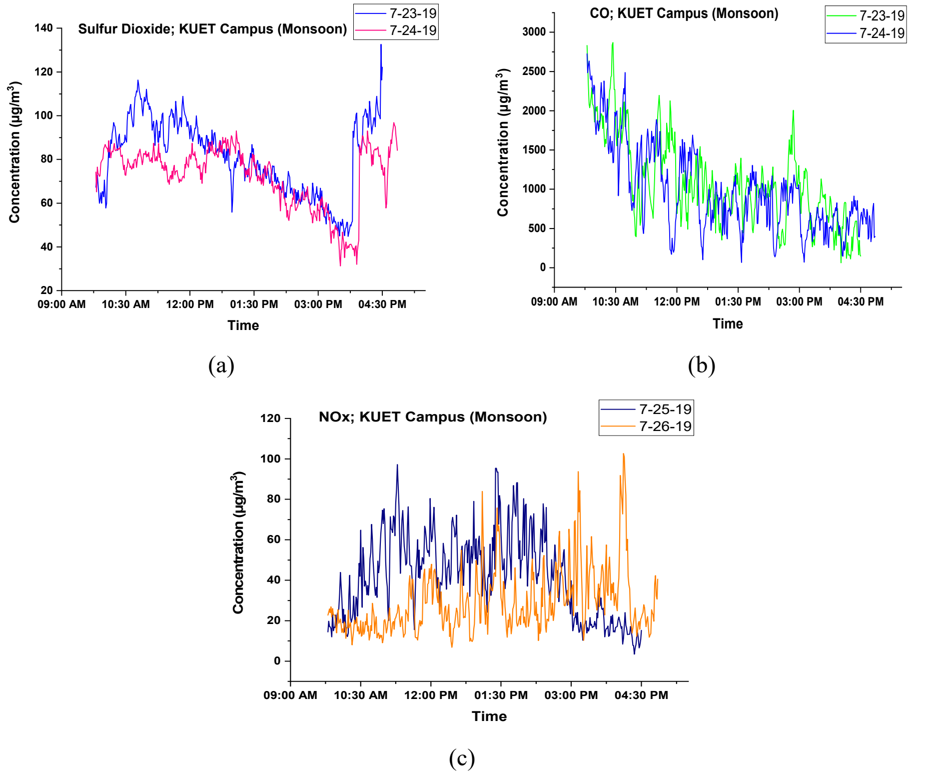
Table 3 Average concentrations of SO_2, CO and NOx at nine locations

Location	*SO_2 mean (min–max) ($\mu g/m^3$)*	*CO mean (min–max) ($\mu g/m^3$)*	*NOx mean (min–max) ($\mu g/m^3$)*
Newmarket	148 (52–486)	3,104 (1,192–8,719)	69 (30–120)
KUET Campus (Winter)	118 (6–316)	2,118 (1,529–3,589)	55 (10–90)
Bagmara CA	216 (156–317)	1,841 (949–2,726)	114 (70–140)
Rupsha ghat	130 (110–195)	2,935 (1,476–5,478)	116 (90–150)
KUET Campus (Monsoon)	77 (31–133)	1,036 (67–2,867)	36 (4–102)
Banargati RA	134 (50–233)	1,435 (937–2,213)	11 (1– 15)
Khulna Railstation	193 (25–325)	1,754 (1,022–3,372)	41 (8–98)
Sonadanga	152 (16–356)	2,102 (731–3,639)	68 (20–120)
Nirala RA	224 (95–447)	2,234 (165–4,271)	57 (10–120)
Average (Khulna City)	155 (6–447)	2,062 (67–8,719)	63 (1–150)
Standards (BNAAQS)	365 (24-hr avg)	10,000 (8-hr avg)	100 (annual avg)

3.2 Diurnal variation of gaseous pollutants

The daily variation in the concentrations of SO_2, CO and NOx at respective monitoring locations were observed and among them Figure 1 presents the variation in daily mass concentration of SO_2 [Figure 1(a)], CO [Figure 1(b)] and NOx [Figure 1(c)] at KUET campus monitored in monsoon. Two different color lines in the following figure indicate individual monitoring period. It was observed that increasing and decreasing rate of gaseous pollutants concentration followed almost same trend for all the locations. Daily peak values of the concentration of SO_2, CO and NOx appeared in the morning and afternoon segment for almost all the locations. The specific time duration for the higher concentration of pollutants of morning and afternoon segment are 09:30 AM to 11:00 AM and 03:00 PM to 4:30 PM. The concentration of NOx at the concerned location was found to be varied in different ways from SO_2 and CO. Though the variation of NOx was different, the peak values appeared in the morning and afternoon segment as SO_2 and CO. This trend of variation is relevant with the activities of this city. Most of the offices and other activities of a day start at the morning and close at afternoon, therefore maximum vehicular movement occurs within these two segments. The higher vehicular movement at morning and afternoon may support the peak values within these two segments. Identified segments containing the higher concentration of pollutants can be taken into consideration in order to regulate the provision in controlling the pollution.

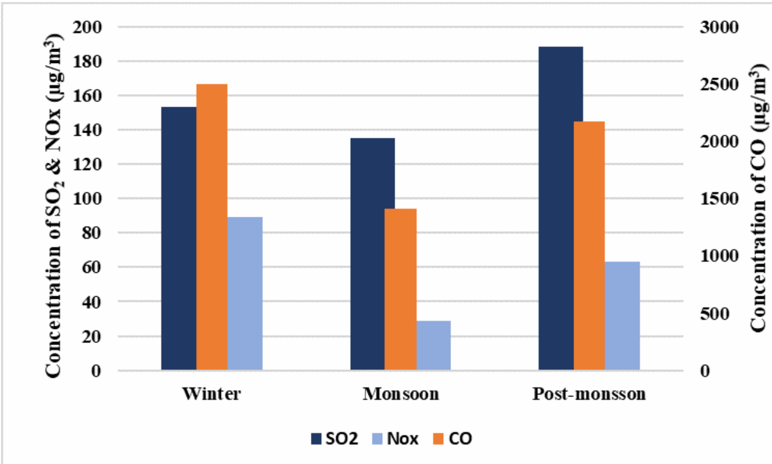
Figure 1 Variation in daily mass concentration of (a) SO_2, (b) CO and (c) NOx at KUET campus (see online version for colours)



3.3 *Seasonal variation of gaseous pollutants*

Seasonal variation of the concentration of SO_2, CO and NOx are shown in Figure 2. The seasons were demarcated as pre-monsoon from March to May, monsoon from June to September, post-monsoon from October to November and Winter from December to February. Seasonal variation was calculated from the average concentration of different locations which evidenced a concave parabolic shape. Higher values of SO_2, CO and NOx appeared in winter and post-monsoon and lower values found in monsoon. The highest value of SO_2 found in post-monsoon reaching 188 $\mu g/m^3$ and lowest value appeared in monsoon as 135 $\mu g/m^3$. Maximum CO appeared in winter as 2,500 $\mu g/m^3$ where the minimum value found in monsoon as 1,408 $\mu g/m^3$. Highest NOx found in winter reaching 89 $\mu g/m^3$ and lowest was in monsoon as 29 $\mu g/m^3$. Meteorological conditions such as less precipitation, lower boundary layer height, wind direction and lower temperature in winter compared with those in other seasons can exacerbate the pollution of air. The seasonal variations found similar to the study conducted by Zhao et al. (2016) for CO and SO_2. Concentrations of these two pollutants were considerably higher during winter and post-monsoon than during monsoon. Mukherjee et al. (2013) and Wang et al. (2014) also showed the similar results for SO_2, CO and NOx concentrations.

Figure 2 Seasonal variation of SO_2, CO and NOx (see online version for colours)



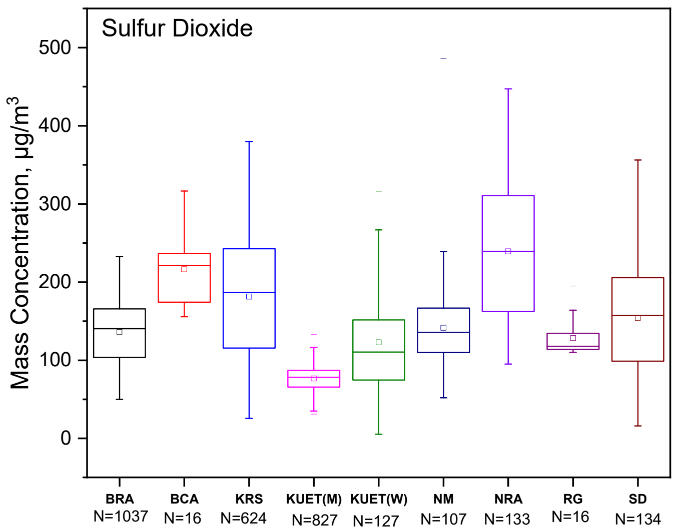
3.4 Variation in total mass concentration

The variation in total mass concentration of SO_2, CO and NOx for eight monitoring locations in Khulna City is presented in Figure 3(a) to 3(c) consecutively. The data is presented in box and whisker plots to show the variation of statistical parameters due to the higher variation in mass concentration of SO_2, CO and NOx. Number of observed data are presented with respective location's name. Khulna rail station, Nirala residential area and Sonadanga showed significantly larger variation for SO_2 concentration among all locations, whereas KUET campus showed smaller variation in SO_2 concentration which was measured in monsoon. Larger variation in SO_2 concentration of those three locations could be happened due to the effect of locomotives and other vehicular movement at Khulna rail station and emissions from large number of motor vehicles at Nirala residential area and Sonadanga.

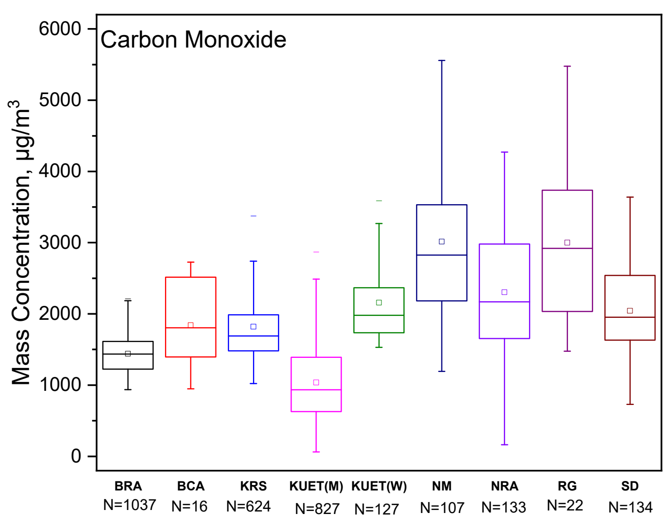
Among all the locations which were monitored, Bagmara commercial area, Newmarket, Nirala residential area and Rupsha ghat exhibited comparatively higher variation in CO concentration than others. Same scenario could be experienced from the variation in NOx concentration. Bagmara commercial area is loaded with different ice factories, sea food processing industries and shrimp processing industries excluding motor vehicles and motor vessels reaching the area due to purchase and transport of materials. The activities of these industries may lead to show higher variation. The solid waste burning at Nirala residential area, emissions from crematorium, dockyard at Rupsha ghat and burning fuels by motor vehicles could make the change in mass concentration variation of CO and NOx. Air pollution mobilising activities of these specific locations can be controlled to improve the air quality. The location named as Banargati residential area presented lower variation in mass concentration for both CO and NOx.

Another observation from the Figure 3 is comparatively higher variation in mass concentration of CO and NOx at KUET campus (Monsoon) where this location showed smallest variation in SO_2 concentration among all the locations. Specific activity was observed during the monitoring period of this location which includes the burning of octane. As any incomplete combustion of fuel leads to produce air polluting substance such as CO and NOx, therefore that burning activity may cause the competitively higher variation in CO and NOx.

Figure 3 Variation in total mass concentrations of gaseous pollutants for nine locations, (a) SO_2 (b) CO (c) NOx (see online version for colours)

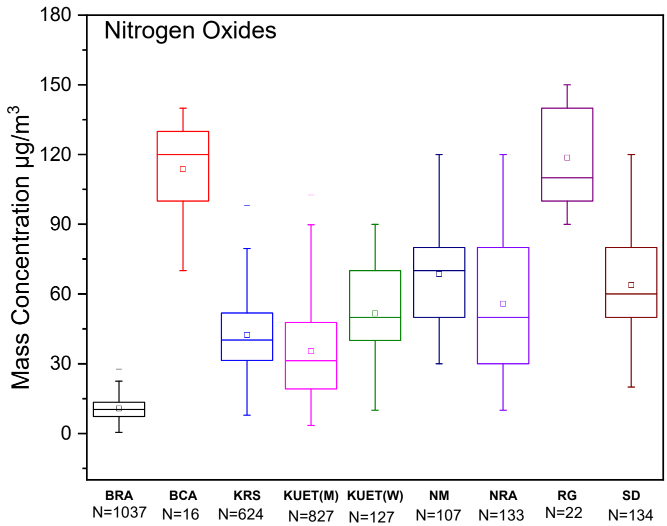


(a)



(b)

Figure 3 Variation in total mass concentrations of gaseous pollutants for nine locations, (a) SO_2 (b) CO (c) NOx (continued) (see online version for colours)



(c)

3.5 Air quality index for gaseous pollutants

Air quality index (AQI) of SO_2, CO and NOx for eight observed locations in Khulna City is presented in Table 4. AQI values found within good and moderate for SO_2, CO and NOx among all considered locations except AQI of NOx at Bagmara commercial area and Rupsha ghat. AQI of Bagmara commercial area and Rupsha ghat found to be in caution range which indicates health concern. Industrial activities and other sources, which emit polluting substance to the air of these two locations may affect the AQI value. On the other hand, air quality of Banargati residential area and KUET campus (Monsoon) found to be good as per air quality index. These two locations were monitored in monsoon.

Table 4 Air quality index (AQI) of gaseous pollutants at nine locations

Season	*Location*	*AQI for SO_2*	*AQI for CO*	*AQI for NOx*	*AQI*
Winter	Newmarket	41 (Good)	31 (Good)	69 (Moderate)	Moderate
	KUET Campus (W)	32 (Good)	21 (Good)	55 (Moderate)	Moderate
	Bagmara CA	59 (Moderate)	18 (Good)	114 (Caution)	Caution
	Rupsha ghat	36 (Good)	29 (Good)	116 (Caution)	Caution
Monsoon	KUET Campus (M)	21 (Good)	10 (Good)	36 (Good)	Good
	Banargati RA	37 (Good)	14 (Good)	11 (Good)	Good
	Khulna Railstation	53 (Moderate)	18 (Good)	41 (Good)	Moderate
Post-monsoon	Sonadanga	42 (Good)	21 (Good)	68 (Moderate)	Moderate
	Nirala RA	61 (Moderate)	22 (Good)	57 (Moderate)	Moderate

4 Conclusions

This study assessed the concentration of gaseous air pollutants at eight locations in urban areas of Khulna City as the very first endeavour. Diurnal and seasonal variation of gaseous air pollutants concentrations was observed in this study which guided to find out the trend of variation. This study also observed the variation in total mass concentration in order to trace the spatial fluctuations of gaseous pollutants' concentration within the monitored locations. The key findings of this study are enlisted below:

- highest average concentration of SO_2, NOx and CO were found as 224 $\mu g/m^3$, 116 $\mu g/m^3$ and 3,104 $\mu g/m^3$ respectively
- daily peak values of SO_2, CO and NOx appeared in the morning and afternoon segment for almost all the locations
- highest average concentrations of CO (2,500 $\mu g/m^3$) and NOx (89 $\mu g/m^3$) reported in winter season
- the variation in total mass concentration of SO_2, CO, and NOx indicates the specific contribution of heavy metal industries, ice industries, food processing industries, etc. and activities situated along with monitoring locations
- in accordance with the air quality index of SO_2, CO and NOx, air quality was found within good to moderate condition for all considered locations except one location for NOx.

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